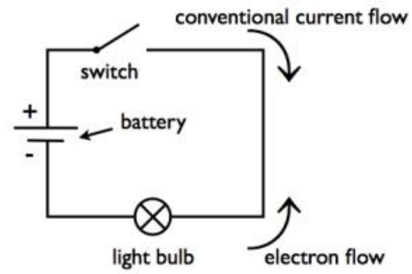
AP Physics Lab #15: Exploring Electrical Resistance (Big Idea 5)

5.C.3.2: The student is able to design an investigation of an electrical circuit with one or more resistors in which evidence of conservation of electric charge can be collected and analyzed.

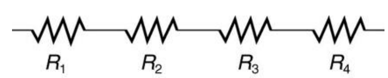
In this four part lab you will explore the factors that affect the flow of electrical current through a conductor.

Exploring Electrical Circuits Pre-Lab:



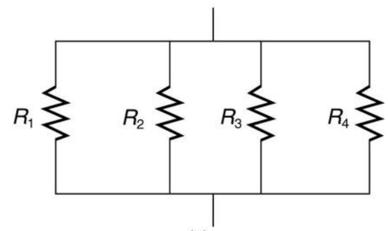
A path through which electrons flow is called an electrical circuit. Any break in that path will cause the flow of electrons to cease. The circuit to the right shows a cell (a source of potential difference), a path through which electrons flow, and a risistor. Notice that the current in the circuit, as we define it, is in the opposite as the flow of electrons. This is simply a convention which states that, by definition "current is the flow of positive charge". Generally, electric current does not flow unimpeded through conductors. The atoms and molecules within wires and batteries have a tendency to somewhat hinder the flow of electrons. This hindrance is called electrical resistance. Resistance is measured in ohms. The ohm (symbol: Ω) is the SI derived unit of electrical resistance, named after German physicist Georg Simon Ohm. There are a number of factors that contribute to the electrical resistance of a material. These include the composition of the material, the cross sectional area, of the material through which electrons must travel, and the length of the material. Generally, the smaller the cross section, the more difficult it is for electrons to squeeze through the conductor. Also, the longer the material, the more resistance the electrons encounter. A material's ability to resist the movement of electric charge is known as its resistivity (rho; ρ) and is measured in ohm-meters (Ω•m). The overall resistance of a material can be expressed as: $\mathbf{R = \rho L/A}$ where L is the length (m) and A is the cross-sectional area of the object (m^2). Metals that are good conductors have low resistivities, while substances that are poor conductors have high resistivities. The equation above assumes a constant temperature, since temperature also affects the resistance of a material. Temperature and resistance are directly proportional to one another.

The flow of electric current is also affected by the potential difference or voltage in the circuit. Unlike the effect of resistance, an increase in voltage will increase the flow of electrons. Voltage, in a sense, pushes electrons through the circuit. The greater the voltage, the greater the push. The relationship between the current, resistance, and voltage is summarized by Ohm's law: V = IR, where current, I, is measured in Amperes, A; voltage is measured in volts, V; and resistance is measured in Ohms, Ω. The rate at which electrical energy is used in a circuit is summarized by Joule's law: **P = IV**, where P represents the electrical power consumed in a circuit. Similar to mechanical power, electric power is measured in J/s or Watts, W. Electrical devices are usually rated according to how much power they consume. For example, a 1500 W hair dryer consumes 1500 J of energy during every second of operation.



(a)

P1). Four light bulbs are linked together in a chain to create what is called a series circuit (diagram a). The light bulbs cause resistance, just as a resistor would. What do you expect the resistance in the circuit is compared to a circuit that only has one bulb? Explain your answer.

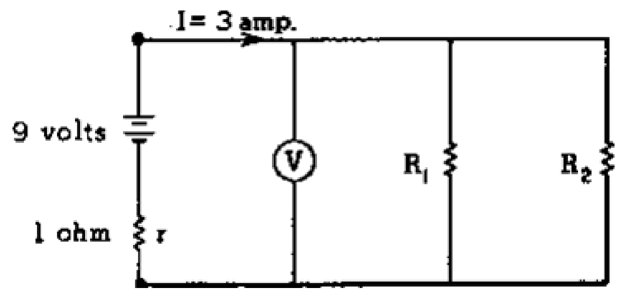


(b)

P2). The same four light bulbs are now linked together in a fashion called a parallel circuit (diagram b). What do you expect the resistance in a parallel circuit is compared to the circuit in which the light bulbs are connected in series? Explain your answer.

