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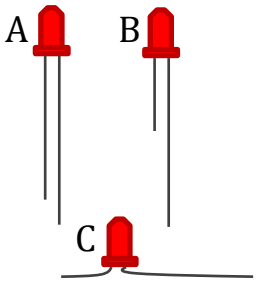
Nature of Science Paper Circuit

Materials

Paper Circuit Templates Printed on White Cardstock (last page)
3mm LEDs - Red, Yellow, Green, Blue, and White
Copper Tape with Conductive Adhesive ¼" Wide
Button Batteries 2032
Medium Binder Clips 5/8" Capacity

Materials Prep

LEDs only work when electricity is flowing through them in the correct direction. LEDs (light emitting diodes) have a negative (shorter) lead and a positive (longer) lead. There is just a slight difference between the lengths of the two leads. (Figure A) It is best to snip about a quarter inch off the negative lead to make it even shorter. (Figure B) This can be done with wire cutters or scissors. It is also recommended that you split the two leads apart. (Figure C) Make sure the leads are not touching each other.



Students will need about 20" of copper tape to complete the circuit. Cut the copper tape in advance of the lesson to expedite circuit construction. They do not need scissors to cut the copper tape. It tears easily with your hands.

Student Directions to Construct Paper Circuit

- Number the position of the LEDs 1-5 on the lines provided.
- Start by measuring out the copper tape you will need for the two legs of the circuit and tearing it at the correct length.
- Carefully adhere the copper tape to the circuit template.
  - **NOTE:** Do NOT pull the backing off the long length of copper tape. It will curl up and is hard to straighten out.
- Use small ¾" pieces of copper tape to secure the positive (long) lead of the LEDs right on top of the positive leg of the circuit.
  - **NOTE:** The LEDs should be placed in the order on the card your table received.
  - **NOTE:** Do NOT tape the negative (short) lead to the other side. This will allow you to use the negative lead as a switch to open and close the circuit.
- Fold the paper circuit template over on the solid line. It is easier to fold it backward and then fold it forward.
- Place a 2032 button battery down on the negative leg with the negative side down and the positive side (with writing) up.
- Fold the paper circuit over to connect the circuit to the battery on the positive side and use a medium binder clip to hold it securely in place. Check to make sure LEDs are lighting up one at a time. Bend negative leads up so the circuit is open and only closes when you push on the negative lead to use it like a switch.

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Student Directions for Experiment

- Play to discover the rules of the LEDs.
  - Which ones can be lit at the same time?
  - Which ones cannot be lit at the same time?
  - How many can be lit at the same time?
  - Write down the rules you observe and be prepared to share them with the group.

Teacher Facilitation

Before starting, let each group of students decide which university they will represent – University of Arizona, Arizona State University, Stanford University, etc. You can have up to 16 groups but you don't have to have that many. Explain how even though science is collaborative in nature, scientists are still human and like to be the first to publish evidence supporting new ideas in science. Because of that they should try to keep their observations and evidence secret from the other universities until the universities "publish" or make their results public at the end of the lesson. Today they will be researching the properties of LEDs (light emitting diodes) in parallel circuits.

Next give students the supplies they will need to build their circuits. Each student will need a circuit template, one of each color of LED, 20" of copper tape, a 2032 button battery, and a medium binder clip. Each group should be given a different card indicating the order of the LEDs. If asked if all the tables have the same cards, just answer with "Every university is studying the same circuit."

The students should then follow the directions above to build their circuits. It is best to have them ask clarifying questions as a university and not aloud to the entire class. What they are asking might be related to something they have noticed which could be an advantage. NOTE: If asked if the number 1 should be closer to the battery or the number 5, have a quick discussion as a scientific community and set the paper circuit standard for numbering – either 1 is near the battery or 5. It ultimately does not matter as long as the scientific community agrees to number it the same way. You can have discussions about if one makes more sense than the other, then take a vote.

Once students have built the circuits and confirmed each individual LED is working independently, then you can give them the research focus:
How do the LEDs behave in this circuit? What are there rules or patterns you can communicate with the broader scientific community to help make predictions about the behavior of the LEDs in this circuit?

You can either choose to let students work silently and individually first and then share with their group or start just working as a group. Either way, they should quietly at their universities share the rules they are observing and record them. The goal is to come to a consensus about what rules govern the LEDs. You should hear students come up with rules like:

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"LEDs 1, 2, and 3 will light up together."
"LEDs 3, 4 and 5 will light up together."
"The red LED will not light with the blue LED."
"The red and yellow LED will light together."
"The red, yellow, and green LED will light together but the green LED is dimmer."
"The green, blue, and white LED will light together."
"The blue and white LEDs will light together."
"The yellow LED will not light with the blue or white LED."
And so on. The hope is that some tables will have rules based on the order and some will have rules based on the color. You can gently hint at patterns to get groups to include both kinds of rules.

