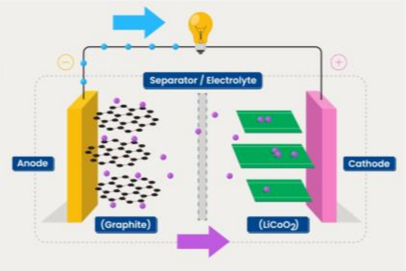
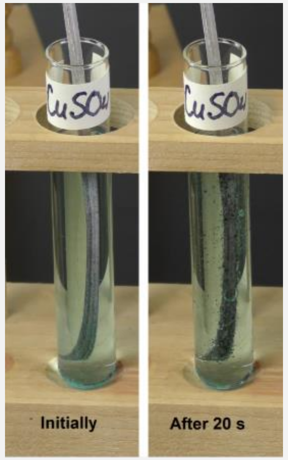
Activity FlowChart

Part 1: Describe how you think a Li ion battery works.



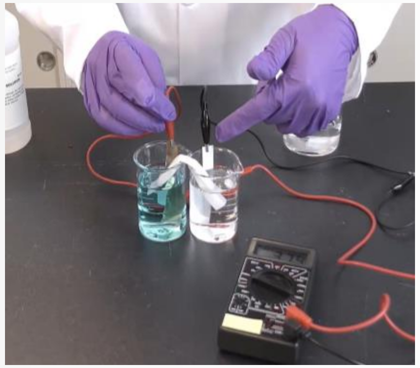
DAY 1

Part 2: Understand by observation that materials, when combined, can produce electricity through chemical reactions.



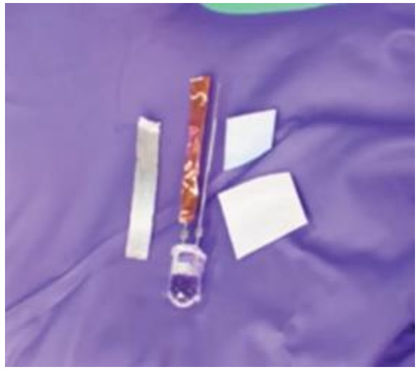
DAY 2

Part 3: Observe that the chemical reactions can be used to power a device; and that your choice of materials determines voltage. Optional: design and build a beaker battery at target voltage.



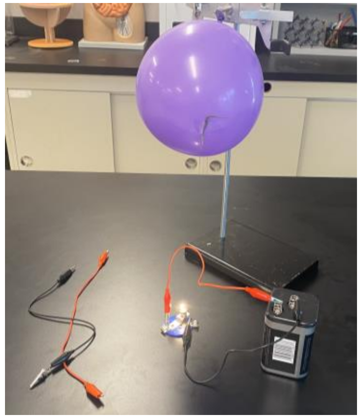
DAY 3

Part 4: Consider energy density and portability: build a smaller battery.



DAY 4

Parts 5-7: Observe Joule heating in action to understand how Li ion battery fires start.



DAY 5

Pacing Guide – Why Do Li Ion Batteries Fail?

Day 1 – Introduction & Modeling Electron/Ion Flow

- Teacher prep: PPT Slides 1–4.

Activities

- Use slides to introduce the focus on electron movement.
- Class discussion on why devices may overheat.
- Students sketch a Li-ion battery, labeling anode, cathode, separator, and electrolyte.
- Add arrows showing electron and Li^+ movement; indicate a possible short-circuit path.

Day 2 – Redox Reactions in Action

- Teacher prep: $CuSO_4$, $MgSO_4$, Mg and Cu strips; goggles and gloves; PPT Slides 5–7.

Activities

- Predict/demo Mg in $CuSO_4$ and Cu in $MgSO_4$.
- Students record observations and link results to reduction potentials.
- Connect to galvanic cells using the “stair step” model of electron flow.

Day 3 – Big Battery Build (Cu/Mg vs Zn/Cu)

- Teacher prep: Cu/Mg cell with salt bridge; Zn strips; voltmeter/lightbulb; PPT Slides 8–12.

Activities

- Teacher demo: Mg/Cu galvanic cell powering a load.
- Students identify anode/cathode, record visual evidence.
- Replace Mg with Zn; compare voltages.
- Students calculate E°cell (Mg/Cu vs Zn/Cu) and discuss voltage differences.
- Stack multiple cells to observe additive voltage.

Day 4 – Small Battery Build & Claim–Evidence–Reasoning

- Teacher prep: Copper foil, Mg ribbon, filter paper ($CuSO_4$ + Na_2SO_4), LEDs, PPT Slides 13–14.

Activities

- Students in pairs build a mini Mg/Cu battery to light an LED.
- Label anode, cathode, salt bridge; write half-cell reactions.
- CER task: explain why stacked cells increase brightness/voltage.
- Reflection: why contact quality matters (LED goes out when pressure released).

Day 5 – Short Circuits, Joule Heating & Synthesis

- Teacher prep: Lamp circuit w/short wire, steel wool vs Al foil, PPT Slides 15–17.

Activities

- Demo: lamp vs short circuit; students diagram intended vs short paths.
- Discuss how shorts cause failure and fire risk.
- Steel wool demo to illustrate Joule heating ($P = I^2R$).
- Students write a one-paragraph synthesis: connect battery design, current flow, heating, and fire risk.
- Assign practice set for reinforcement.

STUDENT PACKET

Why Do Li^+ Ion Batteries Fail?

Name:

Class:

Date:

WHAT YOU'LL DO IN THIS UNIT

- Learn how a phone battery powers your device.
- Investigate how chemical potential energy converts to electrical energy
- Observe how a large magnesium-copper battery works.
- Devise a method for increasing the voltage of the magnesium-copper battery
- Shrink that idea into a handheld battery to light a small lightbulb.
- Observe what moving electrons can do when a short path for them to follow is intentionally created.
- Synthesize your observations to describe why battery fires start.

PART 1: DEVELOP A MODEL

1. Have you ever felt a device get too hot? What do you think is happening inside?

2. Draw a simple model of a Li ion battery connected to a load, or device. Label the anode, cathode, separator, and electrolyte.

3. Indicate the directions of electron and Li^+ ion movement. Also, draw a line to indicate the path electrons might take in a short circuit.

Bridge

From Model to Reality

You've sketched how electrons and ions move in a battery. But how do we know which direction they actually go? We need to see which reactions are spontaneous.

PART 2: SPONTANEOUS REDOX REACTIONS

Your teacher will provide the materials needed to explore redox reactions.

Materials

1 M copper(II) sulfate solution, 1 M magnesium sulfate solution, Mg strip, Cu strip, test tubes, test tube holder

Safety

Goggles and gloves.

Steps

1. Prediction Prompt: Will both Mg in $CuSO_4$ and Cu in $MgSO_4$ react the same way? Why or why not?

2. Place a Strip of Mg metal in a small volume of 1M copper(II) sulfate solution in a test tube. What happens?

3. Place a strip of Cu metal in a small volume of 1M magnesium sulfate solution in a test tube. What happens?

4. What do your observations tell you about how to convert chemical potential energy to electrical energy?

5. Reflection Prompt: Why do you think one reaction happened while the other did not?

Bridge

From Redox Reactions to Batteries

You just discovered that Mg will spontaneously lose electrons to Cu^{2+}, but the reverse doesn't happen. That's the basis of every battery: a spontaneous "downhill" reaction. Let's scale this up into a visible version that can power something.

PART 3: BIG BATTERY BUILD

Your teacher will build a battery by using strips of metal, beakers, and aqueous solutions of ionic compounds. Your job is to make observations and ask questions.

6. Prediction Prompt: Which strip will lose electrons, and which will gain electrons?

7. Draw what you see. Label the Mg strip, Cu strip, the two liquids, the salt bridge, and the load. The load is the thing the cell powers. It can be a voltmeter or a lightbulb.

8. Which strip loses electrons? How do you know? Is this an anode or cathode? What chemical properties make this metal more likely to gain electrons in this pairing?

9. Which strip gains electrons? How do you know? Is this an anode or cathode? What chemical properties make this metal more likely to lose electrons in this pairing?

10. Why is the salt bridge needed? What happens when the salt bridge is removed?

11. What signs are there that a chemical reaction occurs?

12. Calculate the standard reduction potential for this cell. Explain in your own words what causes electrons to move from the anode to the cathode.

13. Why did the battery voltage decrease when your teacher replaced the Mg with Zn?

14. Build a battery that uses Cu and Mg and has a higher voltage than the first Cu/Mg battery you observed. Describe what you changed and explain why you changed it.

Bridge

From Big to Small

The beaker battery is called a Galvanic cell. It proves chemistry can push electrons through a wire and power a phone. The problem is phones aren't big enough to hold beakers! Chemists have figured out how to make smaller batteries. You will now make a small battery that can power a small lightbulb.

