Developed and written by DaNel Hogan – danel.hogan@waterscenterst.org. STEMAZing.org

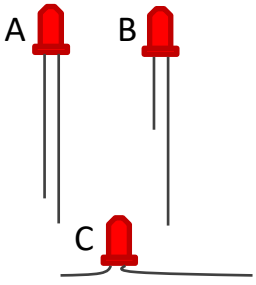
Paper Circuit Supplies and Teacher Tips

Supplies

¼" copper foil tape with conductive adhesive (http://bit.ly/QuarterCopperTape)
Button batteries CR2032 (http://bit.ly/40ButtonBatteries2032)
3mm LEDs – red, yellow, green, blue, and white (http://bit.ly/3mmLED)
Medium sized binder clips (1¼" with $^{5}/_{8}$" capacity)
Invisible Tape
Masking Tape
Scissors

Tips

- Have students practice making shapes and turns with masking tape to determine the best way to make corners while keeping the tape in one continuous piece. This practice will help eliminate wasting copper tape when they are building their paper circuits.
- LEDs should be taped on top of the copper tape to ensure the best connection instead of taping them down to the paper with the adhesive side of the copper tape. You can tape the LEDs down using a small piece of copper tape (~1/4") overtop the original copper tape.
- All circuits have predetermined sections to them with the lengths given. You can cut these in preparation for the lesson to eliminate waste of the copper tape.
- Try to keep the copper tape in each section in one single, continuous piece. If the tape does get broken apart, overlap the tape to make a good connection. It may be necessary to use another piece of continuous tape if careful observations are trying to be made.
- Each circuit will indicate which colors of LEDs can be used. Different colors have different resistive properties and require different voltages to light up. When used in combination, circuits may not work or may work but in confusing ways. So, pay attention to the recommended colors and let students explore color combinations as an extension activity.
- The point of these lessons is for students to make observations and base conclusions on those observations related to resistance in a wire, properties of series and parallel circuits and so on. If they ask testable questions, whenever possible, let them explore those questions on their own.
- To prep LEDs (Fig. A), cut an extra ¼" off the anode – the short leg (Fig. B). This makes it obvious which side is the anode (negative, short side) and which side is the cathode (positive, long side). Once the anode is trimmed, you can bend the anode and cathode apart (Fig. C).



- Note: The paper circuit pages can be printed single-sided and stapled together. They have also been made so that when cut along the borders, they will fit into a standard sized composition notebook.
- If you are particularly interested in exploring the REAL primary colors with your students, you can find more resources related to that topic here: https://stemazing.org/primary-colors/
- SAFETY WARNING: Button batteries can be very dangerous if swallowed. The acid inside the stomach acts like a conductor short circuiting the battery and can damage the stomach and intestinal tract. Seek immediate medical attention for anyone who swallows a battery.

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Paper Circuit 1 (PC1)

