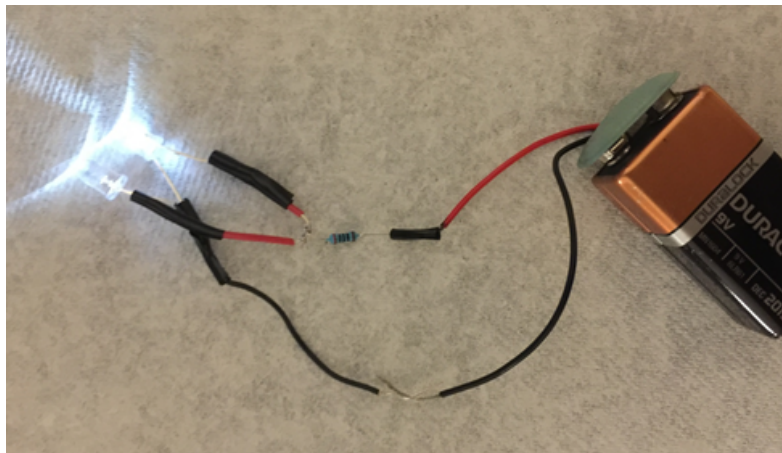


LED-Flashlight

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The Ohio State University-Colombia Collaboration



LED Flashlight

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Subject: Physics

Topic: Circuits & Electricity

Level/Grade: knowledge of algebra assumed

Lab duration: 45min-60min

Project Description:

A circuit that incorporates basic electronic components and uses them to create an LED flashlight for emergency occasions or everyday life. The students will be able to explain how this circuit is an example of Kirchhoff's law.

Objectives:


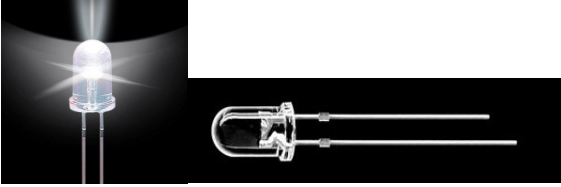

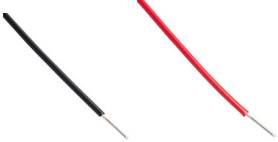

- Develop the techniques necessary to construct a circuit.
- Obtain basic knowledge on electricity and circuit components.
- Apply Ohm's Law, Kirchhoff's Current/Voltage Law, and the Power Law to a given circuit.

Organization: First, we will give the parts list so you can gather the materials you will need. Then we will introduce the electrical schematic. After that, we will discuss some basic circuit laws, and do some examples. There will be a worksheet for you to practice. Finally, we will give instructions for how to build your LED flashlight.

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Materials for each LED Flashlight:

Description	Suggested Vendor	Price (US Dollars)	Quantity Needed per Student
<p>9V Battery</p> 		≈\$1 USD	1
<p>Bright White LEDs 5mm Clear White</p> 	Newark 73P7832 (Cree C535A-WJN-CS0V0151)	\$0.20	2
<p>Resistor: 200 Ohm, carbon film, 1/2Watt, 5% tolerance</p> 	Newark 59K8250	\$0.11	1
<p>Hook-up wire, insulated, 22 AWG, solid (comment: any insulated wire around this size will work and the color doesn't really matter)</p> 	Jameco #2152876 (black) #2152905 (red) Note these are 25 foot spools.	\$7.95 for 25-foot spool	1 red & 1 black, each of about 2in (5cm) long.
<p>9-V Battery Clip</p> 	Amazon http://www.amazon.com/Black-Leather-Housing-Battery-Connector/dp/B00BXX42LQ/ref=sr_1_3?s=electronics&ie=UTF8&qid=1433172349&sr=1-3	\$6.40 for pack of 20	1

(Continued next page)

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List of materials, continued

<p>Cardboard or strong paper. (will be used to build the box)</p>  <p>Or, you can use an old cereal box.</p>	Walmart	\$0.99 one poster size sheet	1 rectangle at least 21 cm by 14 cm
<p>Electrical Tape</p> 	local hardware store	\$0.63 for 3/4 inches x 60 FT	1

Necessary Tools for the classroom:

- Wire Strippers
- Scissors
- Hot glue gun and glue or tape or a stapler**
- Hole Puncher**

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Important Concepts

Current

Electric current is the flow of electric charge via electrons. Similar to water flowing through a pipe. Electrical current is defined as the amount of charge that moves past a location in the wire per unit time. Current is measured in amperes, or amps.

Voltage

Voltage is a measure of the potential difference between two points, which causes the current to flow. Voltage is measured in volts, which is abbreviated as V.

Resistance

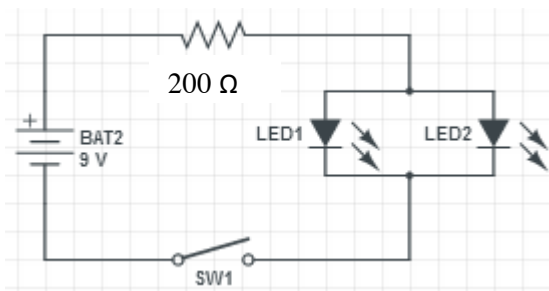
Resistance is the opposition to the flow of current through a conductor. The unit for resistance is the Ohm and is abbreviated with the uppercase Greek letter Ω .

Schematic Drawings

A schematic is an engineering drawing of an electrical circuit. A schematic drawing of the LED flashlight circuit is shown in Figure 1a. Each component of the circuit is represented by a unique symbol on the schematic. The solid lines represent the wires on the circuit board that connect the different components. Metals that have a low resistance, such as copper and aluminum, are used for circuit connections because they are good conductors of electricity. Part (b) shows the electrical symbols for some common components. In this project, we'll be using a battery, a resistor, two light-emitting diodes, some wire, and we'll be improvising a switch.