Please note that the electromotive force (EMF, $\mathcal{E}$) typically means the source voltage of the circuit, while the term voltage, which can mean the EMF, is more general and can be applied to the voltage drop between different points of the circuit. Now, real batteries are constructed from materials which possess non-zero resistivities. It follows that real batteries are not just pure voltage sources. They also possess internal resistances (r). It is remotely possible that College Board will ask a question about a battery with internal resistance or label the battery with the symbol $\mathcal{E}$. To find the voltage of the battery with internal resistance simply subtract the voltage drop caused by the internal resistance: $V_{battery} = \mathcal{E} - Ir$.

P3). In the circuit shown to the right, the current delivered by the 9-volt battery of internal resistance 1 ohm is 3 amperes. The power dissipated in R_2 is 12 watts.



a). Determine the reading of voltmeter (V) in the diagram.

b). Determine the resistance of R_2.

c). Determine the resistance of R_1.

P4). Three lamps were connected in a circuit with a battery of constant potential. The current, potential difference, and resistance for each lamp are listed in the data table.

	Current (A)	Potential Difference (V)	Resistance (Ω)
lamp 1	0.45	40.1	89
lamp 2	0.11	40.1	365
lamp 3	0.28	40.1	143

a). Using standard circuit symbols, draw a circuit showing how the lamps and battery are connected.

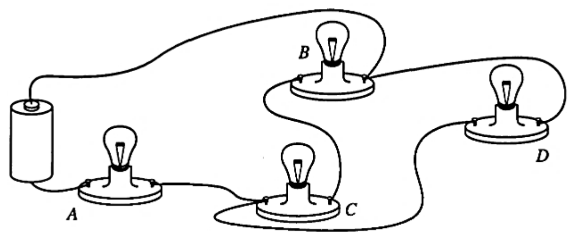
b). What is the potential difference supplied by the battery?

c). Calculate the equivalent resistance of the circuit.

d). If lamp 3 is removed from the circuit, what would be the value of the potential difference across lamp 1 after lamp 3 is removed?

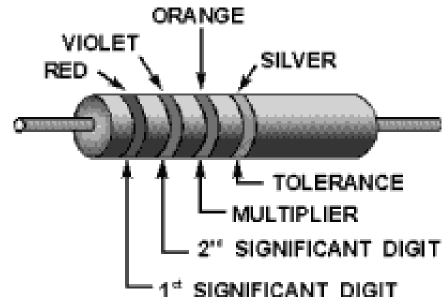
e). If lamp 3 is removed from the circuit, what would be the value of the current in lamp 2 after lamp 3 is removed?

P5). In the circuit shown to the right, A, B. C, and D are identical light bulbs. Assume that the battery maintains a constant potential difference between its terminals (i.e., the internal resistance of the battery is assumed to be negligible) and the resistance of each light bulb remains constant.



a). Draw a diagram of the circuit using the symbols for resistors and a cell. Label the resistors A, B. C, and D to refer to the corresponding light bulbs.

b). List the bulbs in order of their brightness, from brightest to least bright. If any two or more bulbs have the same brightness, state which ones. Justify your answer.



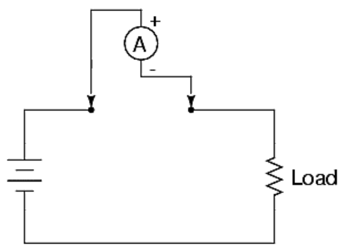
Exploring Electrical Circuits Lab:

Materials: resistor board I, resistor board II, three light-bulb board, power supply, three D-cell batteries holder (if power supplies unavailable), digital multimeter (DMM), 12" wire leads with alligator clips.

