Resistance and Ohm's Law - MBL

In this experiment you will investigate different aspects of Ohm's Law, which relates voltage, current, and resistance. A computer will be used to collect, display, and help you analyze the data.

THEORY

$$\text{Ohm's Law:} \quad V = IR \tag{1}$$

where V is voltage, I is current, and R is resistance.

Factors that can affect resistance include:

- Temperature. Resistance generally increases as temperature increases, although this is not true for all materials.

- The density of charge carriers in the device. Semiconductors are good examples of materials in which the number of charge carriers changes as the applied voltage changes.

A resistor is a device with some resistance. Examples include the element in a toaster, the filament in a light bulb, or even just a length of wire. For a wire of length L and cross-sectional area A, made from a material with a resistivity ρ, the resistance is given by:

$$R = \rho \, L/A \tag{2}$$

On a circuit diagram the symbol for a resistor is: —⩗⩗—

When resistors are connected together in a circuit, the overall resistance of the circuit can be found by using the following relationships. These show the total resistance obtained when resistors are placed in series or in parallel.
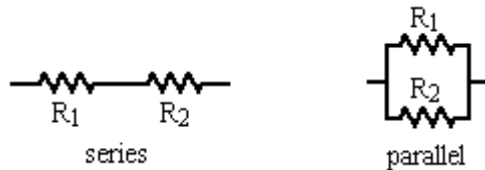

$$\text{Adding resistors in series:} \quad R = R_1 + R_2 \tag{3}$$

$$\text{Adding resistors in parallel:} \quad 1/R = 1/R_1 + 1/R_2 \tag{4}$$

In series circuits the current is the same through each resistor. In parallel circuits the voltage is the same across each resistor.

In addition to resistors, you will use several other devices in the circuit in this experiment. These are shown below, along with the symbol used to represent them in a circuit diagram.

Power supply ⊣|⊢ +   Switch ⟋

Ammeter —(A)—   Light bulb —(lll)—

Voltmeter —(V)—   Diode —▷|—
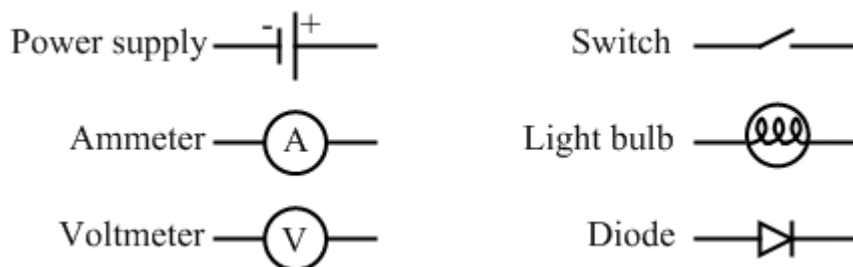
A current at any point in a circuit can be measured with an ammeter. Ammeters are placed in series with the device through which the current is being measured, to ensure that the current through the ammeter is the same as the current through the device. The ammeter should also have a very small resistance, so it will change the current in the circuit by a negligible amount.

Potential differences (voltages) in a circuit are measured using voltmeters. These are placed in parallel, because devices in parallel have the same voltage across them. Voltmeters need to have high resistance to ensure they have minimal impact on the currents and voltages in the rest of the circuit.
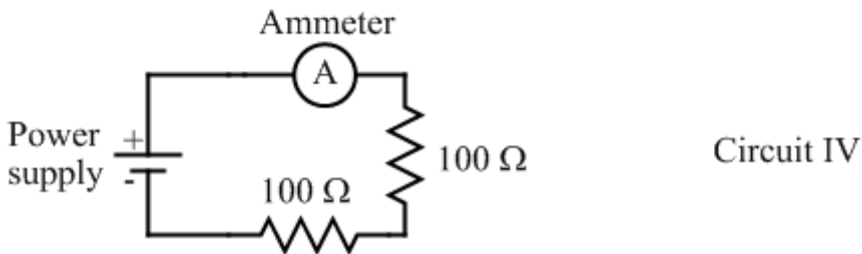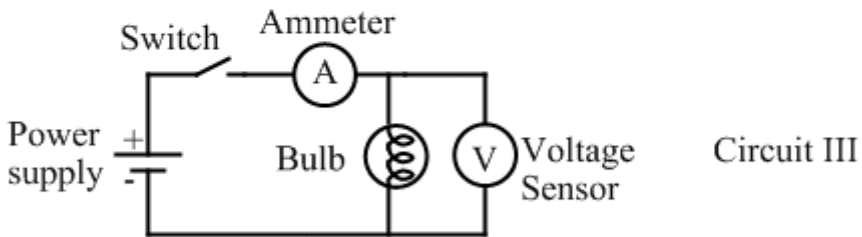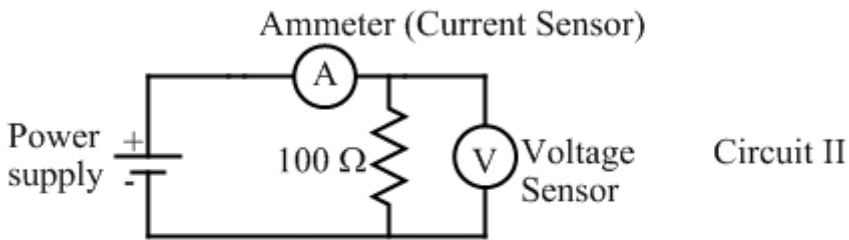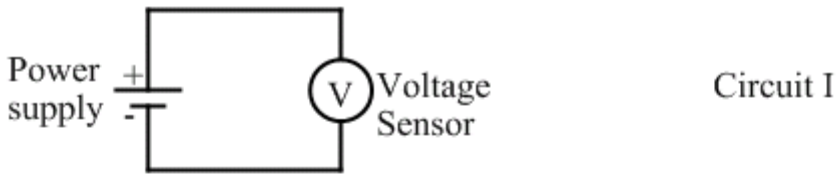
HINTS ON WIRING CIRCUITS

