FLEET ARC CENTRE OF EXCELLENCE IN FUTURE LOW-ENERGY ELECTRONICS TECHNOLOGIES

FLEET Schools. Activity 10: Graphite circuits

Learning intentions

Students will develop a deeper understanding of conductors and insulators and resistance and how to construct an effective circuit.

Before the experiment

You will use graphite, a form of carbon that we can find in a pencil, to help make a circuit. You will examine the conductivity (how well something conducts electricity) and resistivity (how well a material prevents the flow of electricity) of graphite.

If you pool what you have learned so far in this resource, you will understand why you should never stick any object into a power socket, why you can shock friends by rubbing your shoes on the carpet, and how you can bring light into the world, and toasters, electric cars, Lego® technic toys….etc.

Hypothesis

You will use your pencil to draw two thick lines that will act as the electrical wires in a circuit. Use your knowledge of conductors, insulators, circuits and resistance to construct a hypothesis based on how conductive you think paper and graphite are and whether the graphite will work as a conductor to make a circuit.

Consider what will affect the ability of graphite to conduct a current?
Consider how the length of your graphite circuits will affect the brightness of your LED and think about the reasons for what you observe? Think about resistance.

Materials

Years 4-6

- Pencil (2B or softer)
- Clean sheet of paper
- 9V battery
- LEDs (approx. 3000MCD - millicandela)

Extension for 7-9

- Multimeter

Safety:

*Do not leave batteries connected to a circuit as this will cause the wires to heat up and be a possible fire hazard – a good example of resistance.
*Do not use damaged batteries as they may leak caustic chemicals.
*Do not connect the LED terminals directly onto the 9V battery. This will blow the LED.

Teacher notes

For each student, it is likely that there was a variety of distances the LED got from the battery before it stopped working. Can they explain why? Each student had the same battery, pencil and LED? Get students to consider what factors make each student's experiment different? How could they control for this difference should someone else want to repeat this experiment?

Emphasize that controlling for variables as much as possible is an important element of

Teaching notes: running the activity

Method

1. First step is to test the conductivity of the paper itself. Place the 9V battery and LED electrodes onto a clean part of the paper to see if you can get the LED to work. Move the LED and battery closer together, further apart to see if the LED will work.
2. Draw some circuits and test the conductivity of graphite. Use the pencil to colour in the circuit lines on your sheet. If you are doing this at home or

any experimental design to enable someone that wanted to repeat your experiment to be able to compare their results with yours and know if what you found is real or not.

Get students to consider whether people are insulators or conductors? How might they SAFELY test for this? Think about what happened in Activity 5 when you placed a finger between the two strips of negative charged plastic that were repelling each other at the time?

Extra fun stuff to do

Make squishy circuits

Get cooking and make insulating and conducting dough. Use the dough, your 9V battery and LED to make some creative circuits. The University of St. Thomas took squishy circuits to a new level and there are different YouTube experiences to be had. Here is one from Rough Science.

Question for students: what ingredients in the two doughs make them either an insulator or conductor? Answer: Salt is an electrolyte made up of Na+ and Cl- ions. The negative ions supply electrons and facilitate the flow of charge in the conducting dough. Sugar is not an electrolyte; it has no free ions to facilitate the flow of charge. It therefore makes the dough act as an insulator.

What is happening

This activity is about understanding circuits and resistance. If you have set up your experiment properly you will have formed a closed circuit from your battery along the wires (or graphite), through the LED and back to other battery terminal.

Electrons – the charged particles – can only move when there is a continuous (closed) circuit for the electrons to flow through. Any break in that circuit and the electrons will not flow and there will be zero current. An effective circuit needs a power or energy source, which in our case is a battery. The battery is a source of electrons (from the negative terminal) and the force that pushes the electrons through a circuit once you have a closed or complete

school, use the positive and negative terminals on your 9V battery to make two marks on the paper that you can use as guides to work out the width of your graphite circuit lines. See Figure 1. Make the lines about 0.5-1 cm wide and 8-10 cm long. You need to colour them quite heavily, so you need to go over them a few times.

