Lab 3 - DC Circuits and Ohm’s Law

OBJECTIVES

- To learn to apply the concept of potential difference (voltage) to explain the action of a battery in a circuit.
- To understand how potential difference (voltage) is distributed in different parts of series and parallel circuits.
- To understand the quantitative relationship between potential difference and current for a resistor (Ohm’s law).

OVERVIEW

In a previous lab you explored currents at different points in series and parallel circuits. You saw that in a series circuit, the current is the same through all elements. You also saw that in a parallel circuit, the sum of the currents entering a junction equals the sum of the currents leaving the junction.

You have also observed that when two or more parallel branches are connected directly across a battery, making a change in one branch does not affect the current in the other branch(es), while changing one part of a series circuit changes the current in all parts of that series circuit.

In carrying out these observations of series and parallel circuits, you have seen that connecting light bulbs in series results in a larger resistance to current and therefore a smaller current, while a parallel connection results in a smaller resistance and larger current.

In this lab, you will first examine the role of the battery in causing a current in a circuit. You will then compare the potential differences (voltages) across different parts of series and parallel circuits.

Based on your previous observations, you probably associate a larger resistance connected to a battery with a smaller current, and a smaller resistance with a larger current. You will explore the quantitative relationship between the current through a resistor and the potential difference (voltage) across the resistor. This relationship is known as Ohm’s law. You will then use Kirchhoff’s circuit rules to completely solve a DC circuit.

INVESTIGATION 1: Batteries and voltages in series circuits
So far you have developed a current model and the concept of resistance to explain the relative brightness of bulbs in simple circuits. Your model says that when a battery is connected to a complete circuit, there is a current. For a given battery, the magnitude of the current depends on the total resistance of the circuit. In this investigation you will explore batteries and the potential differences (voltages) between various points in circuits.

In order to do this you will need the following items:

- two voltage probes
- two 1.5 volt D batteries (must be very fresh, alkaline) and holders
- six wires with alligator clip leads
- two #14 bulbs in sockets
- momentary contact switch

You have already seen what happens to the brightness of the bulb in circuit in Figure 3.1 (a) if you add a second bulb in series as shown in circuit 3.1 (b). The two bulbs in Figure 3.1 (b) are not as bright as the original bulb. We concluded that the resistance of the circuit is larger, resulting in less current through the bulbs.

Prediction 1-1: What do you predict would happen to the brightness of the bulbs if you connected a second battery in series with the first at the same time you added the second bulb, as in Figure 3.1 (c)? How would the brightness of bulb A in circuit 3.1 (a) compare to bulb B in circuit 3.1 (c)? To bulb C? Do this before coming to lab.

Activity 1-1: Battery Action

1. Connect the circuit in Figure 3.1 (a), and observe the brightness of the bulb.

2. Now connect the circuit in Figure 3.1 (c). [Be sure that the batteries are connected in series – the positive terminal of one must be connected to the negative terminal of the other.]
**Question 1-1:** What do you conclude about the current in the two bulb, two battery circuit as compared to the single bulb, single battery circuit?

**Prediction 1-2:** Look carefully at the circuits in Figures 3.1(a) and 3.2. What do you predict about the brightness of bulb D in Figure 3.2 compared to bulb A in Figure 3.1(a)? **Do this before coming to lab.**

![Figure 3.2](image)

3. Connect the circuit in Figure 3.2 (a series circuit with two batteries and one bulb). **Only close the switch for a moment to observe the brightness of the bulb – otherwise, you will burn out the bulb.**

**Question 1-2:** How does increasing the number of batteries connected in series affect the current in a series circuit?

When a battery is fresh, the voltage marked on it is actually a measure of the **emf (electromotive force)** or electric potential difference between its terminals. **Voltage** is an informal term for emf or potential difference. We will use these three terms (**emf, potential difference, voltage**) interchangeably.

Let’s explore the potential differences of batteries and bulbs in series and parallel circuits to see if we can come up with rules for them as we did earlier for currents.

How do the potential differences of batteries add when the batteries are connected in series or parallel? Figure 1-3 shows a single battery, two batteries identical to it connected in series, and two batteries identical to it connected in parallel.
Prediction 1-3: If the potential difference between points 1 and 2 in Figure 3.3(a) is known, predict the potential difference between points 1 and 2 in Figure 3.3(b) (series connection) and in Figure 3.3(c) (parallel connection). **Do this before coming to lab.**
Activity 1-2: Batteries in Series and Parallel

You can measure potential differences with voltage probes connected as shown in Figure 3.4.