Next, we will discuss some common circuit laws you will need to do this project.

Circuit Schematic for the LED Flashlight



Component	Schematic
Battery	
Resistor	
Light-Emitting Diode (LED)	
Switch	
Wire	

Figure 1. Schematic drawings. (a) Schematic diagram of the LED circuit; (b) Symbols for common electrical components.

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Electric Circuit Laws

In this section we'll cover some basic circuit theory.

Ohm's Law

The voltage difference V (Volts) across a resistor is equal to the product of the current I (amperes) and the resistance R (Ohms):

$$\text{Ohm's Law} \qquad V = I * R \qquad (\text{Volts}) = (\text{Amps}) * (\text{Ohms})$$

Power Law

The power dissipated P (watts) in a component with resistance R is equal to the product of the voltage V (Volts) across the component and the current I (amperes) flowing through it:

$$\text{Power Law\#1} \qquad P = I * V \qquad (\text{Watts}) = (\text{Amps}) * (\text{Volts})$$

Power can also be calculated using two other formulas:

$$\text{Power Law\#2} \qquad P = I^2 * R \qquad (\text{Watts}) = (\text{Amps})^2 * (\text{Ohms})$$

$$\text{Power Law\#3} \qquad P = \frac{V^2}{R} \qquad (\text{Watts}) = (\text{Volts})^2 / (\text{Ohms})$$

Depending on the information given one can pick what formula to use. For example, if the current and resistance is given the second equation can be used to calculate power.

Resistors Connected in Parallel or Series

Resistors are electric components that regulate or limit the flow of electrical current in a circuit. Figure 2 shows an example with resistors connected in parallel. Figure 3 shows an example of resistors connected in series. Circuits with resistors connected in parallel have to be treated differently than circuits with resistors connected in series. Some major differences are:

1. Resistors connected in parallel have the same voltage V across them
2. Resistors connected in series have the same current I_0 flowing through them

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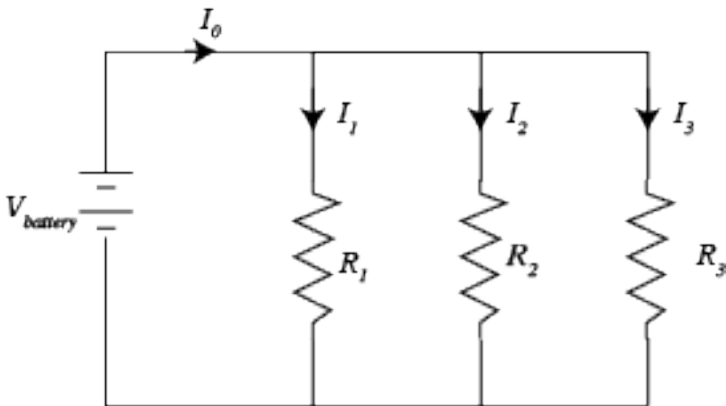


Figure 2: Resistors in Parallel

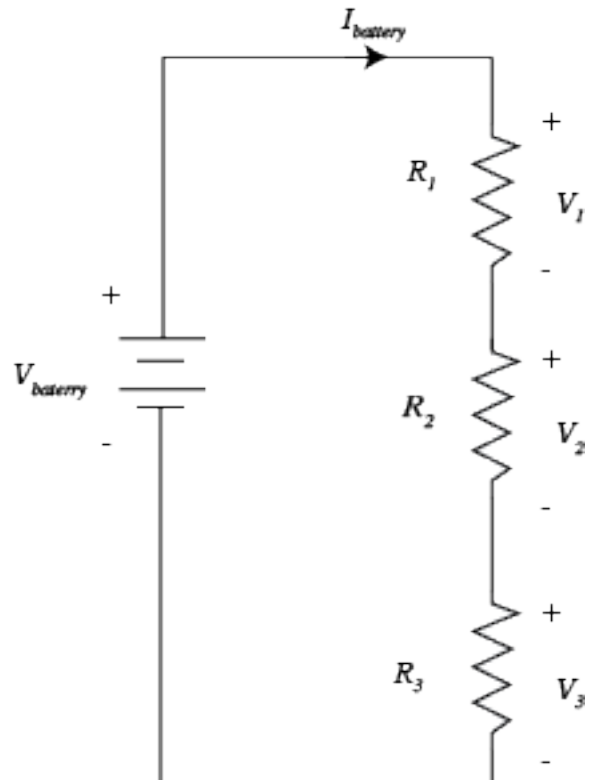


Figure 3: Resistors in Series

Resistors connected in Parallel

From Figure 1, one can see that the same voltage $V_{battery}$ appears across each resistor. Thus all the resistors have the same voltage as the battery ($V_{battery}$)

$$V_{battery} = V_{Resistor\ 1} = V_{Resistor\ 2} = V_{Resistor\ 3} = V_{Resistor\ 4}$$

The current (I) will get divided among the resistors found in the circuit. Kirchhoff's's current law states that total current flowing into a node has to equal the total current flowing out. In this case, I_0 is the current flowing in, and the current flowing out is the total of the three currents I_1 , I_2 , and I_3

Kirchhoff's Current Law

$$I_0 = I_1 + I_2 + I_3 + \dots + I_x$$

Example (Fig 2 based): If the initial current I_0 equals 15 Amps, and there are three 15Ω resistors present, each resistor receives a current of 5 Amps ($I_1 = 5A, I_2 = 5A, I_3 = 5A$). At the end of the circuit all the currents will add back together and the final current will equal 15 Amps just as it did at the beginning.