PART 4: SMALL BATTERY BUILD

Your teacher will provide the materials. You will build a small battery that can light up a small LED.

Materials

1 M Copper(II) sulfate solution, 1 M sodium sulfate solution, copper foil conductive sheet, filter paper, red LED, magnesium ribbon, distilled or deionized water.

Safety

Goggles and gloves. Handle papers with forceps.

Steps

15. Measure 2 mL, each of the 1 M copper(II) sulfate solution and the 1 M sodium sulfate solution using a 10 mL graduated cylinder. Pour into separate medium sized weigh boats or small beakers (50 mL)
16. Using tweezers, dip the larger (1 cm^2) pre-cut filter paper into the sodium sulfate solution and the smaller (1/2 cm^2) pre-cut filter paper into the copper(II) sulfate solution. Dip long enough to completely coat each filter paper (about 10 seconds)
17. Place both on a separate weigh boat to let dry until the filter papers are damp with solution, not dripping. You can hold each with tweezers and gently wave to decrease drying time.
18. While filter paper is drying, make predictions. Illustrate the experiment and identify the anode, cathode, salt bridge, and evidence of electron flow; and the lit LED. Include the half-cell reactions taking place.
19. Arrange the components to build your battery. Squeeze the LED terminals between your thumb and index finger to promote strong contact among the components. Add a drop of DI water if necessary, but not too much to drown the battery. Darken the room or cup your hand over the LED to watch it light.

Questions

1. Which side is the positive side (cathode)?

2. Describe what happens to light up the LED, using words or symbols.

3. In one sentence describe how this mini cell is the same idea as the beaker cell.

4. What happened when you stopped applying pressure to keep the components in your battery tightly stacked? Why?

What Happens When Electrons Take Paths Not Meant for Them?

You just converted chemical energy to electrical energy and used the energy to power an LED. You did this by creating an intentional path the electrons naturally followed. What if electrons bypass the load and take a shorter path?

PART 5: FUSE DEMO

Your teacher will build a circuit and then intentionally provide the electrons with an unintended path to follow. This is called a short circuit because the path is shorter than the intended, designed path.

1. Prediction Prompt: What do you think will happen if electrons bypass the lamp and take a shorter path?

2. Draw the circuit with arrows that indicate the intended path of electron flow.

3. Draw the shortened path intentionally created for the electrons.

4. What happened along the shortened path when electrons were directed through it? What was the result?

Bridge

Why Did the Wire Get So Hot?

You cannot see with your own eyes what happens when electricity moves through a wire, but you can do an experiment to deduce what happens and understand what can cause a battery to catch fire.

PART 6: JOULE HEATING

Your teacher will run a similar experiment for you to observe that will help you better understand a phenomenon called Joule heating.

5. Prediction Prompt: What do you think will happen when current passes through steel wool compared to aluminum foil?

6. What happened when your teacher used aluminum strip instead of steel wool? Why?

7. What happened when your teacher used a single piece of steel wool to connect the battery's anode and cathode directly? Why?

PART 6: SUMMARIZE

1. Describe in a paragraph how a battery creates electrical current, how electrical current can lead to high temperatures, and how high temperatures can cause fires.

STUDENT PACKET, ANSWERS

Why Do Li^+ Ion Batteries Fail?

Name:

Class:

Date:

WHAT YOU'LL DO IN THIS UNIT

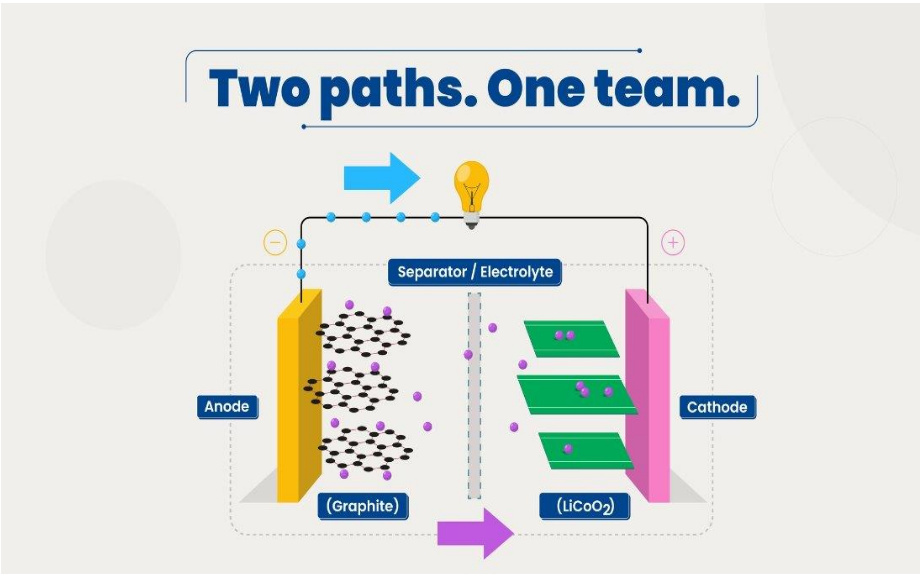
- Learn how a phone battery powers your device.
- Investigate how chemical potential energy converts to electrical energy
- Observe how a large magnesium-copper battery works.
- Devise a method for increasing the voltage of the magnesium-copper battery
- Shrink that idea into a handheld battery to light a small lightbulb.
- Observe what moving electrons can do when a short path for them to follow is intentionally created.
- Synthesize your observations to describe why battery fires start.

PART 1: DEVELOP A MODEL

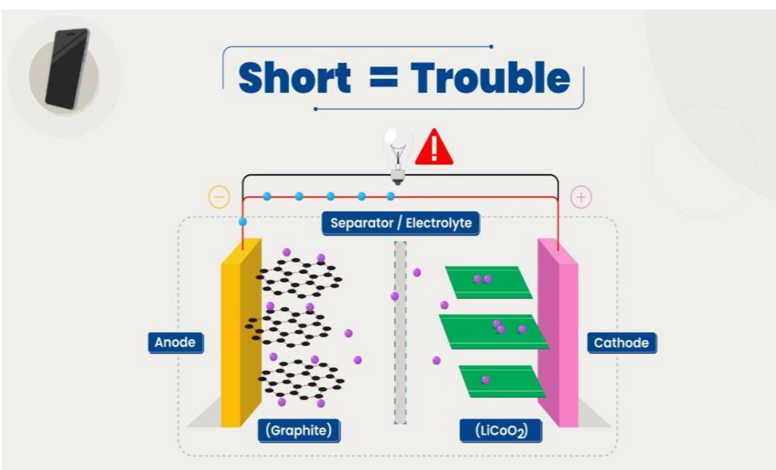
– Have you ever felt a device get too hot? What do you think is happening inside?

The battery is undergoing internal resistance and unwanted side reactions. As current flows, heat is generated. If the battery is stressed or damaged, electrons may take unintended short paths, causing rapid heating that can lead to runaway reactions.

1. Draw a simple model of a Li ion battery connected to a load, or device. Label the anode, cathode, separator, and electrolyte.



2. Indicate the directions of electron and Li^+ ion movement. Also, draw a line to indicate the path electrons might take in a short circuit.



From Model to Reality

You've sketched how electrons and ions move in a battery. But how do we know which direction they actually go? We need to see which reactions are spontaneous.

PART 2: SPONTANEOUS REDOX REACTIONS

Your teacher will provide the materials needed to explore redox reactions.

Materials

1 M copper(II) sulfate solution, 1 M magnesium sulfate solution, Mg strip, Cu strip, test tubes, test tube holder

Safety

Goggles and gloves.

Steps

1. Prediction Prompt: Will both Mg in $CuSO_4$ and Cu in $MgSO_4$ react the same way? Why or why not?

   No. Magnesium is more reactive than copper, so Mg will reduce Cu^{2+} ions, but copper is not reactive enough to reduce Mg^{2+}.

2. Place a Strip of Mg metal in a small volume of 1M copper(II) sulfate solution in a test tube. What happens?

   The Mg strip darkens and reddish copper metal deposits on its surface; the blue solution fades as Cu^{2+} is reduced to Cu(s).

3. Place a strip of Cu metal in a small volume of 1M magnesium sulfate solution in a test tube. What happens?

   No visible reaction occurs because copper cannot reduce Mg^{2+} ions.

4. What do your observations tell you about how to convert chemical potential energy to electrical energy?

   Energy is released only when a spontaneous redox reaction occurs. That "downhill" electron flow can be harnessed to drive current through a wire.

5. Reflection Prompt: Why do you think one reaction happened while the other did not?

   Because magnesium has a much lower reduction potential than copper, it more readily loses electrons. Copper cannot displace magnesium because magnesium ions require much more energy to be reduced.

Bridge

From Redox Reactions to Batteries

You just discovered that Mg will spontaneously lose electrons to Cu^{2+}, but the reverse doesn't happen. That's the basis of every battery: a spontaneous "downhill" reaction. Let's scale this up into a visible version that can power something.