Once each university has secretly and quietly determined the rules and patterns they see, then you can facilitate a scientific conference. All the universities are attending the National Paper Circuit Conference in Tucson, Arizona.

Option 1:
One university will present their observations and rules first and then the others will have a chance to contribute to what we know about paper circuits with LEDs in parallel. Pick one university to share their rules. At the end of their sharing, pick another university to share their rules. Discuss whether those universities agree or not and then facilitate a discussion about the rules, ultimately coming to consensus color and not order of the LEDs determines how they behave.

Option 2:
Have one university share just a single rule they discovered. Other universities can then either agree or disagree with that rule. If they disagree, then they have to demonstrate an experiment which contradicts the rule. As an example, if one university says LEDs 1, 2, and 3 will light up together. Another university could show that on their circuit, it doesn't work. Keep going like this until all the rule have been shared and challenged if necessary.

After the scientific community has agreed to the rules governing the paper circuits, you can share with them two additional bits of information.

1) The order of colors in the visible spectrum of light is also the order of energy of the photons. Least amount of energy – red, orange, yellow, green, blue, indigo, and violet – most amount of energy. (White is composed of all colors of light.)
2) The voltage ratings of the LEDs is as follows: (Red – 1.8-2.2 V; Yellow – 1.8-2.2 V; Green – 2.8-3.2 V; Blue – 2.8-3.2 V; White – 2.8-3.2 V)

Have a discussion about how this information supports the rules they discovered through their experiments.

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What ARE the Rules?
The white, blue, and green LEDs can all light up together at full brightness.

The red and yellow LEDs can light up together at full brightness and the green LED will light up slightly when they are all connected at the same time. You may have to turn the room lights out to see this.

The white and blue LEDs will not light up if either or both the red and yellow LEDs are connected.

The green LED will only light up slightly if either the red and yellow LEDs are connected.

More rules can exist that are subsets of the rules above like:
The white and blue LED can light up together.
The white LED will not light up when the red LED is lit.
And so on… the main conclusion is that it is color and not order which seems to matter.

What the Heck?
LEDs are complicated little devices but here is an explanation in a nutshell. You are encouraged to investigate more about LEDs to get a more complete picture. Here is a particularly good site: https://electronics.howstuffworks.com/led.htm

Depending on the particular LEDS, you will note the forward voltage for the red and yellow LEDs are generally lower than forward voltage for the white, blue, and green LEDs. LEDS are non-ohmic devices which means they behave in some strange ways in terms of resistance. When they do not have electricity running through them, they have a really high resistance. Once electricity is running through them, the resistance drops to almost nothing.

Small differences in resistance and differences in forward voltage drive the strange behavior we see regarding which LEDs will light together and which will not. (Red – 1.8-2.2 V; Yellow – 1.8-2.2 V; Green – 2.8-3.2 V; Blue – 2.8-3.2 V; White – 2.8-3.2 V) The red and yellow LEDs have less resistance than the other colors. Therefore, the electric current will tend to choose the path of least resistance if all the LEDs are connected at the same time. That means, the red and yellow LEDs will light at full brightness, the green just slightly, and the others not at all. In various other combinations, the LEDs with similar voltages and resistance can all light at the same time and if an LED with lower resistance is connected, the current will tend to travel only through that LED. The result is either the other LEDs not working or dimming.

Another way to explain what we see is based on the energy required to create the photons for the various colors of light. In order from lowest to highest energy (red, orange, yellow, green, blue, indigo, and violet) with white being a combination of colors requiring more energy. So, it makes sense that red and yellow light should be easier to create and require less forward voltage than the other colors.

Cut these out and give them to different student groups.