![Figure 3.4](image)

1. Open the experiment file **L03.A1-2 Batteries**.
2. Connect voltage probe VP_A across a single battery (as in Figure 3.4(a), and voltage probe VP_B across the other identical battery. The red lead of the voltage probe goes to the + side of the battery.
3. Record the voltage measured for each battery below:

   Voltage of battery A: ____________ V
   Voltage of battery B: ____________ V

4. Now connect the batteries in series as in Figure 3.4(b), and connect probe VP_A to measure the potential difference across battery A and probe VP_B to measure the potential difference across the series combination of the two batteries. Record your measured values below.

   Voltage of battery A: ____________ V
   Voltage of A and B in series: ____________ V

**Question 1-3:** Do your measured values approximately agree with your predictions? If not, explain.
5. Now connect the batteries in parallel as in Figure 3.4(c), and connect probe VP_A to measure the potential difference across battery A and probe VP_B to measure the potential difference across the parallel combination of the two batteries. Record your measured values below.

Voltage of battery A: ___________ V
Voltage of A and B in parallel: ___________ V

**Question 1-4:** Do your measured values agree with your predictions? Explain any differences.

**Question 1-5:** Write down a simple rule for finding the combined voltage of a number of batteries that are

Connected in series:

Connected in parallel:

**Do NOT do it:** However, what would happen if you wired two batteries of unequal voltage in parallel, hook any two batteries together ”anti-parallel”, or simply short circuit a single battery? To a very good approximation, a real battery behaves as if it were an ideal battery in series with a resistor. Since this ”internal resistance” is usually quite small, the voltages can cause a tremendous amount of current to flow which, in turn, will cause the batteries to overheat (and probably rapture).

You can now explore the potential difference across different parts of a simple series circuit. Consider the circuit shown in Figure 3.5

**IMPORTANT NOTE:** The switch S_1 should remain open except when you are making a measurement. It is in the circuit to save the battery. Use the momentary contact switch for S_1.
Prediction 1-4: If bulbs A and B are identical, predict how the potential difference (voltage) across bulb A in Figure 3.5 will compare to the potential difference across the battery. How about bulb B? Do not answer before lab.

Activity 1-3: Voltages in Series Circuits


2. Connect the voltage probes as in Figure 3.5 to measure the potential difference across bulb A and across bulb B. Record your measurements below.

   Potential difference across bulb A: ____________ V
   Potential difference across bulb B: ____________ V

   Don’t be concerned if the actual bulb voltages are somewhat different. Ideal bulbs would have the same voltage.

3. Now use one probe VP_A to measure the voltage across both bulbs A and B. Record your measurement below.

   Potential difference across bulbs A and B: ____________ V
**Question 1-6:** Formulate a rule for how potential differences across individual bulbs in a series connection combine to give the total potential difference across the series combination of the bulbs.

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**INVESTIGATION 2: Voltages in Parallel Circuits**

Now you will explore the potential differences across different parts of a simple parallel circuit.

You will need the following material:

- three voltage probes
- knife switch
- 1.5 V D cell battery (must be very fresh, alkaline) with holder
- two #14 bulbs with holders
- eight alligator clip
- leads
- momentary (push down) contact switch

**Activity 2-1: Voltages in a Parallel Circuit**

1. Open the experiment file **L03.A2-1 Parallel Circuits**, which should be showing three voltage graphs as a function of time.

2. Connect the circuit shown in Figure 3.6. Remember to use the momentary contact switch for S₁ and to leave it open when you are not taking data.

![Figure 3.6](image)

3. Make sure both switches are open. **Start taking data with the computer.** Leave both switches S₁ and S₂ open for a couple of seconds. Then close switch S₁ and after a second or two, close switch S₂. After another second or two stop taking data and open both switches. Make sure you remember what switches were open and closed on your computer.
display showing both voltages. The voltage probe connections as shown in Figure 3.6 will result in positive voltages. The red lead is positive. If you measure negative voltages, you probably have the leads switched.

4. Use the Smart Tool to make the following voltage measurements of your data:

<table>
<thead>
<tr>
<th></th>
<th>$S_1$ open</th>
<th>$S_1$ closed</th>
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<tbody>
<tr>
<td>$S_2$ open</td>
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<tr>
<td>Voltage across battery:</td>
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<td>Voltage across bulb A:</td>
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<tr>
<td>Voltage across bulb B:</td>
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V

5. **Print** out one set of graphs for your group.