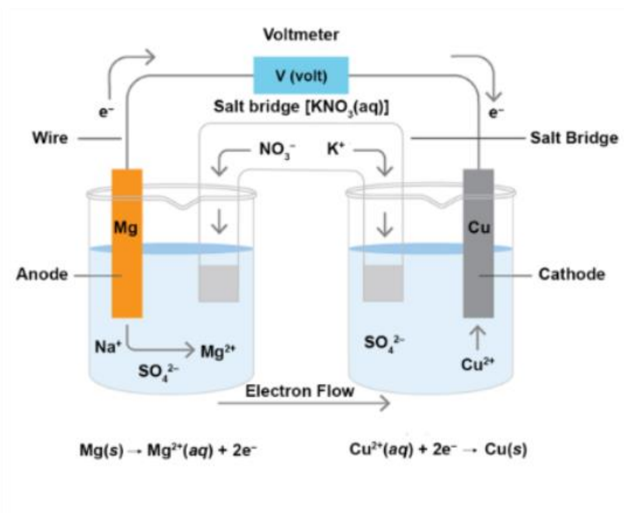
PART 3: BIG BATTERY BUILD

Your teacher will build a battery by using strips of metal, beakers, and aqueous solutions of ionic compounds. Your job is to make observations and ask questions.

6. Prediction Prompt: Which strip will lose electrons, and which will gain electrons?

   Magnesium will lose electrons (anode). Copper will gain electrons (cathode).

7. Draw what you see. Label the Mg strip, Cu strip, the two liquids, the salt bridge, and the load. The load is the thing the cell powers. It can be a voltmeter or a lightbulb.



8. Which strip loses electrons? How do you know? Is this an anode or cathode? What chemical properties make this metal more likely to gain electrons in this pairing?

   Magnesium loses electrons; it is the anode. Its stronger tendency to oxidize makes it more likely to give up electrons.

9. Which strip gains electrons? How do you know? Is this an anode or cathode? What chemical properties make this metal more likely to lose electrons in this pairing?

   Copper gains electrons; it is the cathode. Its higher reduction potential makes it more likely to accept electrons.

10. Why is the salt bridge needed? What happens when the salt bridge is removed?

    The salt bridge allows ion flow to maintain electrical neutrality. Without it, charge builds up in each half-cell and the flow of electrons stops.

11. What signs are there that a chemical reaction occurs?

    Copper metal plates onto the electrode; the magnesium electrode corrodes/dissolves; solution color may change.

12. Calculate the standard reduction potential for this cell. Explain in your own words what causes electrons to move from the anode to the cathode.

    E°cell = E°cathode − E°anode = (+0.34 V for Cu^{2+}/Cu) − (−2.37 V for Mg^{2+}/Mg) = +2.71 V. Electrons move because magnesium has a much stronger drive to oxidize than copper, so there is an overall "downhill" potential difference.

13. Why did the battery voltage decrease when your teacher replaced the Mg with Zn?

    Because zinc is less reactive than magnesium. Its standard potential is −0.76 V, so the Cu/Zn cell only produces about +1.10 V, much less than Cu/Mg.

14. Build a battery that uses Cu and Mg and has a higher voltage than the first Cu/Mg battery you observed. Describe what you changed and explain why you changed it.

    Stacking multiple Cu/Mg cells in series increases the voltage. Each adds about 2.7 V, so two cells can light a bulb at ~5.4 V.

Bridge

From Big to Small

The beaker battery is called a Galvanic cell. It proves chemistry can push electrons through a wire and power a phone. The problem is phones aren't big enough to hold beakers! Chemists have figured out how to make smaller batteries. You will now make a small battery that can power a small lightbulb.

PART 4: SMALL BATTERY BUILD

Your teacher will provide the materials. You will build a small battery that can light up a small LED.

Materials

1 M Copper(II) sulfate solution, 1 M sodium sulfate solution, copper foil conductive sheet, filter paper, red LED, magnesium ribbon, distilled or deionized water.

Safety

Goggles and gloves. Handle papers with forceps.

Steps

15. Measure 2 mL, each of the 1 M copper(II) sulfate solution and the 1 M sodium sulfate solution using a 10 mL graduated cylinder. Pour into separate medium sized weigh boats or small beakers (50 mL)
16. Using tweezers, dip the larger (1 cm^2) pre-cut filter paper into the sodium sulfate solution and the smaller (1/2 cm^2) pre-cut filter paper into the copper(II) sulfate solution. Dip long enough to completely coat each filter paper (about 10 seconds)
17. Place both on a separate weigh boat to let dry until the filter papers are damp with solution, not dripping. You can hold each with tweezers and gently wave to decrease drying time.
18. While filter paper is drying, make predictions. Illustrate the experiment and identify the anode, cathode, salt bridge, and evidence of electron flow; and the lit LED. Include the half-cell reactions taking place.
19. Arrange the components to build your battery. Squeeze the LED terminals between your thumb and index finger to promote strong contact among the components. Add a drop of DI water if necessary, but not too much to drown the battery. Darken the room or cup your hand over the LED to watch it light.

Questions

1. Which side is the positive side (cathode)?

   The copper side is the cathode (positive electrode).

2. Describe what happens to light up the LED, using words or symbols.

   Mg oxidizes ($Mg \rightarrow Mg^{2+} + 2e^-$). Electrons flow through the LED to copper. Cu^{2+} ions in solution are reduced to Cu. The LED lights when electrons flow through it.

3. In one sentence describe how this mini cell is the same idea as the beaker cell.

   Both use a spontaneous redox reaction between Mg and Cu^{2+} *to generate a current that powers a device.*

4. What happened when you stopped applying pressure to keep the components in your battery tightly stacked? Why?

   The LED went out because poor contact increased resistance and interrupted the electron flow.

What Happens When Electrons Take Paths Not Meant for Them?

You just converted chemical energy to electrical energy and used the energy to power an LED. You did this by creating an intentional path the electrons naturally followed. What if electrons bypass the load and take a shorter path?

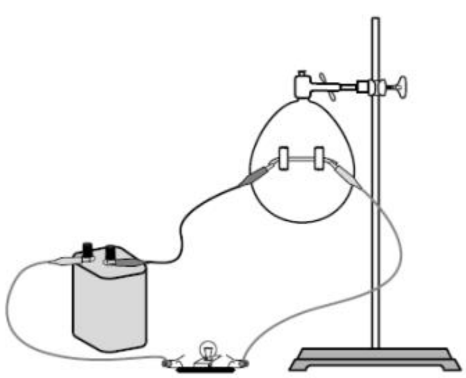
PART 5: FUSE DEMO

Your teacher will build a circuit and then intentionally provide the electrons with an unintended path to follow. This is called a short circuit because the path is shorter than the intended, designed path.

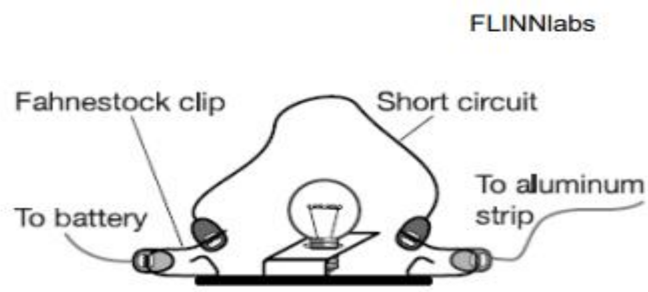
1. Prediction Prompt: What do you think will happen if electrons bypass the lamp and take a shorter path?

   They will flow rapidly through the wire, generating heat instead of lighting the lamp.

2. Draw the circuit with arrows that indicate the intended path of electron flow.



3. Draw the shortened path intentionally created for the electrons.



4. What happened along the shortened path when electrons were directed through it? What was the result?

   The wire increased in temperature. The lamp did not light because the electrons bypassed it.

Bridge

Why Did the Wire Get So Hot?

You cannot see with your own eyes what happens when electricity moves through a wire, but you can do an experiment to deduce what happens and understand what can cause a battery to catch fire.

PART 6: JOULE HEATING

Your teacher will run a similar experiment for you to observe that will help you better understand a phenomenon called Joule heating.

5. Prediction Prompt: What do you think will happen when current passes through steel wool compared to aluminum foil?

   Steel wool will heat and glow because it has higher resistance and finer strands. Aluminum foil will not glow because it has lower resistance and more bulk to dissipate heat.

6. What happened when your teacher used steel wool instead of an aluminum strip? Why?

   The balloon popped owing to the high temperature of the steel wool due to high resistance. The steel wool is much thinner and so there are more collisions between electrons and the metal lattice.

7. What happened when your teacher used a single piece of steel wool to connect the battery's anode and cathode directly? Why?

