SNC1D: Key Ideas from the Electricity Unit Name:

As a young scientist, you will be conducting experiments to explore how electricity works. You need to keep track of the new ideas and skills you learn! This will help you unravel the mysteries and solve the puzzles that you will face. At the end of each investigation, you should:

(1) Identify the new skills or ideas you learned that day. Label each as "Skill" or "Idea".
(2) Describe each using just a few words
(3) Indicate the page number from the investigation where you could find more information.

Skill: A small task or routine that you do very often.
Idea: A concept you use to explain or understand what's going on.

Investigation #1: SNC1D: A Mysterious Interaction

Idea: Charging - tiny pieces of charged matter to move from one object to the other. (page 4)

Idea: Positive and negative -

Investigation #2: SNC1D: Charge in Solid Matter

Skill: Charge Equation -

Idea: Neutral -

Skill: Charge Diagram -

Idea: Electron -

Idea: Model of Charges -

Investigation #3: SNC1D: Conductors and Insulators

Investigation #4: SNC1D: The Polarization of Insulators

Investigation #5: SNC1D: Conductors and InsulatorsSNC1D: The Polarization of Conductors

Investigation #7: SNC1D: Electron Current

Investigation #8: SNC1D: Electric Circuits and Current

Investigation #9: SNC1D: Current Flow and Loads

Investigation #10: SNC1D: Electric Energy

Investigation #11: SNC1D: Energy, Current, and Resistance

Investigation #12: SNC1D: Ohm’s Law

Investigation #13: SNC1D: Circuit Connections

Investigation #15: SNC1D: Circuit Connections 2

SNC1D: A Mysterious Interaction

Recorder: ___________________
Manager: ___________________
Speaker: ___________________
0 1 2 3 4 5

Scientists and detectives have a lot in common. They both try to solve mysteries using clues or evidence. Today you will explore a mystery and use evidence to help figure out what happened.

A: Mysterious Effect

You teacher has a plastic bag and pipe. You did not see if anything "was done" to these objects before this experiment.

1. **Observe.** Your teacher shows what they can do! Describe what you see happening. Don't describe anything that you cannot see!

2. **Reflect** (*individually*)**.** To figure out what is going on here, what questions would you ask? One everyone has a few questions, your group should choose one question and write it on your whiteboard.

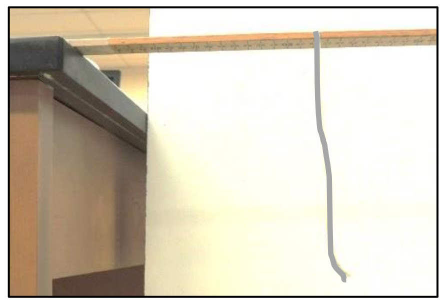
B: Call the Detectives

We will have to do some serious scientific detective work to solve this mystery! Put on your detective hats and lab coats.

1. **Set Up.** Gather the materials you will need. Place your metre stick across the space between two desks and attach the piece of string so it hangs down. The piece of string is your **interaction detector.**

2. **Observe**. Slowly bring each other material near your detector (the string). Describe your observations (it's OK if they are not too exciting).

Materials
- metre stick
- small piece of string
- piece of masking tape
- balloon
- piece of cloth



3. **Set Up.** To do a careful investigation, we need to make sure we don't "contaminate the evidence". Inflate the balloon but **only touch the balloon by the bottom part** with the opening. Carefully rub a small area of the balloon with the piece of cloth. Use a marker to draw a small dot showing the rubbed area.

4. **Observe and Reason.** Albert rushes in, breathless, and makes the claim: "*Rubbing caused a change in both of these objects!"* Use your detector to <u>carefully</u> explore each object. Do you agree with Albert? Explain.

5. **Record.** On your whiteboard, record **one** observation that you think was the most interesting or that you think other groups are most likely to overlook. Show off your detective work! Use 10 words maximum.

6. **Observe and Discuss** (*as a class*). Marie, your lab technician, bursts through the doors with some important results. Her lab has a microscope that can create high resolution images of the surface of objects like the balloon. Record what you observe and the conclusions we can draw from these observations.

Observations	**Conclusions**

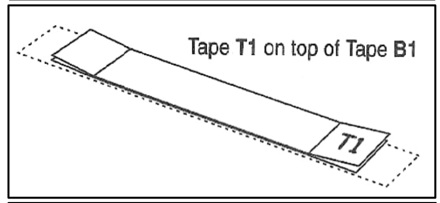
C: Time for Tape

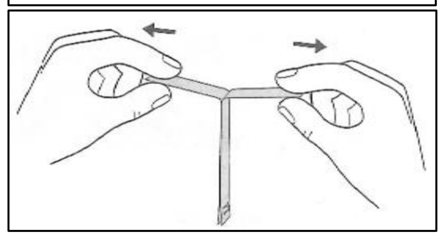
Materials

- Five equal-sized pieces of invisible tape about 15 cm long

Albert makes another claim: "*The* <u>*same*</u> *thing happened to both the balloon and the cloth.*" You are not sure that the evidence supports his claim. When in doubt, do an experiment!

1. **Set Up.** Hang the pieces of tape from your metre stick while you prepare the experiment.
   (a) Fold over the ends of each piece to create "handles". From now on, don't touch any other part of the tape.
   (b) Place one piece on your desk surface. Place the next on the first and label it with pen "B1". Place the third carefully overlapping the second and label it "T1"
   (c) Peel off B1 and T1 together. Then, quickly peel apart B1 and T1. Hang them from your metre stick.
   (d) Repeat this process to create tapes B2 and T2.





from *Physics and Everyday Thinking*

2. **Play**. Be sure to touch the tape by the handles only! Explore how each piece of tape interacts with the others. If the tape "stops working", repeat the set up procedure above.

3. **Observe.** Time for careful detective work. Complete the chart to the right to describe how each tape interacts with the others.

	T1	B1
T2		
B2		

4. **Find a Pattern.** Imagine we brought together all the T-tapes and B-tapes from the whole class. Write a **simple** set of rules that would allow us to predict how any combination of tapes would interact.

5. **Test.** Try your tapes with those from another group. Say your predictions out loud before you test!

6. **Observe and Reason.** Is the interaction between the balloon and cloth the same kind of interaction as the one between the tapes? Try some quick tests and describe your conclusion.

7. **Observe.** Rub an ebonite did with a piece of acetate. Test these objects with your tapes. Based on <u>all</u> your observations today, create a list showing which objects behave like Ts and which behave like Bs.

It's time to introduce some words to help describe what we are seeing. When we rub the objects together they become *charged*. Small amounts of charged matter *transfer* from one object to the other. We will call the T-charged objects *positively* charged and the B-charged objects *negatively* charged.

8. **Apply.** Label the objects in your chart above as *positively charged* or *negatively charged*.

SNC1D: Charge in Solid Matter

Recorder: ___________________
Manager: ___________________
Speaker: ___________________
0 1 2 3 4 5

In your previous investigation, you experimented with charged objects and discovered that they come in two varieties: *positively* and *negatively* charged.

A: The Neutral Zone

1. **Reason.** Marie, your detective supervisor, makes a shocking discovery: "*I don't think the piece of string from the previous investigation belongs to group T or group B!*" Do you agree or disagree with this claim? Support your decision with observations from the previous investigation.

Objects that are not charged are called *neutral*. Neutral objects have a total charge of zero.

2. **Predict.** In a moment your teacher will stick a T tape and B tape back together. When they are stuck together, how will they interact with a single T tape or a single B tape?

3. **Test** (*as a class*)**.** Stick the T and B tape together. Test them with a single T and B tape. Record your observations. Do the results agree with your prediction? Explain.

We use the labels "positive" and "negative" for charges because charging works a lot like the way positive and negative numbers add. We can write a *charge equation* that shows how the positive and negative charges add up to give the total charge or the *net charge* of the object.

4. **Represent.** Let's suppose the B tape has a charge of -1 and the T tape a charge of +1. Write a charge equation that shows how you can find the net charge of the combined B and T tapes.

5. **Observe and Reason** (*as a class*)**.** Isaac enters your lab and says, "I think the balloon had a greater net charge than the ebonite rod.*"* Re-charge the balloon and rod. Do you agree or disagree with Isaac? Explain using careful observations.

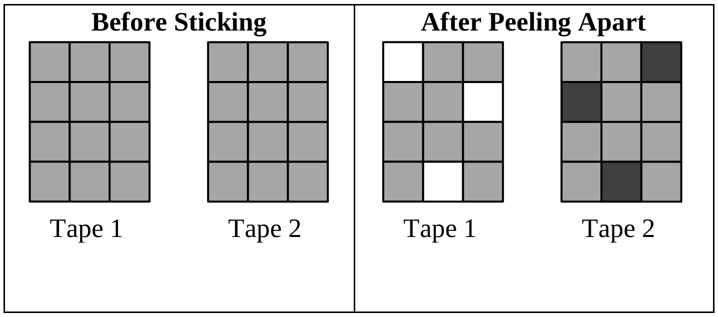
The amount of charge on a rubbed object will depend on many factors such as the types of materials, the amount of surface rubbed, the amount of time since it was rubbed, and more. The net charge of the object can be described using a positive or negative number.