**Question 2-1:** We have been led to believe that the voltage across the battery would be constant. Yet when we close switches $S_1$ and $S_2$ and draw current from the battery, we find that the battery voltage changes. We say “**We are placing a load on the battery**” or “**We have a load on the battery**”. Try to explain what is happening in terms of the battery’s internal resistance.

You have now observed that the voltage across a *real* battery changes when we have a load on it (that is, drawing current from the battery). An *ideal* battery would be one whose voltage did not change at all, no matter how much current flows through it. No battery is truly ideal (this is especially true for a less than fresh battery), so the voltage usually drops somewhat when the load on the battery is increased.

Because of this difficulty, we are now going to replace the battery with an electronic power supply, which has been designed to alleviate this problem. Keep your circuit as is.

**Activity 2-2: Voltages in a Parallel Circuit**

We will replace the battery with an electronic power supply. When you turn the dial, you change the voltage (potential difference) between its terminals. The power supply we are using can provide a constant voltage up to about 20 V producing 1300 mA.

New equipment: HP6213A power supply.

1. Leave the power supply switch turned off except when instructed to turn it on. Turn down the coarse adjustment knob. Make sure the switch on the front is on VOLTAGE, not AMPS. Note that you will read the voltage on the top (analog) scale of the meter. There are three inputs: + (red), -, and ground. We will use the + and – inputs.
2. Disconnect the two leads that now go to the battery and connect the same two wires that went to + and – sides of the battery to the + and – inputs of the power supply.

3. Open both switches \( S_1 \) and \( S_2 \) of your circuit.

4. Turn on the power supply and slowly turn up the coarse knob to 2 V. Do not go over 2 V or you will burn out the bulb. We will now repeat steps 3-5 of the previous activity.

5. **Start taking data with the computer.** Leave both switches \( S_1 \) and \( S_2 \) open for a second or two. Then close switch \( S_1 \) and after a second or two, close switch \( S_2 \). After another second or two stop taking data and open both switches. Make sure you remember what switches were open and closed on your computer display showing both voltages.

6. Use the Smart Tool to make the following voltage measurements of your data:

<table>
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<tr>
<th></th>
<th>( S_1 ) open</th>
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<tbody>
<tr>
<td>( S_2 ) open</td>
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<td></td>
</tr>
<tr>
<td>Voltage across battery:</td>
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<tr>
<td>Voltage across bulb A:</td>
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<tr>
<td>Voltage across bulb B:</td>
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<tr>
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<tr>
<td>Voltage across bulb A:</td>
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<tr>
<td>Voltage across bulb B:</td>
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</table>

7. **Print** out one set of graphs for your group.

**Question 2-2:** Is the voltage across the battery now constant as switches \( S_1 \) and \( S_2 \) are open or closed? Does the power supply act as a constant EMF source?

**Question 2-3:** Are the voltages across both bulbs when the two switches are closed similar to the voltage you measured across the power supply? If not, explain.

**Question 2-4:** Based on your observations, formulate a rule for the potential differences across the different branches of a parallel circuit. How are these related to the voltage across the power supply?
**INVESTIGATION 3: Ohm’s Law**

What is the relationship between current and potential difference? You have already seen that there is only a potential difference across a bulb or resistor when there is a current through the circuit element. The next question is how does the potential difference depend on the current? In order to explore this, you will need the following:

- current and voltage probes
- #14 bulb in a socket
- variable DC power supply
- ten alligator clip
- leads
- 10 Ω resistor (see prelab for color code)

Examine the circuit shown below, which allows you to measure the current through the resistor when different voltages are across it.

![Circuit Diagram](image)

**Figure 3.7:**

**Prediction 3-1:** What will happen to the current through the resistor as you turn the dial on the power supply and increase the applied voltage from zero? What about the voltage across the resistor? **Do this before coming to lab.**

**Ohm’s Law:** The voltage, \( V \), across an *ideal* resistor of resistance \( R \) with a current \( I \) flowing through it is given by Ohm’s Law:

\[
V = IR
\]

**Activity 3-1: Current and Potential Difference for a Resistor**

1. Open the experiment file **L03.A3-1 Ohm’s Law.**
2. Connect the circuit in Figure 3.7. The current probe goes into analog port A, and the voltage probe into port B. Make sure the power supply is turned off and the coarse adjustment knob is turned down. Use a resistor of 10 \( \Omega \). Note that the current probe is connected to measure the current through the resistor, and the voltage probe is connected to measure the potential difference across the resistor.