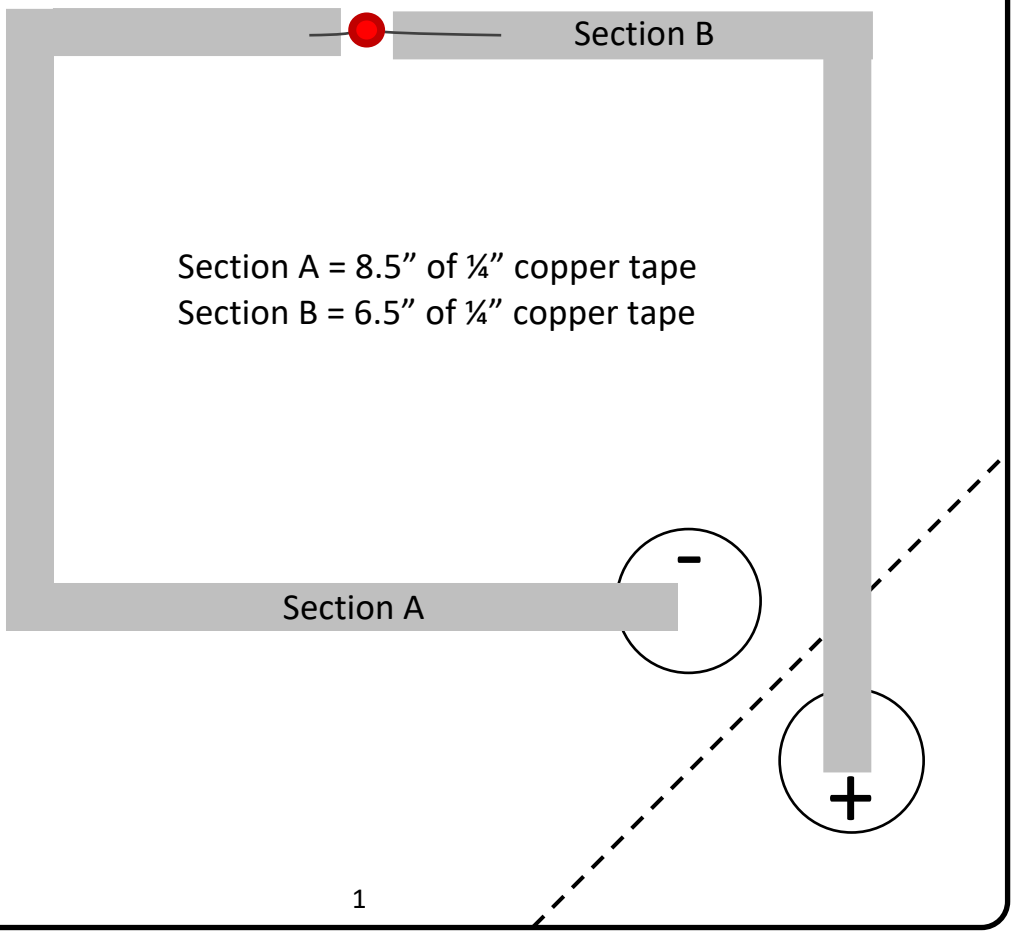
Construct the simple paper circuit shown below using one button battery and any colored LED. Fold the corner up along the dotted line and close the circuit using a binder clip to keep it connected while you make observations.

What do you notice about the working circuit? _____

_____

What do you wonder about the working circuit? _____

_____

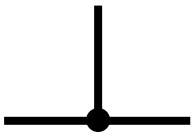


Circuit Diagrams

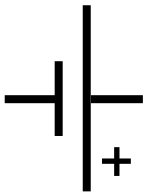
Circuit diagrams, also known as schematics, are drawn using specific symbols for the components, which make up the circuit. These schematics are important when communicating the design of a particular circuit. The ability to build a circuit based on a schematic is an important skill to have for anyone working with electronics. Paper circuits are fairly simple so we will just be using a few of the symbols found in more complex circuit diagrams.

Switch (S) – Single-pole/single-throw (SPST)
This is the most basic kind of switch with two terminals and an angled line coming from one terminal representing the actuator – the part which can be moved to close the circuit and make it run or open the circuit to disconnect it.

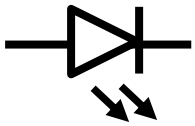
Junction and Node
A junction is anyplace a wire splits into two directions. The node or dot at that junction indicates the wires are connected. In complicated schematics, it is possible for wires to cross each other without being connected.



Battery (B)
Regardless of the shape or kind of battery, it is usually represented using the symbol shown here. If multiple batteries or cells are being used you would repeat the disproportionate, parallel lines. All of the simple paper circuits we are using will utilize a single battery.

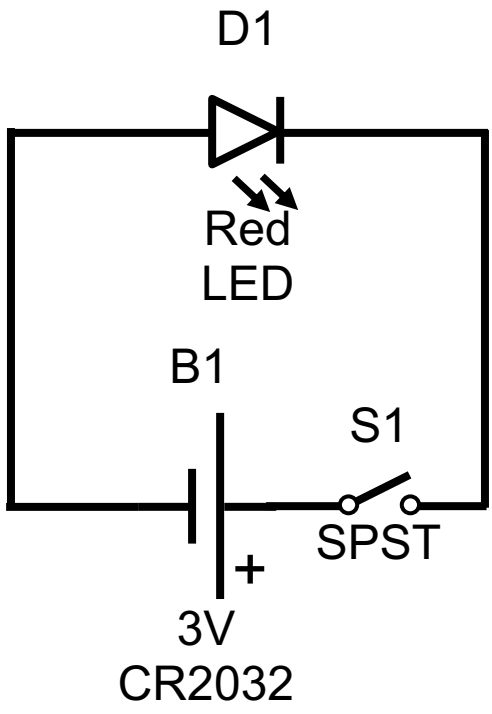


Light Emitting Diode (D)
Simple diodes would be represented with just the triangle next to the line, as shown to the right. However, to signify a light emitting diode or LED the two arrows pointing away from the symbol are included.