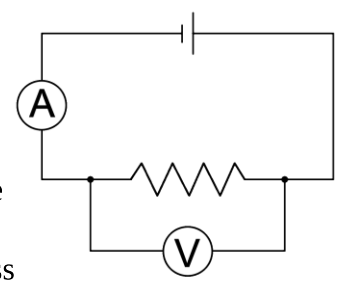
Reading Color Codes of a Resistor: The resistance value of a given resistor is written on its exterior, or may be given as a color code, as shown to the right. On a resistor, the first two colors closest to the end of the resistor represent the first two digits in the value of the resistance, the third value represents the power of ten that it must be multiplied by, and the fourth is the manufactured tolerance (or percent error). For example, a resistor whose four colors are, in order, red, green, orange, and silver, has a resistance of 25,000 Ω (25 kΩ) with a 10% percentage error.

Color	Digit	Multiplier	Tolerance (%)
Black	0	10^0 (1)	
Brown	1	10^1	1
Red	2	10^2	2
Orange	3	10^3	
Yellow	4	10^4	
Green	5	10^5	0.5
Blue	6	10^6	0.25
Violet	7	10^7	0.1
Grey	8	10^8	
White	9	10^9	
Gold		10^{-1}	5
Silver		10^{-2}	10
(none)			20

How to Use a Digital Multimeter (DMM) to Read Current (I): An ammeter can be placed in series in a circuit without affecting the current flow in the circuit as shown to the right. Again, note that an ammeter is connected in series. Set the DMM dial to "10A". Be sure that the black cable is plugged into "COM" and the red cable is plugged into "10A". If the current is less than 0.2 A, then reduce the range of the current by setting the dial between 200 mA and 200 µA. In these ranges, make sure to change the red plug to "VΩmA".



How to Use a Digital Multimeter (DMM) to Voltage (V): A voltmeter must be placed in parallel with a component in a circuit in order to prevent disrupting the current flow in the circuit. Examine the diagram to the right to distinguish between the placement of the ammeter (series) and the voltmeter (parallel). Locate the component of the circuit through which you wish to determine the voltage, and insert the meter leads on either side of the component. Set the DMM dial to "20V" make sure the black cable is plugged into "COM" and the red cable is plugged into "VΩmA". If the voltage is more than 20V or less than 1V, adjust the range appropriately.



Part 1: Determining Resistance Using Ohm's Law: *In this activity you will a) determine the electrical resistance by reading the color code on the resistor, and b) measure the voltage and current through a resistor and use Ohm's law to calculate the resistance of the resistor.*

General Set-up Part 1: Gather resistor board I, a 4.5 volt power supply (or battery), two wire leads with alligator clips, and a DMM. The resistors used in this experiment will lower the current significantly. For this reason, you will need to measure current in the milliamp (mA) range. Set the DMM appropriately and change the red plug if needed.

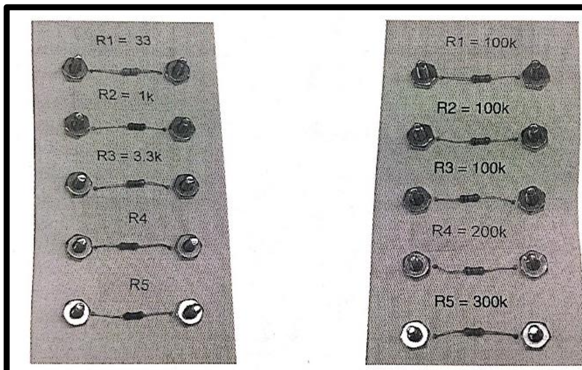


Figure 1a: Cenco Resistor Board I **Figure 1b: Cenco Resistor Board II**

Q1. List the colors, in order, on the labeled resistor, R1, on resistor board I. Based on this information, determine and record the resistance of this resistor. Also, record this information in the data table below.

Resistor #	Resistance, *(as labeled)*	Tolerance (as labeled)	Current I (A)	Voltage V	Calculated Resistance R (Ω)	Calculated % error (Tolerance)
R1						
R2						
R3						
R4	unknown	N/A				N/A
R5	unknown	N/A				N/A

- Connect R1 into the circuit, but leave the power supply disconnected until you are ready to take the measurements. Please do not leave circuits connected for more than 10 seconds. Use the DMM to measure the current and voltage for R1. Record the data in your table.
- Repeat step 3 for each of the remaining resistors on the board (R2-R5) and record your data.

