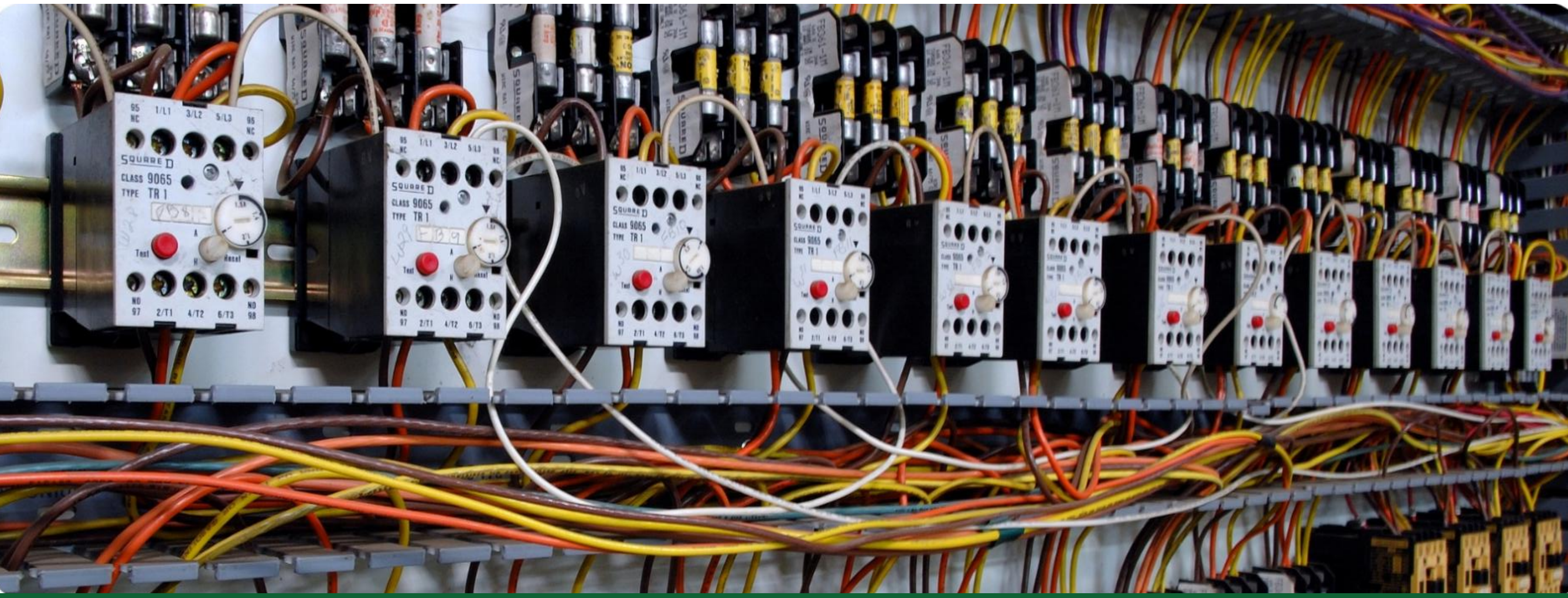
Transit Core Competencies Curriculum

Participant Resource Guide

Electrical Foundations

May 2026



Course Outline

- Module 1: Introduction to Electricity
- Module 2: Basic Electrical Principles
- Module 3: AC and DC Electricity
- **Module 4: Circuit Components & Architecture**
- Module 5: Magnetism and Electromagnetism
- Module 6: Electrical Tools
- Module 7: Safety and PPE

TWC TRANSIT WORKFORCE CENTER

U.S. Department of Transportation
Federal Transit Administration

A program of the Federal Transit Administration administered by the International Transportation Learning Center

Course: Electrical Foundations
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Module 4 – Circuit Components & Architecture