Names and Values
Components in a circuit diagram are labeled with values to define exactly what the component is and names which include a letter prefix indicating the component and a number to ensure each component name in the schematic is unique. Watch for these labels in the example circuit diagrams.

Paper Circuit 1 Diagram



What do you notice about how the circuit diagram is drawn and labeled?

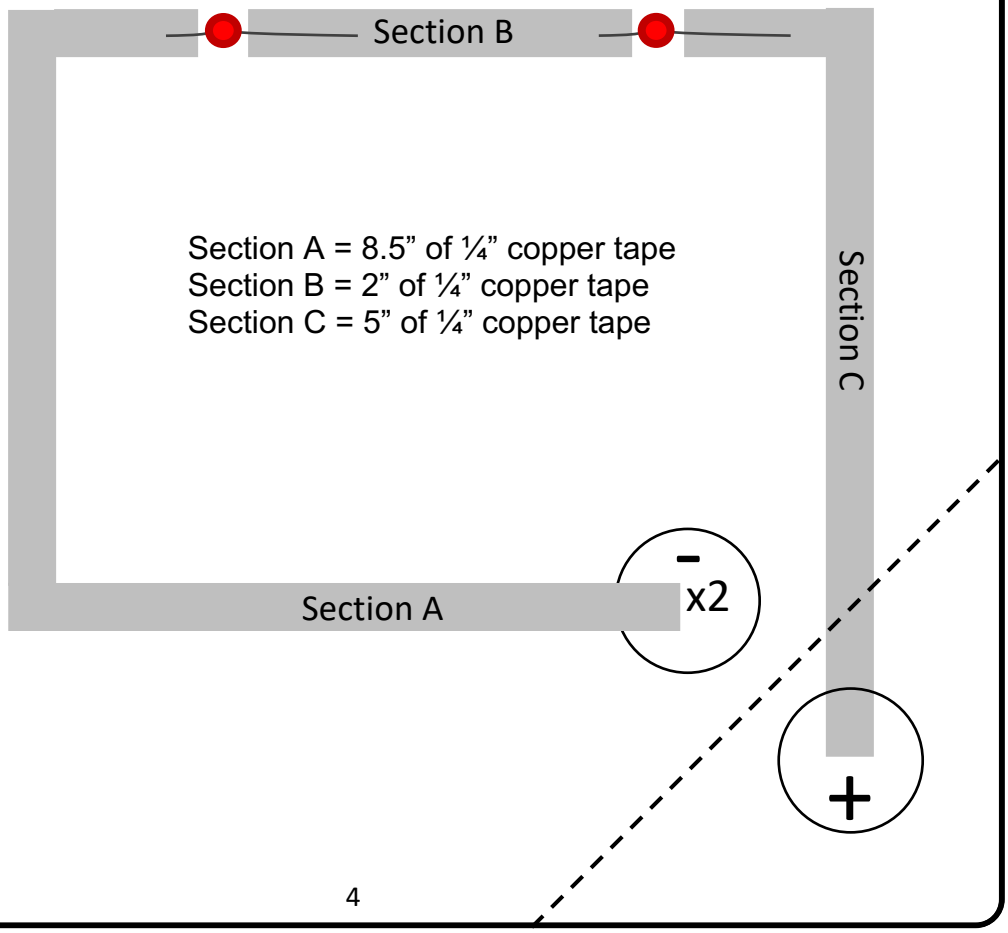
If you used a second LED in your circuit, how do you think it would be labeled?

Paper Circuit 2 (PC2)

Construct the paper circuit shown below. You must use either both red or both yellow LEDS.

NOTE: You are using two button batteries in series for the power source for PC2 and PC3. Make sure you put the first one in place and then stack the other battery on top with the negative side down and the positive side up.

Make sure your circuit works when you connect it to the batteries. Disconnect your circuit and set it aside while you build Paper Circuit 3.



Paper Circuit 3 (PC3)

Construct the paper circuit shown below. All three LEDs must be the same color used in Paper Circuit 2.