3. Measure a distance of 1cm along the circuit from where you will place the battery on the graphite lines. At the 1cm mark, put one LED terminal on one graphite line, the other terminal on the other line. The longer LED leg (terminal) is the positive terminal. The longer leg on the LED must go on the same line as the battery's positive terminal. Once arranged correctly, the LED should light up (once you place the battery on the circuit also).
4. Grab your 9V battery and place the positive terminal on the same graphite line as the positive LED terminal, and the negative battery terminal on the other graphite line with the negative LED terminal. Does your LED light up? If so, do a happy dance to show that you got the light to work first go.
5. If the LED light does not switch on, make sure there is a good connection between the LED terminals and the graphite circuits and between the battery terminals and graphite circuits. Does your light work now? If not consider what might be going wrong. What can you change to make it work? What part of your experiment can you test, and how, to ensure it functions properly? Make detailed notes about what you do.

Consider the components: an LED light, a battery, a graphite circuit. You will need to test each of these components. How will you do that?

6. If your LED lights up, shift the LED further away from the battery. Do this in 1cm increments. For example, if your first test had the LED 1cm away from

circuit. There are also the electrons in the wires connecting the two battery terminals. In a closed circuit, the positive terminal of the battery will also pull electrons through a circuit because of the attractive force between the positive and negative charges.

Remember it is only the electrons that move through the circuit.

It is this flow of electrons in one direction through the circuit that creates the electric current and provides the energy for our LED light. The protons – or positive charged particles – are fixed and cannot move.

Conductors and insulators
Electrical conductors have low resistance. The graphite from the pencil can form a circuit because graphite is an electrical conductor, which means current can flow easily through it, though there are other materials that are better conductors. Get students to think about why we use copper as the conducting material in our electrical wires?

Electrical insulators have high resistance. The paper (made from wood pulp) cannot form a circuit because it is an electrical insulator, which means it does not allow current to flow, at least not without lots more force than you can get from the batteries we used in this experiment.

Materials such as wood and plastic are good insulators.

Resistance
Every material has resistance, except some of those novel materials that FLEET is working on. Read about superfluids and topological insulators here. Copper, gold all conduct electricity well, but they still have some level of resistance, which is why your phones and laptops heat up when you start using them.

The electrons in graphite are not bound too tightly to their atoms (carbon) so they can more easily become free and mobile to move through a closed circuit. The electrons in a material such as plastic or wood are tightly

the battery, try it again with the LED 2cm away, then 3cm, then 4cm and so on. Do you notice anything happening with the LED the further you get from the battery? At what distance from the battery does the LED stop working? Record the distance.

7. Create a whole-class table that records the brightness of the LED at each distance from the battery and the distance each student's LED stopped working. Plot this data on a graph. See an example table below.
8. Have a competition to see who can make the longest circuit with the LED still lighting up.

Extension
Now we get to examine resistance in more depth and play with Ohm's Law. You will need your multimeter for this activity.

Ohm's law is given by $V = IR$
where V = Voltage (measured in volts), I = Current (measured in amps) and R = Resistance (measured in resistance).

Method.
Use the same set up as before with your 9V battery, graphite circuits and LED.

Note the distance from the battery where your LED stopped working. Mark that point.
Switch the multimeter setting to measure resistance or ohms denoted by the symbol Ω.

Note: remove the battery from the circuit for this exercise.

At the marked point, use the multimeter to measure the resistance across one of the graphite wires. To do this, place one multimeter terminal on the graphite wire where the battery terminal was placed and the other multimeter terminal at the marked point on the graphite circuit where your LED stopped working.

Record the multimeter reading, which will be in Ohms, to find out the resistance of your circuit.*

bound to their atoms and it is difficult to free them from their atoms. Such materials have a high resistance and will not easily conduct an electric current, which is why our electrical cords have a plastic coating. That coating protects us from being electrocuted. It is the copper wire inside the protective plastic coating that is the conductor.