B: Creating a Model of Charged Matter

1. **Record.** (*as a class*) Careful experiments show fascinating patterns when we rub materials together. We will use these patterns to create a scientific model that describes charges in solid matter.

We will call one standard amount of charged matter one *unit* of charge. One unit of charge typically represents many billions of tiny charged particles. We can have positive or negative units of charge.

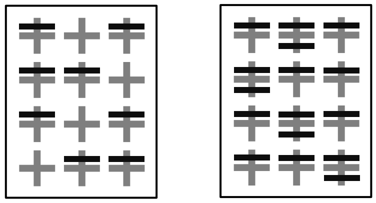
2. **Interpret.** In this example we will represent positively charged matter with a white square, negatively charged matter with a black square, and neutral matter with a grey square. Examine the sets of diagrams that represent our two pieces of tape.
   (a) Under each piece of tape, write its net charge (for example, you might write "-2 units" or "0".)
   (b) Compare the before and after pictures of the two tapes. Which tape lost negative charges? Which tape gained negative charges?



   (c) Draw arrows showing the movement of negative charge from one tape to the other.
   (d) Write a complete statement describing the transfer of charge. For example, "-7 units of charge transferred from Tape 1 to tape 2"

A *charge diagram* shows the units of positive and negative charge that make up an object. When you draw a charge diagram, choose one colour for the "+" symbols and another colour for the "-" symbols. In neutral matter, the positive and negative charges overlap, so draw the minus on the plus, but just up or down a little bit.

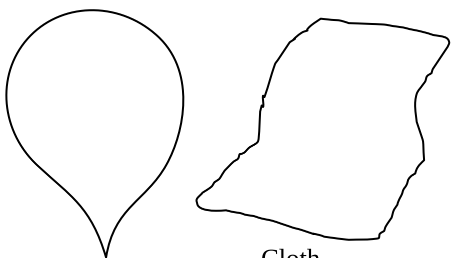
3. **Interpret.** Emmy pulls apart two more pieces of tape. They are represented by the charge diagrams shown to the right.
   (a) Under each piece of tape, write its net charge.
   (b) Which tape lost negative charges? Which tape gained negative charges?



Tape 3 Tape 4

   (c) Draw arrows showing the movement of negative charge from one tape to the other.
   (d) Write a complete statement describing the transfer of charge.

4. **Apply.** In the previous investigation you experimented with a balloon and piece of cloth.
   (a) Was the balloon positively or negatively charged? What about the cloth?
   (b) Draw a charge diagram for the balloon and cloth. Assume that 4 units of charge was transferred. Use different colours!



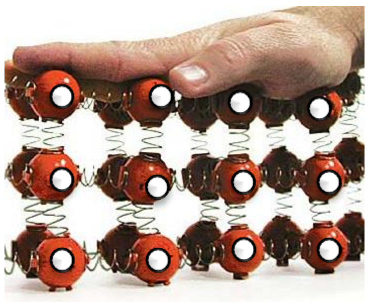
A single atom is made up of positively- and negatively-charged particles. Often, there are equal numbers of each, so the atom is electrically neutral. An atom can only gain or lose its negatively charged particles called *electrons*.

5. **Reason.** One type of atom normally has 6 positive and 6 negative charges. It loses one electron. What is the atom's net charge before and after it loses the electron? Write a charge equation for each.

   Before: After:

Model of Charges in Solid Matter: In a charge diagram, we choose the negative to represent a single electron. The positive represents the rest of an atom, which has a net charge of +1. Together, they make a neutral atom, which we call a *charge-pair*. Electrons (the "-") can be moved from atom to atom. The rest of the atom (the "+") cannot move.

6. **Apply.** Examine the spring model of solid matter at the front of the class. How are the ideas described above represented in this physical model?



SNC1D: Conductors and Insulators

Recorder: ___________________
Manager: ___________________
Speaker: ___________________
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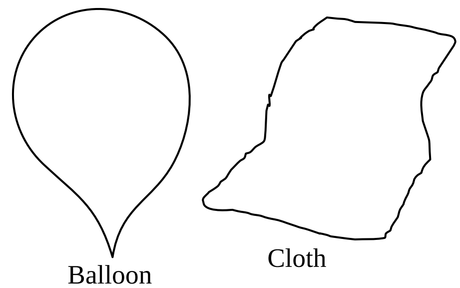
In our previous lesson, we explored a model for electric charge in solid matter. Today, we will explore how the electrons are able to move. Go electrons!

A: Charging by Friction

In our first lesson, we carefully charged a balloon by rubbing it in just one place. Then we used a piece of string as an interaction detector. We observed that the string was attracted only to the rubbed portion of the balloon.

Charge can move from one object to another by rubbing (friction). This mechanism is called *charging by friction*.



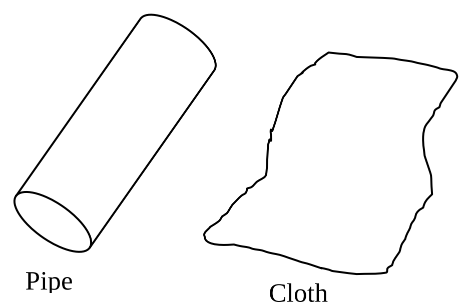
1. **Represent.** Let's say you rubbed just one half of the balloon. Draw a charge diagram for the balloon and cloth that clearly shows which area of the balloon was rubbed. Be sure to use two colours. The cloth loses electrons (you may choose how many).
2. **Represent.** Write a charge equation under each object.
3. **Reason.** Electrons have been added to the surface of the balloon. Are these electrons able to move easily across the surface of the balloon? Explain using your observations from a previous class.

Materials that hold electrons tightly in place are called *insulators*. These electrons are not *mobile*. Often a strong effect like a force of friction is needed to move these electrons around.

B: Charging by Contact

Your teacher has an aluminum sphere on a plastic stand, a plastic (PVC) pipe, a piece of cloth or fur, and some thread.

1. **Represent.** Draw a charge diagram for the pipe and cloth after they are rubbed. The cloth loses electrons (you may choose how many).



2. **Represent.** Write a charge equation under each object.
3. **Observe.** Use your teacher's equipment. Before doing anything, use a piece of thread to verify whether the aluminum sphere is neutral. Describe your observations.
4. **Observe.** Now for the pipe and cloth! Try this:
   - Charge the pipe with the cloth.
   - Touch the charged part of the pipe to the top of the sphere.
   - Bring a piece of thread (the interaction detector) near many parts of the sphere.
   - Bring the thread near the pipe.
   - Place your hand on sphere.
   - Bring the thread near the sphere.
   - Describe your observations.

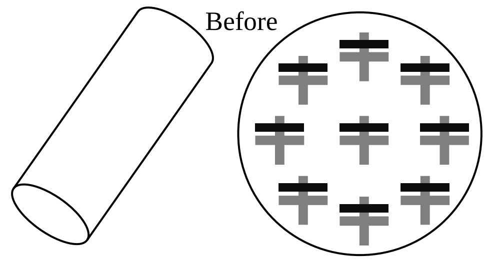
An object can become charged by touching one object to another, allowing electrons to transfer. This mechanism is called *charging by contact*.

5. **Reason.** Based on your observations, what parts of the sphere's surface are now charged?

6. **Reason.** What do you think happened to the charge on the pipe? Is it still charged after contact?

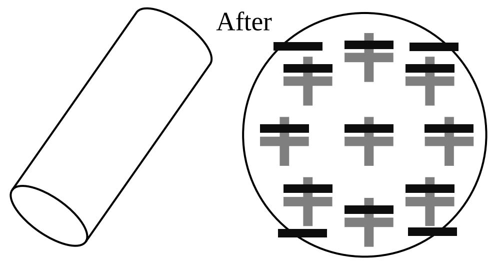
7. **Represent.** Complete the charge diagrams showing the pipe before <u>and</u> after contact.

8. **Explain.** Describe how many electrons in your diagram moved and where they moved.



9. **Reason.** Electrons were added to the surface of the sphere. Are these electrons able to move easily across the surface of the sphere? Explain using evidence from your observations.

10. **Reason.** Electrons all have the same negative charge. What effect do they have on one another?



Materials that allow electrons to easily move are called *conductors*. Electrons in conductors are *mobile*, meaning they are free to move from atom to atom. Metals are common examples of conductors. Electrons repel one another and in a conductor the excess electrons get pushed fairly evenly on to the <u>surface</u> of the material.

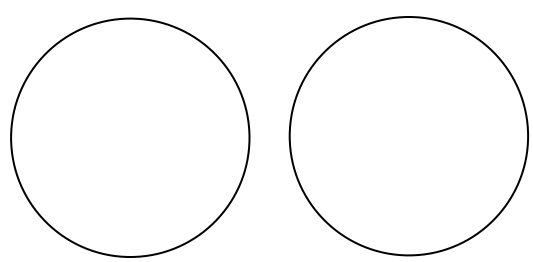
11. **Explain.** At the end of the experiment, you touched the sphere with your hands. What was the net charge of the sphere after you touched it? What do you think happened to the excess electrons that were on the sphere?