Using your batteries, light PC2 first and then PC3. Go back and forth between lighting the two circuits.

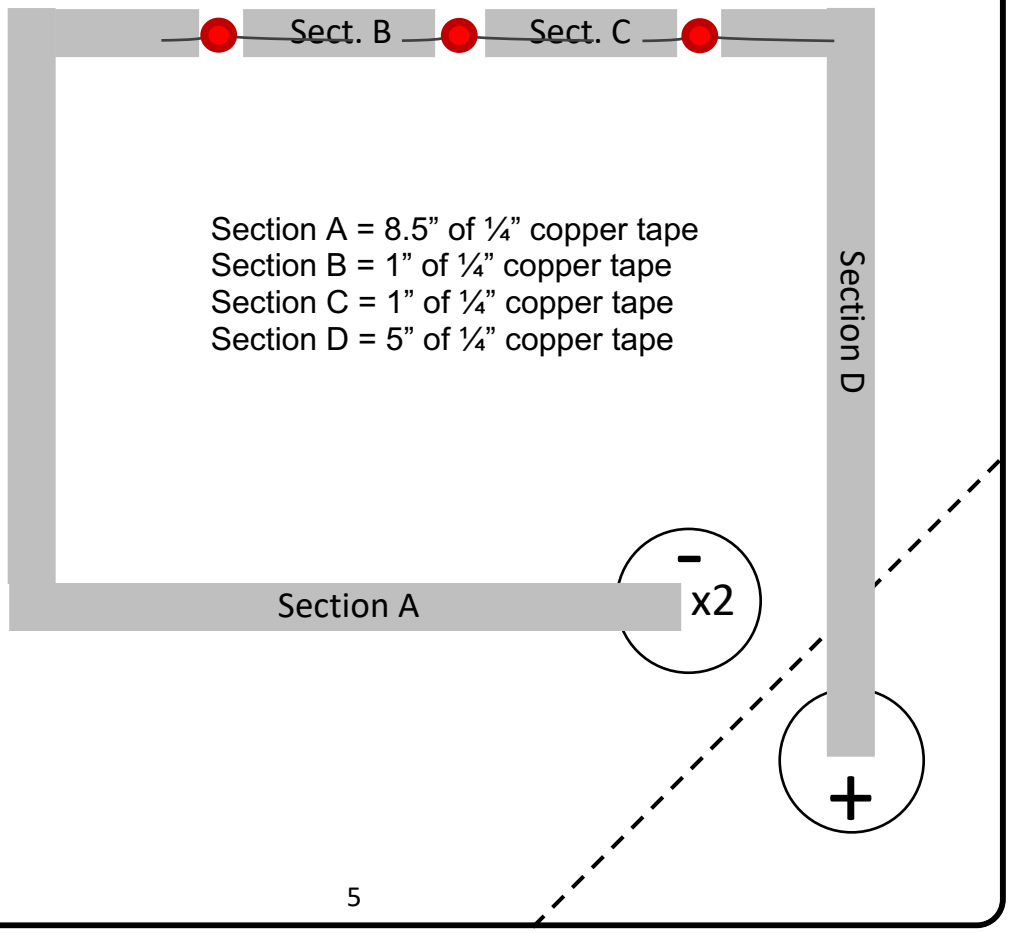
Record any differences you notice. _____