3. **Begin graphing** current and voltage with the power supply set to zero voltage, and watch your data as you slowly increase the voltage to about 3 volts. **Warning**: Do not exceed 3 volts! Stop the computer and turn the voltage down to zero.

   **Question 3-1:** What happened to the current in the circuit and the voltage across the resistor as the power supply voltage was increased? Comment on the agreement between your observations and your predictions?

4. If it’s not already visible, bring up the display for current \( CP_A \) versus voltage \( VP_B \). Notice that voltage is graphed on the horizontal axis, since it is the independent variable in our experiment.

5. Use the **fit routine** to verify that the relationship between voltage and current for a resistor is a **proportional** one. Record the slope.

   \[
   \text{Slope: } \frac{\text{\Omega}^{-1}}{}
   \]

   **Question 3-2:** Determine the resistance \( R \) from the slope. Show your work.

6. On the same graph, repeat steps 2 and 3 for a light bulb. Be sure to increase the voltage **very slowly** for the light bulb, especially in the beginning. **Do not exceed 2.5 V or you will burn out the bulb.** There should now be two sets of data on the \( I \) vs. \( V \) graph.

7. **Print** out one set of graphs for your group.
**Question 3-3:** Based on your data for the light bulb, does it obey Ohm’s Law? Explain.

**Question 3-4:** If you were to repeat the previous measurement with a 22 Ω resistor, describe the graph you would expect to see compared with the 10 Ω resistor. How would the slope differ?

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**INVESTIGATION 4: Measuring Current, Voltage and Resistance**

Figure 3.8 (a) shows a multimeter with voltage, current and resistance modes, and Figure 3.8 (b) shows the symbols that will be used to indicate these functions.

The multimeter available to you can be used to measure current, voltage and resistance. All you need to do is choose the correct dial setting, connect the wire leads to the correct terminals on the meter and connect the meter correctly in the circuit. Figure 3.8 shows a simplified diagram of a multimeter. We will be using the multimeter to make DC (direct current) measurements, so make sure the multimeter is set to DC mode.

A current probe or a multimeter used to measure current (an ammeter) are both connected in a circuit in the same way. Likewise, a voltage probe or a multimeter used to measure voltage (a voltmeter) are both connected in a circuit in the same way. The next two activities will remind you how to connect them. The activities will also show you that when meters are connected correctly, they don’t interfere with the currents or voltages being measured.

You will need:

- digital multimeter
- current probe
• voltage probe
• power supply
• six alligator clip
• leads and wires
• 1000 Ω (1 %), 10 Ω, 22 Ω, and 75 Ω resistors

You found the color codes for these resistors in the prelab. You should write the color codes down here. **Do this before coming to the lab:**

10Ω :

22Ω :

75Ω :

1000Ω :

**Activity 4-1: Measuring Current with a Multimeter**

![Diagram of a circuit with a multimeter](image)

**Figure 3.9:**

1. We want to measure the current in the circuit using the multimeter in the current mode. We cannot use the current probe we have been using, because they are not accurate at low currents. Make sure the power supply is turned down and turned off before beginning.

2. Set up the circuit shown in Figure 3.9. Replace the 10 Ω resistor in the previous circuit with one having 1000 Ω.

3. Remove the current probe and insert the multimeter. In our case the multimeter is being used in the ammeter mode. The + side wire is connected to the mA port and the – side wire to the COM port of the multimeter. Turn on the power.

4. Set the multimeter to the 2 m (for 2 mA) scale on Current to read the current.
5. Turn on the power supply and set the voltage to 2 V.


7. Click on Start and let it run for a few seconds.

8. Read the current on the multimeter. If it reads negative, you hooked the wires up backwards. You may need to change multimeter scales to obtain a precise measurement. Stop the computer. Write down the multimeter current and determine the probe voltage.

   Multimeter current: ____________ A
   Computer voltage across resistor: ____________ V

9. Leave the coarse adjustment knob as it is on the power supply, but turn off the power switch.

10. The 1000 Ω resistors are precise to 1% so we can determine the current through them using Ohm’s law by dividing the voltage across the resistor by the resistance value:

    Calculate current $I$ from Ohm’s law: ____________ A

**Question 4-1:** Compare the two currents determined in steps 8 and 10. Should they be the same? What is the percentage difference?