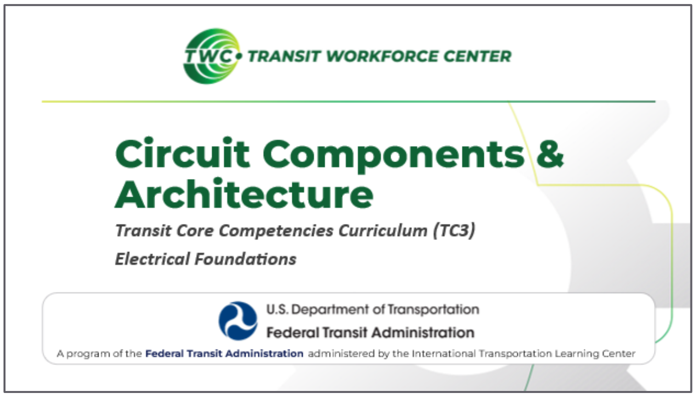
Objectives

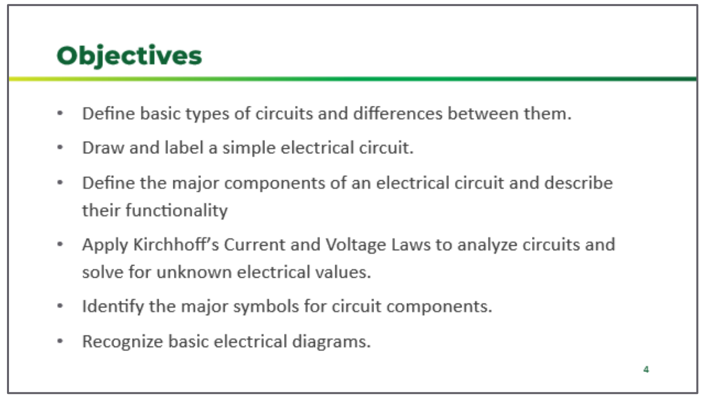
- Define basic types of circuits and differences between them.
- Draw and label a simple electrical circuit.
- Define the major components of an electrical circuit and describe their functionality.
- Apply Kirchhoff's Current and Voltage Laws to analyze circuits and solve for unknown electrical values.
- Identify the major symbols for circuit components.
- Recognize basic electrical diagrams.

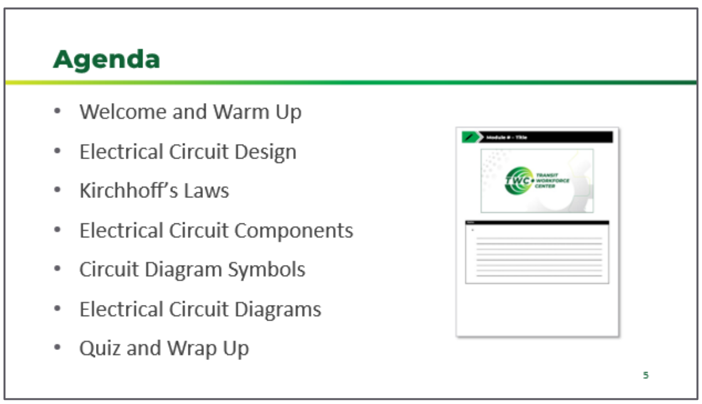
Key Terms

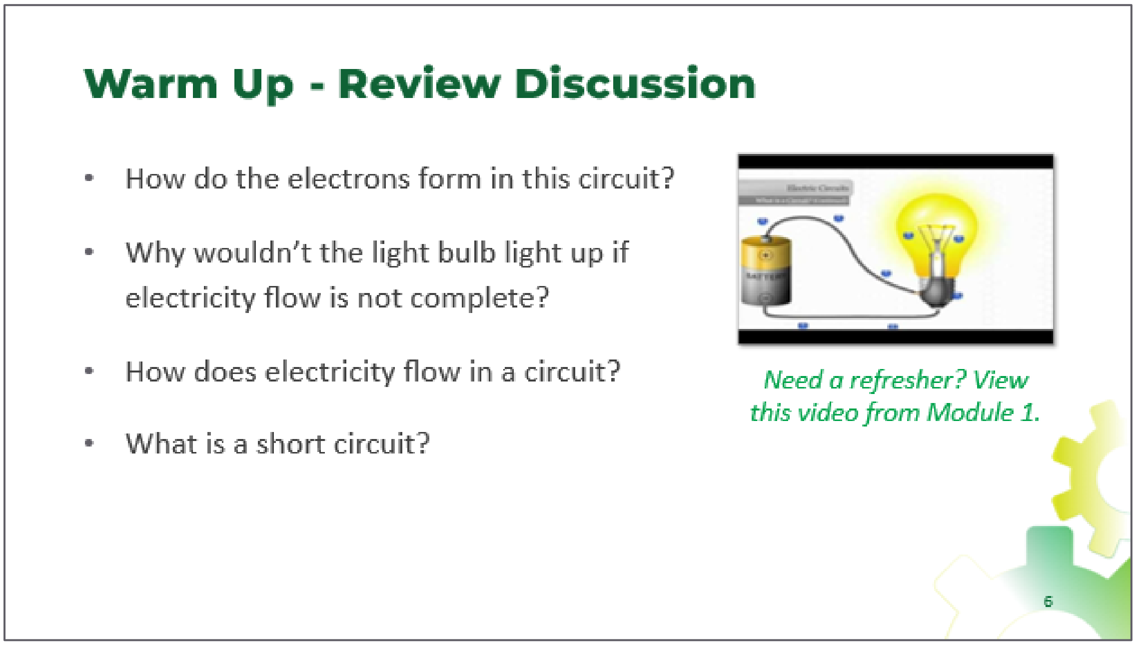
- Block Diagram
- Capacitor
- Circuit Breaker
- Circuit Protection
- Diode
- Electrical Circuit
- Fuse
- Inductor
- Kirchhoff's Current Law (KCL)
- Kirchhoff's Voltage Law (KVL)
- Load
- One-Line Diagram
- Parallel Circuit
- Power Rating
- Power Source
- Rectifier
- Relay
- Resistance (R)
- Resistor
- Schematic
- Sensor
- Series Circuit
- Series-Parallel Circuit
- Switch
- Tolerance
- Transformers
- Transistor
- Wire