_____

_____

_____

_____



Paper Circuit 2 Diagram

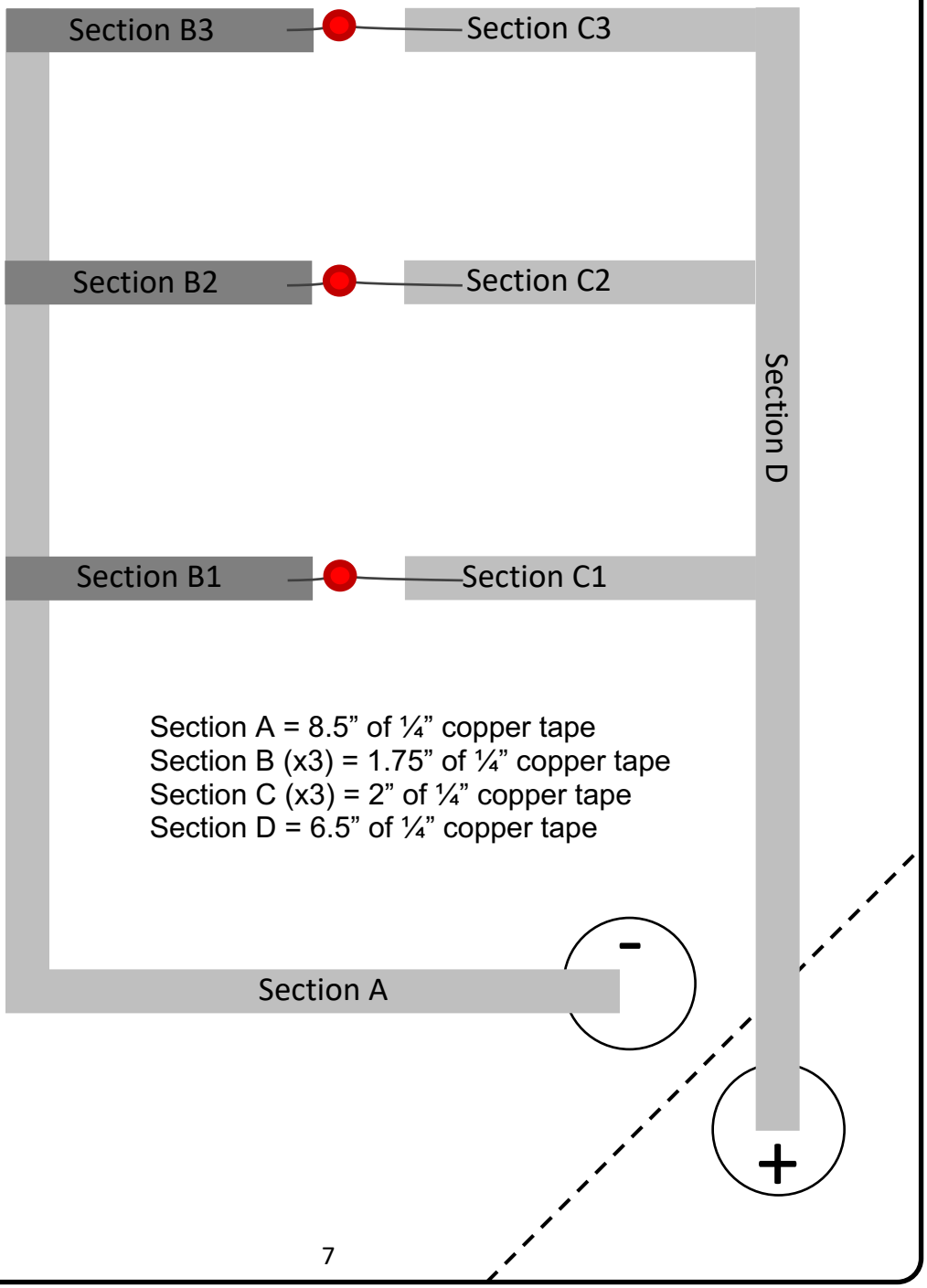
Draw the circuit diagram for Paper Circuit 2 in the space below. Be sure to label all the components and include both batteries.

Paper Circuit 3 Diagram

Draw the circuit diagram for Paper Circuit 3 in the space below. Be sure to label all the components and include both batteries.

Paper Circuit 4 (PC4)

Construct the paper circuit shown below powered by one battery. Use any combination of red and yellow LEDs for the circuit. Only tape the LEDs down on the positive (long leg). This will allow you to use the negative (short leg) as a switch to open and close the circuit.



