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Introduction

The purpose of this lab book is to provide hands-on experience to reinforce the electronic theory data learned in this course. Students will improve their critical thinking skills by connecting circuits from schematics, making measurements with a digital multimeter, organizing data, and analyzing observations.

Most of the projects in this lab manual promote understanding of the intended points made by performing calculations and making measurements. The results are then compared and conclusions are drawn at optimum times during the project.

The projects in this lab manual are designed to help students develop and improve their abilities to:

- Follow instructions carefully.
- Make accurate measurements and calculations.
- Analyze technical data appropriately.
- Draw logical conclusions from their observations and calculations.

When performing each lab experiment make sure the meter and test instruments are set to the correct function and range to ensure an accurate meter reading. There are also many calculations and measurements in these lab projects that will require rounding of decimal points. To ensure a correct answer, make sure each number is rounded to the nearest hundredth (two decimal places). For example, if an answer calculates to 3.457 mA, the correct answer would be 3.46 mA. If an answer calculates to 21.3523 kΩ, the correct answer would be 21.35 kΩ. If the answer is a whole number or if the hundredths place is a zero, the extra zeros do not need to be added. For example, an answer of 10 volts does not need to be written as 10.00 V.

The answers must also be written in metric prefix form with the correct unit label. For example an answer of 11270 Ω should be written as 11.27 kΩ. An answer of .482 A should be written as 482 mA, etc.

For your convenience the Ohm’s Law formulas have been added toward the back of this lab manual. Also included is an instructor sign-off sheet. Have your instructor initial and date this sheet in the appropriate location when the corresponding project is correct and complete. This will help both you and your instructor track your progress throughout the experiments.

We wish you great success during these hands-on experiences and hope that this manual will be both interesting and educational as you prepare to enter the technical world of electronics.
Equipment

- Elenco XK-700 electrical trainer
- Multi-range digital multi-meter (DMM)
- Breadboard jumper wires
- Testing jig (Used for troubleshooting exercises)
- AA battery holder with leads
- AA battery

Components

- Resistors
  - 1 kΩ, carbon film, 1 watt, 5% tolerance
  - 3.3 kΩ, carbon film, 1 watt, 5% tolerance
  - 4.7 kΩ, carbon film, 1 watt, 5% tolerance
  - 6.2 kΩ, carbon film, 1 watt, 5% tolerance
  - 10 kΩ, carbon film, 1 watt, 5% tolerance (4)
  - 18 kΩ, carbon film, 1 watt, 5% tolerance
  - 47 kΩ, carbon film, 1 watt, 5% tolerance (2)
  - 100 kΩ, carbon film, 1 watt, 5% tolerance
  - 220 kΩ, carbon film, 1 watt, 5% tolerance
  - 11 Ω, carbon film, 1/2 watt, 5% tolerance
  - 2 kΩ, carbon film, 1/2 watt, 5% tolerance
  - 300 kΩ, carbon film, 1/2 watt, 5% tolerance
  - 10 MΩ, carbon film, 1/2 watt, 5% tolerance
  - 150 Ω, carbon film, 1/4 watt, 5% tolerance
  - 5.6 kΩ, carbon film, 1/4 watt, 5% tolerance
  - 1.2 kΩ, carbon film, 1/8 watt, 5% tolerance
  - 39 kΩ, carbon film, 1/4 watt, 5% tolerance
  - 270 kΩ, metal oxide, 2 watt, 5% tolerance
  - 2.2 kΩ, carbon composition, 1/2 watt, 5% tolerance
  - 750 kΩ, carbon composition, 1/2 watt, 5% tolerance
Digital Multimeters

Multimeters are very useful test instruments. By operating a multi-position switch on the meter they can be quickly and easily set to be used as a voltmeter, an ammeter or an ohmmeter. Some meters have additional features used to measure capacitance and frequency as well. They have several settings called “ranges” for each type of meter and the choice of either alternating or direct current measurements.

Voltmeter

To test for voltage, first determine whether the application you're testing uses AC or DC voltage. Then set the dial to the appropriate function and plug the red test lead into the correct jack used to measure voltage.

Like all test procedures, when testing voltage, set the meter to the range just higher than the expected voltage and decrement it down as needed to increase the accuracy of the reading. If you don't know the expected range, set the range to the highest one available. Take the black test lead and place it on the negative polarity point of the circuit you want to measure. The red test lead will go on the more positive polarity point. When measuring voltage, the test leads of the meter must always be connected in parallel or “across” the component or circuit to be measured as in Figure P-2 on the next page.
Ammeter
To measure current, break the circuit where you want to take the reading. Set the meter to AC or DC current depending on the source being tested. Plug the test lead into the correct jack to measure the expected current.

Note: Most meters have a separate jack that needs to be used to measure current from 0 to 200mA and from 200mA to 10A or sometimes 20A.

Insert the meter in series or “in line” with the circuit to be measured by placing the red test lead on the positive polarity point and the black lead on the negative polarity point (see Figure P-3). Similar to the voltage, the correct current range needs to be selected. Start by selecting the next range higher than the expected reading. If the meter ever reads “0” when an actual reading should be present, check the fuse for the 200mA port.

Ohmmeter
To test for resistance, first remove the power from the circuit component to be tested. This prevents the meter from becoming damaged by the source. After ensuring that all power is off, set the dial to the resistance function. Select the appropriate range on the dial. Remove the component to be measured from the circuit (This prevents false readings from any other components in the circuit). Make sure the test leads are plugged into the correct jack to measure resistance. Connect your test leads to the component and take the reading.

It’s important that you have good contact between the test leads and the component being tested. Dirt, oil and poor test lead connection can undesirably alter resistance readings.
The Elenco XK-700 Electronic Trainer

This guide will explain the basic operations and features of the Elenco electronic trainer that you will be using for the majority of the lab experiments in this course. Please take a few minutes to read through this guide and study the illustrations so you will become familiar with the different functions of this trainer.

In this user guide you will identify the five main sections of the trainer. You will also learn the purpose and the function of each section.

The five sections of this trainer are listed below. See Figure P-5 for a pictorial diagram of the trainer.

1. Power supply section
2. Variable resistance section
3. Function generator
4. Digital section
5. Breadboard section

![Figure P-5](image-url)
Power Supply

The Elenco trainer has several built in DC power supplies to satisfy most electronic design needs.

The two variable DC power supplies produce up to +20 volts and -20 volts at 500 milliamps. Below 15v the available current is over 1 amp.

Three fixed power supplies produce +12vdc, -12vdc, or +5vdc at 1 amp each.

All of the power supplies are regulated to within 150 millivolts. In other words, if you increase the current draw from no load to 500 milliamps, the voltage will change less than 150 millivolts.

A variety of different voltages are available at the power output terminals. Because the Elenco trainer uses both the +20v and -20v adjustable voltage controls, a combined voltage of up to 40vdc is possible. (See Figure P-7)
The power supply section’s output terminal block also allows for the stepped down AC voltage to be used direct from the center tapped transformer. The transformer provides a voltage of 30VAC from line to line or 15VAC from either line to the center tapped ground (See Figure P-8).

**WARNING:**
Do not short the 15 VAC output to ground!

**Variable resistance section**

The Elenco trainer has two built in variable resistors or “potentiometers” that are available to use for certain lab experiments. The values of the variable resistors are 1k ohm and 100k ohm max. Taking a resistance measurement from one side of the terminal block to the other will give the full value of the resistor (1k ohm or 100k ohm) regardless of the position of the knob. If you take a measurement from either end of the terminal block to the middle wiper connection, you will get a variable value that will change with respect to the position of the knob. (See Figure P-10)
**Function / Signal Generator**

The included function generator is capable of producing sine, square and triangle waveforms. The frequency of this generator is variable from one hertz to over 100,000 hertz in the following five ranges: 10-Hz, 100-Hz, 1-kHz, 10-kHz and 100-kHz. A fine adjustment control makes for easy selection of any frequency between these ranges. The output voltage amplitude is variable between 0 and 15-V_{P-P}. The output of the function generator may be taken from the terminal marked “FREQ” with respect to a ground terminal in the power supply section.

![Image](image.png)

**Figure P-11**

**Digital Section**

The digital section of the trainer consists of two “no bounce” logic switches, 8 LED indicator lamps, 8 data switches and a clock generator. The clock generator output is a 5V pulsating square wave. The frequency of the pulsations can be adjusted with the frequency range selector and fine frequency control in the function generator section.

![Image](image.png)

**Figure P-12**
Breadboard Section

The Elenco trainer is equipped with two breadboards containing a total of 1660 tie points including 6 independent bus lines.

The board is made of plastic with a matrix of holes. Wires and component leads can be pushed into the holes to make appropriate connections. Each “hole” on the board contains a metal spring contact. When a wire or component lead is pushed down into the hole an electrical connection is made with that hole’s spring contact.

The breadboards provide an interconnection between certain holes on the board using metallic “bus” connections made underneath the surface. The holes are internally connected so that each 50 hole horizontal bus line is independent from the other and each small 5 hole vertical bus line is also connected independently. Figure P-14 shows the internal connections of the holes on the breadboard.

Because of the built-in interconnections and the typical circuit board layout, some of the following techniques are commonly used when working with a breadboard.

- A jumper wire can be used to connect the positive source lead to one of the horizontal buss lines marked with a “plus” (+) sign.
- Another jumper wire can be used to connect the negative source lead or GND to one of the horizontal buss lines marked with a “minus” (-) symbol.
- A short jumper wire can then be used to connect each horizontal source connection row to the appropriate point(s) in the circuit on the vertical bus line portion of the board.
- When connecting component leads, plug one lead of a component into a vertical column hole and the other lead of the component into another vertical column hole in a separate bus line. Connect the component, spaced as necessary for the size of the component.
Figures P-15 & P-16 are sample series and parallel circuit connections using a breadboard. These are just a small sample of the many different methods and combinations for connecting circuits using breadboards. These examples are shown using the positive variable voltage supply.

Sample series circuit layout
(a) Pictorial Diagram
(b) Schematic Diagram

Figure P-15

Sample parallel circuit layout
(a) Pictorial Diagram
(b) Schematic Diagram

Figure P-16
Using Meters

Voltmeters

Project Objectives:

- To learn how to safely and effectively measure DC voltage using a digital multi-meter.
- Gain practice in creating simple circuits from pictorial diagrams.
- Learn to adjust a variable DC source for a desired output voltage.

Items Needed:

- Electronics Trainer
- Digital multi-meter
- Jumper Wires
- 1.5V dry cell battery

By completing this project you will learn some of the key procedures used to make safe and accurate measurements with a voltmeter. We will also introduce important points of meter care. Be sure to remember and use these key points whenever you use a meter.

1. Make sure the meter is set on the correct function (ac or dc volts, amperes, or ohms).
2. When using a non-autoranging meter, make sure the range is set high enough for what you are measuring. If you are not sure, start with the highest range and work down until the reading is the most accurate.
3. When measuring voltage, make sure the meter is connected in parallel with what you are measuring.
4. Be sure to observe polarity when measuring dc voltage.
5. Make sure to remove power when making changes to a circuit and connecting test leads.

Experiment 1

1. Following the safety guidelines listed above, use a digital multi-meter (DMM) and measure the voltage of a dry cell battery.

   Cell voltage measures __________________________ V.

2. What mode / function was the meter switched to make this measurement?
   (a) $A_{DC}$   (b) $V_{AC}$   (c) $V_{DC}$   (d) $\Omega$   (e) $A_{AC}$

3. What voltage range will give the most accurate result for this measurement?
   (a) 200mV   (b) 2V   (c) 20V   (d) 200V   (e) 1000V
4. What cell terminal was the red lead connected to? (a) negative (b) positive

5. The negative terminal of the cell should be connected to the ________________ test lead. 
   (a) black (b) red

Experiment 2

1. Connect the voltmeter across the positive output of the variable voltage power supply on your Elenco electronics trainer. Carefully adjust the power supply to 5v, 15v, and 30v output settings, in that respective order. Have the instructor check your settings each time. (Hint) You will need to combine the positive and negative variable voltages on the Elenco trainer to reach 30v.