Q2. Using Ohm's law calculate the resistance, R, for all five resistors.

Q3. Calculate the percentage error (tolerance) for all five resistors. Does the calculated tolerance fall within the accepted range based on the color bands on the resistors?

Part 2: Exploring Resistors in Series: *In this activity you will explore the effect that connecting resistors in series has on the overall resistance of a circuit.*

General Set-up Part 2: Gather resistor board II, a 4.5 volt power supply (or battery), four wire leads with alligator clips, and a DMM. You will need to adjust the current to 2000 µA and for voltage 20V.

- Set-up a one resistor circuit with the 100 kΩ resistor and a 4.5 V power source.

Q4. Record the current and the potential difference across the resistor. Sketch a diagram for your circuit that also indicate placement of the ammeter and voltmeter. Use Ohm's law to calculate the resistance of the resistor in this circuit and compare this experimental value to the manufacturer's rated value.

- Connect two 100 kΩ resistors in series with a 4.5 V power source.

Q5. Using your DMM compare the current through various parts of the circuit and describe your findings. How does the current through a one-resistor circuit (Q8) compare to the current in a two-resistor circuit?

Q6. Measure and record the potential difference across each resistor. How does the voltage through the one-resistor circuit compare to the two-resistor circuit?

Q7. Calculate the resistance for each resistor and compare this value to the total resistance for the circuit.

- Connect three 100 kΩ resistors in series with a 4.5 V power source.

Q8. Sketch the circuit and collect all relevant measurements to calculate the resistance of the circuit.

- Connect three different resistors together across a series.

Q9. Sketch the circuit and collect all relevant measurements to calculate the resistance of the circuit.

Part 3: Exploring Resistors in Parallel: *In this activity you will explore the effect that connecting resistors in parallel has on the overall resistance of a circuit.*

General Set-up Part 3: Gather resistor board II, a 4.5 volt power supply (or battery), six wire leads with alligator clips, and a DMM. You will need to adjust the current to 2000 µA and for voltage 20V.

- Connect two 100 kΩ resistors in parallel with a 4.5 V power source. One end of each resistor is connected to the negative terminal of the battery or power supply, while the other ends are connected to the positive terminal.

Q10. Sketch the circuit and use an ammeter to calculate the current through each resistor. Next, measure the current before and after the junction of the circuit.

Q11. Measure the potential difference for the battery (if applicable) and the potential differences across each resistor. Describe the relationship between the voltages of the two resistors.

Q12. Calculate the resistance of the resistors in the circuit and compare these values to the manufacturer's ratings. Using the total voltage and the total current, calculate the total resistance of the circuit.

- Connect three 100 kΩ resistors in parallel with a 4.5 V power source.

Q13. Sketch the circuit and determine the equivalent resistance. Compare and contrast the equivalent resistance to each of the three individual resistors.

- Connect three different resistors in parallel with a 4.5 V power source.

Q14. Sketch the circuit and use your DMM to measure the current and potential difference through each resistor. Calculate the resistance across each resistor.

Part 4: Light Bulbs in Series and Parallel: *In this activity you will design your own experiment to explore the properties of light bulbs connected in series and in parallel.*

General Set-up Part 4: You will be provided with a set of three light bulbs, a 4.5 V battery supply, six wire leads with alligator clips, and a DMM. The light bulbs are not all alike.

Design an experiment to answer the five questions below. Include all relevant data, diagrams, and calculations.

Q15. What is the relationship between the brightness of a bulb and its electrical resistance?

Q16. What happens to the brightness of a pair of identical light bulbs if connected in series, compared to a single light bulb connected to the same battery?

Q17. What happens to the brightness of a pair of identical lightbulbs if connected in parallel, compared to a single light bulb connected to the same battery?

Q18. What happens to the brightness of a pair of unlike light bulbs if connected in series?

Q19. What happens to the brightness of a pair of unlike light bulbs if connected in parallel?

Please self-assess your lab report using the rubric/checklist.