Paper Circuit 4 Diagram

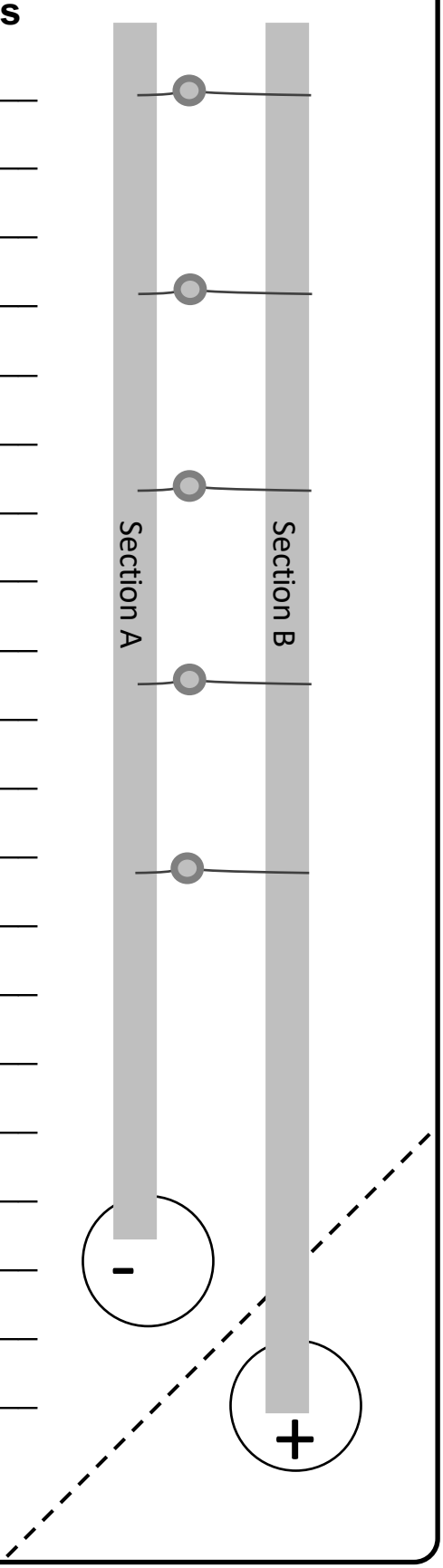
Draw the circuit diagram for Paper Circuit 4 in the space below. Be sure to label all the components.

Paper Circuit 5 (PC5)

Construct the paper circuit on the next page. Section A is 7” long. Section B is 8” long. You will need one red, one yellow, one green, one blue, and one white LED for this experiment and one battery. Tape the positive (long leg) of the LEDs to the positive leg of the circuit. This will again allow you to use the negative (short leg) as a switch to open and close the circuit. They can be placed in any order you want.

Play to discover the rules of the LEDs. Which ones can be lit at the same time? Which ones cannot? Determine how they work together so you could predict if any combination is connected which ones will light and which ones will not light up.

PC5: Parallel Circuit LED Lighting Rules



Paper Circuit 6: 3D Circuit Construction

When using paper circuits to light up art projects, presentations, maps, greeting cards, etc. you may want to use multiple colors. Based on what you just learned in the last circuit, you now know this can be complicated. You can use invisible tape as an insulator and build circuits in layers.

Construct Paper Circuit 6 found on the next page. First lay down copper tape Sections A and B. Then put invisible tape on top of the sections as shown with the outlines. Then lay down copper tape Sections C and D on top of the tape and original circuit as shown.

Sections A and D are 9.5” long.