   5v setting correct. Instructor initial: ________________
   15v setting correct. Instructor initial: ________________
   30v setting correct. Instructor initial: ________________

2. What mode / function was the meter switched to make this measurement?
   (a) $A_{DC}$ (b) $V_{AC}$ (c) $V_{DC}$ (d) Ω (e) $A_{AC}$

3. What voltage range was the meter set to for the 5v and the 15v measurements?
   (a) 200mV (b) 2V (c) 20V (d) 200V (e) 1000V

4. What voltage range was the meter set to for the 30v measurement?
   (a) 200mV (b) 2V (c) 20V (d) 200V (e) 1000V

5. The red lead was connected to the ________________ terminal of the power supply? 
   (a) positive (b) negative
Using Meters
Ammeters

Project Objectives:
• To learn how to safely and effectively measure DC current using a digital multi-meter.
• Gain practice in creating simple circuits from schematic and pictorial diagrams.
• Learn to adjust a variable DC source for a desired output current.

Items Needed:
- Electronics Trainer
- Digital multi-meter
- Jumper Wires
- 1.5V dry cell battery

In this project please use the following safety precautions when connecting meters to make current measurements.

1. Remove power from the circuit prior to making changes and connecting meters.
2. Break the circuit in an appropriate place and connect the meter in series.
3. Observe polarity when measuring dc current.
4. Use the correct meter mode / function for what you are measuring (dc current mode).
5. Be sure to set the range high enough for what you are measuring. If unsure, start at the highest range and work down until an accurate reading is given.
6. After meter is connected properly, turn power on and take reading.

Experiment 1

1. Set up the DMM to measure current from 0 to 2mA.
   What mode or function should the meter be set to?
   (a) $A_{DC}$  (b) $V_{AC}$  (c) $V_{DC}$  (d) $\Omega$  (e) $A_{AC}$

2. Connect the circuit shown above. (The resistor color bands will be: brown, black, red, gold)

3. Break the circuit at point A and insert the meter. Make sure the meter is in series and there is resistance in the circuit. If there is no resistance in the circuit a dead short will occur and the meter could get damaged or destroyed.

   Does your circuit look like the diagrams above?  Check: (Yes _____, No _____)

4. Connect the 1.5V cell to the circuit and read the ammeter.

   Current measured is: ________________ mA
1. Disconnect the previous circuit. Set up the meter to read current in the range from 0 to 20mA.

2. With the power OFF, insert the 1kΩ resistor into the breadboard section of the Elenco trainer. Make sure the resistor leads are in separate bus lines so the circuit will not be “shorted”.

3. Connect a jumper from the positive variable power supply terminal to one side of the resistor.

4. Connect another jumper from the middle “ground” terminal to the black test lead on the DMM.

5. Take the red test lead from the DMM and connect it to the open lead of the resistor. Your circuit should now look like the illustration above.

6. Set the voltage control on the power supply to the zero output setting. Turn the power on and slowly increase the output until you measure 10mA through the circuit. Have the instructor check your setting.

   **Instructor initial:** ____________________

7. What is the voltage applied to the circuit when the power supply is adjusted so that there is a current flow of 5mA?

   **Please review the voltage safety rules!**

   Voltage measures ________________V. Current measures ________________ mA.
Using Meters
Ohmmeters

Project Objectives:
• To develop an understanding of the ohmmeter function of a DMM.
• To learn how to use the variable resistance section of the Elenco trainer.

Items Needed:
- Electronics Trainer
- Jumper Wires
- Digital multi-meter
- 10k Ω resistor
- 1k Ω resistor
- 47k Ω resistor

In this project please use the following safety precautions when connecting meters to make resistance measurements.
1. Disconnect the circuit from the power source.
2. Isolate the component being measured from the rest of the circuit.
3. Use the correct meter mode / function for what you are measuring. (ohms)
4. Be sure to use the appropriate range for the expected resistance.
5. When finished making measurements, be sure to turn the meter OFF.

Experiment 1

1. Using the resistance function of a DMM, measure and record the resistance value of a 1kΩ (1000Ω), 10kΩ (10,000Ω), and a 47kΩ (47,000Ω) resistor.

   The 1kΩ (brown, black, red) resistor measures ____________________ Ω.

   The 10kΩ (brown, black, orange) resistor measures ____________________ Ω.

   The 47kΩ (yellow, violet, orange) resistor measures ____________________ Ω.

2. Did the three resistors exactly measure to their specified value? ____________________

3. List some reasons why there may be differences from the measured and the specified value.
   ___________________________________________________________________
   ___________________________________________________________________
   ___________________________________________________________________
   ___________________________________________________________________
   ___________________________________________________________________

4. Which ohmmeter range should have been used to measure the three resistors?

   Range used for 1kΩ = ____________________

   Range used for 10kΩ = ____________________

   Range used for 47kΩ = ____________________
1. Insert jumper wires into the two outside terminals for the 1kΩ and 100kΩ potentiometers (variable resistors) on your Elenco trainer. What are the resistance measurements? Make sure the power supply is not connected!

   1kΩ potentiometer measures: _______________ Ω. Meter range used: ______________

   100kΩ potentiometer measures: _______________ Ω. Meter range used: ______________

2. When the ohmmeter is connected in this manner, what happens when you attempt to adjust the resistance by turning the potentiometer’s knob? ________________________________

   Why? ___________________________________________________________________
   ___________________________________________________________________

3. Now move one of the jumper wires from the outside terminal to the middle “wiper” terminal. You should now be able to adjust the resistance by turning the potentiometer’s knob.

4. Set the 1kΩ potentiometer to 350Ω. Have the instructor check your measurement.

   Meter range used: _______________ Instructor initial: _______________

5. Set the 100kΩ potentiometer to 18kΩ. Have the instructor check your measurement.

   Meter range used: _______________ Instructor initial: _______________


Ohm’s Law
Relationship of I and V with a Constant R

Project Objectives:
- To prove the direct relationship of current to voltage when a set resistance is given.
- To obtain more practice connecting circuits and using a DMM to make measurements.

Items Needed:
- Electronics Trainer
- Jumper Wires
- Digital multi-meter
- 10k Ω resistor (brown, black, orange)

While completing this project, keep in mind that Ohm’s Law states \( E = I \times R \)

- Be sure to disconnect power when connecting meters and making changes to the circuit!
- When measuring current, make sure a resistance is always in the circuit to avoid shorting the circuit and damaging the meter.

Experiment

1. Select the correct meter function and range to measure dc current from 0 to 2mA.
2. Using the positive variable voltage as the source V, connect the circuit shown in figures 4-1 and 4-2. Make sure the meter is in series with the circuit.
3. Increase the positive variable voltage until the meter reads 1mA.
4. Making sure not to change the state of the variable voltage knob, turn off the power and disconnect the meter from the circuit.
5. Using Ohm’s Law, calculate the expected voltage of this circuit.

\[
\text{Calculated voltage} = \frac{E}{R} = \text{Expected voltage} \text{ V.}
\]

6. Select the correct meter function and range to measure dc voltage from 0 to 20 volts.
7. Connect the circuit and the meter to take a voltage reading across the 10kΩ resistor. Remember, the meter must be in parallel when measuring voltage. See figure 4-3 for a schematic diagram.

\[
\text{Measured Voltage} = \text{Voltage reading} \text{ V.}
\]
8. Repeat steps 1 through 7, this time setting the current at 1.5mA. What is the calculated voltage of this circuit?

Calculated voltage = ____________________________ V.

9. What is the measured voltage?

Measured Voltage = ____________________________ V.

10. Increasing the voltage of the circuit caused the current to ____________________________.

   (a) increase    (b) decrease

11. As this lab experiment clearly proved, electric current is ____________________________ related to the voltage applied in the circuit.

   (a) directly    (b) inversely
Ohm’s Law
Relationship of I and R with a Constant V

Project Objectives:
• To prove the inverse relationship of current to resistance when a set voltage is given.
• To obtain practice in connecting circuits and using a DMM to make measurements.

Items Needed:
- Electronics Trainer
- Jumper Wires
- Digital multi-meter
- Resistors 10kΩ, 3.3kΩ, 1kΩ

• Be sure to disconnect power when connecting meters and making component changes to the circuit!
• When measuring current, make sure a resistance is always in the circuit to avoid shorting the circuit and damaging the meter.

Experiment

1. Select the correct meter range to measure dc current from 0 – 2mA.
2. Using the positive variable voltage as the source V, connect the circuit shown in figures 5-1 and 5-2. Make sure the meter is in series with the circuit.
3. Turn on the power supply and increase the positive variable voltage until the meter reads 1mA.
4. Measure the circuit voltage and be sure not to change it for the rest of the steps in this experiment.

\[ \text{Voltage measures} = \text{__________________________ V} \]

5. Use Ohm’s Law and calculate the resistance (R) from the measured values of voltage (V) and current (I).

\[ \text{Calculated Resistance} = \text{__________________________ } \Omega \]

6. What would the current of the circuit be if the 10kΩ resistor were replaced with a 3.3kΩ (orange, orange, red, gold) resistor?

\[ \text{New calculated current} = \text{__________________________ mA} \]
7. What would the current of the circuit be if the 10kΩ resistor were replaced with a 1kΩ (brown, black, red, gold) resistor?

New calculated current = _____________________ mA

8. Turn the power supply off and remove the 10kΩ resistor from the circuit. Replace it with a 3.3kΩ resistor.

9. Measure the new current reading. Make sure the meter range is set correctly to the calculation in step 6.

Resistance now = 3.3kΩ Current now measures: _____________________ mA

10. Turn the power supply off and remove the 3.3kΩ resistor from the circuit. Replace it with a 1kΩ resistor.

11. Measure the new current reading. Make sure the meter range is set correctly to the calculation in step 7.

Resistance now = 1kΩ Current now measures: _____________________ mA

12. Keeping the circuit voltage constant at _____________________ volts and decreasing the resistance caused the circuit current to ____________________.

   (a) increase    (b) decrease

13. From this we conclude that current is ______________________ related to resistance.

   (a) directly    (b) inversely
Ohm’s Law
Relationship of Power to V with a Constant R

Project Objectives:
- To show the use of the power formula by demonstrating how power is related to voltage squared for a set resistance.
- To obtain practice in connecting circuits and using a DMM to make measurements.

Items Needed:
- Electronics Trainer
- Digital multi-meter
- Jumper Wires
- 10k Ω resistor

- While completing this project, keep in mind that the power formula states that (P = E x I)
- Be sure to disconnect power when connecting meters and making component changes to the circuit!

Experiment

1. Connect the circuit shown in figures 6-1 and 6-2.
2. Adjust the Source V to obtain 1mA of current and measure the voltage.
   
   Current = ______________________ mA
   
   Voltage = ______________________ V

3. Using the power formula, calculate the power dissipated by the resistor.
   
   Calculated Power = ______________________ mW

4. Change the Source V to obtain 2mA of current and measure the voltage. Using the power formula, calculate the power dissipated by the resistor.
   
   Current now = ______________________ mA
   
   Voltage now = ______________________ V
   
   Calculated Power now = ______________________ mW

5. When we doubled the voltage the current increased by how many times? ____________.
   
   Therefore the product of V x I increased ____________ times.
6. Using the \( P = V^2/R \) formula, calculate the power for the measured values in step 4.

\[
V = \frac{\text{measured value}}{\text{unit}} \quad R = \frac{\text{measured value}}{\text{unit}} \quad \Omega
\]

\[\text{P calculated} = \frac{\text{measured value}}{\text{unit}} \text{ mW}\]

7. Change the Source V to 5 volts. Measure the current value and calculate the power by using both of the above formulas.

\[
V_{\text{now}} = \frac{\text{measured value}}{\text{unit}} \quad I_{\text{now}} = \frac{\text{measured value}}{\text{unit}} \mu\text{A}
\]

\[\text{P calculated using the formula } (P = V \times I) = \frac{\text{measured value}}{\text{unit}} \text{ mW}\]

\[\text{P calculated using the formula } (P = V^2/R) = \frac{\text{measured value}}{\text{unit}} \text{ mW}\]

8. When compared to the 20 volt condition, we now have ______ the voltage.

(a) \( \frac{1}{2} \)  (b) \( \frac{1}{4} \)  (c) \( \frac{1}{8} \)  (d) \( \frac{1}{16} \)

9. When compared to the 20 volt condition, we now have ______ the power dissipation.

(a) \( \frac{1}{4} \)  (b) \( \frac{1}{8} \)  (c) \( \frac{1}{16} \)  (d) \( \frac{1}{32} \)

10. Assume this circuit has an applied voltage of 8 volts. Calculate and predict what the circuit current and power would be.

\[\text{Predicted current} = \frac{\text{measured value}}{\text{unit}} \mu\text{A} \quad \text{Predicted power} = \frac{\text{measured value}}{\text{unit}} \text{ mW}\]

11. Change the circuit to 8 volts. Measure the current and calculate the power based on the measurements.

\[\text{Measured current} = \frac{\text{measured value}}{\text{unit}} \mu\text{A} \quad \text{Calculated power} = \frac{\text{measured value}}{\text{unit}} \text{ mW}\]

12. Is the current with the applied 8 volts higher than when there were 5 volts applied? ______

Is the calculated power higher or lower? ________________

Does the change correlate with the concept of power being equal to \( V^2/R \)? ________________
Ohm’s Law
Relationship of Power to I with a Constant R

Project Objectives:
• To show the use of the power formula by demonstrating how power is related to current squared for a set resistance.
• To obtain practice in connecting circuits and using a DMM to make measurements.