But, suppose the resistors are not all the same? How do we find the individual currents? For that, we use Ohm's Law

Ohm's Law

$$V=IR$$

Each resistor has the same voltage $V_{battery}$ across it, so the individual currents are

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$$I_1 = \frac{V_{battery}}{R_1}$$

$$I_2 = \frac{V_{battery}}{R_2}$$

$$I_3 = \frac{V_{battery}}{R_3}$$

The total current I_0 is then

$$\begin{aligned} I_0 &= I_1 + I_2 + I_3 = \frac{V_{battery}}{R_1} + \frac{V_{battery}}{R_2} + \frac{V_{battery}}{R_3} \\ &= V_{battery} \left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \right] \end{aligned}$$

If we rearrange this equation, we can write

$$V_{battery} = I_0 \left(\frac{1}{\left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \right]} \right)$$

Comparing this to Ohm's Law, $V=IR$, we can see that the quantity in the parentheses acts like the equivalent resistance R_{eq} of the entire circuit. For example, suppose each of the three resistors were 15Ω . Then the equivalent resistance would be

$$\begin{aligned} \text{Equivalent Resistance} \quad \frac{1}{R_{eq}} &= \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots + \frac{1}{R_x} = (R_{eq})^{-1} \\ \frac{1}{R_{eq}} &= (R_{eq})^{-1} = \frac{1}{15\Omega} + \frac{1}{15\Omega} + \frac{1}{15\Omega} = \frac{3}{15\Omega} = \left(\frac{3}{15\Omega} \right)^{-1} = \frac{15\Omega}{3} = 5\Omega \end{aligned}$$

That is, we could redraw the circuit as shown in Figure 3

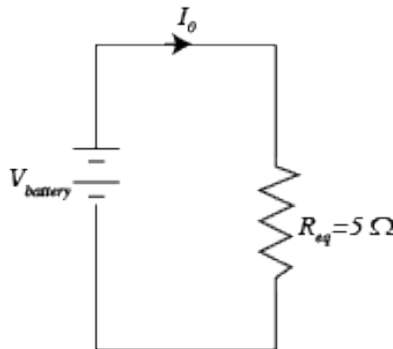


Figure 3. The equivalent circuit to Figure 1 if each of the resistors if 15Ω .

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Resistors connected in Series

Next, let's consider the situation where the resistors are connected in series. Figure 2 is shown here again. In this case, the current will not get divided while passing through the resistors. Therefore, the current from the battery is the same in all the resistors found in the circuit.

$$I_{battery} = I_{Resistor\ 1} = I_{Resistor\ 2} = I_{Resistor\ 3} = I_{Resistor\ 4}$$

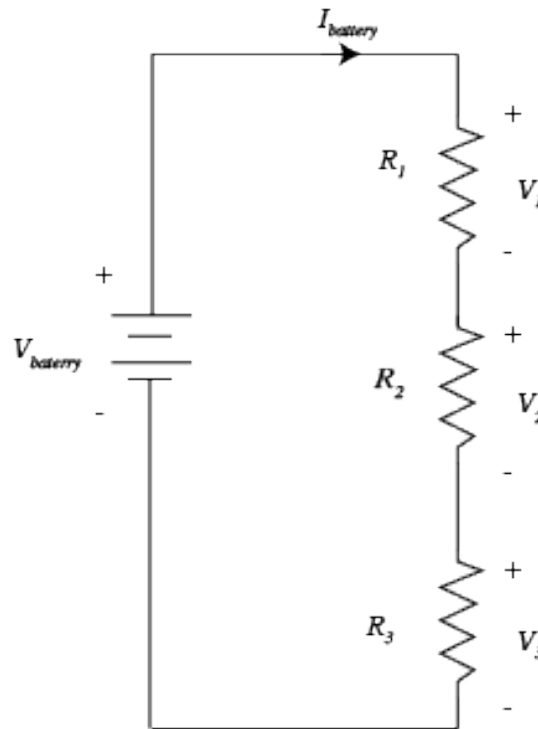


Figure 2, repeated. Resistors in series.

In this case, we will apply another law, Kirchhoff's voltage law. This law says that if you sum all of the voltages around a closed loop, they will add up to zero. To apply this rule, pick any spot in a closed loop, for example, let's pick the lower left hand corner. As we go around the loop, if we encounter a "-" sign first, we give the voltage a negative sign. If we come to the "+" sign first, we make it positive. Suppose we are traveling clockwise (the law will work in either direction). The first voltage we come to is the battery, but we run into the minus sign first, so we write down $-V_{battery}$. Continuing around, we hit the "+" sign of V_1 first, so we make it positive. When we've gone all the way around the loop, the total voltage accumulated has to be zero, or

Kirchhoff's Voltage Law

$$-V_{battery} + V_1 + V_2 + V_3 = 0$$

$$V_{battery} = V_1 + V_2 + V_3$$

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We also know the voltage across each resistor is $V=IR$, and we said earlier that in the series case, all the currents were equal. Thus

$$V_1 = I_{\text{battery}} R_1$$

$$V_2 = I_{\text{battery}} R_2$$

$$V_3 = I_{\text{battery}} R_3$$

We can combine this with the previous equation to write

$$V_{\text{battery}} = I_{\text{battery}} R_1 + I_{\text{battery}} R_2 + I_{\text{battery}} R_3 = I_{\text{battery}} (R_1 + R_2 + R_3)$$

Comparing this to Ohm's Law $V=IR$, we can identify an equivalent resistance for the series case:

$$R_{eq} = R_1 + R_2 + R_3 + \dots + R_x$$

Example (Fig 2 based): If the initial current I_o equals 25 Amps, there are 3 5Ω resistors present, and the voltage (V) of the battery or initial voltage has a value of 9V, the following will be true:

All the resistors will receive the same amount of current, which is 25 Amperes.