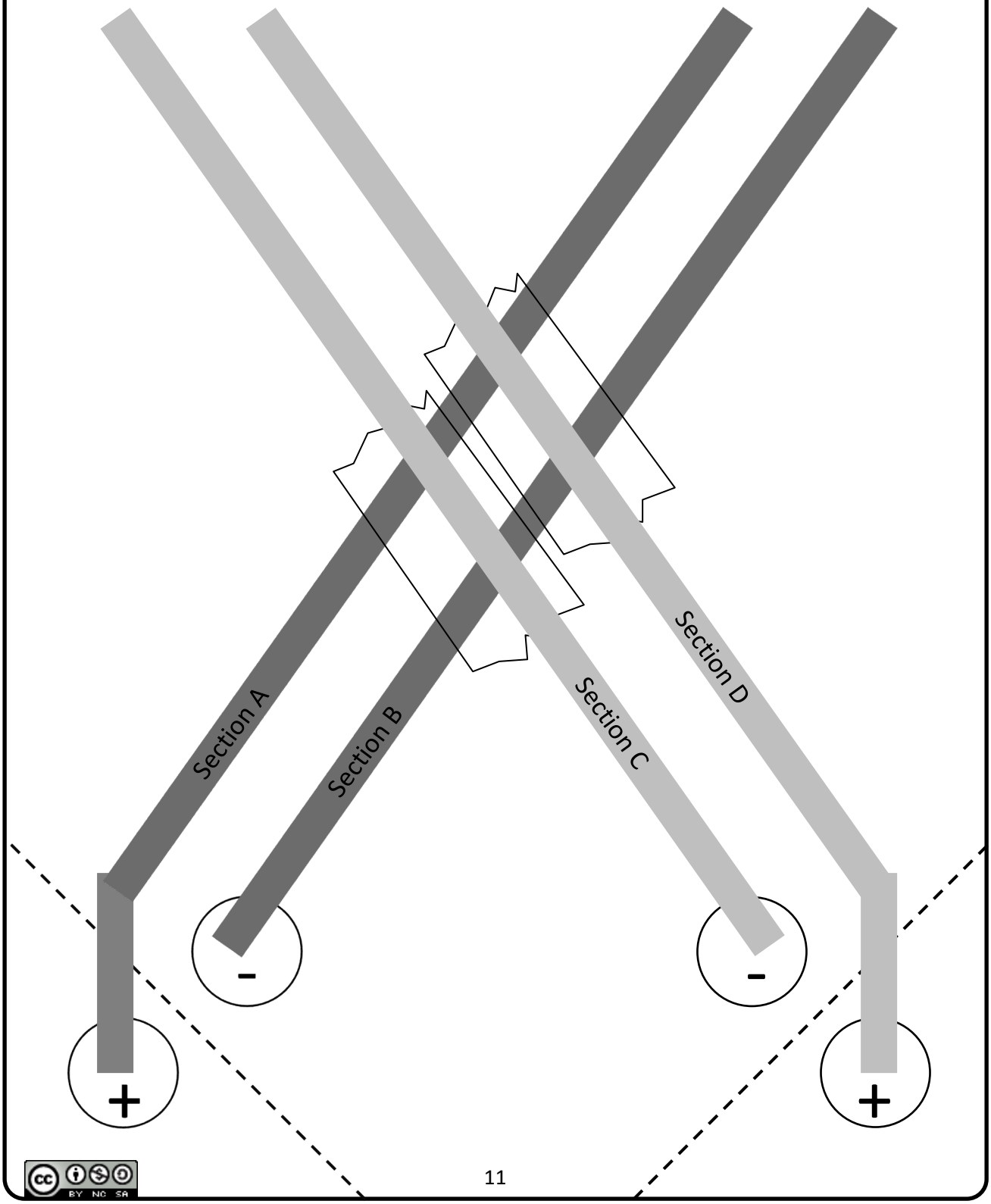
Sections B and C are 8” long.

Use what was learned with PC5 to incorporate at least four LEDs of a variety of colors into PC6. Once the two circuits are complete, draw diagrams of them below.