Items Needed:
- Electronics Trainer
- Digital multi-meter
- Jumper Wires
- 10k Ω resistor

• While completing this project, keep in mind that the power formula states that \( P = E \times I \)
• Be sure to disconnect power when connecting meters and making component changes to the circuit!

Experiment

1. Connect the circuit shown in figure 7-1.
2. Adjust the applied voltage \( V_A \) to 14 volts.
3. Break the circuit and insert an ammeter to measure the current.
   \[ I = \text{_______________ mA} \]
4. Use the measured values of \( V \) and \( I \) and calculate \( P \) using the power formula.
   \[ P \text{ calculated} = \text{_______________ mW} \]
5. Decrease \( V_A \) until \( I \) equals 1/2 its original value.
   Measure the new voltage and calculate \( P \) using both formulas.
   \[ V \text{ now} = \text{_______________ V} \]
   \[ I \text{ now} = \text{_______________ µA} \]
   \[ P \text{ calculated using the formula } (P = V \times I) = \text{_______________ mW} \]
   \[ P \text{ calculated using the formula } (I^2 \times R) = \text{_______________ mW} \]
   \[ P \text{ calculated is } \text{___________ times} \text{ the power dissipated when } I \text{ was double the value of current.} \]
   (a) 1/2    (b) 1/4    (c) 1/8    (d) 1/16
6. We can conclude from this that power is proportional to \( I^2 \) when the resistance remains unchanged. So if the current in a circuit doubles, the power dissipation will increase by
   \[ \text{_______________ times} \]
   (a) 1    (b) 2    (c) 3    (d) 4
7. If the current in a circuit decreases to one-third its value, the power must decrease to
   \[ \text{_______________ its value.} \]
   (a) 1/3    (b) 1/4    (c) 1/6    (d) 1/9
8. What would happen if \( V_A \) was changed to 4.67 volts (approximately 1/3 the original 14V value)
   \[ \text{New } V_A = \text{_______________ V} \]
   \[ V \times I \text{ now} = \text{_______________ mW} \]
   \[ I_{\text{CALC}} = \text{_______________ µA} \]
   \[ I^2 \times R \text{ now} = \text{_______________ mW} \]
   Is the power approximately one-ninth that when 14 volts were applied? \[ \text{_______________} \]
Resistors
Resistor Color Codes

Project Objective:
- To provide a hands-on experience with the resistor color code.
- To determine if the resistor is operating within its specified tolerance by using an ohmmeter to measure its resistance.

Items Needed:
- Digital multi-meter
- Resistors:
  - 2 watt - 270kΩ
  - 1 watt - 6.2kΩ
  - 1/2 watt - 11Ω, 2kΩ, 2.2kΩ, 300kΩ, 750kΩ, 10MΩ
  - 1/4 watt - 150Ω, 5.6kΩ
  - 1/8 watt - 1.2kΩ, 39kΩ

When making resistance measurements, make sure there is no power applied to the circuit.

Experiment

1. List the 10 colors used in the resistor color code to represent the following numbers.
   
   0 = ________________________________  5 = ________________________________
   1 = ________________________________  6 = ________________________________
   2 = ________________________________  7 = ________________________________
   3 = ________________________________  8 = ________________________________
   4 = ________________________________  9 = ________________________________

2. List the colors used in the resistor color code to represent the following tolerance levels.
   
   The color used to represent 5% tolerance = ________________________________
   The color used to represent 10% tolerance = ________________________________
   How is a 20% tolerance represented? ________________________________

3. Complete the table on the next page to determine if the resistors are operating within their specified tolerance ratings.

Example:
If we have a 1kΩ resistor with a 5% tolerance that measures 965Ω we can find if it is operating within its tolerance rating by dividing the smaller number by the larger number and subtracting from 100%. In this case the smaller number is the measured value and the larger number is the given (color code) value.

If we take 965Ω and divide by 1000Ω we get .965

We end up with a percentage of the measured value to the given value. To find out if the resistor is operating within its tolerance we need to subtract from 100% so we move the decimal point two places.

100% – 96.5% = 3.5%
The percent of difference between the measured value and the given color code value of the resistor is 3.5%. Therefore the 1kΩ resistor is operating within its 5% tolerance.

Complete the table below. Use an ohmmeter to measure each resistor. Refer to the example above to calculate if each resistor is operating within its tolerance rating.

<table>
<thead>
<tr>
<th>Resistor measures?</th>
<th>% of difference</th>
<th>In tolerance (yes/no)</th>
</tr>
</thead>
<tbody>
<tr>
<td>270kΩ - 2 watt</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.2kΩ - 1 watt</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11Ω - 1/2 watt</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2kΩ - 1/2 watt</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.2kΩ - 1/2 watt</td>
<td></td>
<td></td>
</tr>
<tr>
<td>300kΩ - 1/2 watt</td>
<td></td>
<td></td>
</tr>
<tr>
<td>750kΩ - 1/2 watt</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10MΩ - 1/2 watt</td>
<td></td>
<td></td>
</tr>
<tr>
<td>150Ω - 1/4 watt</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.6kΩ - 1/4 watt</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.2kΩ - 1/8 watt</td>
<td></td>
<td></td>
</tr>
<tr>
<td>39kΩ - 1/8 watt</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. Use Ohm’s Law to determine if the resistor’s power rating would be sufficient in each of the following conditions.

Would the power rating be sufficient if 11 volts were applied across the 1.2kΩ resistor?

______________________________________________________________

Would the power rating be sufficient if 50 mA were flowing through the 150Ω resistor?

______________________________________________________________

Would the power rating be sufficient if 350 volts were applied across the 300kΩ resistor?

______________________________________________________________
Series Circuits

Resistance in Series Circuits

Project Objective:
- To verify the series circuit resistance formula by making resistance measurements under various circuit conditions.

Items Needed:
- Electronics Trainer
- Digital multi-meter
- Jumper Wires
- Resistors: 3-10kΩ, 47kΩ, 100kΩ, & 220kΩ

When making resistance measurements, make sure there is no power applied to the circuit.

Experiment

1. Connect the circuit as shown in Figure 9-1.

Remember! Disconnect the power supply in this project!

2. Measure the resistance of the entire circuit using an ohmmeter. Remember to correctly label your answers.
   
   \[ R_{\text{total}} = \]_________________________.

3. Measure the resistance of each individual resistor, and record the values below.
   
   \[ R_1 = \]_________________________.
   \[ R_2 = \]_________________________.
   \[ R_3 = \]_________________________.

4. Since the total resistance of a series circuit equals the sum of the individual resistances,
   
   \[ R_1 + R_2 + R_3 = \]_________________________.

   Therefore \( R_T = \)_________________________.

5. What would the new \( R_T \) be if \( R_3 \) were changed to a 47kΩ resistor?
   
   Predicted \( R_T = \)_________________________.

6. Change \( R_3 \) to 47kΩ and measure the new total resistance.

   New \( R_T = \)_________________________.

7. In conclusion, if any single resistance in a series circuit increases, then the total resistance will ___________________. If any single resistance in a series circuit decreases then the total resistance will ___________________.

8. Configure the circuit so that \( R_1 = 220\Omega \), \( R_2 = 100\Omega \), and \( R_3 = 47\Omega \). Predict \( R_T \) and then measure \( R_T \) to verify.

   Predicted \( R_T = \)_________________________. Measured \( R_T = \)_________________________.

   Does the measured value equal the predicted value? ___________________.

   What could cause a difference? ___________________
Series Circuits
Current Flow in Series Circuits

Project Objective:
• To verify that the current in a series circuit is the same no-matter where the measurement is taken in the circuit.

Items Needed:
- Electronics Trainer
- Jumper Wires
- Digital multi-meter
- Resistors: 1kΩ, 4.7kΩ, 3.3kΩ, & 10kΩ

Make sure power supply is off when connecting meters or changing circuit components.

Experiment

1. Connect the initial circuit as shown in Figure 10-1.
2. Apply 11 volts to the circuit and measure the current.
   \[ \text{Current} = \text{____________________} \]
3. Swap positions of \( R_1 \) and the ammeter and record the new current reading.
   \[ \text{Current reading is now} \text{____________________}. \]
4. Swap positions of the ammeter with each of the remaining resistors and record the current readings.
   \[ \text{In every case, the current reading was} \text{____________________}. \]
   \[ \text{It doesn’t matter where the current measurement is taken in a series circuit. The current reading remains the same. This indicates that there is only} \text{____________________ path for current to flow}. \]
5. Change \( R_3 \) to a 10kΩ resistor. Move the meter to different points in the circuit and record the current readings.
   \[ \text{In all cases, the current reading was} \text{____________________}. \]
   \[ \text{By increasing the resistance in a series circuit we are affecting the current flow through all parts of the circuit. If we were to change} \text{\( R_T \)} \text{by decreasing it, would it change the} \text{\( I_T \)?} \text{____________________}.\]
   \[ \text{Would} \text{\( I_T \)} \text{increase or decrease?} \text{____________________}. \]
6. Now change \( V_A \) to 30 volts. Move the meter to different points in the circuit and record the current readings.
   \[ \text{In all cases, the current reading was} \text{____________________}. \]
   \[ \text{Increasing the} \text{\( V_A \)} \text{in a series circuit caused} \text{\( I_T \)} \text{to change through all parts of the circuit. It changed by the same amount in every point in the circuit. This is because the current throughout the entire series circuit is} \text{____________________ current}. \]
   \[ \text{a.) different} \quad \text{b.) alternating} \quad \text{c.) the same} \quad \text{d.) direct} \]
Series Circuits
Voltage in Series Circuits

Project Objective:
- To use measurements and calculations to demonstrate the proportional relationship of resistance and voltage in a series circuit.

Items Needed:
- Electronics Trainer
- Digital multi-meter
- Jumper Wires
- Resistors: 1kΩ, 4.7kΩ, 18kΩ

Make sure power supply is off when connecting meters or changing circuit components.

Experiment

1. Connect the initial circuit as shown in Figure 11-1.

2. Apply 12.5 volts to the circuit and fill in the following table.

<table>
<thead>
<tr>
<th>V_A =</th>
<th>V_1 =</th>
<th>V_2 =</th>
<th>V_3 =</th>
<th>I_T =</th>
</tr>
</thead>
</table>

3. Since the current is the same through all the resistors, the voltage drop across each resistor is directly related to its __________________________.

4. Add the individual voltage drops and record the sum.

\[ V_1 + V_2 + V_3 = __________________________. \]

Kirchhoff’s Voltage Law states that the sum of voltage drops around a closed loop circuit must equal the applied voltage (V_A). Does it? __________________________.