Our bodies behave like conductors. When a very large conductor (like you) contacts a small conductor (like the sphere), all of the excess charge moves from the small to the large conductor. The small conductor becomes neutral. This process is called *grounding*. In reality, a tiny bit of charge is left behind, but we will always assume that all the charge moves.

C: Two Spheres!

1. **Apply**. Your teacher has two identical aluminum spheres. One sphere has a net charge of -6 units, the other is neutral. The two spheres are touched together and are then separated.
   (a) Draw a charge diagram for the two spheres <u>after</u> they have been separated.
   (b) Write a charge equation for each sphere.

2. **Predict.** You will bring a thread near each sphere. What will you observe?



3. **Test.** Use your teacher's equipment to test your prediction. Do your observations agree with your prediction? Explain.

SNC1D: The Polarization of Insulators

Recorder: ____________________
Manager: ____________________
Speaker: ___________________
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In your investigations, you have probably noticed a few situations where a neutral object interacts with a charged object. Why this happens is another mystery that we must solve!

A: Virtual Balloons!

You will need the simulator: https://phet.colorado.edu/en/simulation/balloons (or Google "PhET static"). Start the simulator. It will run in the browser of most computers and phones.

1. **Play.** Take a few minutes and play with the simulator. Make sure each person in your group spends equal amounts of time trying it out.

2. **Observe and Explain.** Reset the simulator (click the ). Don't rub the balloon. What happens if you let go of the balloon near (but not touching) the sweater? Explain why this happens.

3. **Observe.** Rub the balloon against the sweater. According to the simulation, what parts move and what parts remain in place?

4. **Observe.** Is there any evidence for an interaction between the charged balloon and the neutral wall? According to the simulator, what happens to the charges in the wall?

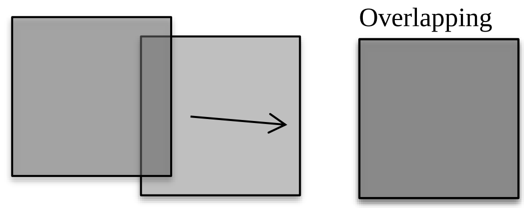
5. **Explain.** Why is the charged balloon attracted to the neutral wall?

B: Shifting Charges

In the previous example, we saw evidence that the electrons in the wall moved because of an interaction with the charged balloon. The wall is also an insulator, so this is a very limited electron movement. Your teacher has pieces of coloured plastic. You need one of each colour.

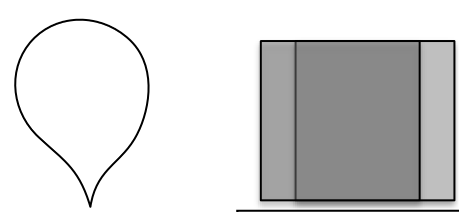
1. **Describe.** The coloured plastic represents the charge of the electron and the rest of the atom. You can pick which is which. Describe which colour is positive and which is negative.

2. **Describe and Represent.** Place the pieces one on top of the other so they overlap perfectly. Describe the colour you see. Write a charge equation for your "colour atom".



3. **Explain.** Now we bring the charged balloon near your "atom". Describe how the balloon will interact with each coloured piece (attract or repel?)

4. **Represent.** Draw a charge diagram for your balloon. Write a charge equation for the balloon and for your "colour atom".



5. **Set Up.** In an insulator, electrons are tightly attached to the rest of its atom, so they cannot move far. Shift your negative plastic piece a little bit to the appropriate side.

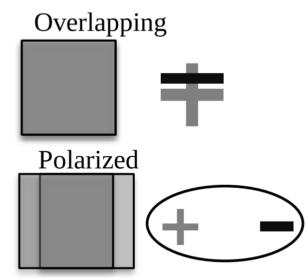
6. **Interpret.** In your diagram on the previous page, label the colours you see and label each part as positive, negative, or neutral.

7. **Reason.** Overall, did the net charge of your "colour atom" change? Did it gain or lose any electrons?

C: Polarization

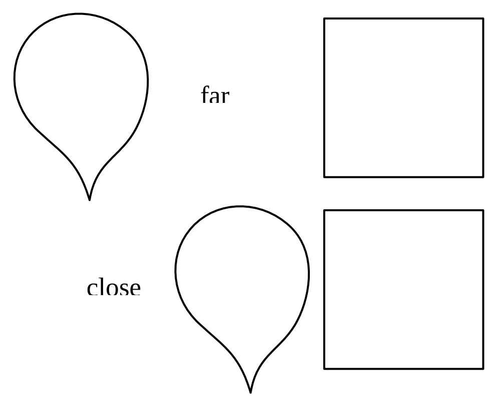
When a charged object is near a neutral object, the electrons in the atoms of the neutral object will be pushed a very tiny amount (much less than the size of an atom) towards or away from the charged object. As a result, one side of the atom becomes positively charged and the other negatively charged. This process is called *polarization* and we say that the atom or the material has become *polarized.* Note well that the atom (or material) is still neutral. In an insulator, electrons remain tightly attached to the polarized atom – they are not mobile.

When we draw charge diagrams, we show polarization by shifting the electron in the appropriate direction and drawing an oval around them to show that they are still attached. Note that our diagram greatly exaggerates the distance the electron moves.

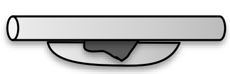


1. **Represent.** Complete the charge diagrams showing the balloon and wall when the balloon is far away (no polarization) and when the balloon is close to the wall. Write a charge equation for the balloon and the wall.

   Balloon: Wall:



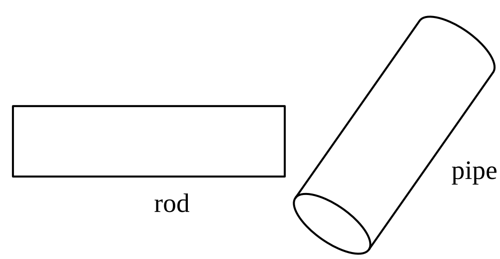
2. **Set Up.** Gather the materials you need for the next experiment. Use the modeling clay to hold the rod in the watch glass. It should be able to spin easily.



Materials
- Plastic (ebonite) rod
- Plastic (PVC) pipe
- cloth
- match glass
- modelling clay

3. **Observe.** Try this out:
   - Charge the pipe with the cloth (the cloth loses electrons)
   - Hold the pipe near either end of the ebonite rod.
   - Record your observations.

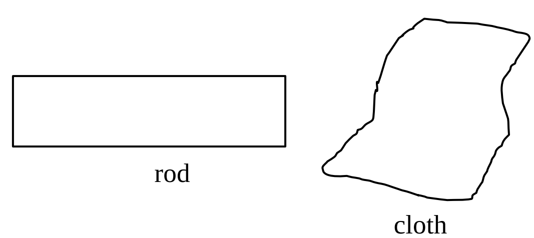
4. **Represent.** Draw a charge diagram for the rod and the pipe when they are near one another. In what direction do the electrons in the rod shift?



5. **Represent.** Suppose you charge the cloth on the pipe again. Then you bring the cloth near the ebonite rod (don't do this yet!) Draw the charge diagrams for this situation. Be careful when you decide the direction in which the rod's electrons shift!

6. **Predict**. How will the cloth and the rod interact? Will they attract or repel?

7. **Test and Evaluate.** Now you can try this out! Do your observations agree with your prediction? Explain.



SNC1D: The Polarization of Conductors

Recorder: ___________________
Manager: ___________________
Speaker: ___________________
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We have one last mystery to explore and will start off with an observation experiment.

A: The Two Spheres

You teacher has two spheres hanging side by side. Both spheres are made from Styrofoam but one is wrapped with aluminum foil.

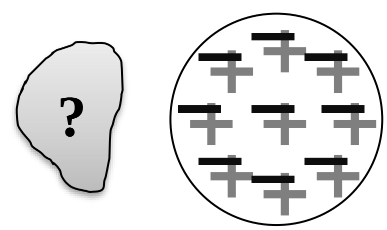
1. **Observe and Reason.** Your teacher brings a thread nearby each sphere. What can we conclude about the charge of the two spheres? What is your evidence?

2. **Predict.** Your teacher will slowly bring a charged pipe near both spheres at the same time. Predict how the spheres will interact with the pipe.

3. **Test.** Observe as your teacher slowly brings the pipe near the two spheres. Record your observations. Was there any difference in how the two spheres interacted with the pipe?

4. **Reason.** Which sphere had the strongest interaction with the pipe? What is different about the mobility of electrons in the two spheres?