Circuit Components & Acrhitecture









Notes:

- Watch the video and answer the following questions:
    1. How do the electrons from in this circuit?
    2. What is a complete circuit?
    3. Why wouldn't the light bulb light up if electricity flow is not complete?
    4. How does electricity flow in a circuit?
    5. What is a short circuit?

  Video link: https://www.youtube.com/watch?v=VnnpLaKsqGU

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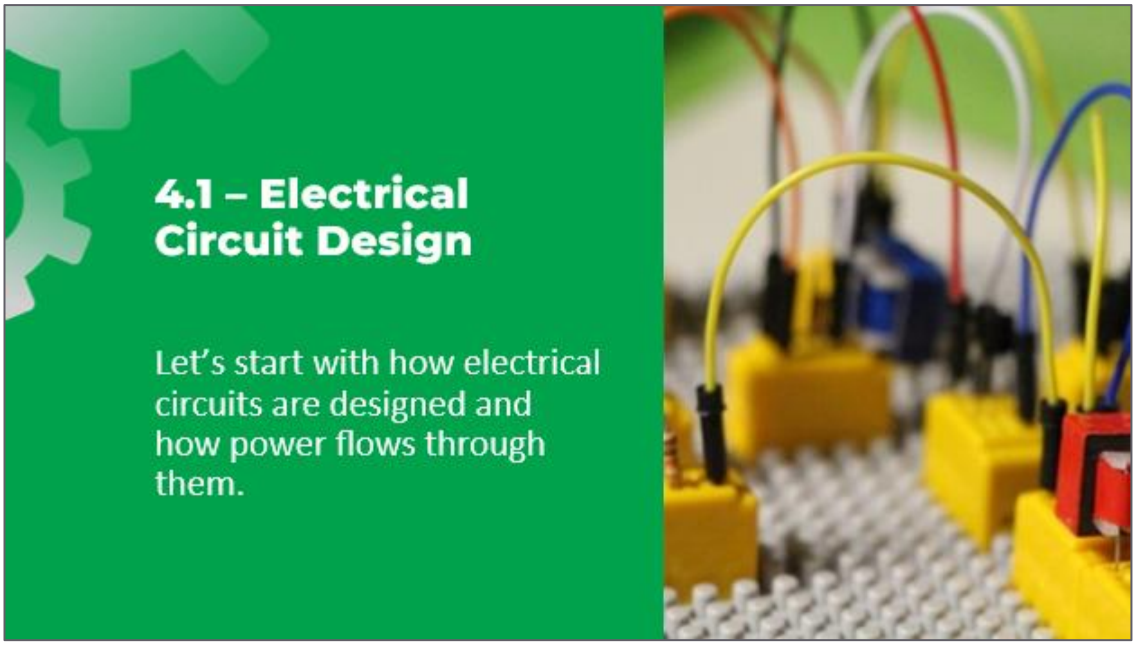

Notes:

- In this section, you'll learn about how electrical circuits are designed and how power flows through them.