5. Calculate the percentage of the applied voltage that is dropped by each of the resistors. Use the following example for V_1 then solve for V_2 & V_3. **Percentage** = \[ \frac{V_1}{V_A} \times 100 \]

\[ V_1 = __________________________ \% of V_A \]

\[ V_2 = __________________________ \% of V_A \]

\[ V_3 = __________________________ \% of V_A \]

6. Predict what value V_3 would be if V_A were increased to 22 volts.

\[ V_3 \text{ Predicted} = __________________________. \]

Change V_A to 22 volts and measure V_3.

\[ V_3 \text{ Measured} = __________________________. \]

7. V_3 is now what percentage of V_A? __________________________ \%

Is this the same percentage as when the applied voltage = 12.5 volts? __________________________
Changing the applied voltage does not change the voltage drop percentages of $V_A$. If one of the $R$s were changed, would the distribution percentages change? __________________

In conclusion, in a series circuit, the largest $R$ will drop the __________________ voltage, and the smallest $R$ will drop the __________________ voltage.

8. Assuming $V_T = 22$ volts, calculate $V_1$ and $V_2$ using the voltage divider formula.

$$(V_x = \frac{R_x}{R_T} \times V_T)$$

$V_1$ calculated = __________________. $V_2$ calculated = __________________.

9. Measure $V_1$ and $V_2$ with 22 V applied to the circuit.

$V_1$ measured = __________________. $V_2$ measured = __________________.

Do the measured values of $V_1$ and $V_2$ validate the calculations using the voltage-divider formula? __________________
Series Circuits
Power in a Series Circuit

Project Objective:
- To demonstrate that power distribution in a series circuit is directly related to the distribution of resistance.
- To verify that the total power equals the sum of all the individual power dissipations.

Items Needed:
- Electronics Trainer
- Digital multi-meter
- Jumper Wires
- Resistors: 1kΩ, 4.7kΩ & 10kΩ

Make sure power supply is off when connecting meters or changing circuit components.

Experiment

1. Connect the initial circuit as shown in Figure 12-1.

2. Apply 20 volts ($V_A$) to the circuit. Measure each of the individual voltage drops and the current, and then calculate the power dissipated by each resistor.

   \[ V_1 = \text{___________________________} \]
   \[ V_2 = \text{___________________________} \]
   \[ V_3 = \text{___________________________} \]
   \[ I_T = \text{___________________________} \]

   \[ P_1 \text{ calculated} = \text{___________________________} \]
   \[ P_2 \text{ calculated} = \text{___________________________} \]
   \[ P_3 \text{ calculated} = \text{___________________________} \]

Since the current is the same through all the resistors, the power dissipated by each resistor is directly related to its _________________.

a.) power rating  b.) physical size  c.) composition  d.) resistance

The resistor with the largest value $R$ will dissipate the ___________________________ power.

a.) most  b.) least

The resistor with the smallest value $R$ will dissipate the ___________________________ power.

a.) most  b.) least

3. Record the sum of all the individual resistor power dissipations.

\[ P_1 + P_2 + P_3 = \text{___________________________} \]

Calculate the total power by using the formula: $P_T = V_T \times I_T$

\[ P_T = V_T \times I_T = \text{___________________________} \]
In conclusion, the total power in a series circuit equals the __________________ of all the individual power dissipations.

a.) product b.) sum

4. What is the percentage of \( P_1 \) to \( P_3 \)? \( P_1 = \frac{\text{_____________}}{\text{__________}} \) % of \( P_3 \).

The percentage of power between two resistors in a series circuit is the same as the percentage of ______________________ between the same two resistors.

5. What would happen to \( P_T \) if the applied voltage were reduced to half its original value? (Fill in the appropriate blanks using fractions.)

\[ P_T = \frac{\text{_____________}}{\text{__________}} \] as much as it did before. The individual power dissipations would be equal to \( \frac{\text{_____________}}{\text{__________}} \) the original value.

When the voltage is decreased to one-half for a given resistance, the circuit current will \( \frac{\text{_____________}}{\text{__________}} \) to \( \frac{\text{_____________}}{\text{__________}} \). This causes the power, or \( V \times I \) to be \( \frac{\text{_____________}}{\text{__________}} \) the original value. If the resistances remain the same but the voltage is changed, the actual value of power dissipated will (change, not change) \( \frac{\text{_____________}}{\text{__________}} \) but the percentage of \( P_T \) dissipated by a given resistance will (change, not change) \( \frac{\text{_____________}}{\text{__________}} \).

6. Change the \( V_A \) to 10 volts. Fill in the blanks by calculating and measuring the following values.

\[ V_A = \frac{\text{_____________}}{\text{__________}} \]
\[ V_2 = \frac{\text{_____________}}{\text{__________}} \]
\[ I = \frac{\text{_____________}}{\text{__________}} \]
\[ P_2 = \frac{\text{_____________}}{\text{__________}} \]
\[ P_T = \frac{\text{_____________}}{\text{__________}} \]
\[ V_3 = \frac{\text{_____________}}{\text{__________}} \]
\[ V_1 = \frac{\text{_____________}}{\text{__________}} \]
\[ P_3 = \frac{\text{_____________}}{\text{__________}} \]
\[ P_1 = \frac{\text{_____________}}{\text{__________}} \]

When the applied voltage was decreased to half its original value, current decreased to \( \frac{\text{_____________}}{\text{__________}} \) its original value and the total power dissipated in the circuit decreased to \( \frac{\text{_____________}}{\text{__________}} \) its original value. The power dissipated by each resistor also decreased to \( \frac{\text{_____________}}{\text{__________}} \) its original value.

Does this information verify step 5? ____________
Series Circuits
Detecting an Open in a Series Circuit

Project Objective:
- To provide experience with the change that occurs when an open develops in a series circuit.
- To prove that the applied voltage appears across the open portion of a series circuit.

Items Needed:
- Electronics Trainer
- Digital multi-meter
- Jumper Wires
- Resistors: 1kΩ, 4.7kΩ & 10kΩ

Make sure power supply is off when connecting meters or changing circuit components.

Experiment

1. Connect the initial circuit as shown in Figure 13-1.

2. Adjust the $V_A$ to 15 volts. Measure and record the current and individual voltage drops.
   \[
   I_T = \text{__________________________} \\
   V_1 = \text{__________________________} \\
   V_2 = \text{__________________________} \\
   V_3 = \text{__________________________}
   \]

3. Simulate an open circuit by removing $R_2$ and leave the circuit open between $R_1$ and $R_3$. Measure and record the current and individual voltage drops.
   \[
   I_T = \text{__________________________} \\
   V_1 = \text{__________________________} \\
   V_2 \text{(across open)} = \text{__________________________} \\
   V_3 = \text{__________________________}
   \]

Since there is only one path for current to flow in a series circuit, creating an open within the circuit will cause ________________.

a.) continuity       b.) discontinuity

The total resistance of the circuit then appears to be infinitely ________________.

a.) high       b.) low

The voltage drop across $R_1$ and $R_3$ were ___________ volts because, with zero current, the $I \times R$ must equal ___________.

If any part of a series circuit opens, $R_T$ will (increase, decrease) ________________

to ________________ and $I_T$ will (increase, decrease) ________________
to ______________________. The voltage drops across the unopened resistors will 
(increase, decrease) __________________ to __________________ and the 
voltage across the open resistor will (increase, decrease) __________________ to 
____________________.

4. Predict the results if $R_3$ were to be removed from the circuit instead of $R_2$.

$I_T = ________________________

$V_1 = ________________________

$V_2 = ________________________

$V_3 = ________________________

5. Replace $R_2$ and remove $R_3$ as suggested in step 4. Make the following measurements and 
record the results below.

$I_T = ________________________

$V_1 = ________________________

$V_2 = ________________________

$V_3 \text{ (across open) } = ________________________

Do these results verify the results of step 3? __________________
Series Circuits
Detecting a Short in a Series Circuit

Project Objective:
To provide experience with the changes that occur when a short develops in a series circuit.

Items Needed:
- Electronics Trainer
- Digital multi-meter
- Jumper Wires
- Resistors: 47kΩ & 2 - 10kΩ

Make sure power supply is off when connecting meters or changing circuit components.

Experiment

1. Connect the initial circuit as shown in Figure 14-1.

2. Adjust the $V_A$ to 15 volts. Measure and record the current and individual voltage drops.
   \[
   I_T = \quad \vdots \quad V_1 = \quad \vdots \quad V_2 = \quad \vdots \quad V_3 = \quad \vdots 
   \]

3. Simulate a resistor “shorting out” by removing $R_3$ and replacing it with a jumper wire. Measure and record the circuit current and individual voltage drops.
   \[
   I_T = \quad \vdots \quad V_1 = \quad \vdots \quad V_2 = \quad \vdots \quad V_3 (\text{across short}) = \quad \vdots 
   \]

   Shorting out $R_3$ caused the circuit $R_T$ to $(\text{increase, decrease}) \quad \vdots 
   \quad \to \quad \vdots \quad \text{ohms. This caused } I_T \text{ to } \quad \text{(increase, decrease)} \quad \vdots 
   \]

   The new current value caused the voltage drops across the unshorted resistors in the circuit to
   $(\text{increase, decrease}) \quad \vdots 
   \]

   The resistance of the simulated short (jumper wire) is essentially $\quad \vdots \quad$ ohms. Therefore, since $V = I \times R$, the voltage drop across the shorted resistor of a series circuit will essentially equal $\quad \vdots 
   
   We can conclude that if there is a short in any part of a series circuit, the $R_T$ will $(\text{increase, decrease}) \quad \vdots 
   \quad \text{; } I_T \text{ will } \quad \text{; the}

   \quad \text{voltage drop across the unshorted } R \text{ will } \quad \text{; and the voltage across the shorted } R \text{ will } \quad \text{; to } \quad \vdots
Parallel Circuits
Resistance in Parallel Circuits

Project Objective:
- To verify that the total resistance in a parallel circuit is less than the least value resistance in parallel.
- To provide practice using parallel resistance formulas and confirming them through circuit measurements.

Items Needed:
- Electronics Trainer
- Digital multi-meter
- Jumper Wires
- Resistors: 18kΩ, 100kΩ, 220kΩ & 3 - 10kΩ

When making resistance measurements, make sure there is no power applied to the circuit.

Experiment

1. Connect the circuit as shown in Figure 15-1.

2. Measure $R_T$ at points A and B.

   \[ R_T = \frac{R_1 \times R_2}{R_1 + R_2} \]

3. Calculate $R_T$ if a 10kΩ resistor were to be inserted between points C and D. Use the product over sum formula.

   $R_T$ calculated = ___________________________.

   When two equal resistors are connected in parallel, the total resistance is equal to ___________________________ the resistance of one branch.

4. After calculating $R_T$, use an ohmmeter and measure at points A and B with a second 10kΩ resistor inserted at points C and D.

   $R_T$ measured = ___________________________.

5. Calculate $R_T$ if a third 10kΩ resistor were to be inserted between points E and F. Use the reciprocal formula.

   \[ R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}} \]

   $R_T$ calculated = ___________________________.

   When three equal resistors are connected in parallel, the total resistance of the circuit is equal to ___________________________ the resistance of one branch.

6. After calculating $R_T$, use the ohmmeter and measure at points A and B with a third 10kΩ resistor inserted at points E and F.

   $R_T$ measured = ___________________________.

Figure 15-1
7. Using both parallel resistance formulas calculate $R_T$ if $R_2$ were changed to 100kΩ and $R_3$ were changed to 18kΩ.

Product over sum, $R_T$ Calculated = _______________________.

Reciprocal, $R_T$ Calculated = _______________________.

8. Change the circuit as described in step 7 and measure the total resistance of the circuit at points A and B.

$R_T$ measured = _______________________.

In conclusion, the total resistance in a parallel circuit is less than the (highest, lowest)
____________________ value resistive branch in parallel.

9. Now replace $R_3$ with a 220kΩ resistor. Calculate the total resistance using either formula then measure $R_T$ at points A and B.

$R_T$ calculated = _______________________.

$R_T$ measured = _______________________.

Does this result confirm the conclusion in step 8? _______________________

No matter how large the value of resistive branch that is added to a parallel circuit, the total resistance of the parallel circuit will be (higher, lower) ______________________ than the least value resistive branch in parallel.
Parallel Circuits
Current Flow in Parallel Circuits

Project Objective:
- To verify that the amount of current through parallel branches is inverse to the branch’s resistance value.
- To confirm Kirchhoff’s Current Law by verifying that the total current in a parallel circuit equals the sum of the individual branch currents.