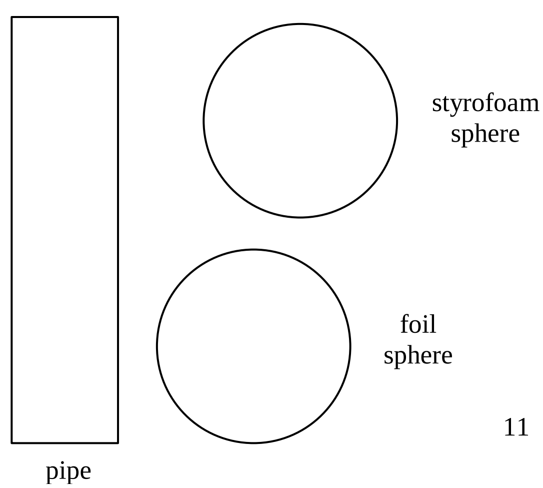
Insulators hold electrons attached tightly to their parent atoms. Metals allow electrons to move freely from one atom to another. When a metal becomes polarized, the electrons shift slightly more than they do in an insulator, giving them a greater polarization. Another interesting difference is that electrons in a metal move as one group. This is often called the *electron sea*.



5. **Reason.** In the sample diagram above, the metal is polarized.
   (a) What is the charge of the mystery object nearby? Explain how you can tell.

   (b) How does the diagram show the movement of the electron sea?

6. **Represent.** Complete a set of charge diagrams for the two-sphere experiment (remember the new technique for polarized insulators). Write a charge equation for each object.



B: Party Time!

Your teacher has two piles of confetti: one pile made of paper and one made of aluminum foil. Later, you will bring a charged pipe near each pile. But first, you will make some predictions!

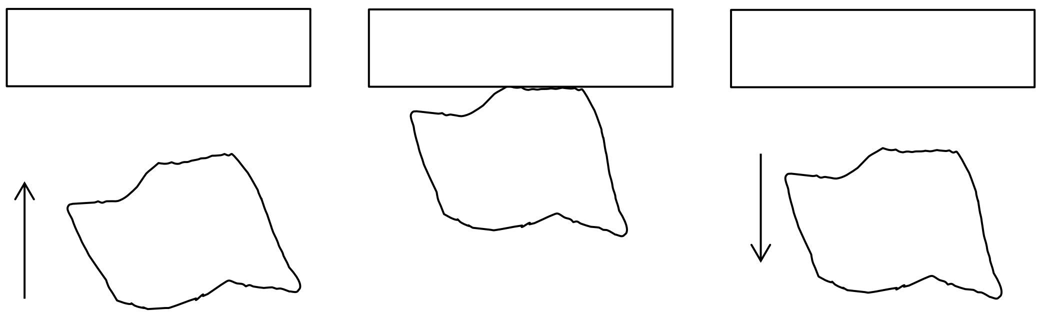
1. **Predict.** Which confetti will have the strongest interaction with the charged pipe? Explain.

2. **Predict.** When you bring the charged pipe near each pile, what do you think you will <u>see</u> happen.

3. **Test.** Bring the charged pipe near the paper pile first. Then bring the pipe near the foil confetti. Record your observations.

4. **Represent.** Draw a sequence of charge diagrams for the pipe and a piece of foil confetti. Write a charge equation for each object at each moment in time.

5. **Explain.** Using at most six words, describe the main idea that explains what is happening at each moment in time.



(1) The foil confetti is moving upwards

(2) The foil confetti touches the rod

(3) The foil confetti is moving downwards

C: Waterfall

Water is a truly amazing substance (as you will learn in grade 11 chemistry). We will model water as an insulator since charges don't move easily in very pure water. Your teacher has a stream of water gently falling from a tap. You will bring a charged pipe near the stream of water, after you make your predictions!

1. **Represent.** A single droplet of water falls past the charged pipe (they don't touch). Draw a charge diagram for a falling droplet of water and the charged pipe. Write a charge equation for each.

2. **Predict.** What will happen to the droplet as it falls past the pipe? Draw a simple sketch showing the path of the droplet and the pipe.

3. **Test.** Try this out at the front sink**.** Do your observations agree with your prediction? Explain.

SNC1D: Electron Current

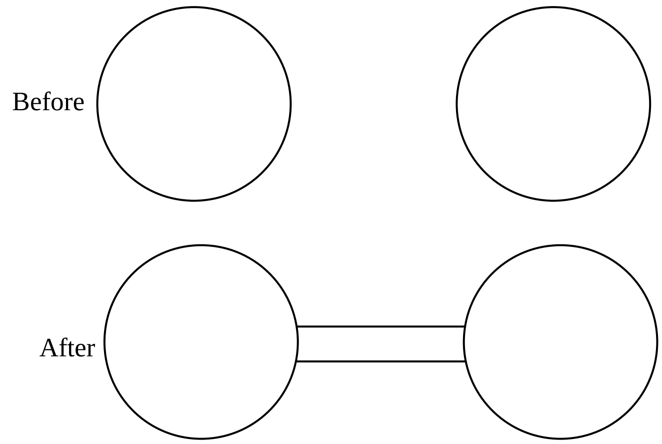
Recorder: ____________________
Manager: ____________________
Speaker: ____________________
0 1 2 3 4 5

Static means “at rest”. In our investigation of static electricity, the electrons spend most of their time “at rest” on the object. But not all the time! Today we will explore what happens when those charges are not static.

A: Get Your Charges Runnin’

1. **Reflect.** What are examples of situations we have explored so far where electrons move from one object to another (polarization doesn’t count!).

2. **Represent.** Your teacher has two metal spheres. One is charged and the other is neutral. You connect a wire (made of metal) between the two spheres. Draw a set of charge diagram for the two spheres before and after they wire is connected. Write a charge equation for each.



3. **Predict.** You bring a piece of thread near the two spheres. What will you observe:
   (a) Before the wire is attached?

   (b) After the wire is attached?

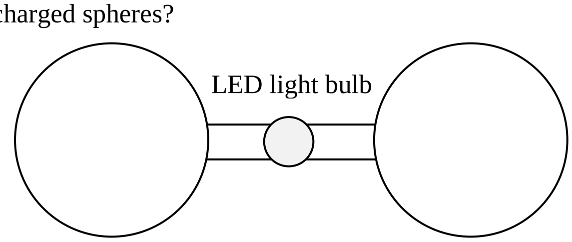
4. **Test.** Try it out:
   - charge the first sphere
   - use the thread
   - connect the wire between the two spheres
   - use the thread
   - record your observations

A *hypothesis* is a possible explanation for what is going on. We call an explanation a hypothesis because the explanation is not yet confirmed.

5. **Reason.** Create a hypothesis. What do you think happens in the wire when it is connected between the two spheres? Support your hypothesis with evidence.

To make a prediction, we assume that a hypothesis is correct. We use the hypothesis to explain what will happen (what we would observe) in a new situation.

6. **Predict.** Your teacher has a very sensitive LED light bulb that will be connected in between the two spheres. What will you observe when the wire is connected between the charged and uncharged spheres?



7. **Test.** (*as a class)* Your teacher will run this experiment for you.
   - Record your observations.
   - Is your hypothesis supported or refuted?

B: The Electron Current

We use evidenced to *support* or *refute* hypotheses. When observations disagree with a prediction, the hypothesis is refuted and we stop using it. When observations support a hypothesis, we keep on testing it! Each time a hypothesis is supported, we gain confidence that it is a useful scientific explanation.

Moving electrons are called a *current* of electricity. We can imagine a river of electrons flowing from our electron sea!

1. **Explain.** Use our new vocabulary to explain what happens in the wire when we connected it between the two spheres. Draw an arrow on your diagram showing the direction in which the current flows.

2. **Predict.** We will try the same experiment again, with the LED light bulb. This time, after the wire is connected we will bring the thread near both spheres. What will we observe?

3. **Test and Evaluate.** (*as a class*). Your teacher will run this experiment for you.
   - Record your observations.
   - Do your observations agree with your prediction?
   - Is your hypothesis supported or refuted?

4. **Reason.** Albert says, “When the bulb is in the wire, I think that electrons get used up. They are changed into light.” Do you agree or disagree with Albert? Use evidence from our experiments to explain.

5. **Reason.** How long does the current of electrons last? What is your evidence?

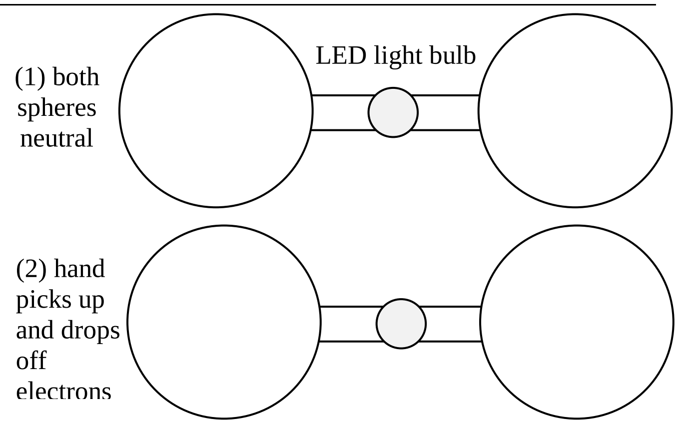
6. **Crazy Ideas.** Keep the light on! Imagine you could change something about the set-up of this experiment. What could you do or change to try to keep the light on?

C: The Invisible Hand

We have two metal spheres that are neutral and connected by a wire with a bulb. Imagine an invisible hand picks up electrons from one metal sphere and moves them to the other. It repeats this process for as long as it can.