   It glowed brightly and may have burned out. Direct connection (short circuit) allowed huge current with no load, causing rapid heating through Joule's law ($P = I^2R$). Again, the balloon popped.

PART 7: SUMMARIZE

1. Describe in a paragraph how a battery creates electrical current, how electrical current can lead to high temperatures, and how high temperatures can cause fires.

   A battery works by separating two half-reactions so that electrons must travel through a wire, generating current. As current flows, resistance in wires and materials produces heat (Joule heating). If electrons bypass the designed path in a short circuit, very high currents can flow, leading to intense heating. This heating can damage the separator, cause thermal runaway, ignite flammable electrolyte, and ultimately result in battery fires.


STOP

Why Do Lithium-ion Batteries Fail? Here's What You Will Do To Find Out.

FLINN SCIENTIFIC

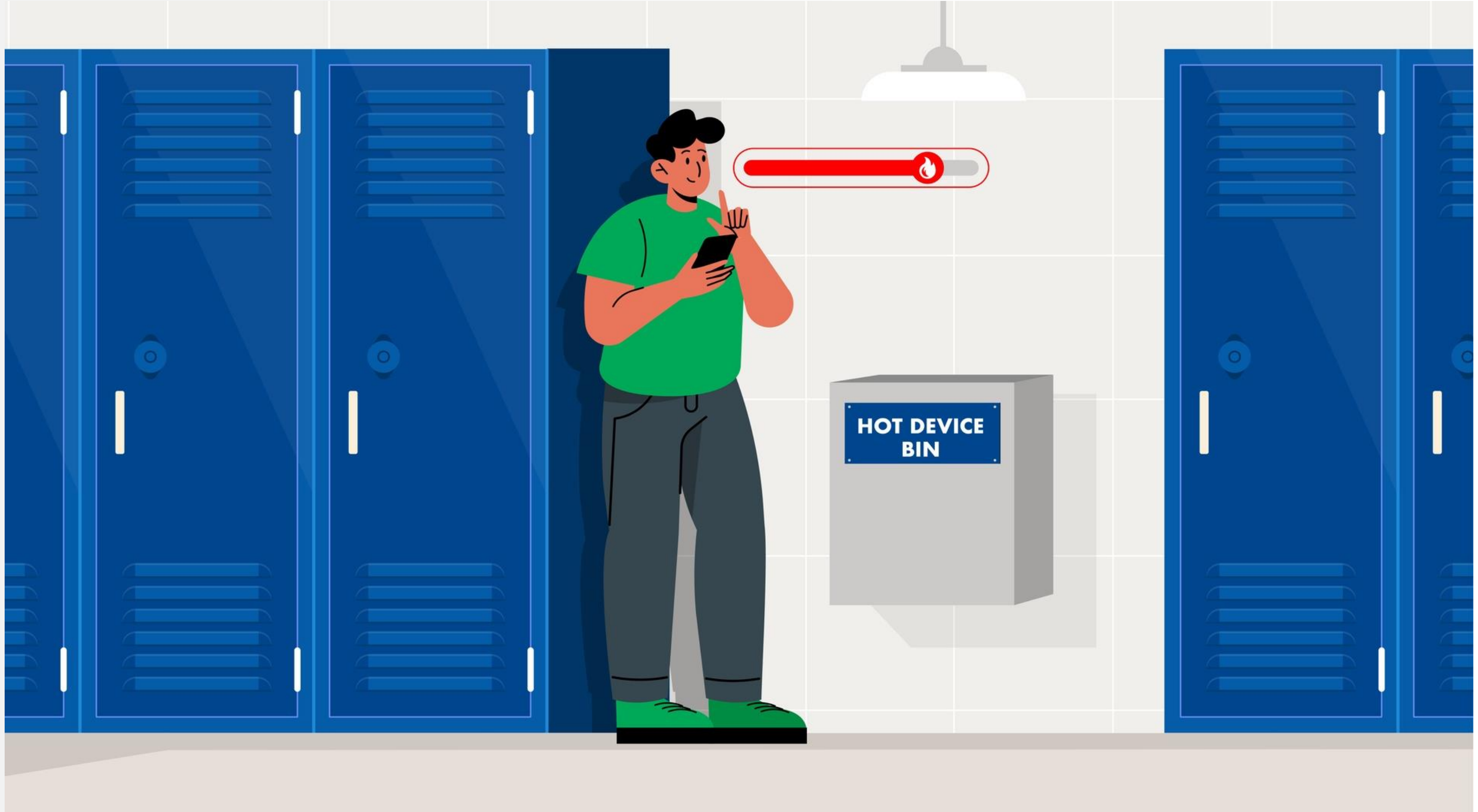
- Learn how a phone battery powers your device.
- Understand the difference between a spontaneous and non-spontaneous process.
- Observe how a large magnesium-copper battery works.
- Shrink that idea into a handheld battery to light a small lightbulb.
- Relate the small Mg/Cu battery to commercial Li ion batteries.
- Observe what happens when electrons take non-designed paths.
- Synthesize your observations to describe why battery fires start.

Lithium-ion battery fire warning

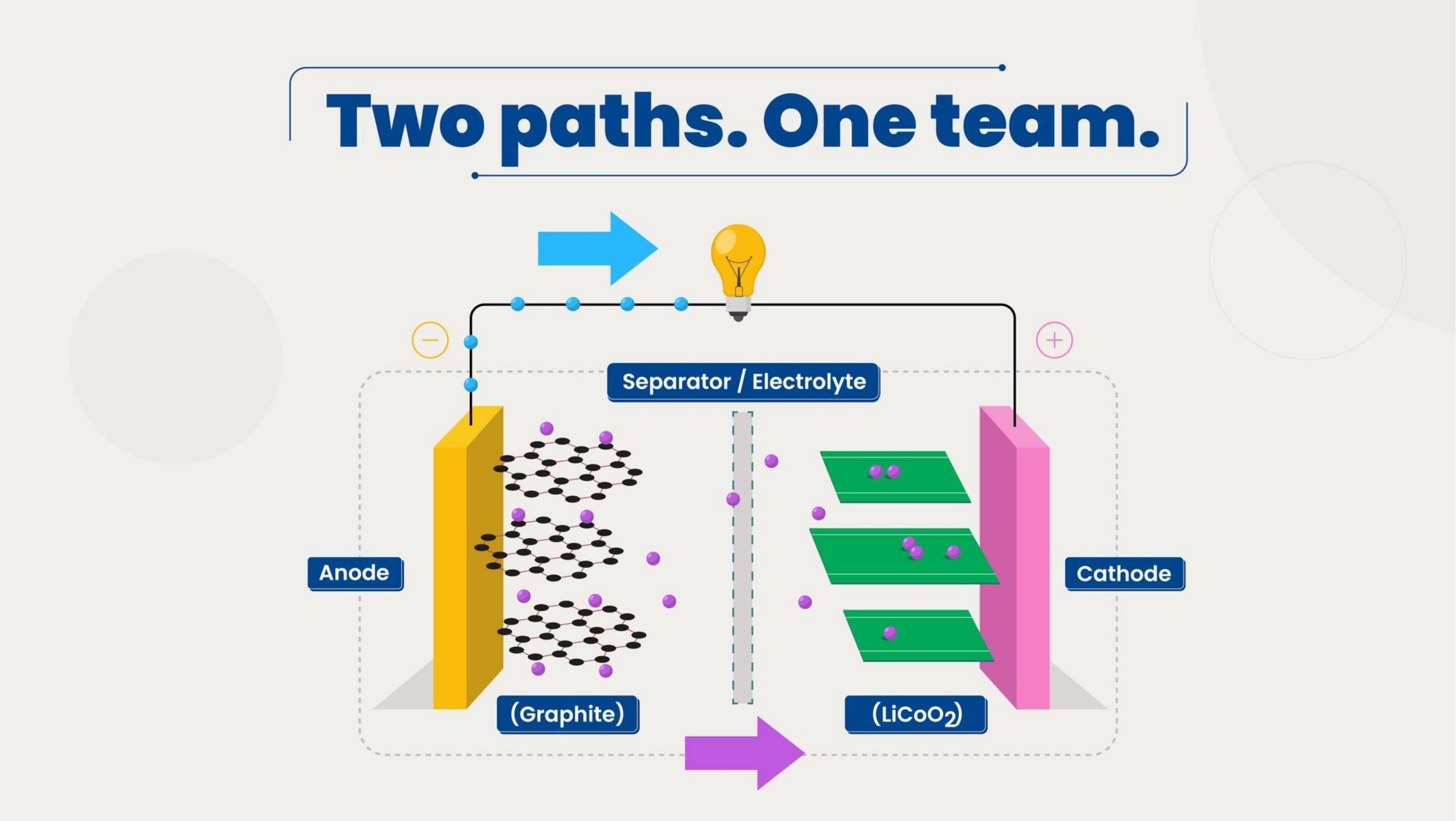
PART 1: DEVELOP A MODEL

FLINN SCIENTIFIC

Have you ever felt your phone get hot? What do you think is happening inside?