Items Needed:
- Electronics Trainer
- Digital multi-meter
- Jumper Wires
- Resistors: 10kΩ, 18kΩ, 47kΩ, 100kΩ

Make sure power supply is off when connecting meters or changing circuit components.

Experiment

1. Connect the circuit as shown in Figure 16-1 and set the applied voltage to 10 volts.
2. Find the total circuit current and the current flowing through each parallel branch by breaking the circuit at the appropriate “X” in Figure 16-1 and measuring with an ammeter.
   Remember, the ammeter leads must be connected in series when taking current measurements!

   \[ I_1 = \text{_________} \quad I_3 = \text{_________} \]

   \[ I_2 = \text{_________} \quad I_T = \text{_________} \]

   The resistance value in \( R_2 \) is roughly _______ times larger than the resistance in \( R_1 \). The current through \( R_2 \) is roughly _______ the current through \( R_1 \). The resistance value in \( R_3 \) is roughly _______ times larger than the resistance in \( R_1 \). The current through \( R_3 \) is roughly _______ the current through \( R_1 \). We can conclude from this experiment that the current through parallel branches is inversely proportional to the branches’ _______. We can also observe from the measured currents that the total circuit current is equal to the _______ of the individual branch currents.

3. Remove \( R_2 \) from the circuit and replace it with a 100kΩ resistor. Leave the applied voltage at 10 volts and measure and record the circuit currents one at a time.

   \[ I_1 = \text{_________} \quad I_3 = \text{_________} \]

   \[ I_2 = \text{_________} \quad I_T = \text{_________} \]

   Did the current through \( R_1 \) or \( R_3 \) change when \( R_2 \) was increased to 100kΩ? _______
Did the total current change? _______________. If so, was the change in $I_T$ the same as the change in $I_2$? _______________. This proves that $I_T$ is the sum of all the _______________ currents. Since $R_1$ is $1/10$ the value of $R_2$, $I_1$ should be _______________ times the value of $I_2$. Is it? _______________
Parallel Circuits

Voltage in Parallel Circuits

Project Objective:
- To verify that branch voltages are equal in a parallel circuit.
- To verify that each branch voltage equals the applied voltage in parallel circuits.

Items Needed:
- Electronics Trainer
- Digital multi-meter
- Jumper Wires
- Resistors: 3 - 10kΩ, 100kΩ, 220kΩ

Make sure power supply is off when connecting meters or changing circuit components.

Experiment

1. Connect the circuit as shown in Figure 17-1.

2. Apply 12 volts to the circuit and measure and record all of the branch voltages.

   \[ V_A = \text{_______________________________}. \]

   \[ V_1 = \text{______________________________}. \]

   \[ V_2 = \text{______________________________}. \]

   \[ V_3 = \text{______________________________}. \]

   What two facts can we conclude from the above measurements?

   _____________________________________________________________

   _____________________________________________________________

   _____________________________________________________________

   _____________________________________________________________

3. Change the value of \( R_3 \) from 10kΩ to 100kΩ. Keep the applied voltage at 12 volts and measure all of the branch voltages and the source voltage and record the results below.

   \[ V_A = \text{______________________________}. \quad V_2 = \text{______________________________}. \]

   \[ V_1 = \text{______________________________}. \quad V_3 = \text{______________________________}. \]

   Did all of the voltages measure the same as in step 2? __________________________

   This indicates that if the resistance value of a branch in a parallel circuit is changed, it will not affect the branch voltages. These branch “voltages” are not separate voltages but are in fact the same voltage.

   Does the total circuit current change if one branch resistance changes? ______________________

   Does the current change through the unchanged resistance branches? ______________________

   Does the current change through the changed resistance branch? ______________________
4. Add a fourth parallel branch by inserting a 220kΩ resistor to the end of the circuit. We will label this resistor as $R_4$. Measure and record the circuit voltages with the 12 volts applied.

$V_A = \underline{\hspace{2cm}}$, $V_3 = \underline{\hspace{2cm}}$.
$V_1 = \underline{\hspace{2cm}}$, $V_4 = \underline{\hspace{2cm}}$.
$V_2 = \underline{\hspace{2cm}}$.

We can conclude that when we add additional resistive branches to a parallel circuit, this change $\underline{\hspace{2cm}}$ affect the voltage across the other parallel branches.
Parallel Circuits
Power in a Parallel Circuit

Project Objective:
- To verify that the power dissipation in a parallel branch is inverse to that branch’s resistance value.
- To verify that total power in a parallel circuit is equal to the sum of all the individual branch power dissipations.

Items Needed:
- Electronics Trainer
- Digital multi-meter
- Jumper Wires
- Resistors: 2 - 10kΩ, 18kΩ, 47kΩ

Make sure power supply is off when connecting meters or changing circuit components.

Experiment

1. Connect the circuit as shown in Figure 18-1.
   ![Figure 18-1](image)

2. Apply 12 volts to the circuit. Break the circuit at the appropriate "X" in Figure 18-1 to measure each of the branch currents. Record the results below.
   \[ I_1 = \text{______________________________} \]
   \[ I_2 = \text{______________________________} \]
   \[ I_3 = \text{______________________________} \]

   Since the total circuit current is equal to the \( \text{sum of the individual branch currents} \), the total current for this circuit must be \( \text{______________________________ mA} \).

   Since the total power in a resistive circuit can be calculated as \( \text{______________________________ times} \) \( \text{______________________________} \), then the total power dissipated by this circuit is \( \text{______________________________ mW} \).

3. Calculate the individual power dissipations of the three branch resistances.
   \[ P_1 = \text{______________________________} \]
   \[ P_2 = \text{______________________________} \]
   \[ P_3 = \text{______________________________} \]

   Does \( P_1 + P_2 + P_3 \) equal the answer given for \( P_T \) in step 2? \( \text{______________________________} \)

   Which resistor dissipates the most power? \( \text{______________________________} \) Is this the largest or the smallest value resistor in the circuit? \( \text{______________________________} \)

   Which resistor dissipates the least power? \( \text{______________________________} \) Is this the largest or the smallest value resistor in the circuit? \( \text{______________________________} \)

   In conclusion, the smaller a branch resistance is in a parallel circuit, the \( \text{______} \) amount of power it will dissipate. The voltage through each
branch is equal and the current is __________________ proportional to the branch resistance. Therefore \( V \times I \) will be greater if the resistor is of __________________ value.

4. Remove \( R_2 \) and replace it with a 10kΩ resistor. Complete the following table by measuring each branch current and calculating the individual power dissipations and the total circuit power. Keep the applied voltage at 12 volts.

<table>
<thead>
<tr>
<th>( V_A = )</th>
<th>( I_1 = )</th>
<th>( I_2 = )</th>
<th>( I_3 = )</th>
<th>( P_1 = )</th>
<th>( P_2 = )</th>
<th>( P_3 = )</th>
<th>( P_T = )</th>
</tr>
</thead>
</table>

When the resistance in one branch changed did it cause the power dissipated in that branch to change? ____________________________

When the resistance in the one branch changed did it cause the power dissipated through the unchanged resistive branches to change? ____________________________

When the resistance in the one branch changed did it cause the total power dissipated in the circuit to change? ____________________________
Parallel Circuits
Detecting an Open in a Parallel Circuit

Project Objective:
- To provide experience with the change that occurs when an open develops in a parallel circuit.
- To verify that the total circuit current will decrease by the same amount that was passing through the defective branch prior to it becoming open.

Items Needed:
- Electronics Trainer
- Digital multi-meter
- Jumper Wires
- Resistors: 47kΩ, 100kΩ, 220kΩ

Make sure power supply is off when connecting meters or changing circuit components.

Experiment

1. Connect the circuit as shown in Figure 19-1.

2. Apply 30 volts to the circuit. Measure the total circuit current and the individual branch currents. Calculate \( R_T \).
   \[
   I_T = ____________________________.
   \]
   \[
   R_T = ___________________________.
   \]
   \[
   I_1 = ____________________________.
   \]
   \[
   I_2 = ____________________________.
   \]
   \[
   I_3 = ____________________________.
   \]

The total resistance is less than the __________________________ value resistance branch.
   a.) highest  b.) lowest  c.) both a & b

The total circuit current is equal to the __________________________ of the branch currents.

3. Remove resistor \( R_1 \) to simulate an open in that particular branch. Keep the applied voltage at 30 volts and measure the total circuit current and the individual branch currents. Calculate \( R_T \).
   \[
   I_T = ____________________________.
   \]
   \[
   I_2 = ____________________________.
   \]
   \[
   R_T = ___________________________.
   \]
   \[
   I_3 = ____________________________.
   \]

If any branch of a parallel circuit becomes open, \( R_T \) will __________________. Therefore, since the voltage remained the same, \( I_T \) will __________________.

Did the current through \( R_2 \) and \( R_3 \) change when \( R_1 \) became open? __________________________

\( R_T \) increased because when \( R_1 \) became open there was one less __________________ path.

The current through the open branch decreased to __________________ mA.

When \( R_1 \) became open, what happened to the current through the unopened branches?
Did the voltage across all the branches change when $R_1$ became open? 

4. Using the normal circuit condition values in step 2, calculate each branch power dissipation and the total circuit power dissipation.

$$P_T = \underline{\hspace{1cm}}$$  
$$P_2 = \underline{\hspace{1cm}}$$

$$P_1 = \underline{\hspace{1cm}}$$  
$$P_3 = \underline{\hspace{1cm}}$$

5. Calculate each branch power dissipation and the total circuit power dissipation using the values when $R_1$ was open in step 3.

$$P_T = \underline{\hspace{1cm}}$$  
$$P_2 = \underline{\hspace{1cm}}$$

$$P_1 = \underline{\hspace{1cm}}$$  
$$P_3 = \underline{\hspace{1cm}}$$

When one branch of a parallel circuit becomes open, is the power dissipated by the other branches affected? 

Is $P_T$ affected? 

$P_T$ will \underline{\hspace{1cm}} by the same amount of power that was being dissipated by the opened branch before it became open.
Parallel Circuits
Detecting a Short in a Parallel Circuit

Project Objective:
To provide experience with resistance changes that occur when a short develops in a parallel circuit.

Items Needed:
- Electronics Trainer
- Digital multi-meter
- Jumper Wires
- Resistors: 47kΩ, 100kΩ, 220kΩ

Do not use the power supply for this project!

Experiment

1. Connect the circuit as shown in Figure 20-1.

2. Using an ohmmeter, measure between points A and B to find the total resistance of the circuit. Remember, there is to be no power applied to the circuit when making resistance measurements!

   \[ R_T = \] ________________.

3. Simulate \( R_1 \) becoming shorted by removing it and replacing it with a jumper wire. Measure the new \( R_T \) and record the result below.

   New \( R_T = \) ________________.

   When a branch of a parallel circuit is shorted, \( R_T \) (increases, decreases) ________________ to ________ Ω. Without connecting the power supply, assume there is 10v applied between points A and B. How much current would be going through \( R_2 \)? ________________.

   How much current would be going through \( R_3 \)? ________________.

   With the assumed 10v applied, what would the voltage reading be across \( R_2 \)? ________________

   Across \( R_3 \)? ________________.

   Assume there is 0.01Ω of resistance in the shorted circuit. Use the assumed 10v applied and calculate the circuit current using Ohm’s Law.

   \[ I_T = \] ________________.

   Would this be enough current to blow the fuse on the power supply? ________________

4. Remove the jumper wire and place \( R_1 \) back into the circuit. Now simulate a short in branch \( R_2 \) by replacing resistor \( R_2 \) with a jumper wire. Measure and record \( R_T \) again.

   \[ R_T = \] ________________.

   A short in any branch of a parallel circuit will cause \( R_T \) to ________________ to ________ Ω.

   Does the current through the “un-shorted” branch increase or decrease? ________________
Does the current through the “shorted” branch increase or decrease? ____________________

Does the voltage through all the branches increase or decrease? ____________________

If any one branch of a parallel circuit is shorted it appears that all the branches are shorted. Although only one branch contains the actual shorted element that causes the undesired low path of resistance nearly approaching _________ Ω.
Combination Circuits  
Resistance in Series-Parallel Circuits

Project Objective:  
To verify series and parallel resistance rules as they apply to series-parallel combination circuits.