1. **Represent.**
   (a) Draw the charge diagram for the first situation.
   (b) Draw the charge diagram for the second situation. The hand removes 3 electrons from the right sphere and puts them on the left sphere.

2. **Reason.** In which diagrams will there be an electron current? Draw an arrow showing this current.



An electrical *source* recycles electrons so they can be reused by the other parts in an electric *circuit*. A battery or a phone charger are examples of electrical sources. Without a source doing its job, electron currents very quickly stop flowing.

SNC1D: Electric Circuits and Current

Recorder: ______________________
Manager: ______________________
Speaker: ______________________
0 1 2 3 4 5

Last time we learned about the important role of a source in an electric circuit. Now it's time to figure out what a circuit is.

A: How Many Ways Can You Light a Bulb?

You will need a battery, a light bulb and a single wire.

1. **Explore.** Connect the battery bulb and wire together in a variety of ways. In the chart, draw a simple visual **sketch** (not a circuit diagram!) of **two** arrangements that cause the bulb to light up and two arrangements **that don't**.

2. **Record.** On your whiteboard, draw one example of the arrangement that causes the bulb to light up. Do this quickly (it doesn't need to be a work of art.)

3. **Share.** (*as a class*) Compare your whiteboards with the rest of the class. What do they all have in common? Complete the box below.

Bulb lights	Bulb doesn't light

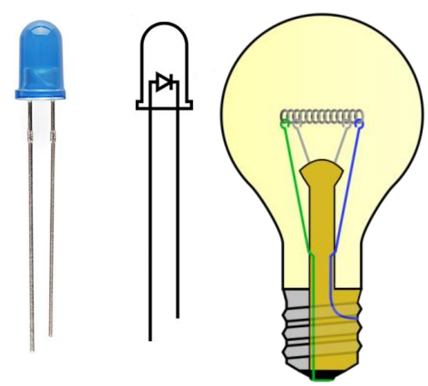
A *closed* circuit is one in which an electric current can flow. An *open* circuit does not allow an electric current to flow.

A closed circuit …

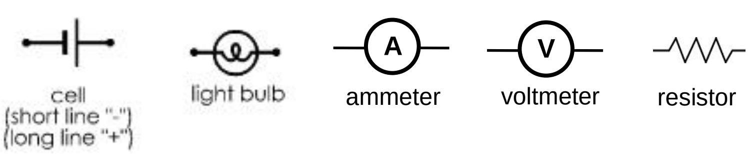
4. **Apply.** Label the diagrams you drew above as a "closed circuit" or an "open circuit".

5. **Reason.**
   (a) Why is it necessary to have two different connections to the bulb? Why can't you have two connections going to the same part on the bulb?

   (b) Draw arrows on the diagrams of the bulbs showing an example of the electron current in each.



A circuit diagram is a simplified drawing of an electric circuit. Instead of drawing realistic pictures of the parts in a circuit, we use simple symbols like the ones shown below. All wires are drawn using straight lines and right angle corners.



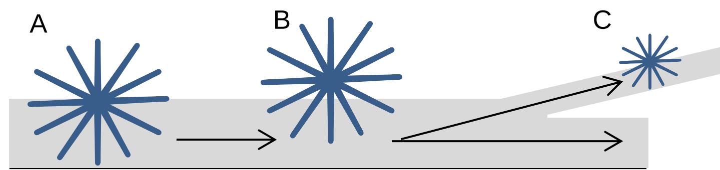
6. **Represent.** Draw a circuit diagram for each design you came up with in question A#1. Be sure to use a ruler.

Bulb lights	Bulb doesn't light

B: Measuring Current Flow

Scientists often use *analogies* to help themselves understand science. Analogies help by relating a new idea to familiar idea. One helpful analogy is that electron current works in some ways like water flowing down a river. We want to measure electron current, so let's start by thinking about how we might measure a river current.

1. **Reason.** In this analogy, we are trying to measure the flow of water (the water current) by measuring the turning of a paddlewheel. In the examples shown below, which setup would give us the most reliable measurement of the total water current flowing by? Explain.

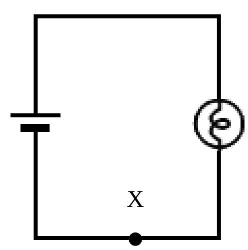


An *ammeter* is a tool that measures the size and direction of the electron current that flows through it. To measure the current travelling through one point in a circuit, disconnect the circuit at that point, insert the ammeter into that location of the circuit, and connect the wires so the current flows through the ammeter. Electric current is measured in units of *amperes* (A).

3. **Represent.** Examine the circuit shown to the right.
   (a) Label the positive and negative terminals of the battery in the circuit diagram.
   (b) Draw an arrow to show the direction the electron current will move as it leaves the negative terminal of the battery.

4. Represent. We want to measure the amount of current flowing through point X in this circuit. Draw a revised version of this circuit with an ammeter inserted at point X.

5. **Build.** To build this circuit, how many wires will you need? Find all your materials and construct the circuit.

Original Circuit	Revised Circuit with Ammeter
	

6. **Observe.** Record the current measurement of the ammeter beside the symbol in your circuit diagram. (Always write the unit after a measurement: 0.15 A) Please disconnect the circuit when you are not making your measurements to save the batteries.

7. **Reason.** In a different circuit, a student measures a value of 0.45A. How does the flow of electrons in her circuit compare with yours?

8. **Test and Explain.** Reverse the leads going into and out of the ammeter. Observe the meter reading. Why do you think the reading appears different?

SNC1D: Current Flow and Loads

Recorder: ______________________
Manager: ______________________
Speaker: ______________________
0 1 2 3 4 5

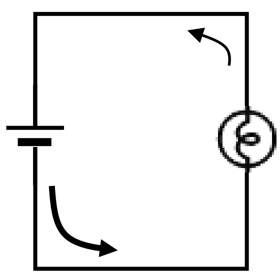
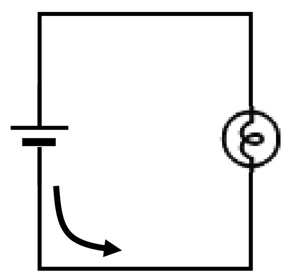
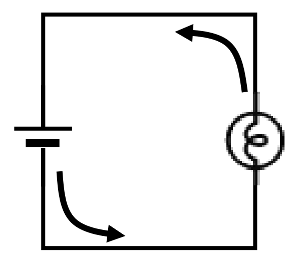
If we ask a grade 8 student to explain what happens to electrons as they move through a bulb, two common explanations or hypotheses are often given. We will explore and test these hypotheses.

A: Testing Current Hypotheses

Science works by testing the predictions made using different hypotheses. To goal is to find evidence that supports one hypothesis and refutes all the others.

Important Question: What happens to the number of electrons when they travel through a bulb?

1. **Read.** The chart below shows three possible hypotheses. Take a moment to read each hypothesis.

Hypothesis A: **"Some electrons are used up.** They are used up by the bulb and turn into light.**"**	**Hypothesis B:** **"All the electrons are used up.** All the electrons that enter the bulb are used up and turn into light.**"**	**Hypothesis C:** **"The same number of electrons enters and leaves the bulb.** None are used up or change into light.**"**
Predictions A: 	**Predictions B:** 	**Predictions C:** 

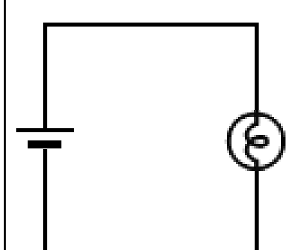
2. **Design.** In order to test the hypotheses, you need to decide what current measurements to make. On each diagram, draw an ammeter at each point in the circuit where you would like to make a measurement.

3. **Reason.** Emmy says, "I think we can test hypothesis A using just one current measurement after the bulb." Marie says, "I don't know. I think we need to make two current measurements to decide if hypothesis A is correct." Who do you agree with? Explain.

4. **Predict.** Make a prediction for the current readings of each ammeter you have drawn in the circuits above. Use words like: "smaller", "larger", "the same", or "none". Record the prediction beside each ammeter.

*** *Call your teacher over to check your predictions* ***

Observations:



5. **Build.** Build the circuit using just one ammeter. You can move the ammeter to make your second measurement. Draw an ammeter for each measurement in the observation circuit to the right.

6. **Observe.** Record your measurements beside each ammeter in the observation circuit.

7. **Evaluate.** Which hypotheses are refuted and which are supported? Write "Refuted" or "Supported" in the centre of each prediction circuit diagram above. On a whiteboard, record your conclusion (nothing else!) for each hypothesis.

8. **Conclusion** (*as a class*). What happens to the number of electrons when they travel through a bulb?

Electrons are **not** used up in any part of an electric circuit. They make the complete trip around the full circuit loop.

B: What's Going on in the Bulb?

This leaves us with an important mystery to solve. What is happening in something like a bulb? To explore this, your teacher has a piece of steel wool connected to a source (a power supply).

Circuit Diagram:

1. **Represent.** Draw a circuit diagram for the equipment your teacher has set up. Use the battery symbol for the power supply and the resistor symbol (go back to the previous lesson) for the steel wool.

2. **Observe.** Your teacher will turn on the power supply. Record your observations.