The equivalent resistance will equal 15Ω , because the values of the resistors are added. $5\Omega+5\Omega+5\Omega = 15\Omega$

Finally, let's calculate the power dissipated by a particular resistor. Figure 4 shows a circuit.

We know that $P=IV$, so we need to find the current and the voltage in R . From Kirchhoff's voltage law, we can write

$$-10 + V_R = 0$$

$$V_R = 10V$$

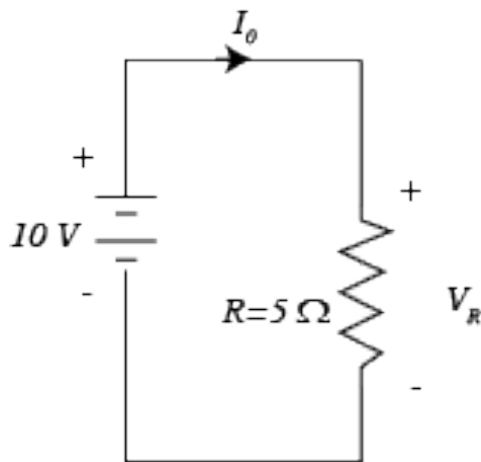


Figure 4. A circuit example to calculate power

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Then, from Ohm's Law $V=IR$, we can find the current:

$$V_R = I_0 R$$
$$I_0 = \frac{V_R}{R} = \frac{10}{2} = 5A$$

From this, we can find the power $P=IV$, or $P=I_0 V_R=(10)(5)=50W$. Notice that this is the power dissipated. It is positive. If the number had come out negative, that would have told us that the resistor was producing power, which would give us a clue that we had made a mistake somewhere.

The Flashlight Circuit

Let's analyze the circuit for the LED flashlight using the laws we just learned. Figure 5 shows the schematic diagram for the flashlight. There is a 9V battery for the power source. Next, there is a resistor in series with a pair of parallel-connected light emitting diodes. The switch lets current flow when it is closed, but not flow when it is open. We'll use the switch to turn the flashlight on and off. The diodes emit light when current flows through them. We need to determine the value of the resistor and the power it has to dissipate.

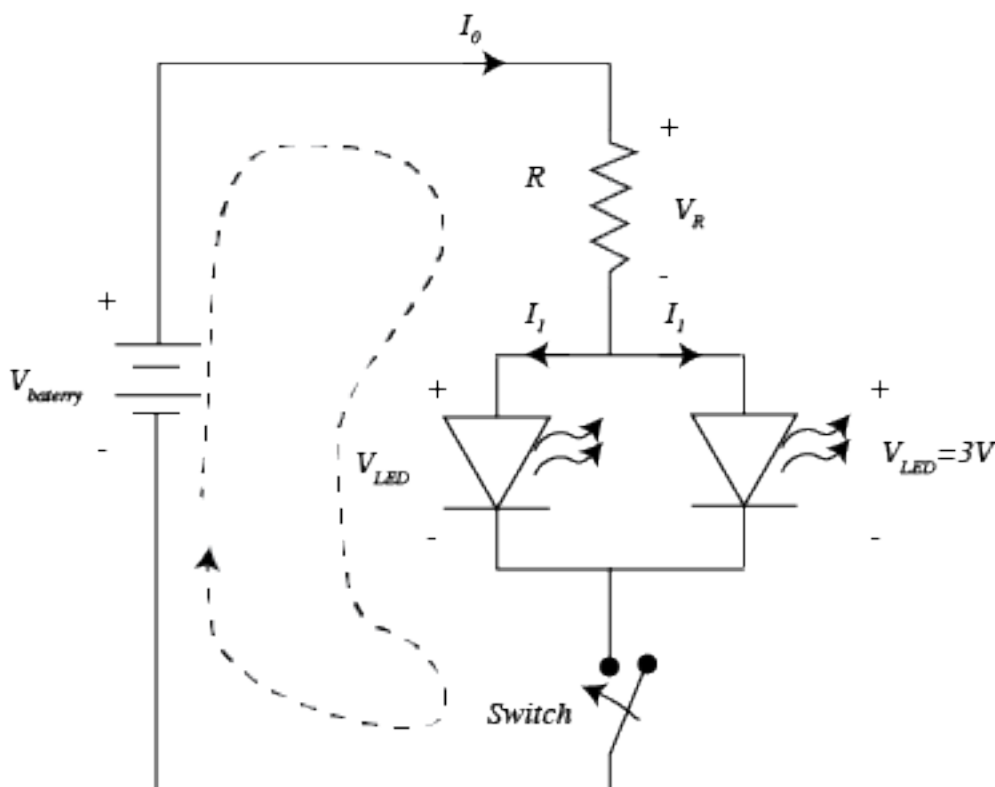


Figure 5. The flashlight circuit.

To analyze this circuit, we start by noticing that since the LEDs are in parallel, they have the same voltage across them. For white LEDs, that voltage is generally around 3 V. Now we can apply Kirchhoff's voltage law around one of the loops. We choose the one shown by the dotted line. Starting just below the battery, we have

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$$-V_{battery} + V_R + V_{LED} = 0$$

$$V_R = 9 - 3 = 6V$$

Next, we choose the resistor to limit the current to a safe value that won't damage the LEDs. A typical value might be $I_l = 30$ mA, or 0.03 Amps. The voltage across the resistor is 6V, and the current is 0.03 A, so we can use Ohm's law to find the resistance:

$$V_R = I_0 R$$

$$R = V_R / I_0 = 6V / 0.03A = 200\Omega$$

Now, the 30 mA (0.03 A), flows through *each* LED. From Kirchhoff's current law, the current flowing through the resistor is the sum of the currents flowing out, or

$$I_0 = I_1 + I_1 = 0.03 + 0.03 = 0.06A = 60mA$$

To calculate the power dissipated by the resistor, we use the power law:

$$P = IV = I_0 V_R = (60mA)(6) = 0.36W$$

When we buy resistors, however, they usually come in $\frac{1}{4}$ W or $\frac{1}{2}$ W, meaning they can safely dissipate one quarter or one half Watt. Since we need to dissipate 0.36 W, a quarter-watt resistor will not be big enough- it might overheat. So we choose a $\frac{1}{2}$ Watt resistor.