Charge is Moving!



Bridge: From Model to Reality

Now let's see what makes electrons move!

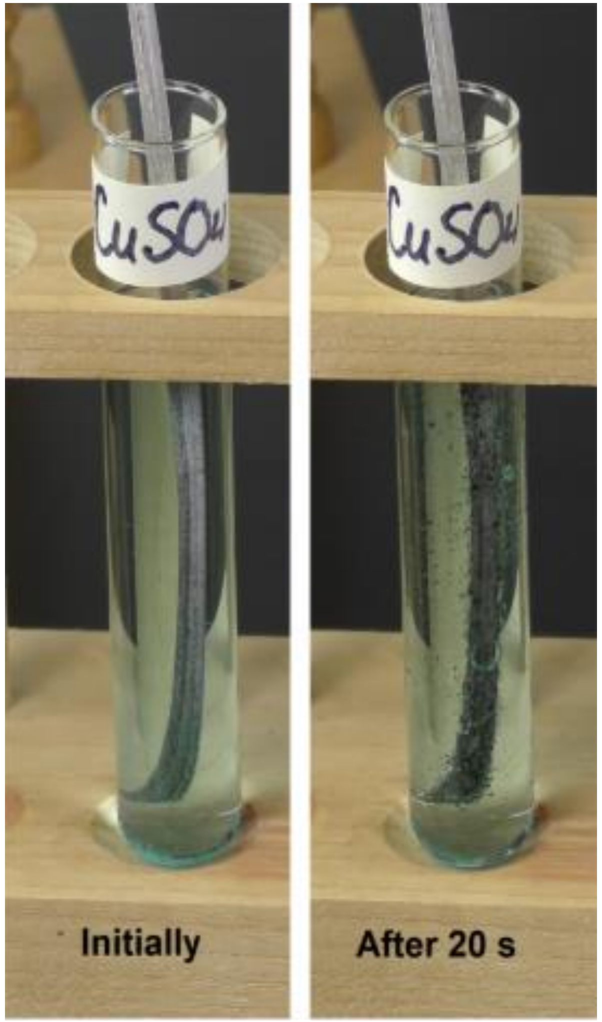
PART 2: SPONTANEOUS REDOX REACTIONS

FLINN SCIENTIFIC

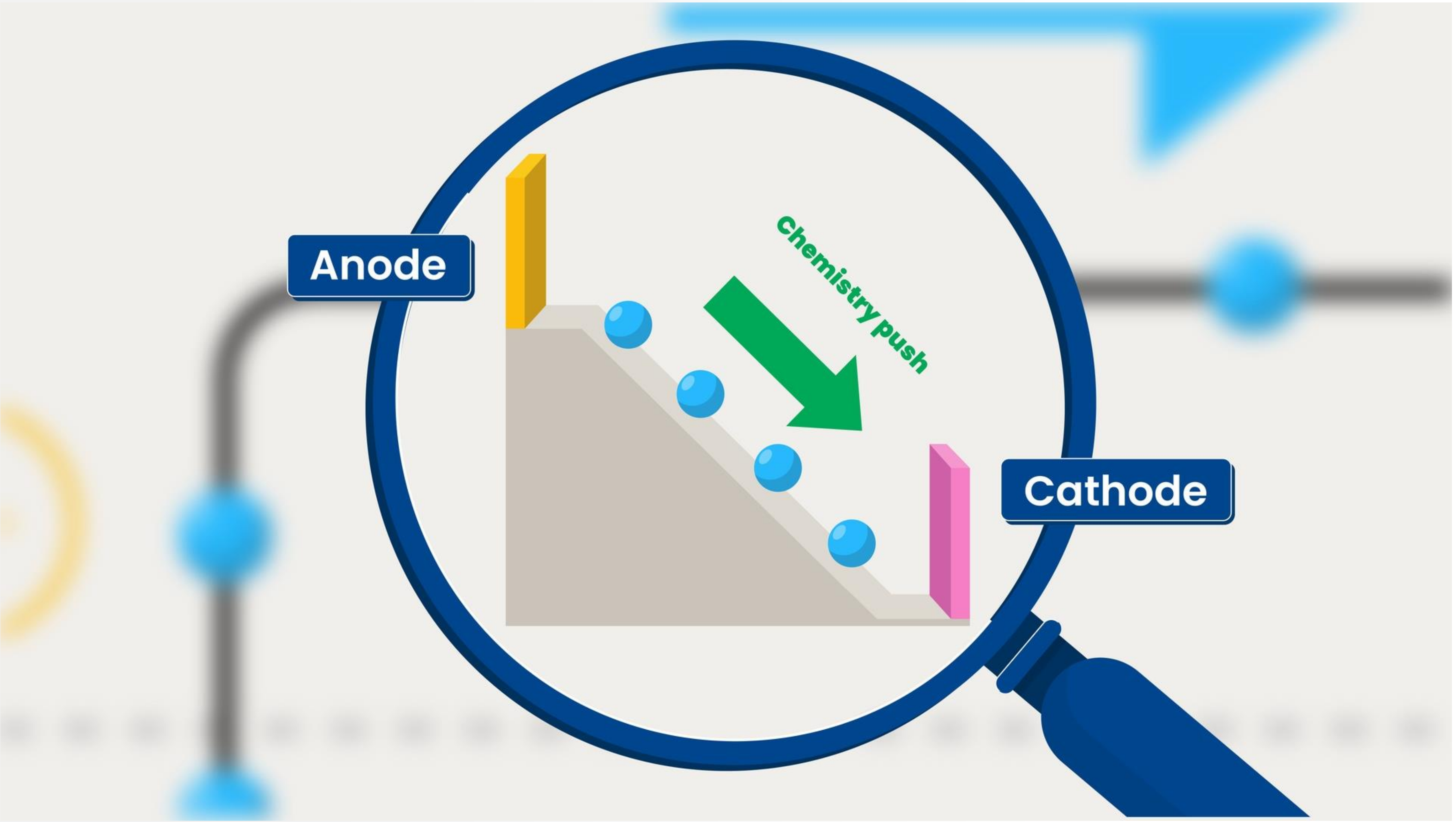
$$\mathbf{Mg(\mathit{s}) + Cu^{2+}(\mathit{aq}) \rightarrow Cu(s) + Mg^{2+}(aq)}$$

- Placing a strip of Mg metal in a solution of copper(II) sulfate produces electrons that move.

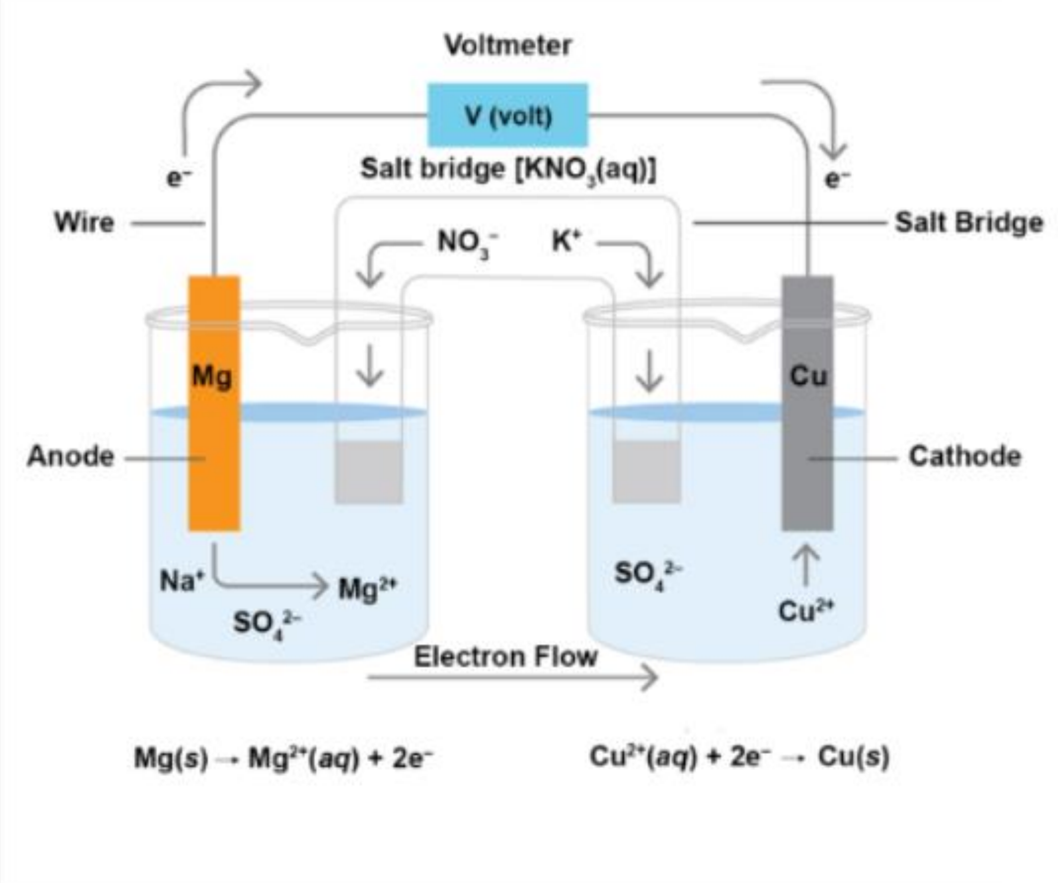
- Predict: Will Cu in $MgSO_4$ react the same way?