3. **Reason** (*as a class*). Something is being transferred from the electrons to the piece of steel wool. What is being transferred?

When we study an electric circuit, we track what is happening to the electrons in it. We call this group of electrons the *system of electrons*. A *load* is a device in a circuit that takes away energy from the system of electrons. A *source* is a device that adds energy to the system of electrons.

C: Learning the Ropes

Where do the electrons flowing in a circuit start from? We will use an analogy to help answer this question. A loop of rope is a good model for the flow of electricity in a simple circuit like ours. After the demonstration and discussion led by your teacher, answer the following questions about this model.

1. **Reason.** Complete the chart below by explaining what each part of the rope model represents about an electric circuit.

Rope Model	Real Circuit
The rope itself (or each particle of the rope)	
The moving rope	
The metal rings	The wire (everything else that makes up the wire, except for the moving electrons).
Student holding the rope tightly	
Student pulling the rope	

2. **Reason.** According to the rope model, where are the electrons located before we "turn on the battery"?

3. **Reason.** In addition to moving the rope, the student pulling the rope transfers something to the student holding the rope tightly. What is being transferred and what evidence supports your hunch?

4. **Reason.** According to the rope model of an electric circuit, what role does a battery play in an electric circuit (what does it do)? What role does the bulb play?

5. **Observe.** Watch the simulation of the electric circuit when the switch is closed. Do your observations agree with question C#2? Explain.

SNC1D: Electric Energy

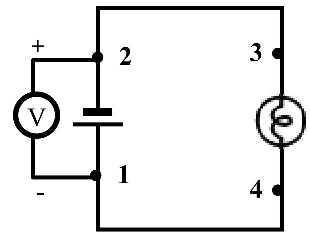
Recorder: ______________________
Manager: ______________________
Speaker: ______________________
0 1 2 3 4 5

Electric circuits perform very helpful jobs for us. They light up our rooms, play our music, and text our friends. All of this happens because of energy transfers.

A: Looking for Energy Transfers

Energy is a sneaking thing, so we need to be clever to find energy transfers. To do that, we will use a special device, a *voltmeter.*

A *voltmeter* measures the change in energy of a group of electrons as they move from one point in a circuit to another. A voltmeter is always making a comparison of energies at two different points. To use a voltmeter, connect the meter's two leads to two different points in a circuit. The voltmeter measures in units of *volts* (V), which are related to changes in energy.



1. **Build.** Construct the circuit we used last class. Don't connect the voltmeter yet.

2. **Test.** Connect the two leads of your voltmeter (by touching a conducting material) at points 1 and 2 in the circuit diagram. If you don't see a reading, switch which lead touches which point.

3. **Observe.** Complete the chart below. Connect the voltmeter at the different points in the circuit numbered in the chart below. Always include a unit with each measurement: 0.5 V.

Voltmeter leads connected at points	Part of circuit charge moves through	Observed meter reading
1 and 2		
2 and 3		
3 and 4		
4 and 1		

4. **Record.** Write the results from your chart on a whiteboard, but don't share them yet. Be a good scientist: make sure you reliably report all your measurements!

5. **Test and Reason.** Connect the two leads of the voltmeter to the same point in the circuit. Explain why you get this reading.

Voltages (volt readings) are related to energy transfers. A source adds energy to the system of electrons, so we call its voltage a voltage *rise*. A load removes energy from the system of electrons, so we call its voltage a voltage *drop*. We will use these labels instead of writing a positive or negative symbol in front of the voltage measurement.

6. **Apply.** For each interval between two points decide:
   - does the energy of the system of electrons increase, decrease, or stay the same.
   - is there a voltage rise or drop?

Interval	System energy	Voltage Rise or Drop
1 - 2		
2 - 3		
3 - 4		
4 - 1		

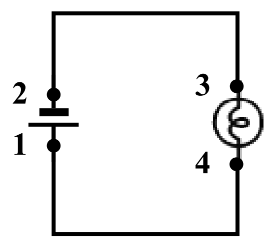
7. **Reason.** To simplify our work with wires, we will always make an important assumption. Complete the box below describing that assumption. (Hint: the voltage drop for wires is very close to…)

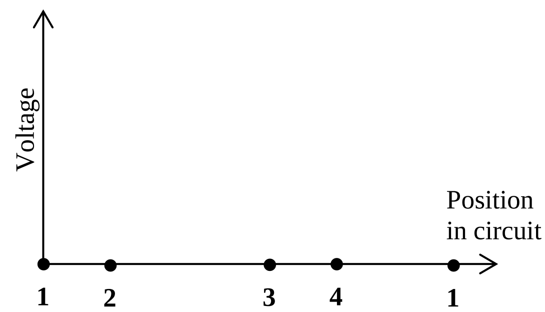
In our model of electric circuits, we will always make the *ideal wire assumption*:

A *voltage graph* represents the energy transfers that take place along one loop of a circuit. The vertical axis represents the voltage of the system of electrons and the horizontal axis represents the position of the electrons along the circuit. For convenience, we choose the starting value to be zero.

8. **Represent.** Draw a voltage graph for your circuit. The exact values are not important, but the ideas are. Label each interval with words describing the part of the circuit.

9. **Reason.** The position marked "1" appears twice in the graph. Explain why. How should the voltage values at the "1"s compare?





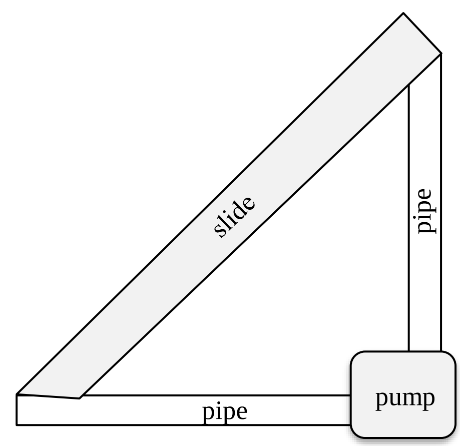
B: A Model for Energy Transfer – The Waterslide!

Let's return to our analogy with the flow of water. Now that energy is involved, we will add in a pump to push water upwards and a waterslide so it can flow back down.

1. **Reason.** Decide what part of the water model corresponds with what part of a real circuit.

2. **Reason.** Height might be the tricky one to connect. The pump uses energy to push the water up to the slide. What electrical idea is this the closest to?

Water Model	Real Circuit
Pump	
Slide	
Pipe	
Water flow	
Height	



3. **Reason.** If the slide was open so you could see the water moving, what would happen to the water as it travels down the slide? Use your imagination!

4. **Observe.** Watch your teacher's simulation of a simple circuit. Compare the speed of the electrons at different points in the circuit. Does the speed change anywhere?

5. **Evaluate.** Do your observations match your response to question B#3? Does the water model work?

6. **Crazy Ideas.** To fix the water model, we need to add something to the slide that will slow down the water as it travels down the slide. What would you add? Come up with at least four ideas. Record one on your whiteboard, but don't share it yet.

7. **Share** (*as a class*). Share your whiteboards with the class. After the discussion, record the idea the class chose in the bottom row of the water model chart.

SNC1D: Energy, Current, and Resistance

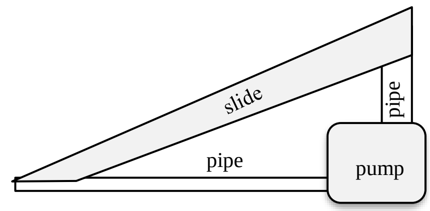
Recorder: ______________________
Manager: ______________________
Speaker: ______________________
0 1 2 3 4 5

Our examination of the water model for electric circuits helped us find a new idea in the study of electricity: resistance.

All loads have *resistance*, a property that opposes the movement of electrons through the load and causes the system of electrons to lose energy. In high school, we will assume that the wires and the source in a circuit have no resistance. Resistance is measured in units of *ohms* (Ω)

A: Back to the Waterslide!

1. **Reason.** Think of the waterslide from our previous investigation. Imagine changed the waterslide from we had a very weak pump that could only lift water to a very short height, so the same slide was tilted at a very small angle. How would the water current at the bottom of the slide compare with the slide we explored in the previous class?



2. **Reason.** What if we had a very powerful pump, so we could make the same slide very steep? How would the water current at the bottom of the slide compare with the slide we explored in the previous class?

3. **Reason.** What characteristics of the waterslide affect the water flow at the bottom of the slide?

4. **Record.** Write your chosen characteristics on a whiteboard, but don't share them yet.

B: Change the Pump

We want to check whether the ideas from our waterslide model work for real circuits! For the next few investigations, you will build your circuits using a simulator. Google: "PhET circuit". It should run on most laptops and phones.

1. **Build.** Use the simulator to construct a simple circuit with one bulb and one battery. This will correspond to our waterslide from yesterday.

2. **Represent.** Draw a circuit diagram.

3. **Observe.** Use the voltmeter and ammeter to measure the current and voltage for the bulb and the battery. Record these values next to each element in your circuit diagram. Remember to include the units!

4. **Reason.** Now we want to install the "weak pump". What should we change in the circuit? What should we not change?