Paper Circuit 6 Diagrams

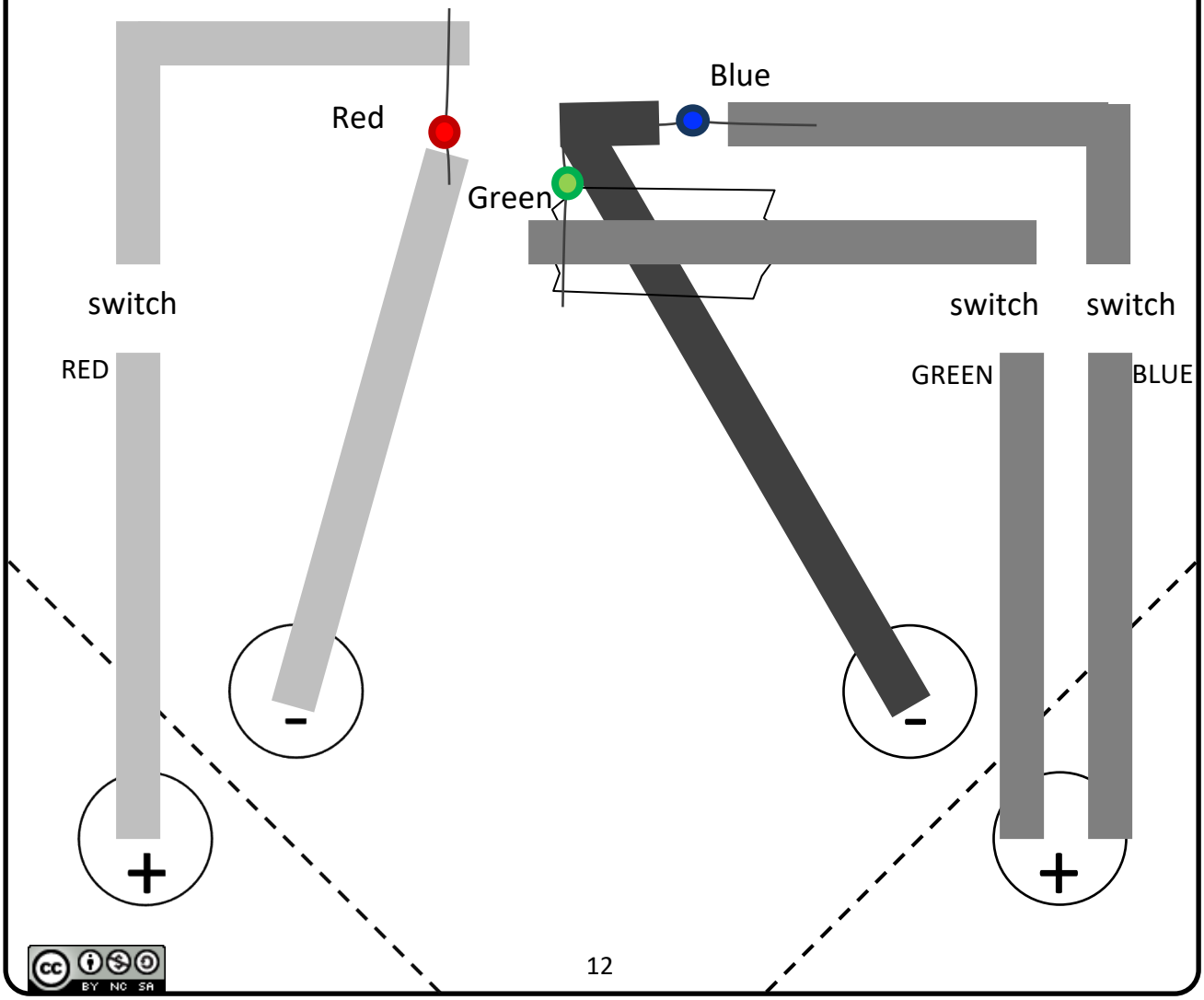
Draw the circuit diagrams for the two circuits in PC6 in the space below. Be sure to label all the components.

PC6: 3D Circuit Construction



PC7: Primary Colors of Light Circuit

Build the circuit below by putting copper tape on the darkest grey line first. Then put a piece of scotch tape on top of the copper tape where it shows to insulate the bottom copper tape from the copper tape you place on top of it. This is the same technique used in PC6. Be careful about where you put the negative (short) leg and the positive (long) leg of the LEDs – it matters. This circuit uses two batteries to power the red, green, and blue LEDs in order to do experiments with color addition. You will need to build the reflection box on page 14 for the light show.



How to Build Switches for PC7

To build the switches for the three locations in PC7, you need put copper tape down until you get to the end of the shaded line, then with the backing still on, bend the tape backward and then fold it over on itself as shown below. The folded section should be about ¾". Cut or tear the copper tape where the overlap ends and then create a tape tag by sticking the copper tape to itself. These switches need to be one single piece otherwise the difference in resistance impacts the performance of the circuit. In this way, the copper tape tag can be a switch which you either connect or disconnect as you try out different combinations of colored light to explore color addition.

RGB Light Show

Follow the directions on the next page to build a box. Put the box on top of your red, green, and blue LEDs to test what colors you get with different combinations of colored lights. This works best in a darkened room.

Red + Blue = _____ Blue + Green = _____

Red + Green = _____ R + G + B = _____

NOTE: The primary colors are generally taught wrong in school. They are NOT red, yellow, and blue. Instead, the primary colors of paint are cyan, yellow, and magenta and the primary colors of light are red, green, and blue. The secondary colors of light, which you discovered above by turning on different combinations of two primary light colors at the same time, are actually the primary colors of paints or pigments used for color subtraction. Confirm your findings and check out all the colors you can create by changing the intensities of the colored lights using this PhET Color Vision simulation: https://bit.ly/RGBcolorvision

Light Show Reflection Box

Carefully cut along all the dotted lines. Then, fold along the solid lines to create a box. Tape it together with invisible tape. Put this on top of your red, green, and blue LEDs in Paper Circuit 7 to test what colors you get with different combinations of colored lights.