Items Needed:  
- Electronics Trainer  
- Digital multi-meter  
- Jumper Wires  
- Resistors: 1kΩ, 4 - 10kΩ

Make sure power supply is off when connecting meters or changing circuit components.

Experiment

1. Connect the circuit as shown in Figure 21-1.

2. Calculate the total circuit resistance from the resistor values given.
   \[ R_T = \ \text{__________________________}. \]

3. Apply enough voltage to obtain a total circuit current of 1.2mA. Measure and record the following voltages.
   \[ V_A = \ \text{__________________________}. \]
   \[ V_1 = \ \text{__________________________}. \]
   \[ V_2 = \ \text{__________________________}. \]
   \[ V_3 = \ \text{__________________________}. \]
   \[ V_4 = \ \text{__________________________}. \]
   Since the applied voltage is _________________ V and the total circuit current is _________________ mA, then according to Ohm’s Law the total resistance must be _________________ Ω. Is this close to the result in step 1? _________________

Which resistors in this circuit are in parallel? _________________

Is the voltage the same across these resistors? _________________

Which resistors are in series and carry \( I_T \)? _________________

4. Disconnect the power supply and the ammeter from the circuit and measure the total resistance with an ohmmeter.
   \[ R_T = \ \text{__________________________}. \]

In conclusion, in series-parallel combination circuits, the total resistance equals the sum of all the components in _________________ plus the equivalent resistance of parallel components whose combined resistance is effectively in _________________ with the components in the main line.
5. Calculate what the total resistance of the circuit would be if a 10kΩ resistor \( R_5 \) were added in parallel to \( R_2 \). Use Figure 21-2 as a reference.

\[ R_{T\,\,\text{calc}} = \text{___________________________} \]

6. Connect the circuit as described in step 5 and measure \( R_T \). **Make sure there is no power applied to the circuit.**

\[ R_{T\,\,\text{meas}} = \text{___________________________} \]

Briefly describe the process used to calculate \( R_T \) for this circuit.

_________________________________________________________________________

_________________________________________________________________________

_________________________________________________________________________

_________________________________________________________________________

Would \( R_T \) change if the jumper above \( R_3 \) and \( R_4 \) and below \( R_2 \) and \( R_5 \) were to be removed from the circuit? _____________________
Combination Circuits
Current in Series-Parallel Circuits

Project Objective:
To better understand the characteristics of current flow in series-parallel combination circuits by combining both the series and parallel circuit analysis methods previously learned in the course.

Items Needed:
- Electronics Trainer
- Jumper Wires
- Digital multi-meter
- Resistors: 1kΩ, 3.3kΩ, 4 - 10kΩ, 2 - 47kΩ, 100kΩ

Make sure power supply is off when connecting meters or changing circuit components.

Experiment

1. Connect the circuit as shown in Figure 22-1.

2. Connect the ammeter to read \( I_T \) and apply just enough voltage to have a total circuit current of 600µA.
Measure all of the voltage drops and the current through each component. Record your results below.

\[
\begin{align*}
V_A &= \text{______________________________} . \\
V_1 &= \text{______________________________} . \\
V_2 &= \text{______________________________} . \\
V_3 &= \text{______________________________} . \\
V_4 &= \text{______________________________} . \\
V_5 &= \text{______________________________} . & I_3 &= \text{______________________________} . \\
V_6 &= \text{______________________________} . & I_4 &= \text{______________________________} . \\
V_7 &= \text{______________________________} . & I_5 &= \text{______________________________} . \\
I_1 &= \text{______________________________} . & I_6 &= \text{______________________________} . \\
I_2 &= \text{______________________________} . & I_7 &= \text{______________________________} . \\
\end{align*}
\]

Which components have the total circuit current flowing through them? ________________

What is the resistance of only the parallel portion of the circuit after it has been simplified?

__________________________

It should be noted that in series-parallel circuits, the current flow through a given component depends on where the component is located in the circuit. The series “portion” of the circuit can be solved by using the same rules as used in __________________________ circuits, and the parallel “portion” can be solved by using the rules for __________________________ circuits. The circuit can then be finalized by combining the results of both the series and the parallel portions of the circuit.
3. Predict what will happen to all the circuit currents if $R_6$ were changed to a 47kΩ resistor. Indicate below whether each current will *increase, decrease or stay the same*.

$I_1$ will __________________________.  $I_5$ will __________________________.

$I_2$ will __________________________.  $I_6$ will __________________________.

$I_3$ will __________________________.  $I_7$ will __________________________.

$I_4$ will __________________________.  $I_T$ will __________________________.

Increasing the resistance value of any component in a series-parallel combination circuit will cause the total current to __________________________.  This is true with not only combination circuits but for any circuit.  It is possible for component currents to increase in a parallel circuit because of the changed resistance value.  This is due to the fact that a larger percentage of the total current will pass through the unchanged parallel branch.

4. Verify your predictions in step 3 by replacing $R_6$ with a 47kΩ resistor.  Measure all of the circuit voltage drops and currents using the same applied voltage used in step 2.

$V_1 = \underline{\phantom{0000}}$.  $I_1 = \underline{\phantom{0000}}$.

$V_2 = \underline{\phantom{0000}}$.  $I_2 = \underline{\phantom{0000}}$.

$V_3 = \underline{\phantom{0000}}$.  $I_3 = \underline{\phantom{0000}}$.

$V_4 = \underline{\phantom{0000}}$.  $I_4 = \underline{\phantom{0000}}$.

$V_5 = \underline{\phantom{0000}}$.  $I_5 = \underline{\phantom{0000}}$.

$V_6 = \underline{\phantom{0000}}$.  $I_6 = \underline{\phantom{0000}}$.

$V_7 = \underline{\phantom{0000}}$.  $I_7 = \underline{\phantom{0000}}$.

$V_A = \underline{\phantom{0000}}$.  $I_T = \underline{\phantom{0000}}$.

Do these measurements agree with the predictions in step 3?  __________________________

5. Change $R_6$ from the 47kΩ to a 3.3kΩ resistor.  This resistor is less than the original 10kΩ used in step 2.  Predict which currents will increase and which ones will decrease.  Record your predictions below.  After predicting, make measurements as needed to verify or correct your predictions.

Which currents will increase?  __________________________

Which currents will decrease?  __________________________

Decreasing the resistance value of any component in a series-parallel combination circuit will cause the total current to __________________________.  This is true with not only combination circuits but for any circuit.  It is possible for a component current to decrease in a parallel circuit when the total circuit current is increased.  This is because a smaller percentage of the total current will pass through the unchanged parallel branch.
Combination Circuits
Voltage in Series-Parallel Circuits

Project Objective:
- To better understand the characteristics of voltage distribution in a series-parallel circuit by taking measurements and making observations.
- To verify that a component’s voltage drop is affected by that component’s value and location in a series-parallel circuit.

Items Needed:
- Electronics Trainer
- Digital multi-meter
- Jumper Wires
- Resistors: 1kΩ, 3 - 10kΩ, 18kΩ

Make sure power supply is off when connecting meters or changing circuit components.

Experiment

1. Connect the circuit as shown in Figure 23-1.

2. Assume there is a total current of 700µA. Calculate all of the circuit voltages and record the results below.

\[ V_1 = \] \[ V_2 = \]
\[ V_3 = \]
\[ V_4 = \]
\[ V_5 = \]

What would the applied voltage need to be to obtain these results? ________________________________

3. Apply the correct amount of voltage to obtain 700µA of total circuit current. Measure all of the circuit voltages and record the results below.

\[ V_1 = \] \[ V_4 = \]
\[ V_2 = \] \[ V_5 = \]
\[ V_3 = \] \[ V_A = \]

Did the measurements confirm the calculations in step 2? ________________________________

Did the largest resistor have the largest voltage drop? ________________________________ Why or why not?

Which components does \( I_T \) pass through? ________________________________

The combined resistance of the parallel section can be considered to be in series with the
4. Will \( V_3 \) increase or decrease if \( R_5 \) is replaced with a jumper wire? ____________________.

5. Make the circuit change suggested in step 4.

Did \( V_3 \) change as predicted in step 4? ____________________

When the resistance in a parallel branch is decreased, this causes the total circuit current to _________________. This causes the voltage drops of the components that are in series with the main line to _________________. Because of this, a lesser amount of applied voltage is dropped across \( R_3 \).
Combination Circuits
Power in a Series-Parallel Circuit

Project Objective:
• To illustrate the power distribution characteristics of a combination circuit by making measurements and calculations.
• To verify that the electrical parameters of a series-parallel circuit are influenced by the “electrical location” rather than the physical location of a component.

Items Needed:
- Electronics Trainer
- Digital multi-meter
- Jumper Wires
- Resistors: 1kΩ, 10kΩ, 18kΩ, 47kΩ

Make sure power supply is off when connecting meters or changing circuit components.

Experiment

1. Connect the circuit as shown in Figure 24-1.

2. Apply the correct amount of voltage to obtain 1.2mA of total circuit current. Calculate $R_T$ and $V_A$ and record your results below.

\[ R_{T \text{ calc}} = \text{__________________________}. \]

\[ V_{A \text{ calc}} = \text{__________________________}. \]

3. Measure each individual voltage drop and calculate the power dissipated by each component in the circuit.

\[ V_A = \text{__________________________}. \]

\[ V_1 = \text{__________________________}. \]

\[ V_2 = \text{__________________________}. \quad P_1 = \text{__________________________}. \]

\[ V_3 = \text{__________________________}. \quad P_2 = \text{__________________________}. \]

\[ V_4 = \text{__________________________}. \quad P_3 = \text{__________________________}. \]

\[ P_T = \text{__________________________}. \quad P_4 = \text{__________________________}. \]

What two units are directly proportional to the power dissipated in this series-parallel circuit?
1. ____________________________ 2. ____________________________

Is this true with any circuit? ____________________________

Do the components in the parallel portion of the circuit dissipate more or less power with a higher resistor value? ____________________________

Do the components in the series portion of the circuit dissipate more or less power with a higher resistor value? ____________________________

Which component in the circuit dissipated the most power? ____________________________
Notice that this is not the largest resistance value in the circuit. Only in a simple series circuit the largest resistance value dissipates the most power. Also notice that it is not the smallest resistance value in the circuit. Only in a simple parallel circuit the smallest resistance value dissipates the most power. This proves that power distribution in a series-parallel circuit depends on the electrical ______________________ of the component being considered.

4. Swap $R_3$ and $R_4$. Use voltage measurements to determine if the powers dissipated by each of the resistances have changed.

Are the results the same or different? ______________________

Obviously the ______________________ location of the components is not important but the ______________________ location determines the distribution of power in a series-parallel combination circuit.
Combination Circuits
Detecting an open in a Series-Parallel Circuit

Project Objective:
- To demonstrate the effects of an open occurring in both the series and parallel portions of a combination circuit.
- To observe what happens to the total circuit current when an open occurs in a series-parallel circuit.

Items Needed:
- Electronics Trainer
- Digital multi-meter
- Jumper Wires
- Resistors: 1kΩ, 3 - 10kΩ, 47kΩ

Make sure power supply is off when connecting meters or changing circuit components.

Experiment

1. Connect the circuit as shown in Figure 25-1.

2. Apply the correct amount of voltage to obtain 1.2mA of total circuit current. Measure the circuit voltages and record them below.

\[ V_A = \] ________________
\[ V_1 = \] ________________
\[ V_2 = \] ________________
\[ V_3 = \] ________________
\[ V_4 = \] ________________
\[ V_5 = \] ________________

3. Measure the current through each component.

\[ I_T = \] ________________
\[ I_3 = \] ________________
\[ I_4 = \] ________________
\[ I_5 = \] ________________

Which resistances in this circuit does \( I_T \) flow through? ________________ This is because these resistances are in ________________ with the main line.

What resistances have the same voltage drop? ________________ This is because these resistances are in ________________ with the main line components.

4. Remove resistor \( R_5 \) from the circuit. This will simulate an “open” in the main line of the circuit. Measure and record the following circuit voltages.

\[ V_A = \] ________________
\[ V_3 = \] ________________
\[ V_1 = \] ________________
\[ V_4 = \] ________________
$V_2 = \text{______________________________}$. 
$V_5 = (\text{across the open}) \text{______________________}$. 