**Question 4-2:** When used correctly as an ammeter, the multimeter should measure the current through a resistor without significantly affecting that current. Do we want the ammeter to have a large or small resistor? What would be the resistance of a perfect ammeter? Why? What happens to the probe voltage you measure in the circuit if the ammeter is removed? How do you explain this result?

**Activity 4-2: Measuring Voltage with a Multimeter**

Now we want to examine the use of a multimeter as a voltmeter.
1. Set up the basic circuit in Figure [3.10] by connecting the multimeter (in the voltmeter mode) across the resistor. Note the + and – connections labeled on the figure. The connections on the voltmeter will be between the sockets labeled V (for +) and COM (for -). Set the multimeter scale to measure 2 V (or 20 V if the voltage is greater than 2 V). If the current is in the direction shown in Figure [3.10] then + voltage will be measured. Otherwise, it will be - voltage.

**Important:** Use the **volts** setting and connect the leads to the **voltage** terminals on the multimeter.

2. When ready, turn on the power supply, which should still have the same setting as in the previous activity. Continue to use the experimental file **L03.A4-1 Multimeters**.

3. Click Start. Read the voltage on the multimeter and write it down. Stop taking data and turn off the power supply.

4. Determine the probe voltage and write it down:
   - Multimeter voltage: ___________ V
   - Computer probe voltage: ___________ V

**Question 4-3:** Compare the two voltages measured here and in step 8 of Activity [4.1]. Should they all be the same? Explain and discuss your results.
**Question 4-4:** When used correctly as a voltmeter, the multimeter should measure the voltage across a resistor without significantly affecting that voltage. How could you determine if this voltmeter appears to behave as if it is a large or small resistor? Describe your method and test it. Discuss your results.

**Activity 4-3: Measuring Resistance with a Multimeter**

Next we will investigate how you measure resistance with a multimeter. In earlier experiments, you may have observed that light bulbs exhibit resistance that increases with the current through the bulb (i.e. with the temperature of the filament). To make the design and analysis of circuits as simple as possible, it is desirable to have circuit elements with resistances that do not change. For that reason, *resistors* are used in electric circuits. The resistance of a well-designed resistor doesn’t vary with the amount of current passing through it (or with the temperature), and they are inexpensive to manufacture.

One type of resistor is a carbon resistor, and uses graphite suspended in a hard glue binder. It is usually surrounded by a plastic case. For several years resistors have had their value identified with a color code painted on it. That is now slowly changing to have the resistance value painted on it.

![Cutaway view of a carbon resistor showing the cross sectional area of the graphite material](image)

**Figure 3.11:**

The color code on our resistors tells you the value of the resistance and the tolerance (guaranteed accuracy) of this value. You did a prelab problem to help you learn this. We are using four-band resistors in the lab. The first two stripes indicate the two digits of the resistance value. The third stripe indicates the power-of-ten multiplier.

The following key shows the corresponding values:

<table>
<thead>
<tr>
<th>Color</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>black</td>
<td>0</td>
</tr>
<tr>
<td>brown</td>
<td>1</td>
</tr>
<tr>
<td>red</td>
<td>2</td>
</tr>
<tr>
<td>orange</td>
<td>3</td>
</tr>
<tr>
<td>yellow</td>
<td>4</td>
</tr>
<tr>
<td>green</td>
<td>5</td>
</tr>
<tr>
<td>blue</td>
<td>6</td>
</tr>
<tr>
<td>violet</td>
<td>7</td>
</tr>
<tr>
<td>grey</td>
<td>8</td>
</tr>
<tr>
<td>white</td>
<td>9</td>
</tr>
</tbody>
</table>

The fourth stripe tells the tolerance according to the following key:

<table>
<thead>
<tr>
<th>Color</th>
<th>Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>red or none</td>
<td>± 20%</td>
</tr>
<tr>
<td>silver</td>
<td>± 10%</td>
</tr>
<tr>
<td>gold</td>
<td>± 5%</td>
</tr>
<tr>
<td>brown</td>
<td>± 1%</td>
</tr>
</tbody>
</table>
As an example, look at the resistor in Figure 3.12. Its two digits are 1 and 2 and the multiplier is $10^3$, so its value is $12 \times 10^3$, or 12,000 $\Omega$. The tolerance is $\pm 20\%$, so the value might actually be as large as 14,400 $\Omega$ or as small as 9,600 $\Omega$.