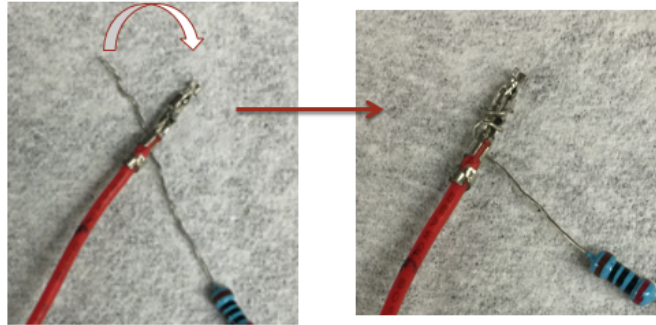
Now that we have analyzed some circuits, let's go on to build the flashlight!

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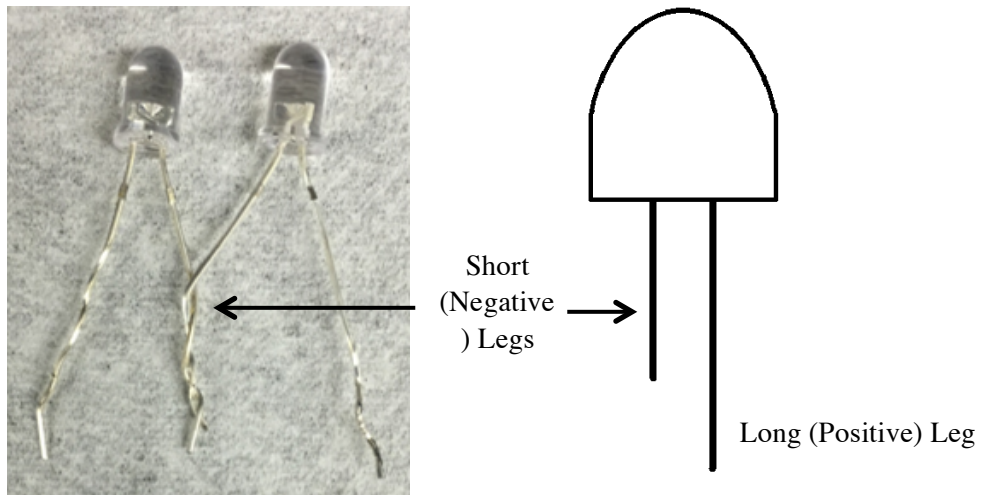
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Instructions:

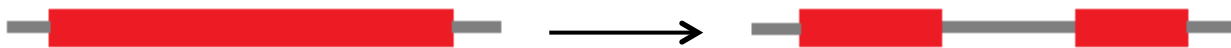
1. Attach the resistor to the end of the wire from the battery clip that has red insulation by twisting them together. The clip has two wires; the one with the black insulation will not be attached to any other component.



2. Each LED has a short (negative) and long (positive) leg. Connect the two short legs of the LED together by twisting them. Make sure they're twisted tightly. Wrap the connection in electrical tape.



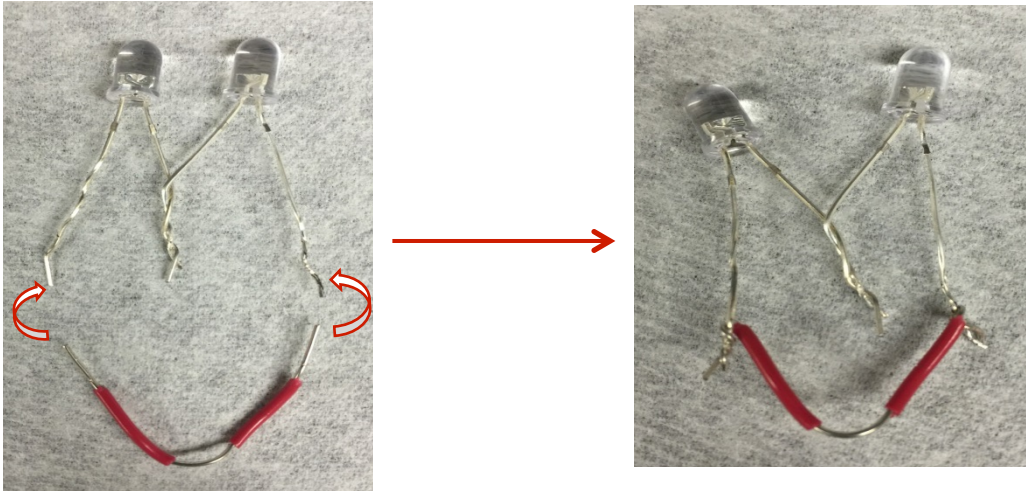
3. Use the wire strippers to strip the insulation from the last half-inch of each end of red and black hookup wires (these are not the battery clip wires). Then, for the red hookup wire only, split the insulator in the middle, leaving it exposed but with insulation on both sides. The easiest way to do this is by using the wire strippers to cut some of the insulation and slide the insulation to the side.