Circuit Diagram

5. **Observe.**
   - Click on the battery and reduce the value to half.
   - Measure the current and voltage values.
   - Describe how the values changed compared with the first waterslide.

6. **Reason.** Time for the "powerful pump"! What quantity should you change and how should you change it?

7. **Observe.** Make the change. Measure the current and voltage values. Describe how the values changed compared with the first waterslide.

8. **Find a pattern.** Describe the pattern you observed for the current in the load when you changed the voltage drop.

C: Change the Slide

Return your pump (the battery) to its original value. Now we want to explore what happens if we change the rocks in the slide.

1. **Reason.** We will keep our normal pump (9 V) throughout the next set of tests. Imagine that we add many more rocks to the slide. What will happen to the water flow at the bottom of the slide?

2. **Observe.** Double the resistance of the bulb. Measure the current and voltage values. Describe how the values changed compared with the first waterslide.

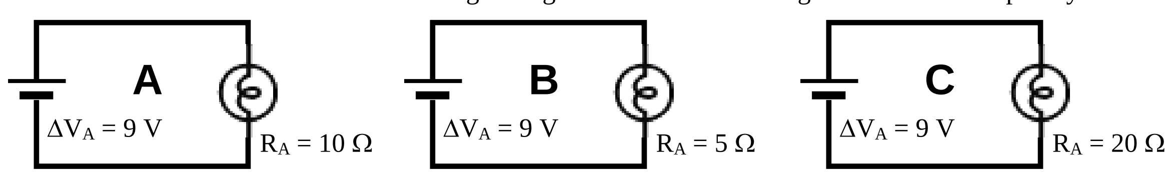
3. **Reason.** Imagine we remove many (but not all!) of the rocks from the slide. What will happen to the water flow at the bottom of the slide?

4. **Observe.** Reduce the resistance of the bulb by half. Measure the current and voltage values. Describe how the values changed compared with the first waterslide.

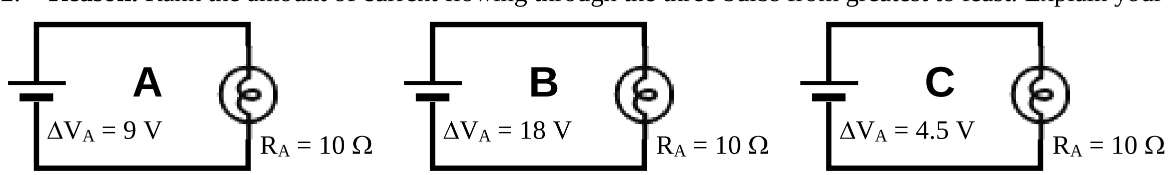
5. **Find a pattern.** Describe the pattern you observed for the current in the load when you changed the resistance of the load.

D: Circuit Puzzles – No Simulator!

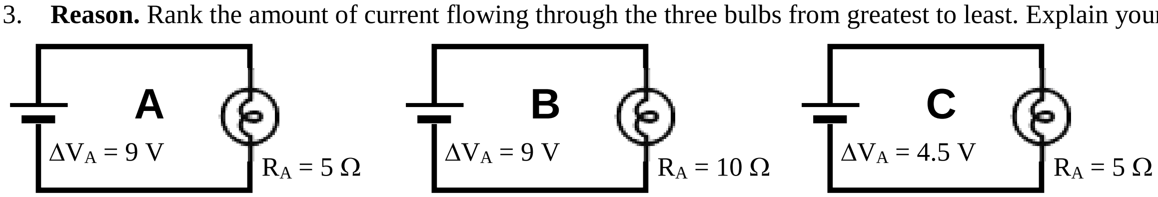
1. **Reason.** Rank the amount of current flowing through the three bulbs from greatest to least. Explain your ranking.



2. **Reason.** Rank the amount of current flowing through the three bulbs from greatest to least. Explain your ranking.



3. **Reason.** Rank the amount of current flowing through the three bulbs from greatest to least. Explain your ranking.



SNC1D: Ohm's Law

Recorder: ______________________
Manager: ______________________
Speaker: ______________________
0 1 2 3 4 5

The power of science comes from its ability to make and check predictions. Occasionally, we can find a very powerful relationship between different quantities that allows us to make precise predictions. Finding this relationship is our goal today. You will use the simulator. Google: "PhET circuit"

A: Design an Experiment

We have observed an important relationship between the voltage drop across a bulb and the current flowing through it. We want to precisely describe this relationship.

1. **Reflect.** Think back to the previous investigation. What was the relationship between the voltage drop across a bulb and the current flowing through it?

2. **Reason.** To study this relationship carefully, we need to design an experiment. We will be building our simple circuit once again! In the simulator:
   (a) what characteristics of the bulb or battery can we change?

   (b) what quantities do we have the tools to measure?

> In a scientific experiment, there are often many characteristics that we could change. To find a clear relationship between any two quantities, we make a change to just one quantity and then see what happens to the other.

3. **Reason.**
   (a) Which characteristic can we carefully change in order to observe its effect on the current flowing through the bulb?

   (b) Which characteristic should we keep constant throughout the experiment?

> In an experiment, the quantity that we carefully change is called the *independent variable*. We choose the values for the independent variable every time we change it. The goal of an experiment is to see what effect changing the independent variable has on the other quantity. We want to see how the other quantity *depends* on the different values of the independent variable. This second quantity is called the *dependent variable*.

4. **Apply.**
   (a) Which quantity will be your independent variable (the one whose values you will choose)?

   (b) Which quantity will be your dependent variable (the goal of the experiment is to find out what happens to this when we change the other)?

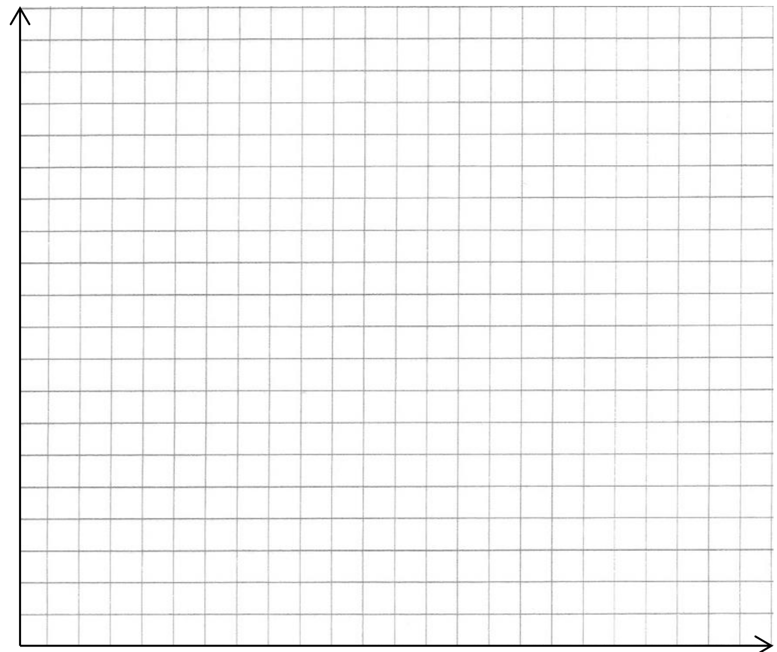
5. **Design.** Create a table of values for your two variables:
   - Record the name of each variable at the top of your table. The independent variable is always recorded first.
   - Use the simulator to explore the range of possible values for the independent variable.
   - Record possible values for the independent variable in your chart. Charge the values by simple, equal amounts.
   - Your experiment is now ready!

6. **Observe.** Conduct your experiment and complete your table of values. Take a picture of the table with your phone – it's that awesome! (Actually do this)

Graphs are a powerful tool for picturing information. Use this checklist to help you construct a graph for a scientific experiment:

- the independent variable is recorded along the horizontal axis and the dependent variable on the vertical axis.
- label each axis with the name of the variable and the units. For example: voltage drop (V)
- choose a scale for each axis that increases by a simple, easy to read amount: 1, 2, 5, 10, etc.
- choose a scale such that your data takes up a majority of the grid space (so it's not squished on one side)
- plot each pair of measurements on the grid with a small dot
- write a title for your graph. Describe what it is comparing.

7. **Represent.** Construct a graph to picture the data you have collected.



Graphs help us find patterns that might be hard to see by looking at numbers in a table. Based on the appearance of the data in the graph, we want to decide:

- does the data show a *linear relationship* (does it look like a straight line)?
- does the data show a *non-linear relationship* (does it follow a curve)?

8. **Find a Pattern.** What pattern (what kind of relationship) does your data follow?

If the data shows a linear relationship, we use a ruler to draw a *line of best-fit* that passes as close to the data points as possible. If the data shows a non-linear relationship, we do our best to draw a smooth curve (no zig-zags!) that passes through as many points as possible.

9. **Represent.** Draw a line or curve through the data points on your graph.

10. **Interpret.** Suppose the voltage drop across the resistor was 65 V. Use your graph to predict how much current would flow through the bulb.

11. **Interpret.** Suppose the current flowing through the resistor was 4.5 A. Use your graph to predict the voltage drop that produces this current.