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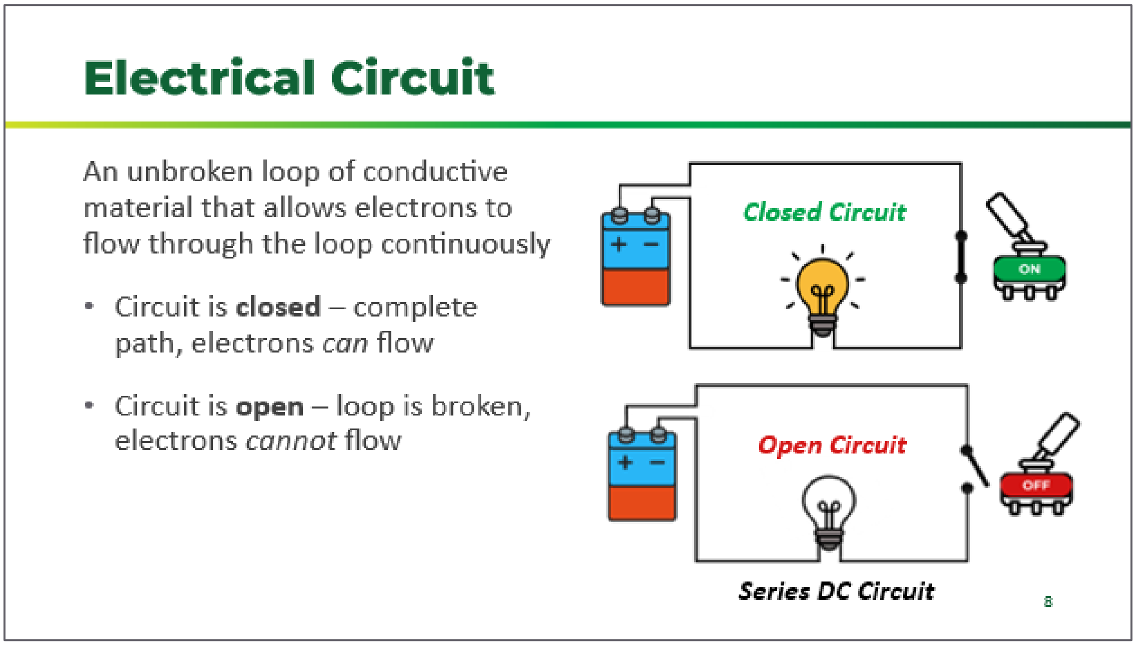

Notes:

- An **electrical circuit** is an unbroken loop of conductive material that allows electrons to flow through the loop continuously.
    - If the **circuit is closed**, there is a complete path meaning electrons *can* flow.
    - If the **circuit is open**, the loop is broken and the electrons cannot flow.
- Check out the images on the slide – they demonstrate the open and closed states.
- You will typically see this in systems powered by batteries, DC power supplies, or rectifiers.
- The voltage level in a DC circuit stays constant over time — unlike alternating current, where it changes direction periodically.
- In a closed circuit, current flows through the intended path — through the load, like the light bulb shown here.
- A **short circuit** can occur when current takes an unintended low-resistance path, bypassing the load or components in the circuit.
    - Instead of flowing *through* the bulb, it takes a shortcut around it.
- In DC circuits, a short circuit can cause a quick increase in current because there is little to slow it down. The sudden spike can cause overheating and fire hazards.
    - That's why protection devices like fuses and circuit breakers are critical in all electrical systems — they interrupt the circuit before damage occurs.
- Basically, any time the hot wire (positive) directly make contact with the neutral/ ground wire (negative) there is a short circuit.