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4. Connect the leftover legs (long legs) of the LEDs to ends of the red electric hook-up wire.



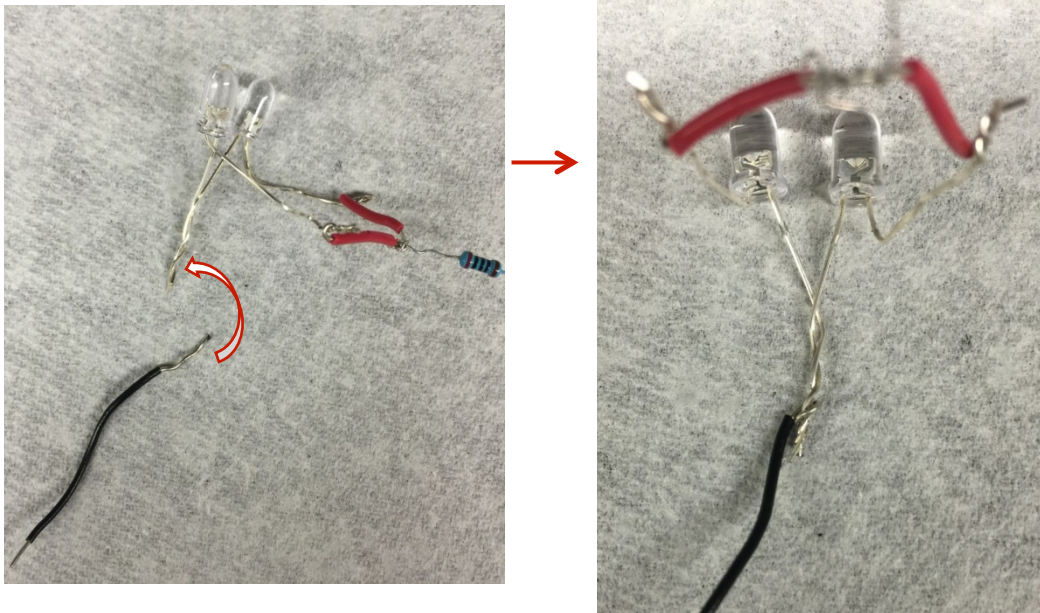
5. Twist the leftover resistor leg from step 2 to the middle of the electric wire.



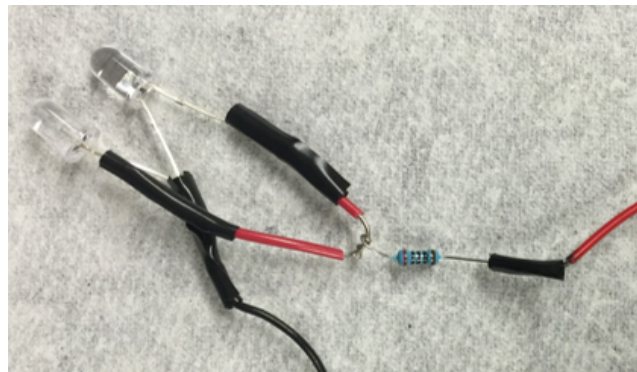
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6. Connect the black electric wire to the short legs from step 3..



7. After all the connections are made, ensure that they are correct and tight enough. The connection is tight enough if it cannot easily be disconnected and doesn't slip if you gently tug on it. Use electrical tape to wrap the connections, this will ensure that the tight connection stays in place. The electrical tape also protects the circuit from shorting out- meaning that if two conductors touch that aren't supposed to, the current might find a "short-cut" around the resistors, and damage the LEDs, or the battery, or both.