12. **Find a Pattern.** Students running a similar experiment came up with a table of values that is shown to the right. If you knew a current value, what bit of math could you do to get the voltage value? Explain.

Voltage Drop	Current
10 V	2.0 A
20 V	4.0 A
30 V	6.0 A

13. **Represent.** Use <u>your</u> data table. Write a simple equation that shows how you get the voltage value if you know the current value. Use the symbol "ΔV" for the voltage drop and the symbol "I" for the current.

14. **Interpret.** You probably wrote a number in your equation. What part of your circuit does this number come from? What does it represent?

Ohm's Law (*as a class*):

SNC1D: Circuit Connections

Recorder: ______________________
Manager: ______________________
Speaker: ______________________
0 1 2 3 4 5

Most circuits in our homes and school are designed to run more than one bulb or electrical device at a time! Let's explore how to build these circuits.

A: The Two-Bulb Challenge

Your challenge is simple: find different ways to light two bulbs at the same time, one way that keeps the two bulbs nice and bright, and one way that makes the two bulbs quite dim. You can do this using real bulbs and batteries, or using the simulator.

Materials
- one battery
- two bulbs
- 3 or 4 wires

1. **Set Up.** Gather the materials for your challenge.
2. **Explore.** Experiment with different ways of connecting two bulbs in one circuit. The goal is to find one way that has two bright bulbs and another way that has two dim bulbs.
3. **Represent.** When you find a way that works, draw a circuit diagram. Label the bulbs in each circuit as "bright" or "dim".

Circuit #1	Circuit #2

A circuit has a *series connection* if there is only one path that electrons can follow between two points in the circuit. A circuit has a *parallel connection* if there is more than one path between two points.

4. **Apply.** Which circuit has the two bulbs connected in series? Which circuit has the two bulbs connected in parallel? Write "series" or "parallel" above each diagram.

B: The Reference Circuit

Our next challenge is to figure out how each of these circuits works! To begin, we go back to a single bulb circuit.

Reference Circuit

1. **Build and Represent.** Build a circuit that has only one bulb. Draw a circuit diagram. We will use this as our reference circuit to make comparisons.
2. **Observe.** Compare the brightness of the bulbs in your two previous circuits with the bulb in the reference circuit. What do you notice?
3. **Measure.** Measure the current flowing through the bulb and the voltage drop across the bulb. Record these values next to the bulb in your diagram.
4. **Calculate.** Use Ohm's Law to find the resistance the battery experiences from the circuit. Use the voltage of the battery and the current through the battery. Follow the math work example (you don't need to write the explanations in brackets).

Math Work:

Math Work Example:

Find the resistance of the circuit.	(describe the math)
$\Delta V = I \times R$	(write the equation)
$\frac{\Delta V}{I} = R$	(isolate R)
R = 6 V / 0.3 A	(substitute values)
R = 20 Ω	(calculate result)
The resistance of the circuit is 20 Ω.	(state the result)

C: Current and Series Connections

Now we are ready to carefully explore what happens with series connections.

1. **Design.** Isaac says, "I think the current gets smaller as it goes through each bulb in the series circuit." Albert says, "I don't know. I think it stays the same as it goes through each bulb." Design an experiment to test these predictions. Hint: draw three points on the series diagram above where you would like to make current measurements.

2. **Build and Measure.** Build your circuit with two bulbs connected in series. Measure the current at three locations. Record your measurements next to each point in your diagram.

3. **Evaluate.** Earlier we learned that loads do not "use up" electrons. Do your measurements support or refute this idea? Explain.

4. **Reason.** Are there any points in the series circuit where the current values are different from one another?

Along a path with series connections, the amount of current everywhere along that path is …

5. **Reason.** The amount of current flowing through the series circuit is <u>less</u> than the reference circuit. Use the waterslide and rock model to explain how we can make sense of this result.

6. **Calculate.** Use Ohm's Law to find the total resistance the battery experiences from the circuit. Remember: use the voltage and current of the battery. Show your work carefully, like the previous example.

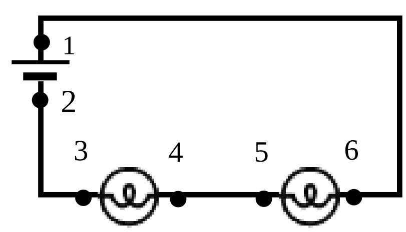
7. **Evaluate.** How does your resistance result compare with the resistance of a single bulb circuit?

Math Work:

When we combine loads in series, the total resistance of the circuit <u>increases</u>.

D: Voltage and Series Connections

Remember that voltages are related to energy gains and losses in a circuit. Let's figure out what happens to the energy of the system of electrons when they go through a series connection.



1. **Observe.** Connect one end of the voltmeter to point 1shown in the circuit diagram. Connect the other end to each other point in the circuit and record your measurements. (Always keep one end connected to point 1)

2. **Represent.** Draw a voltage graph for this circuit using your measurements.

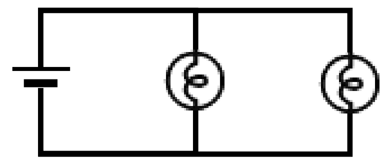
3. **Explain.** Let's say that a group of electrons gained 10 units of energy from the source. Describe what happens to those units of energy as that group of electrons travels through the circuit.

SNC1D: Circuit Connections 2

Recorder: ______________________
Manager: ______________________
Speaker: ______________________
0 1 2 3 4 5

We are almost there! Now it is time to explore parallel connections. You can do this using real bulbs and batteries, or using the simulator.

A: Current and Parallel Connections



1. **Design**. Emmy says, "In a parallel circuit, I think that current from the battery splits up to go to each bulb." Marie says, "I think the same amount of current goes through the battery and the bulbs." Design an experiment to test these predictions. Hint: draw three points in the circuit where you should measure the current.

2. **Build and Measure.** Construct the parallel circuit.
   (a) Connect the ammeter right next to each bulb. Measure the currents and record the values in the diagram.
   (b) Connect the ammeter directly to the battery and then connect the two bulbs to the ammeter. Measure the current and record the value in the diagram.

3. **Evaluate.** Whose prediction was correct? Emmy's or Marie's? Use your measurements to explain.

A *junction point* is a point in a circuit where a path splits up or joins back together.

4. **Apply.** Draw a junction point in the circuit diagram above and label it "splits up". Draw another and label it "joins back".

5. **Represent.** Draw arrows in the circuit diagram showing how the current flow in and out of each junction point.

6. **Calculate.** Use Ohm's Law to find the total resistance the battery experiences from the circuit. Remember: use the voltage and current of the battery. Show your work carefully!

7. **Reason.** How does the total resistance of the parallel circuit compare with the reference circuit from our previous investigation?

Math Work:

8. **Reason.** We will use a new analogy to help us understand this result. Imagine that the battery is a grocery store and the electrons are shoppers who want to pay for their food and get out of the store. A bulb is like a checkout counter.
   (a) Complete the chart showing the electrical ideas that match this analogy.
   (b) Use this analogy to explain why adding a bulb in parallel, helps more electrons to leave the battery.

Store Model	Real Circuit
Store	
Shopper	
Checkout counter	
People leaving store	

When we combine loads in parallel, the total resistance of the circuit decreases.

B: Test Your Ideas

1. **Predict.** You have three bulbs connected in series. How will the brightness bulbs and the current flowing through the three-bulb circuit compare with the two-bulb circuit? Explain.

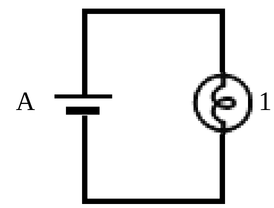
2. **Test and Evaluate.** Build a three-bulb series circuit. Observe the results and make measurements. Do they agree or disagree with your predictions?

3. **Observe.** Unscrew one bulb in your three-bulb circuit. What happens? Would this happen in a parallel circuit?

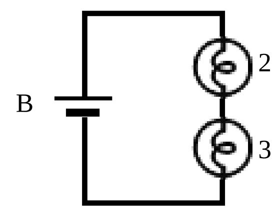
4. **Reason.** Which type of connection (series or parallel) do you think is used to connect multiple lights or appliances in the circuits of our homes or school?

C: Putting it All Together

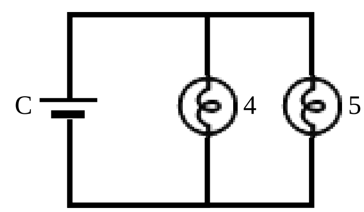
The three circuits we have studied are shown to the right. All have identical batteries and bulbs.



1. **Reason.** Rank the brightness of all five bulbs from greatest to least. Indicate if any are equal. Justify your ranking.



2. **Reason.** Rank the amount of current flowing through each battery from greatest to least. Indicate if any are equal. Justify your ranking.



3. **Reason.** Each circuit is actually the design for a flashlight. You are in the dark. Which one would give you the most light? Explain.

4. **Reason.** People often say that a battery “runs out” after using it for a while. What is a battery actually “running out” of? Charges? Energy? Magic? Explain.

5. **Reason.** Which flashlight’s battery would “run out” first? Which would last the longest? Explain.