Note: A single layer of graphite is called graphene. While graphite is an OK conductor, graphene is effectively a perfect conductor. It will conduct a current with zero energy loss, which is why scientists, including those at FLEET, are investigating graphene's potential as a conductor in circuits – among many other uses.

Testing the components: Quickly touching the LED onto the battery terminals can test the LED – assuming you have a charged battery. However, holding the LED onto the battery for more than a split second will blow the LED.

You can use the multimeter to test the battery and the graphite circuits.

Ohm's Law: V=IR
You are solving for I, which means you can rearrange the formula to enable you to solve for I
I= V/R

Answers for I will vary widely, but you should observe, however, that the figure is extremely small. That is, the answers should reveal that the LED technology requires a tiny amount of current (or electrical energy) to turn on. Compare this to the old incandescent and fluorescent globes.

Reflection
Following completion of Activity 10, get students to draw a circuit again, this time labelling the direction of electron flow. Higher year levels could add a switch or include different circuits such as parallel or series. Compare this to what they drew in Activity 2.

Without using the current setting on the multimeter, use Ohm's law to calculate the threshold current needed to turn on your LED.

You know your battery is 9 volts (V).
Resistance will be in Ohms – the reading from your multimeter. Solve for I (current)

*Remember to convert your volts, Ohms and current to the same units (ie milli or micro volts, Ohms, amps)

Calculate the current (I) to work out what the minimum current required is to get your LED working. Compare your answer to the other students in your class.

Results

Did you get the LED to work in Step 1 where you tested the conductivity of the paper itself?

Did you get your LED to work with the graphite circuits?

What did you have to do to make it work? Describe what you did to make an effective circuit.

What happened when you moved the LED further away from the battery?
Record your results in your table, such as the one below, and then explain the data in words. Plot the data from the whole class on a graph to see if there is a relationship between brightness and length of the circuit.

Discussion

What do you think was happening here? What does your data tell you that might help you answer this and the following questions?
Is graphite a conductor? What else can you say about the graphite wires?

What can you say about the paper? Is it a conductor or insulator?

What happened when you moved the LED further away from the battery? Can you explain the reasons for what you observed?

	Think about what you have learned about resistance and that less current (or electrical energy) can flow through materials that have greater resistance. How will the length of the graphite circuit affect resistance? You can quantify this in the extension below. What makes an effective or closed circuit and how does your knowledge of an effective/closed circuit match what you did in your experiment above? ***Extension*** Base your discussion on the following questions: What can you say about the relationship between the length of the graphite "wire" and resistance? How much current on average is required to get your type of LED to work? What would happen if you could create a circuit that enabled electrons to flow without resistance?

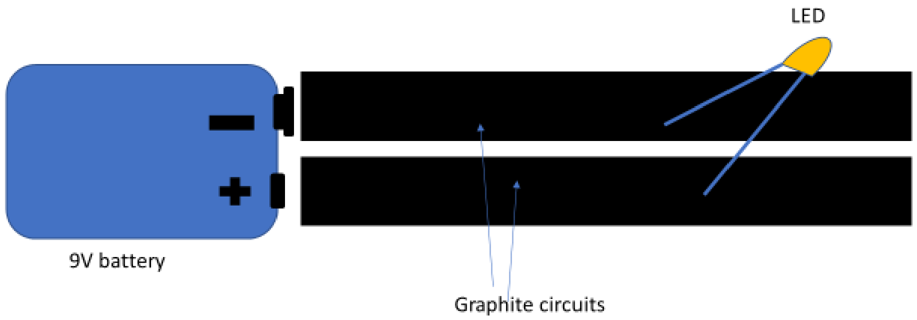

Figure 1. Graphite circuit with a 9V battery and LED

Table 1. example. Recorded measurement of LED brightness with distance from the battery

Distance from Battery	Bright LED	Mid bright LED	Dim LED	No light
1cm				
2cm				
3cm, etc				