Electrons Roll Downhill



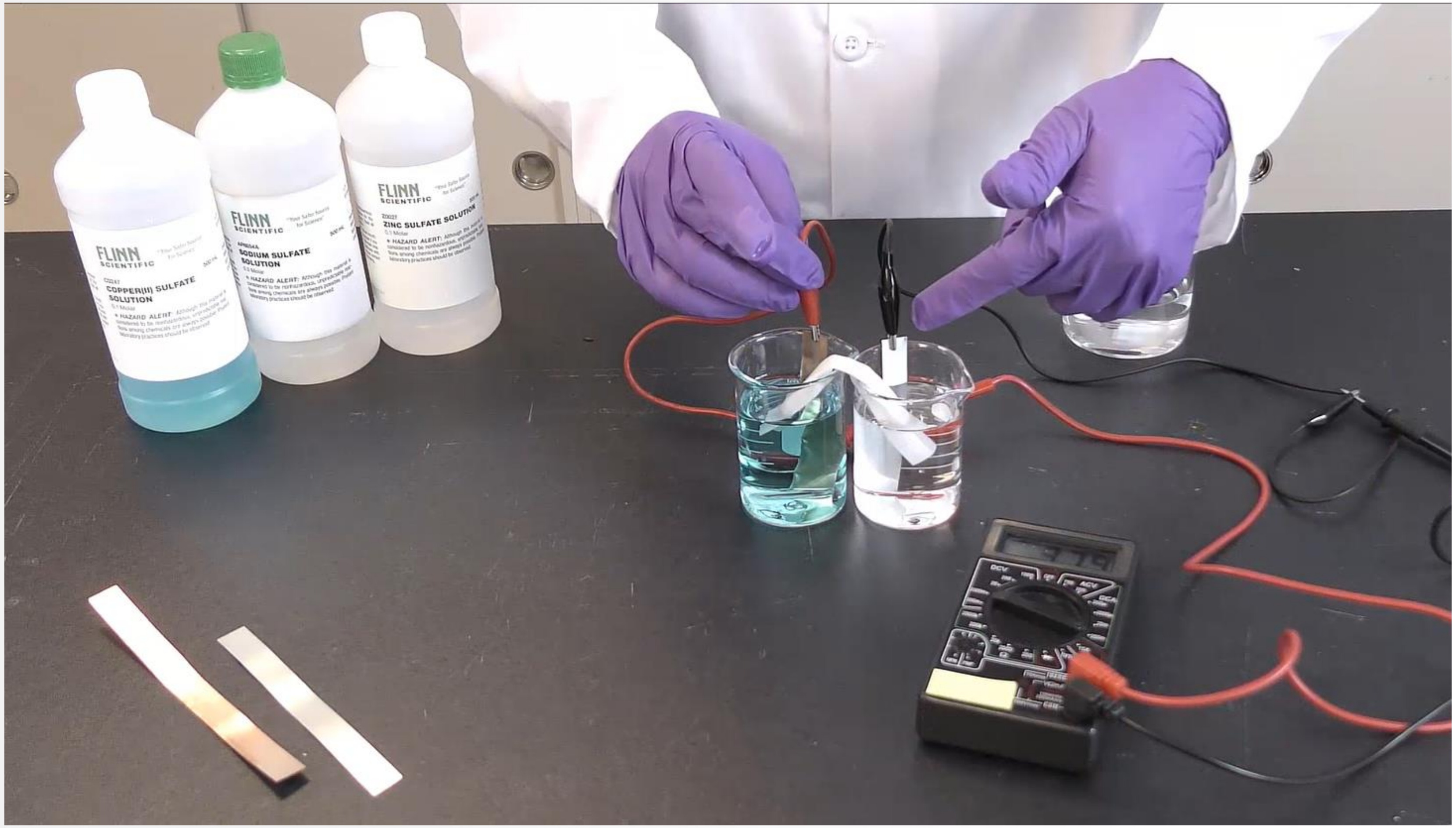
Bridge: From Redox To Batteries



Let's Scale the Mg/Cu Idea Up Into a Battery

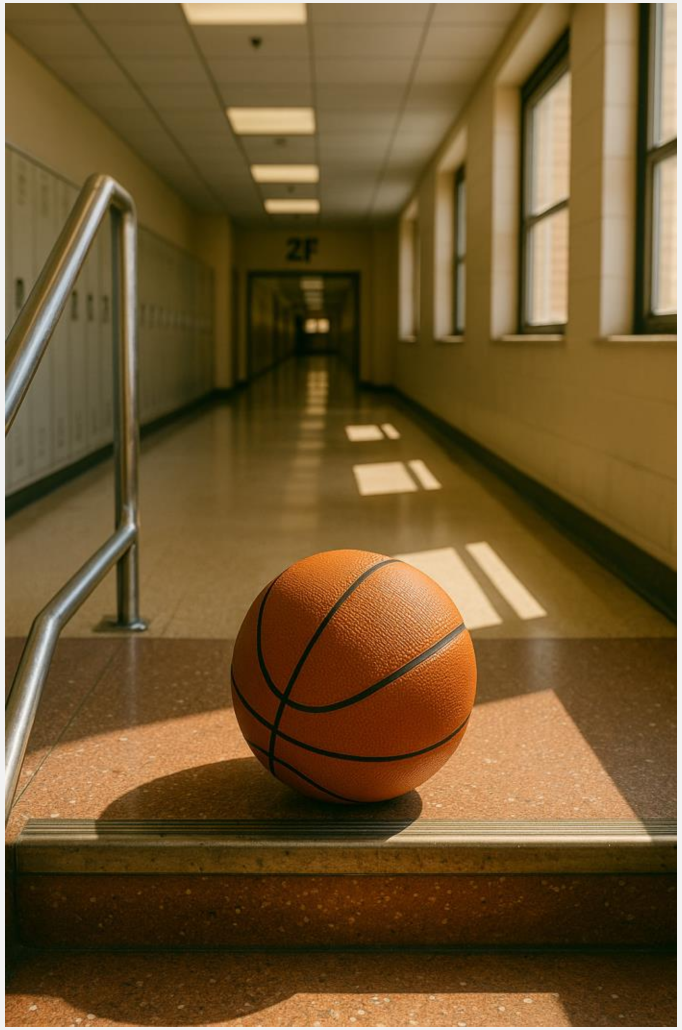
PART 3: BIG BATTERY BUILD

FLINN SCIENTIFIC



Which strip loses electrons? Which gains? Where do they go?

Mg is the top stair, and Cu is the bottom stair



Standard Reduction Potentials at 25°C			
Half Reaction	Potential (V)	Half Reaction	Potential (V)
$F_2 + 2e^- \rightarrow 2F^-$	2.866	$Cu^{2+} + 2e^- \rightarrow Cu$	0.3419
$Ag^{2+} + e^- \rightarrow Ag^+$	1.98	$Cu^{2+} + e^- \rightarrow Cu^+$	0.153
$Ce^{4+} + e^- \rightarrow Ce^{3+}$	1.72	$2H^+ + 2e^- \rightarrow H_2$	0
$PbO_2 + 4H^+ + SO_4^{2-} + 2e^- \rightarrow PbSO_4 + 2H_2O$	1.6913	$Fe^{3+} + 3e^- \rightarrow Fe$	–0.037
$Cr_2O_7^{2-} + 14H^+ + 6e^- \rightarrow 2Cr^{3+} + 7H_2O$	1.36	$Pb^{2+} + 2e^- \rightarrow Pb$	–0.1262
$Cl_2 + 2e^- \rightarrow 2Cl^-$	1.35827	$Sn^{2+} + 2e^- \rightarrow Sn$	–0.1375
$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$	1.229	$Cd^{2+} + 2e^- \rightarrow Cd$	–0.4030
$Br_2(aq) + 2e^- \rightarrow 2Br^-$	1.0873	$Zn^{2+} + 2e^- \rightarrow Zn$	–0.7618
$Ag^+ + e^- \rightarrow Ag$	0.7996	$Al^{3+} + 3e^- \rightarrow Al$	–1.676
$Fe^{3+} + e^- \rightarrow Fe^{2+}$	0.771	$Mg^{2+} + 2e^- \rightarrow Mg$	–2.372
$I_2 + 2e^- \rightarrow 2I^-$	0.5355	$Ca^{2+} + 2e^- \rightarrow Ca$	–2.868

Standard Reduction Potentials

Anode:	$Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$	$E^\circ_{red} = -0.7618$ V
Cathode:	$Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$	$E^\circ_{red} = 0.3419$ V
Cell:	$Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s)$	$E^\circ_{cell} = E^\circ_{red}$ (cathode) – E°_{cell} (anode) $E^\circ_{cell} = 0.3419$ V – (–0.7618 V) = **1.104 V**

When this number is positive you have a functional battery. Math tells you when electrons will roll downhill.