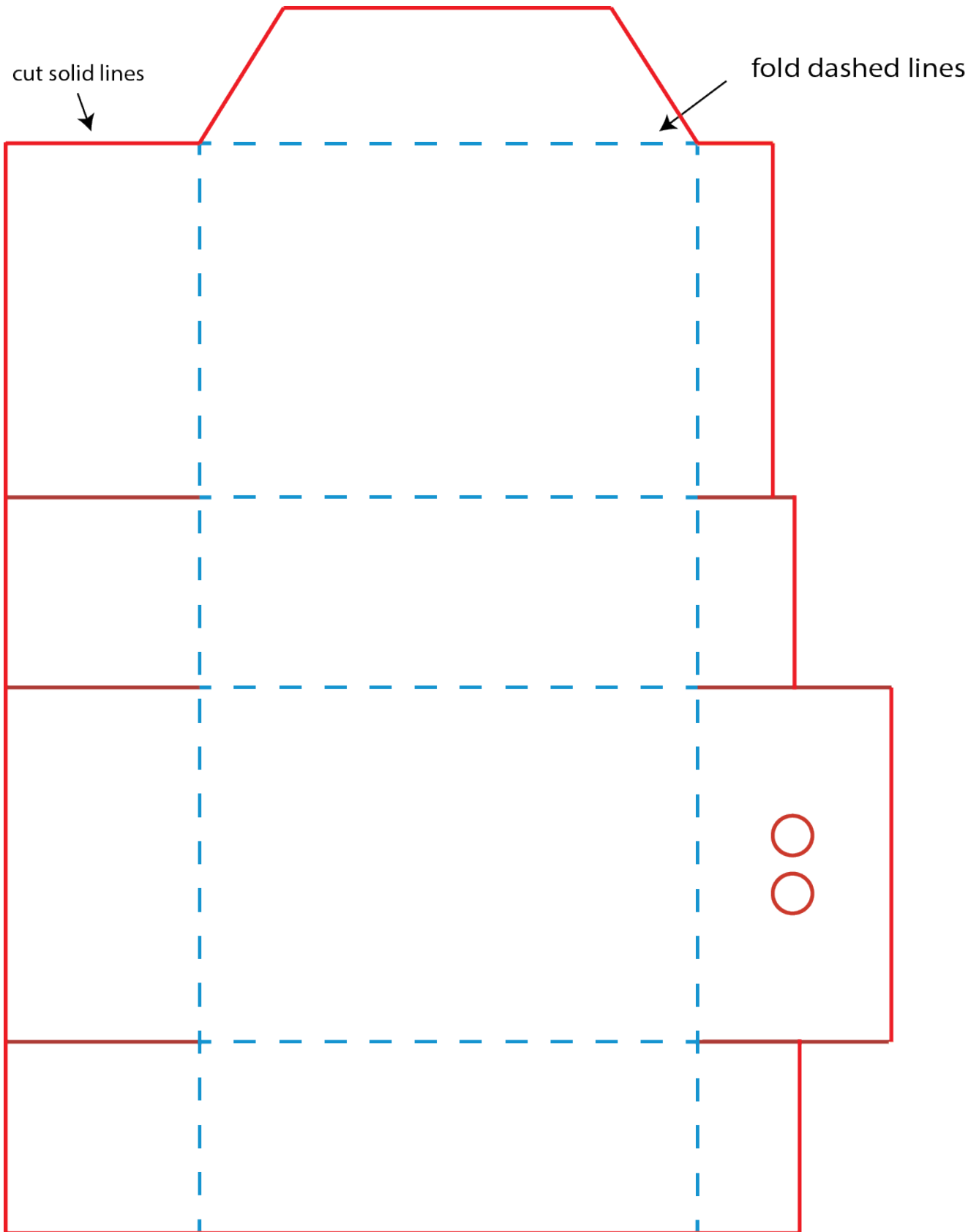
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8. Next assemble the box. A template for the box with can be found on the following page.
 - All the measurements in the figure below are in centimeters (cm).
 - Cut through the red lines and fold the blue edges.
 - Use a stapler or tape to attach the sides of the box to each other
 - Use a hole puncher to make the holes where the LEDs will be placed. The holes are to be approximately the same size as a standard hole puncher. (0.7cm)
 - Picture drawn to scale*

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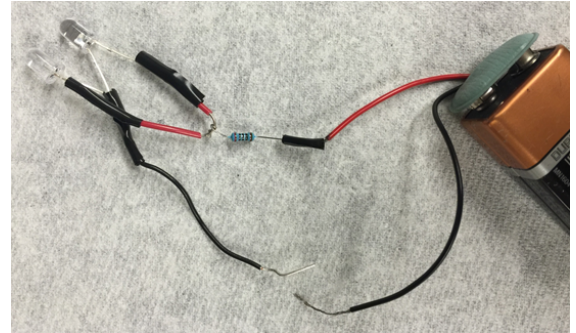
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9. Connect the battery clip to the 9V battery.



10. Place the circuit components inside the assembled box and poke the LED's through the holes. Tape the battery in place inside. Thread the bare ends of the two black wires through the flaps on the end, and close up the box.

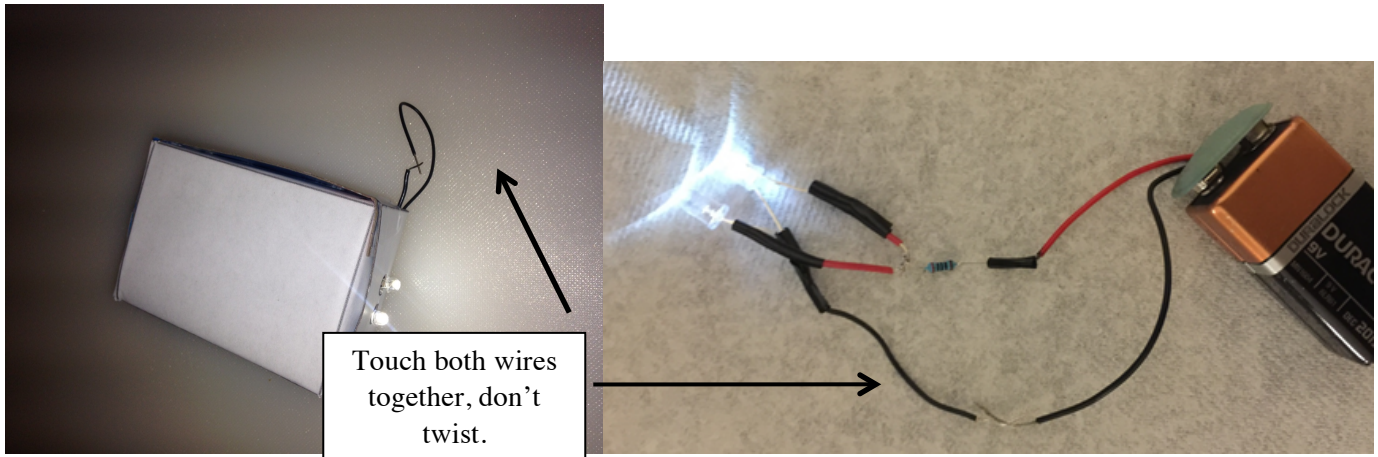


11. Touch the remaining wires together to turn on the LEDs. DO NOT twist these wires, they will serve as the switch in the circuit, when they are not touching the circuit is open, when they touch the circuit is closed.

You built your own flashlight!

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Debugging tips:

- Make sure all the connections are attached properly.
- Double check that the battery clip is on correctly.
- Make sure that the LEDs were twisted properly; both short (negative) legs must be twisted together.
- Circuit components might be faulty, as a last resource change the LEDs, resistor or battery.
- If the battery gets hot, disconnect the battery immediately. Check all connections and make sure no wires are touching that are not twisted together.