Order of LEDs for Paper Circuit

1. Red
2. Yellow
3. Green
4. Blue
5. White

Order of LEDs for Paper Circuit

1. White
2. Blue
3. Green
4. Yellow
5. Red

Order of LEDs for Paper Circuit

1. White
2. Red
3. Green
4. Yellow
5. Blue

Order of LEDs for Paper Circuit

1. Blue
2. Red
3. Yellow
4. White
5. Green

Order of LEDs for Paper Circuit

1. Green
2. Blue
3. Yellow
4. Red
5. White

Order of LEDs for Paper Circuit

1. Yellow
2. Red
3. White
4. Green
5. Blue

Order of LEDs for Paper Circuit

1. Blue
2. Yellow
3. White
4. Green
5. Red

Order of LEDs for Paper Circuit

1. Red
2. Blue
3. Green
4. White
5. Yellow

Order of LEDs for Paper Circuit

1. Green
2. Red
3. Yellow
4. White
5. Blue

Order of LEDs for Paper Circuit

1. Yellow
2. White
3. Blue
4. Green
5. Red

Order of LEDs for Paper Circuit

1. Yellow
2. Red
3. Green
4. Blue
5. White

Order of LEDs for Paper Circuit

1. Green
2. White
3. Red
4. Yellow
5. Blue

Order of LEDs for Paper Circuit

1. Red
2. White
3. Green
4. Yellow
5. Blue

Order of LEDs for Paper Circuit

1. White
2. Green
3. Red
4. Blue
5. Yellow

Order of LEDs for Paper Circuit

1. Blue
2. Green
3. White
4. Red
5. Yellow

Order of LEDs for Paper Circuit

1. White
2. Yellow
3. Red
4. Blue
5. Green

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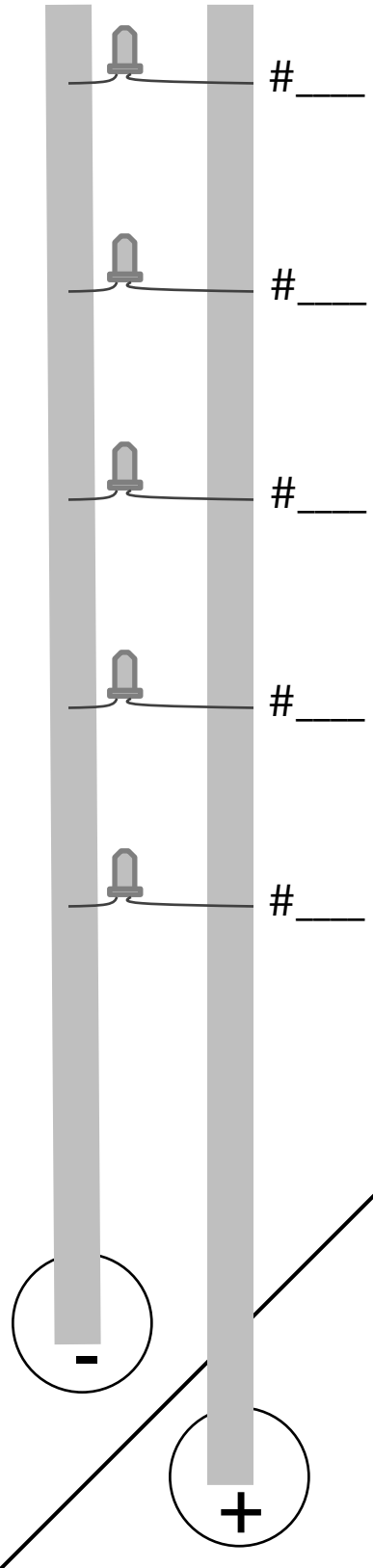

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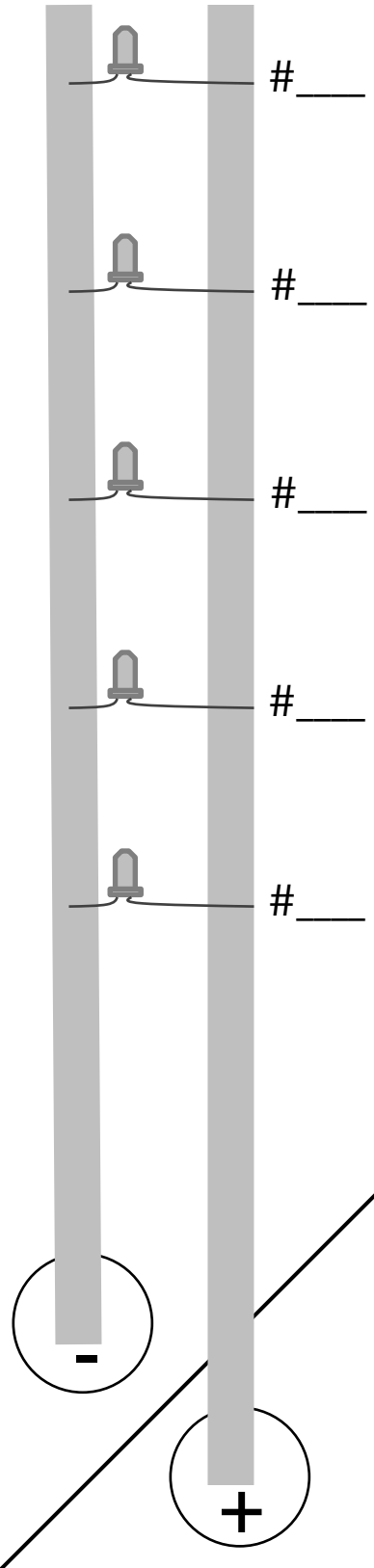

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