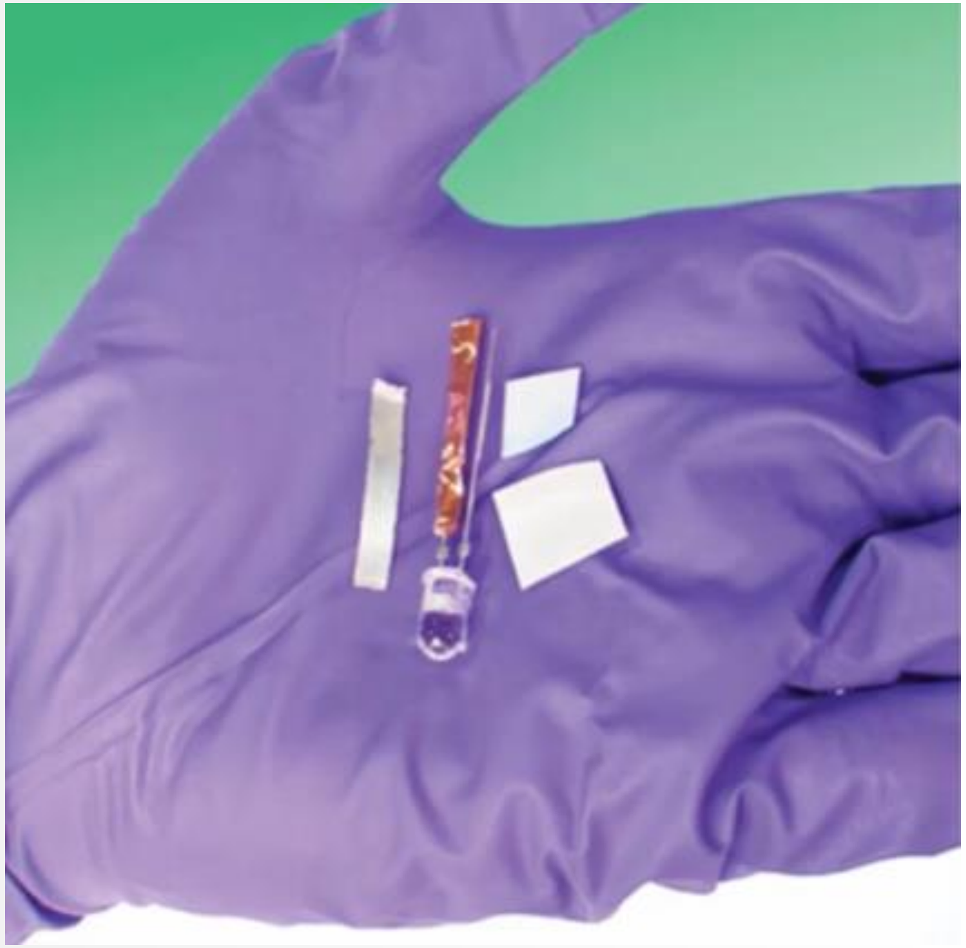
Calculate a Battery's Voltage

Which will give more voltage, a Mg/Cu or Zn/Cu battery?

Standard Reduction Potentials at 25°C			
Half Reaction	Potential (V)	Half Reaction	Potential (V)
$F_2 + 2e^- \rightarrow 2F^-$	2.866	$Cu^{2+} + 2e^- \rightarrow Cu$	0.3419
$Ag^{2+} + e^- \rightarrow Ag^+$	1.98	$Cu^{2+} + e^- \rightarrow Cu^+$	0.153
$Ce^{4+} + e^- \rightarrow Ce^{3+}$	1.72	$2H^+ + 2e^- \rightarrow H_2$	0
$PbO_2 + 4H^+ + SO_4^{2-} + 2e^- \rightarrow PbSO_4 + 2H_2O$	1.6913	$Fe^{3+} + 3e^- \rightarrow Fe$	–0.037
$Cr_2O_7^{2-} + 14H^+ + 6e^- \rightarrow 2Cr^{3+} + 7H_2O$	1.36	$Pb^{2+} + 2e^- \rightarrow Pb$	–0.1262
$Cl_2 + 2e^- \rightarrow 2Cl^-$	1.35827	$Sn^{2+} + 2e^- \rightarrow Sn$	–0.1375
$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$	1.229	$Cd^{2+} + 2e^- \rightarrow Cd$	–0.4030
$Br_2(aq) + 2e^- \rightarrow 2Br^-$	1.0873	$Zn^{2+} + 2e^- \rightarrow Zn$	–0.7618
$Ag^+ + e^- \rightarrow Ag$	0.7996	$Al^{3+} + 3e^- \rightarrow Al$	–1.676
$Fe^{3+} + e^- \rightarrow Fe^{2+}$	0.771	$Mg^{2+} + 2e^- \rightarrow Mg$	–2.372
$I_2 + 2e^- \rightarrow 2I^-$	0.5355	$Ca^{2+} + 2e^- \rightarrow Ca$	–2.868