What happened to the voltage drops across all of the “good” components in the circuit?

_______________________________________________________________________________

The voltage drop across the “open” resistor is equal to the ______________________ voltage.

Explain what happens to $I_T$ when an open occurs to a component that is in series with the source. _____________________________

_______________________________________________________________________________

5. Replace $R_5$. Now remove $R_2$ to simulate it becoming “open”. Measure the circuit voltages and record them below.

$V_A = \text{______________________________}$. 
$V_3 = \text{______________________________}$. 
$V_1 = \text{______________________________}$. 
$V_4 = \text{______________________________}$. 
$V_2 = (\text{across the open}) \text{______________________}$. 
$V_5 = \text{______________________________}$. 

When compared to the values in step 2, what happened to the voltage drops across the components in series with the main line? _____________________________

_______________________________________________________________________________

When compared to the values in step 2, what happened to the voltage drops across the components directly in parallel with the open? _____________________________

_______________________________________________________________________________

What happened to $I_T$ when compared to the calculated value in step 3? _____________________________

_______________________________________________________________________________

It does not matter whether an open occurs in the series or parallel portion of a combination circuit the total circuit resistance will always ______________________ and the total circuit current will ______________________.
Combination Circuits
Detecting a short in a Series-Parallel Circuit

Project Objective:
- To demonstrate the effects of a short occurring in both the series and parallel portions of a combination circuit.
- To observe what happens to the total circuit current when a short occurs in a series-parallel circuit.

Items Needed:
- Electronics Trainer
- Digital multi-meter
- Jumper Wires
- Resistors: 1kΩ, 3 - 10kΩ, 47kΩ

Make sure power supply is off when connecting meters or changing circuit components.

Experiment

1. Connect the circuit as shown in Figure 26-1.
2. Apply the correct amount of voltage to obtain 700 µA of total circuit current. Measure the circuit voltages and record them below.

\[ V_A = \quad \text{(measure here)} \]
\[ V_1 = \quad \text{(measure here)} \]
\[ V_2 = \quad \text{(measure here)} \]
\[ V_3 = \quad \text{(measure here)} \]
\[ V_4 = \quad \text{(measure here)} \]
\[ V_5 = \quad \text{(measure here)} \]

3. Measure the current through each component.

\[ I_T = \quad \text{(measure here)} \]
\[ I_3 = \quad \text{(measure here)} \]
\[ I_1 = \quad \text{(measure here)} \]
\[ I_4 = \quad \text{(measure here)} \]
\[ I_5 = \quad \text{(measure here)} \]

In this circuit, \( I_T \) flows through _____________ and _____________.

The voltage drops of _____________, _____________ and _____________ are the same because they are all in parallel to the main line components.

4. Simulate a short in \( R_1 \) by replacing it with a jumper wire. Measure and record the new voltages.

\[ V_A = \quad \text{(measure here)} \]
\[ V_3 = \quad \text{(measure here)} \]
\[ V_1 = \quad \text{(across the short)} \quad \text{(measure here)} \]
\[ V_4 = \quad \text{(measure here)} \]
5. Remove the jumper wire and replace \( R_1 \). Now simulate \( R_3 \) shorting out by replacing it with a jumper wire. Measure the new voltage drops and record your results below.

\[
\begin{align*}
V_A &= \text{___________________________}. & V_3 &= \text{(across the short) \__________}. \\
V_1 &= \text{___________________________}. & V_4 &= \text{___________________________}. \\
V_2 &= \text{___________________________}. & V_5 &= \text{___________________________}. \\
\end{align*}
\]

Explain what happened to the voltage drops of the components that were in parallel with the short. __________________________________________________________

________________________________________________________________

What happened to the voltage drops of the components that were in series with the main line?

________________________________________________________________

In conclusion, a short anywhere in the circuit will cause total circuit resistance to

\[
\text{___________________________}
\]

therefore the total current will \text{___________________________}. This is true not only for series-parallel combination circuits, but for any circuit.
Circuit Troubleshooting Strategies

The job of a technician frequently entails "troubleshooting" malfunctioning circuits. Good troubleshooting skills, although highly demanded in industry, require a thorough understanding of the basic concepts, and a sense of creativity in applying a solution to correct the problem.

An essential skill to possess is a ready and intuitive understanding of how component faults affect circuits in different configurations.

Not every electrical circuit is similar in design. This means every malfunctioning circuit will require a different method and approach to finding and correcting the problem. This can be very overwhelming to the inexperienced troubleshooter who does not know where to even start. One thing is for certain; having a good understanding of the Ohm’s Law relationships and the rules for series and parallel circuits is the first step to becoming a top-notch electrical troubleshooter.

Troubleshooting Series Circuits

Series circuits are usually the simplest type of circuit to troubleshoot because voltmeters can easily be used to locate voltage drops across specific components in the circuit.

As you learned earlier in this book, there are really only two types of faults in an electrical circuit, opens and shorts.

When using a voltmeter to check for opens and shorts in a series voltage divider circuit, try to think about the Ohm’s Law relationship of voltage and resistance. The higher the resistance a component has, the higher the voltage drop across that component. Consequently, the lower the component resistance, the lower the voltage drop.

An open in the circuit will essentially be an infinite amount of resistance and will therefore have the maximum voltage drop or "source voltage" across it. Any other amount of resistance in the circuit will be irrelevant and will have no voltage drop. Even resistors with large values in the Mega-ohms cannot compare to an infinite amount of resistance.

In Figure T-1, resistor R₂ has become open. This creates a situation where electrical current is not flowing in the circuit. The voltage drop across the open will be equal to the full source voltage and the voltage drop across any other resistance in the circuit will be zero.

![Figure T-1](image-url)
Just as an open in a circuit will act as an infinite amount of resistance, a short in a circuit will act as a resistance value of zero. Since a small amount of resistance in a series circuit will have a small voltage drop, a resistance value of zero will have zero voltage drop. Think of it as measuring the voltage drop across the ends of a small piece of wire in a circuit.

In Figure T-2, $R_1$ has become shorted. This creates a situation where more current is flowing in the circuit than normal. There will be no voltage across the short at $R_1$ and the total source voltage will be measured across all the remaining components in the circuit.

Voltmeters are usually the desired tool for detecting problems in series circuits. If you noticed, however, the voltmeters in Figures T-1 and T-2 indicated the same voltage readings across the same components in both scenarios. If there were a third resistor connected in series, this would be a much easier circuit to troubleshoot because it would create a voltage divider that could be used to determine the open condition in Figure T-1 or the shorted condition in Figure T-2.

With this example circuit, an ammeter could be used in addition to the voltmeter to measure the circuit current. If a current is detected, then an open condition could not exist and the fault would most likely be the scenario in Figure T-2. If no current flow is detected in the circuit, then an open will exist somewhere and would suggest the scenario in Figure T-1.

An ohmmeter could also be used in addition to the voltmeter as long as the individual components or the power supply can be disconnected from the circuit.

**Troubleshooting Parallel Circuits**

Parallel circuits can be very challenging to troubleshoot. This is mainly because of the parallel voltage rule: “The voltage drop across any parallel branch equals the applied voltage”. For example, in Figure T-3, $R_2$ has become open. If a voltmeter were used to troubleshoot this circuit, the source voltage would be detected across all three parallel branches and the technician would be unable to determine which of the three parallel branches is faulted.
If an ohmmeter were used to measure each resistive branch in the circuit (assuming the power supply is disconnected and the components cannot easily be removed from the circuit), the result would be the parallel combination of $R_1$ and $R_3$ across each parallel branch as shown in Figure T-4. In this example, the defective parallel branch is fairly easy to determine from the ohmmeter reading because of the parallel resistance rule: “The total resistance of a parallel circuit is always less than the lowest-value resistive branch”. The meter measures 66.67Ω which is higher than $R_2$’s specified resistance of 50Ω. What if the fault were in one of the other branches? What if there were 20 resistive branches connected in parallel? This could be very difficult and time consuming to diagnose with an ohmmeter. There is a better way.

If an open branch is suspected in a parallel circuit, the best method of locating the open branch is to begin by imagining the circuit has no faults and is functioning properly. Use Ohm’s Law to calculate the total circuit current and the individual branch currents. In the example, the applied voltage is 12 volts. The branch currents can be calculated in the following manner:

$$I_1 = \frac{12\, \text{V}}{100\, \Omega}, \quad I_2 = \frac{12\, \text{V}}{50\, \Omega}, \quad I_3 = \frac{12\, \text{V}}{200\, \Omega}$$

$$I_1 = 120\, \text{mA} \quad I_2 = 240\, \text{mA} \quad I_3 = 60\, \text{mA} = I_T = 420\, \text{mA}$$

If the circuit were functioning properly, a circuit current of 420mA should be measured on its main line.

When the technician measures the current in the example circuit, only 180mA is detected. When the measured circuit current (180mA) is then subtracted from the calculated circuit current (420mA), there is a difference of 240mA. This is the same as the calculated current that should be going through branch $R_2$. This would then indicate that $R_2$ is open.

This method would obviously not work if each parallel branch had the same resistive value. If this is ever the case, begin by looking for signs of excessive heating or loose connections. The last resort would be to unsolder or disconnect one terminal of each resistor and individually check each component with an ohmmeter.

If a short ever occurs in a parallel circuit, this usually spells disaster. Current will always take the path of least resistance. Since a short creates a very low resistance path for current, the total current will be very large and most likely trip the circuit breaker or blow a fuse. If no circuit protection device exists, a shorted parallel branch could very easily damage the power supply or even start an electrical fire.
Shorted parallel branches can be very difficult to locate in a circuit. This is because ohmmeters will indicate zero ohms of resistance across every resistive branch connected in parallel. The circuit also cannot be energized to take voltage and current readings because the circuit protection device will trip. Even if the power supply and protection device could handle the high current, chances are the meter will not.

The best way to diagnose a circuit such as this is to disconnect one end of each resistive component in the circuit and check for resistance with an ohmmeter.

**Troubleshooting Combination Circuits**

Since combination circuits contain both series and parallel portions, the rules for both series and parallel may apply depending on where the fault is located in the circuit.

Suppose we suspect the circuit in Figure T-6 may have a problem. Voltage readings across each component indicate a voltage drop across each series resistance as well as a voltage drop across the parallel resistances. Since each component has a voltage drop, we can determine that no shorted components exist in the circuit. Since the voltage drops across the components in the series portion of the circuit are all less than the source voltage, we can also conclude that the series portion of the circuit contains no opens.

So far this circuit appears to be functional, but there is one more possibility that could easily be overlooked.

An ammeter connected in series with the main current line indicates a total circuit current of 36.92mA. If the current values are calculated with the use of Ohm’s Law, we find that the total circuit current should be 39.40mA.

\[
R_T = \frac{1}{\frac{1}{200\Omega} + \frac{1}{75\Omega}} + 100\Omega + 150\Omega
\]

\[
R_T = 304.55\Omega
\]

\[
I_T = \frac{12V}{304.55\Omega}
\]

\[
I_T = 39.40mA
\]

The ammeter is definitely reading a lower value of current than it should be if this circuit was functioning properly. Since all other possibilities have been eliminated, there must be a missing current path somewhere in the parallel portion of the circuit. This would indicate either branch \( R_3 \) or \( R_4 \) is open.
To further narrow down the possibilities, the circuit can be recalculated assuming R₃ or R₄ is open. This can be done by redrawing and solving the circuit with the absence of one of the parallel resistances. We will begin by removing R₄ from the circuit.

When R₄ is removed from the circuit, the result is a three resistance series circuit that can easily be solved to determine \( I_T \).

\[
R_T = 150\Omega + 100\Omega + 200\Omega
\]

\[
R_T = 450\Omega
\]

\[
I_T = \frac{12\text{V}}{450\Omega} \quad I_T = 26.67mA
\]

With R₄ removed from the circuit to simulate an open, the calculated circuit current is 26.67mA. This does not match the measured 36.92mA.

From this we can determine that R₄ is not the open resistance and through the process of elimination R₃ is the only possible component remaining.