The following page shows circuit diagrams for the different circuits you will use in the experiment. The lines on the diagrams represent the wires you will use to connect the different components to one another.

To connect the first circuit, start with the power supply (the blue box). Connect one of the wires from the voltage sensor to the + terminal of the power supply, and then connect the second wire to the – terminal of the power supply.

You may find it helpful to have the power supply on the left and the voltage sensor on the right, as shown in the diagrams.

For Circuit II, wire the power supply, current sensor, and resistor in a big loop. That puts all those things in series with one another. Then connect one end of the voltage sensor to one end of the resistor, and the other end of the voltage sensor to the other end of the resistor. That puts the voltage sensor in parallel with the resistor.

CIRCUIT DIAGRAMS

Power supply + — [V] Voltage Sensor   Circuit I

Ammeter (Current Sensor)

Power supply + — [A] 100 Ω [V] Voltage Sensor   Circuit II

Switch   Ammeter

Power supply + — [A] Bulb [V] Voltage Sensor   Circuit III

Ammeter

Power supply + — [A] 100 Ω 100 Ω   Circuit IV

PROCEDURE

Part I – Familiarizing yourself with the equipment.

1. Load the software for the experiment by double-clicking on the "Ohm's Law" icon in the Intro I folder. The screen should show a graph, a table, and, in the lower right corner, boxes with the voltage and current readings. Click the ⬚ Zero ⬚ button and select "Zero All Sensors" to make sure the voltage and current readings read zero when they are not connected to anything.

2. Whenever you hit the ▶Collect button, the computer should record voltage and current over a 20-second interval (you can hit the Stop button to end before 20 seconds is up, if you'd like). In this part of the experiment you will graph voltage (potential) as a function of time.

3. Following the diagram for Circuit I, connect the two leads on the voltage sensor (this is connected to Probe 1 on the Dual-Channel Amplifier) to the power supply, which is a blue box. The red lead should go to the + on the power supply and the black lead should go the –. The current sensor should not be connected. Make sure the current knob on the power supply is turned to maximum (fully clockwise), then hit the ▶Collect button and observe what happens when you rotate the voltage knob on the power supply.

4. Now reverse the leads of the voltage sensor (red to –, black to +). Hit the ▶Collect button again and observe what happens now when you rotate the knob on the power supply.

Question 1 – What range of voltages do you have to work with in this experiment?

Part II – Investigating Ohm's Law.

1. In this part of the experiment you will look at graphs of current vs. voltage. To change what is displayed on an axis click on the axis label, check what you want to display, and (for the y-axis only) remove the check(s) for anything you do not want displayed. Set the graph to show current on the y-axis and potential on the x-axis.

2. To set the scales properly, click on one of the numbers to the left of the y-axis. This should bring up a box where you should enter a minimum of –0.3 and a maximum of 0.3 for the manual scaling. Do something similar for the x-axis, clicking on a number below the axis to bring up the axis settings box. This time enter –6 as the minimum and 6 as the maximum.

3. Following Circuit Diagram II, wire up the circuit to measure the voltage and current across a 100 Ω resistor. A resistance box is used as the resistor. Set it for 100 ohms. On the power supply turn both the current and the voltage to maximum.