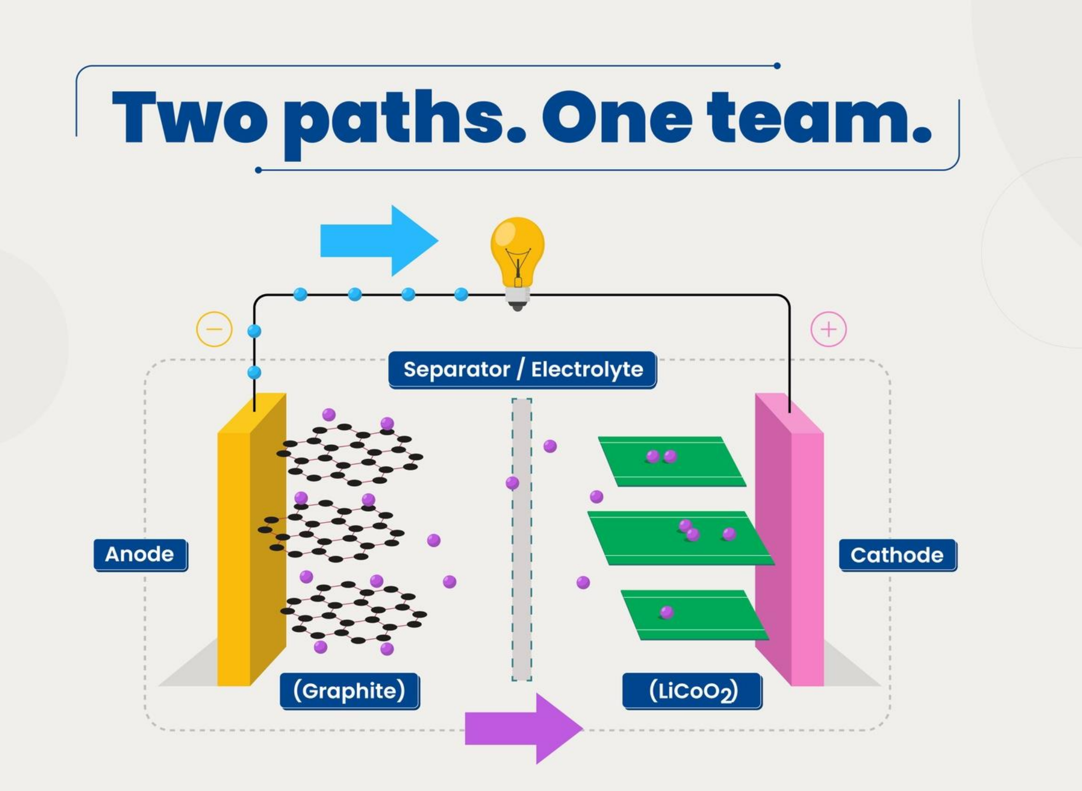
PART 4: SMALL BATTERY BUILD

FLINN SCIENTIFIC



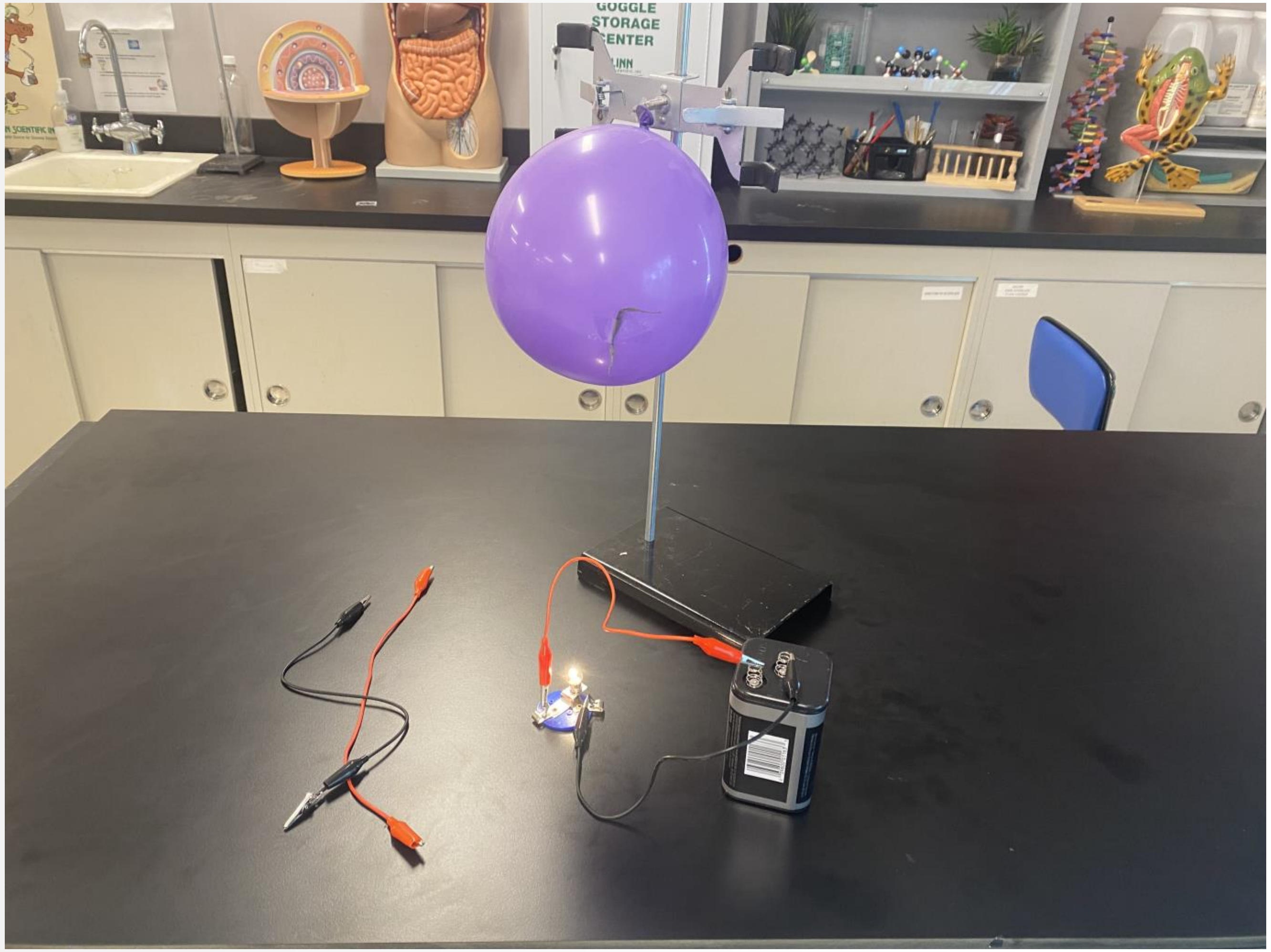
The long prong is the cathode. Predict the arrangement of components needed to light the LED.

Lithium ion batteries work on the same redox principles but with Li instead of Mg and transition-metal oxides instead of Cu^{2+}.



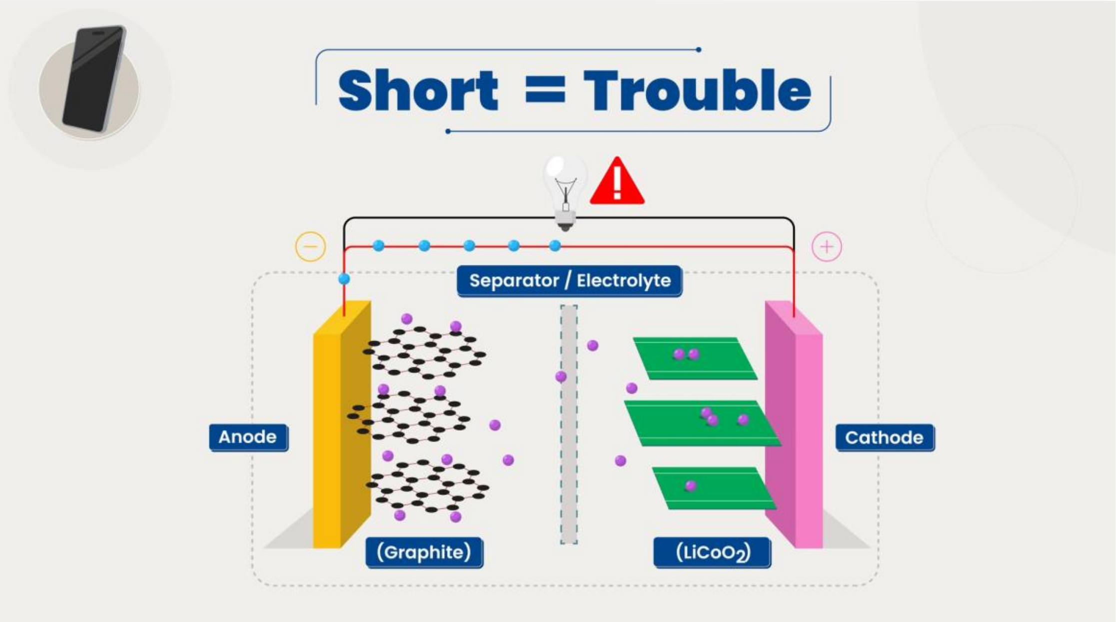
PART 5: FUSE DEMO

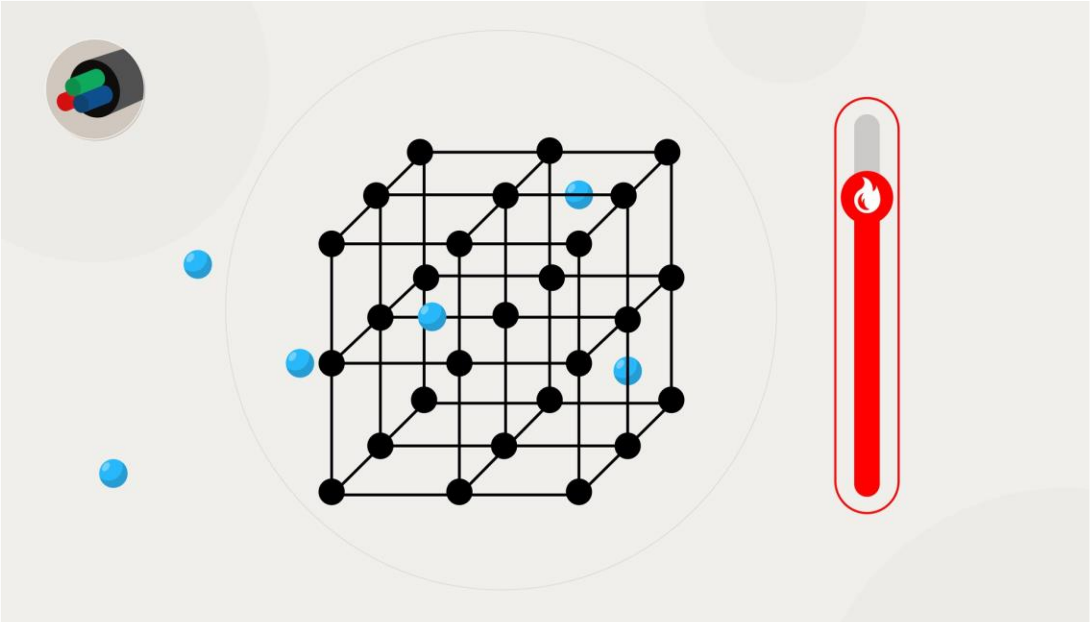
FLINN SCIENTIFIC



What happens if electrons bypass the light?

Bridge: Why Did the Wire Get So Hot?





PART 6: JOULE HEATING

FLINN SCIENTIFIC

$$P = I^2R$$

Imagine students rushing through a hallway. The more students (current) trying to push through, the more collisions occur. If twice as many students run, the crashes don't double, they get four times worse.

PART 7: SUMMARIZE

Describe in a paragraph how a battery creates electrical current, how electrical current can lead to high temperatures, and how high temperatures can cause fires.