The connection of the multimeter to measure resistance is shown in Figure 3.13. When the multimeter is in its ohmmeter mode, it connects a known voltage across the resistor, and measures the current through the resistor. Then resistance is determined by the multimeter from Ohm’s law.

Note: Resistors must be isolated from the circuit by disconnecting them before measuring their resistance. This also prevents damage to the multimeter that may occur if a voltage is connected across its leads while it is in the resistance mode.

1. Choose two different resistors other than 10 $\Omega$ and 1000 $\Omega$ (call them $R_1$ and $R_2$). Write down the colors, resistances and tolerances.

   $R_1$ color code: -------------------------------------- $\Omega$

   $R_1$: _________ $\Omega$ $\pm$ _________ $\%$

   $R_2$ color code: -------------------------------------- $\Omega$

   $R_2$: _________ $\Omega$ $\pm$ _________ $\%$

2. Set up the multimeter as an ohmmeter and measure the resistors:

   $R_1$: _________ $\Omega$  $R_2$: _________ $\Omega$
Question 4-5: Comment on the agreement between the color codes and the measurement. Are they consistent? Discuss.

3. Measure the resistance of the two resistors in series. Use alligator clip wires to connect the resistors.

\[ R_{\text{series}}: \quad \text{Ω} \]

The equivalent resistance of a series circuit of two resistors \((R_1 \text{ and } R_2)\) of resistance \(R_1\) and \(R_2\) is given by:

\[ R_{\text{series}} = R_1 + R_2 \]

Question 4-6: Calculate the equivalent series resistance and compare with your measurement. Comment on the agreement.

4. Measure the equivalent resistance of the two resistors in parallel.

\[ R_{\text{parallel}}: \quad \text{Ω} \]

The equivalent resistance of a parallel circuit of two resistors of resistance \(R_1\) and \(R_2\) is given by:

\[ \frac{1}{R_{\text{parallel}}} = \frac{1}{R_1} + \frac{1}{R_2} \]

Question 4-7: Calculate the equivalent parallel resistance and compare with your measurement. Comment on the agreement.
INVESTIGATION 5: Complex Circuits

We now want to combine series and parallel circuits into more complicated circuits that are used in real electronics that affects our everyday lives. We could use Kirchoff’s rules to determine the currents in such complicated circuits, but now that we know how to use multimeters, we will simply study these complex circuits.

We often want the ability to change the current in a circuit. We can do that by adjusting the voltage in the power supply or we can change the resistor values. We shall first examine the use of variable resistors, called potentiometers.

Activity 5-1: Using Potentiometers

In order to do the following activity you’ll need a couple of resistors and a multimeter as follows:

1. digital multimeter
2. 200 Ω potentiometer
3. a few alligator clip lead wires

A potentiometer (shown schematically in Figure 3.14) is a variable resistor. It is a strip of resistive material with leads at each end and another lead connected to a “wiper” (moved by a dial) that makes contact with the strip. As the dial is rotated, the amount of resistive material between terminals 1 and 2, and between 2 and 3, changes. When turning knobs on most electrical items, you are actually usually turning a potentiometer like this one.

1. Use the resistance mode of the multimeter to measure the resistance between the center lead on the variable resistor and one of the other leads.

   Question 5-1: What happens to the resistance reading as you rotate the dial on the variable resistor clockwise? Counterclockwise?

2. Set the variable resistor so that there is 100 Ω between the center lead and one of the other leads. Show your TA.
Activity 5-2: Prepare Circuit

You will set up the circuit below in Figure 3.15 such that 50 mA will pass through the ammeter (multimeter). Use the power supply for the source of voltage.

![Circuit Diagram](image)

Figure 3.15:

1. You are given two resistors in addition to the potentiometer: 22 Ω and 1000 Ω. The potentiometer must be used in the $R_3$ position, but the other two resistors may be placed in either $R_1$ or $R_2$ as you find necessary.

2. Set the power supply to about 2 V by using the power supply meter scale. The precise value is not important. You are not allowed to change the voltage after initially setting it.

3. You are to determine the positions of the two resistors and adjust the potentiometer to obtain a current of 50 mA in the ammeter (multimeter).

\[
R_1 \text{ (circle value): } 22 \Omega \quad 1000 \Omega \\
R_2 \text{ (circle value): } 22 \Omega \quad 1000 \Omega
\]

4. Show your TA when you are finished. Be prepared to explain how you determined your choice.

TA initials: ______________________________

Please clean up your lab area