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Electricity Worksheet – Pre Lab

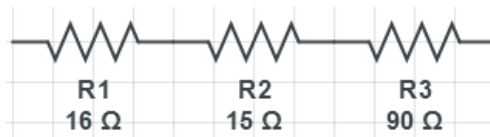
Name: _____ Date: _____

What is the equivalent resistance of each given circuit?

Multiple Choice

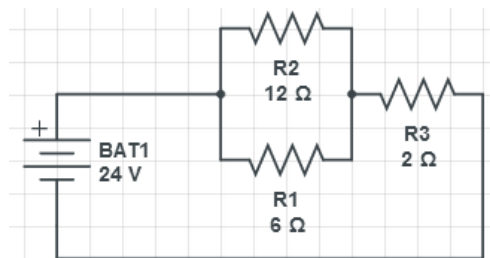
1. Three resistors with values of $16\ \Omega$, $15\ \Omega$, and $90\ \Omega$ are connected in series. What is their equivalent resistance?

- a. $6.86\ \Omega$ c. $31\ \Omega$
b. $121\ \Omega$ d. $29\ \Omega$



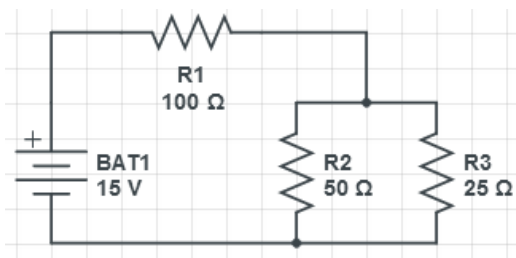
2. Two resistors with values of $6\ \Omega$ and $12\ \Omega$ are connected in parallel. This combination is connected in series with a $2\ \Omega$ resistor and a $24\ \text{V}$ battery. What is the current in the $2\ \Omega$ resistor?

- a. $2.0\ \text{A}$ c. $4.0\ \text{A}$
b. $6.0\ \text{A}$ d. $12.0\ \text{A}$



3. Calculate the power at R1 in the circuit below?

- a. $81\ \text{W}$ c. $2.25\ \text{W}$
b. $1500\ \text{W}$ d. $15\ \text{W}$



4. What unit represents power?

- a. Amps c. Watts
b. Ohms d. Volts

5. What material is best suited to be a conductor?

- a. Aluminum c. Plastic
b. Glass d. Wood

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Electricity Worksheet – Pre Lab Answers & Solutions

Name: _____ **ANSWERS** _____ Date: _____

What is the equivalent resistance of each given circuit?

Multiple Choice

1. Three resistors with values of $16\ \Omega$, $15\ \Omega$, and $90\ \Omega$ are connected in series. What is their equivalent resistance?

- a. $6.86\ \Omega$ c. $31\ \Omega$
b. **$121\ \Omega$** d. $29\ \Omega$



$$R_{eq} = R1 + R2 + R3$$

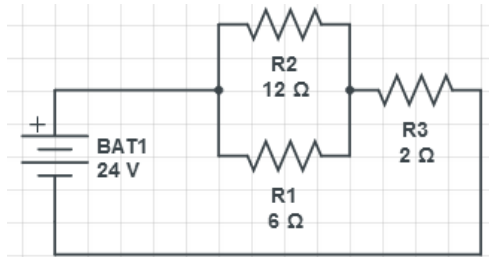
$$R_{eq} = 16\Omega + 15\Omega + 90\Omega = \mathbf{121\Omega}$$

2. Two resistors with values of $6\ \Omega$ and $12\ \Omega$ are connected in parallel. This combination is connected in series with a $2\ \Omega$ resistor and a $24\ \text{V}$ battery. What is the current in the $2\ \Omega$ resistor?

- a. $2.0\ \text{A}$ c. **$4.0\ \text{A}$**
b. $6.0\ \text{A}$ d. $12.0\ \text{A}$

$$R_{eq} = \left(\frac{1}{R1} + \frac{1}{R2} \right)^{-1} + R3 = 6\Omega$$

$$V = IR \rightarrow I = \frac{V}{R} = \frac{24}{6} = \mathbf{4.0\ \text{A}}$$



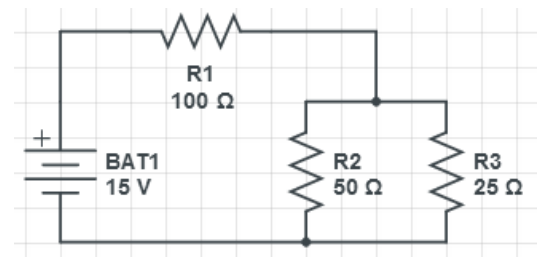
3. Calculate the power at $R1$ in the circuit below, is it consumed or generated?

- a. **$81\ \text{W}$** c. $5.0\ \text{W}$
b. $0.15\ \text{W}$ d. $15\ \text{W}$

$$R_{eq}(\text{of } R2 \text{ and } R3) = \frac{1}{\frac{1}{50} + \frac{1}{25}} = 16.7\ \Omega$$

$$R_{eq}(\text{of entire circuit}) = 16.7\Omega + 100\Omega = 116.7\Omega$$

$$I = \frac{V}{R_{eq}} \quad I = \frac{15\ \text{V}}{116.7\ \Omega} = .9\ \text{A} \quad P = I^2 R = (0.9\ \text{A})^2 (100\ \Omega) = 81\ \text{W}$$



4. What unit represents power?

- a. Amps c. **Watts**
b. Ohms d. Volts

5. What material is best suited to be a conductor?

- a. **Aluminum** c. Plastic
b. Glass d. Wood