4. Hit the ▶Collect button. Over several seconds turn the voltage down to minimum, then quickly reverse the leads at the power supply. Over several seconds turn the voltage knob towards maximum again. This should give you a graph of current vs. voltage covering from about –5 volts to +5 volts. Repeat the process until you are happy with the graph, select the **Data** menu, and choose "Store Latest Run".

Question 2 – Remembering what Ohm's Law says, what do you expect the slope of the current vs. voltage graph to be equal to?

5. Find the slope of the line by selecting the Curve Fit button, [icon]. Select "Linear Fit" from the list and click [Try Fit]. Write down the slope before hitting [OK] , because after hitting [OK] not enough significant figures are shown.

Question 3 – Determine the resistance from the slope. How does it compare to the expected value?

6. Set the resistance box to 200 Ω. Repeat step 4 to obtain a current vs. voltage graph.

Question 4 – Again determine the resistance from the slope. How does it compare to the expected value?

Resistors are fine but, as you should have noticed from the graphs, they're fairly boring in that the resistance doesn't change. Now we'll investigate a light bulb and a light-emitting diode (LED), which give more interesting results.

7. Turn the voltage all the way down and turn the power supply off. (Turning the power off completely gives us no voltage – when the voltage knob is all the way down but the power supply is on there is still some voltage being applied.) Replace the resistance box with the light bulb. Hit the [▶ Collect] button, wait a couple of seconds until the current stabilizes, then gradually increase the voltage to maximum and turn it back down to minimum about twice as fast. This should give you a current-voltage graph for the light bulb that looks somewhat more complicated than those for the resistors.

Question 5 – Use Ohm's Law to determine the resistance of the light bulb at about 1 volt and also at about 5 volts. How do the numbers compare? Examine the graph closely. What happens when the power supply is first turned on? Is the current the same at a particular voltage when the voltage is being increased as it is at that voltage when the voltage is being decreased? How can you explain these results?

8. Now set the current to **minimum** and the voltage to maximum. Replace the light bulb by the LED (light-emitting diode), and gradually turn up the current knob until the current is about 0.100 A. If you don't get any current turn the current back down to minimum, reverse the leads to the LED, and try again. Once again obtain a current-voltage graph by hitting [▶ Collect], turning the voltage knob down to minimum, reversing the leads at the power supply, and turning the voltage knob back to maximum.

Question 6 – When current changes from positive to negative, what it means is that the current has reversed direction in the circuit. Does a resistor behave differently in response to positive and negative currents? In other words, does the resistor have a preferred direction for the current? What about the light-emitting diode?

Question 7 – Compare your graph for the LED to the graph for the 100 Ω resistor. Comment on any differences. What can you conclude about the resistance of the LED?

Part III – Comparing a light bulb and a resistor.

1. Now you will look at graphs of current vs. time. Click on the x-axis label and check "Time". For this part it helps to record data at a faster rate, so from the **Setup** menu choose "Data Collection" and then Sampling. Set the sampling speed to 100 samples/second. You should also click on one of the numbers beside the y-axis and enter a minimum of 0 and a maximum of 0.6.

2. Following Circuit Diagram III, wire up the circuit to measure voltage across and current through a light bulb. Check that your voltage and current readings are positive, and set the knobs on the power supply to give maximum voltage and maximum current.

3. **Open** the switch. Hit the ▶Collect button. After a few seconds close the switch. You should not adjust the knobs on the power supply. Open and close the switch a few times.

Question 8 – What do you observe? When you close the switch is the current constant? Explain your observations.

4. Replace the light bulb by the 100 Ω resistor (the resistance box again). Repeat step 3.

Question 9 – What do you observe this time? Make note, in particular, of any differences you notice between the graph for the light bulb and the graph for the resistor. Explain any differences you see.

Part IV – Investigating series circuits.

Question 10 – What do you think happens when current passes through devices in series? Does the current get used up as it goes through each device, or is it the same everywhere?

1. Wire the circuit to look like Circuit IV, with the ammeter, a 100 Ω resistor and another 100 Ω resistor in series, in that order. With the voltage at maximum, what is the current?

2. Wire the circuit so the ammeter is between the two resistors. Measure the current now. Change the order again, to be resistor, resistor, ammeter. Measure the current a third time.

Question 11 – Compare the readings. What does this tell you about current in series circuits?

Part V – The Mystery Box

Hidden inside each dark blue box are five identical (within 1%) resistors. They are connected in some unknown series-parallel combination to the posts labeled A-D. Your job is to determine how the resistors are connected, and to determine their resistance, by taking only three measurements of resistance with the digital meter, between posts A and B, B and C, and C and D. Each box is unique, so make sure you record the code number written on the label.

Record the three measurements, and then sketch the circuit diagram for your mystery box and figure out the resistance of the five identical resistors.