In order to verify our theory, the circuit can be drawn and re-calculated with the absence of R₃ in the same method.

\[
R_T = 150\Omega + 100\Omega + 75\Omega
\]

\[
R_T = 325\Omega
\]

\[
I_T = \frac{12\text{V}}{325\Omega} \quad I_T = 36.92mA
\]

Sure enough the resultant calculated current when R₃ is removed from the circuit is 36.92mA, a match for the ammeter reading.

This verifies that resistive branch R₃ is the malfunctioning component in the circuit.

**Documentation Methods**

Troubleshooting small 3 or 4 resistance circuits as in the previous examples do not take very many steps and are fairly easy to recall prior observations and conclusions. What if a technician were asked to troubleshoot a large electrical circuit with dozens of components and numerous connection points?

It is always wise to document each step when troubleshooting a circuit. This can be an extremely helpful resource for recalling prior measurements and observations gathered in the troubleshooting sequence. It can also be used as a reference for another technician who may have to troubleshoot the same circuit. A log of these troubleshooting documents can be recorded in a database to determine common faults and failures in the system.

Refer to the circuit in Figure T-10. The light bulb refuses to illuminate when the switch is closed. Suppose a technician were troubleshooting this circuit. See Figure T-11 for an example of how the technician records each of his steps. Notice the table is divided into two columns: Observations and Conclusions.
## Observations

<table>
<thead>
<tr>
<th>Observation</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turned switch ON – no light</td>
<td>Definitely a problem in this circuit!</td>
</tr>
<tr>
<td>Measured 12 volts between terminal blocks TB1-1 and TB2-1</td>
<td>Power supply is functioning properly.</td>
</tr>
<tr>
<td>Measured no voltage across the light bulb (between TB2-2 and TB2-3)</td>
<td>Light bulb is not open, just not receiving any power.</td>
</tr>
<tr>
<td>Measured no voltage across closed switch (between TB1-1 and TB1-3)</td>
<td>Switch is good.</td>
</tr>
<tr>
<td>Measured no voltage between terminals TB1-3 and TB2-3</td>
<td>Wire between TB1-3 and TB2-3 is good</td>
</tr>
<tr>
<td>Measured 12 volts between terminals TB2-1 and TB2-2</td>
<td>Bad connection between those two terminals. Possibly an open wire or dirty connection between wire and terminal block.</td>
</tr>
<tr>
<td>Replaced wire between TB2-1 and TB2-2. Light bulb now works!</td>
<td><strong>Problem Solved!</strong></td>
</tr>
</tbody>
</table>

### Figure T-10

![Diagram of electrical circuit showing a power supply, terminal blocks, and a light bulb.]

### Figure T-11

![Table of observations and conclusions related to the electrical circuit.]
Breadboard Circuits

Most electronics students gain hands-on experience with circuits by building them in temporary form on solderless breadboards. These boards are very convenient for lab use, as they allow students to quickly assemble and re-configure circuits using a wide variety of components.

There is much more to learning electronics than merely building circuits, though. A vital element of electronics education is learning how to diagnose faulty circuits through the use of test equipment.

Unfortunately, the same solderless breadboards that work so well for rapid circuit construction are rather poor for simulating circuit faults. It is very easy to see a component leg lifted to simulate an open, or a jumper wire across a component to simulate a short. In order for the troubleshooting exercises to be valid, students should not be able to inspect the circuits in any way but by using test equipment.

The concept of these exercises works on the principle of taking measurements between test points on a circuit board. Production circuit boards are commonly equipped with metal "test points" used for the connection of test equipment. These test points are especially valuable when the boards are coated with a protective barrier, since the coating prevents direct connection to the component terminals. In cases like this, test points are the only contact points through which circuit signals may be measured.

In the following exercises, student access is limited to their faulted breadboard circuits in the same way, with the breadboard hidden and the test points located some distance away from it. This may be done by using a “testing jig” constructed of a long cable containing several wires and a terminal block.

Figure T-12

Each student is to construct the circuit specified for each exercise, making sure the circuit is completely functional. The “testing jig” must then be inserted into the circuit in order for measurements to be taken at the terminal strip. It is important that the correct colored wires be inserted for their corresponding test points.

Once the circuit is constructed and fully functional with the testing jig in place, have a lab partner or instructor create a fault somewhere in the circuit. This is easily accomplished by lifting a leg or removing a component to simulate an open, or inserting a jumper wire across a component to simulate a short. Once the fault is in place, cover the circuit with something such as a piece of paper so the circuit cannot be visually inspected.
The student may then begin troubleshooting the circuit using only a voltmeter or ammeter (no ohmmeters), the connected terminal block on the testing jig, and a circuit schematic. Each step in the troubleshooting sequence must be documented on the “Observations and Conclusions Table” provided for each exercise.

When finished with the exercises, design your own circuits and have a lab partner troubleshoot them.

When designing a circuit for troubleshooting, it is common practice to insert test-points so that voltage readings can be taken across each component in the circuit. It is also ideal for the troubleshooter to have the ability to measure circuit current. Be sure to design the circuit in such a way that current can be measured by simply removing the jumper wire connecting terminals 1 and 2 on the terminal block and inserting the ammeter leads in its place as shown in Figure T-14.

When generating a fault on a lab partner’s circuit, make sure a resistance still exists in the circuit. Failure to do this will create a dead short and possibly damage the power supply and test equipment.

Complete the table below by assigning the correct colored wire to each test point. Use a troubleshooting jig along with the illustration in Figure T-12 as a reference.

<table>
<thead>
<tr>
<th>Wire Color</th>
<th>Test Point</th>
<th>Connect to:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TP1</td>
<td>positive power supply output (+V)</td>
</tr>
<tr>
<td></td>
<td>TP2</td>
<td>positive supply to circuit (ammeter connection point)</td>
</tr>
<tr>
<td></td>
<td>TP3</td>
<td>ground</td>
</tr>
<tr>
<td></td>
<td>TP4</td>
<td>voltage test point</td>
</tr>
<tr>
<td></td>
<td>TP5</td>
<td>voltage test point</td>
</tr>
<tr>
<td></td>
<td>TP6</td>
<td>voltage test point</td>
</tr>
<tr>
<td></td>
<td>TP7</td>
<td>voltage test point</td>
</tr>
<tr>
<td></td>
<td>TP8</td>
<td>voltage test point</td>
</tr>
</tbody>
</table>

Figure T-13

Install jumper wire to connect circuit to power supply for voltage measurements. Replace jumper wire with ammeter leads to measure circuit current.

Figure T-14
Troubleshooting Exercise 1

Construct the following circuit on a solderless breadboard. Connect the testing jig according to the test points (TP’s) in the schematic diagram. Make sure the correct TP wires are used. You may refer to the table on the previous page.

When finished, have your lab partner or instructor create a fault in the circuit.

While troubleshooting the circuit, you may not view the breadboard connections. You may use either a voltmeter or ammeter (no ohmmeters) to take measurements from the terminal block on the testing jig. Record each step in the troubleshooting process on the “Observations and Conclusions Table” for this exercise.

![Schematic Diagram]

<table>
<thead>
<tr>
<th>Observations</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

+15 V<sub>DC</sub>
**Troubleshooting Exercise 2**

Construct and troubleshoot the following circuit as in the previous exercise. Record your observations and conclusions in the table below.

![Circuit Diagram](image)

<table>
<thead>
<tr>
<th>Observations</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table:**

<table>
<thead>
<tr>
<th>Observations</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Troubleshooting Exercise 3

Construct and troubleshoot the following circuit. Record your observations and conclusions below.

**WARNING:** Do not simulate a short anywhere in this circuit! Doing so could damage the power supply and/or test equipment. There must be a resistance in the circuit at all times!

---

**Observations**

<table>
<thead>
<tr>
<th>TP2</th>
<th>TP4</th>
<th>TP5</th>
<th>TP6</th>
<th>TP7</th>
</tr>
</thead>
<tbody>
<tr>
<td>TP1</td>
<td>TP8</td>
<td>TP3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Conclusions**

<table>
<thead>
<tr>
<th>R1</th>
<th>R2</th>
<th>R3</th>
<th>R4</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 kΩ</td>
<td>100 kΩ</td>
<td>47 kΩ</td>
<td>18 kΩ</td>
</tr>
</tbody>
</table>
Troubleshooting Exercise 4

Construct and troubleshoot the following circuit. Record your observations and conclusions below.

![Circuit Diagram]

<table>
<thead>
<tr>
<th>Observations</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Troubleshooting Exercise 5

Construct and troubleshoot the following circuit. Record your observations and conclusions below.

![Circuit Diagram]

<table>
<thead>
<tr>
<th>Observations</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Troubleshooting Exercise 6

Construct and troubleshoot the following circuit. Record your observations and conclusions below.

**Observations**

<table>
<thead>
<tr>
<th></th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tbody>
</table>
Design your own circuit here:

<table>
<thead>
<tr>
<th>Observations</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tbody>
</table>
Design your own circuit here:

<table>
<thead>
<tr>
<th>Observations</th>
<th>Conclusions</th>
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</table>
Design your own circuit here:

<table>
<thead>
<tr>
<th>Observations</th>
<th>Conclusions</th>
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<tr>
<td></td>
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<td></td>
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</tr>
</tbody>
</table>
Formula Wheels

$E \quad I \quad R$

$P \quad I \quad E$

$E x I$

$I^2 x R$

$E \over I$

$P \over I^2$

$E^2 \over P$

$P \over I$

$\sqrt{P}\over R$

$E \over R$

$\sqrt{P \times R}$
<table>
<thead>
<tr>
<th>Project Number</th>
<th>Project Name</th>
<th>Instructor Initial</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project 1</td>
<td>Voltmeters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Project 2</td>
<td>Ammeters</td>
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<tr>
<td>Project 3</td>
<td>Ohmmeters</td>
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<tr>
<td>Project 4</td>
<td>Relationship of I and V with a Constant R</td>
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</tr>
<tr>
<td>Project 5</td>
<td>Relationship of I and R with a Constant V</td>
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</tr>
<tr>
<td>Project 6</td>
<td>Relationship of Power to V with a Constant R</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Project 7</td>
<td>Relationship of Power to I with a Constant R</td>
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</tr>
<tr>
<td>Project 8</td>
<td>Resistor Color Codes</td>
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<tr>
<td>Project 9</td>
<td>Resistance in Series Circuits</td>
<td></td>
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<tr>
<td>Project 10</td>
<td>Current Flow in Series Circuits</td>
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<tr>
<td>Project 11</td>
<td>Voltage in Series Circuits</td>
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<tr>
<td>Project 12</td>
<td>Power in a Series Circuit</td>
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<tr>
<td>Project 13</td>
<td>Detecting an Open in a Series Circuit</td>
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<tr>
<td>Project 14</td>
<td>Detecting a Short in a Series Circuit</td>
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<tr>
<td>Project 15</td>
<td>Resistance in Parallel Circuits</td>
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<tr>
<td>Project 16</td>
<td>Current Flow in Parallel Circuits</td>
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<tr>
<td>Project 17</td>
<td>Voltage in Parallel Circuits</td>
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<tr>
<td>Project 18</td>
<td>Power in a Parallel Circuit</td>
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<tr>
<td>Project 19</td>
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<tr>
<td>Project 20</td>
<td>Detecting a Short in a Parallel Circuit</td>
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<tr>
<td>Project 21</td>
<td>Resistance in Series-Parallel Circuits</td>
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<tr>
<td>Project 22</td>
<td>Current in Series-Parallel Circuits</td>
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<tr>
<td>Project 23</td>
<td>Voltage in Series-Parallel Circuits</td>
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<td></td>
</tr>
<tr>
<td>Project 24</td>
<td>Power in a Series-Parallel Circuit</td>
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<tr>
<td>Project 25</td>
<td>Detecting an Open in a Series-Parallel Circuit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Project 26</td>
<td>Detecting a Short in a Series-Parallel Circuit</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Troubleshooting Exercise 1</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Troubleshooting Exercise 2</td>
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<td></td>
<td>Troubleshooting Exercise 3</td>
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<td>Troubleshooting Exercise 4</td>
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</tr>
<tr>
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<td>Troubleshooting Exercise 6</td>
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</tbody>
</table>