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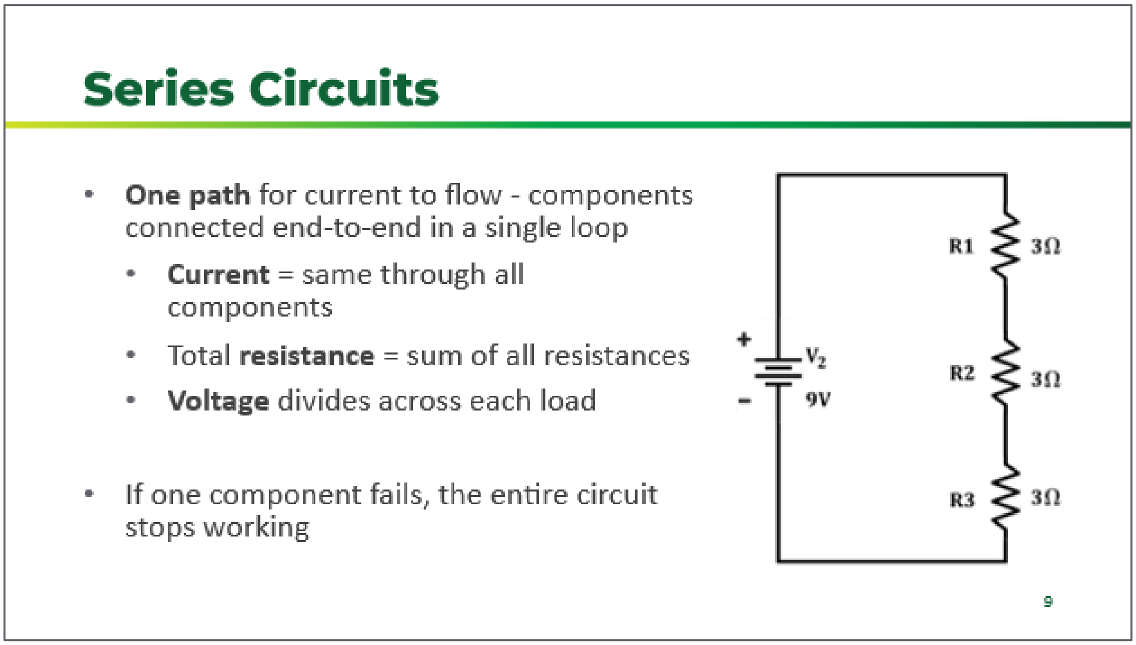
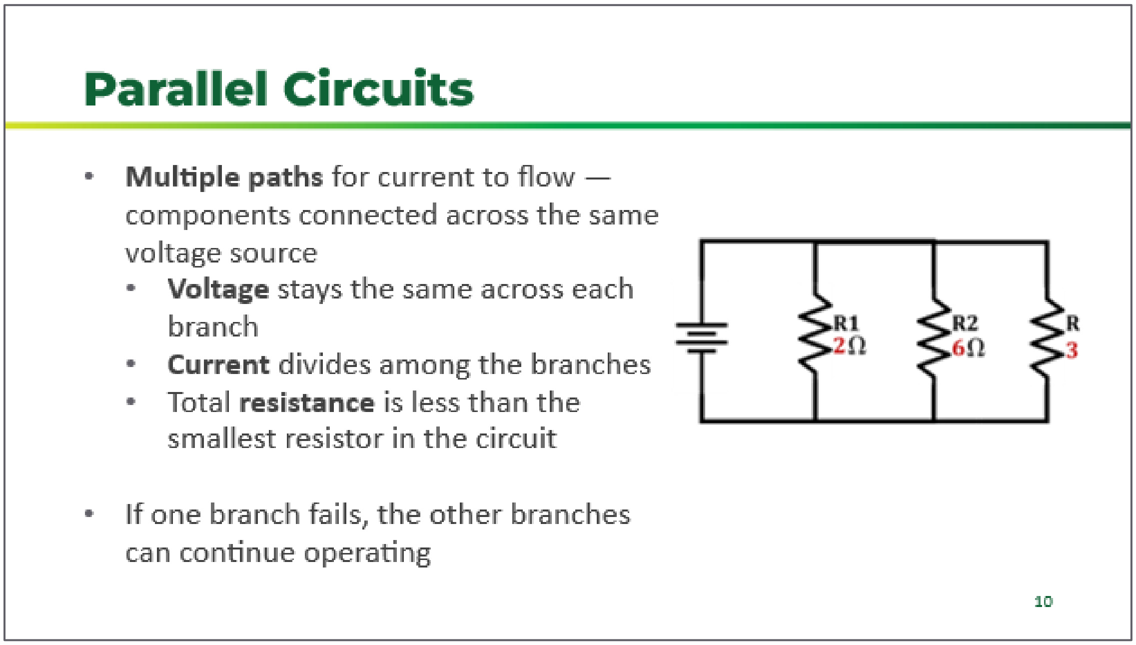


Notes:

- A **series circuit** has only **one path** for current to travel.
- All components are connected **end-to-end in a single loop**, so the same current flows through each component.
- In a series circuit:
  - Current remains <u>constant</u> throughout the circuit.
  - Total resistance is the <u>sum of all individual resistances</u>.
  - <u>Voltage divides across each load</u> based on its resistance.
- Because there is only one path, if one component opens or fails, the entire circuit stops working.



Notes:

- A **parallel circuit** has multiple paths for current to flow.
- Instead of being connected end-to-end in one loop, the components are connected across the same voltage source in separate branches.
- In a parallel circuit:
  - Voltage remains the same across each branch.
  - Current divides among the available paths.
  - Total resistance is always less than the smallest individual resistor in the circuit.
- The last point is important — adding branches actually *reduces* overall resistance.
- Because there are multiple paths, if one branch opens or a component fails, the other branches can continue operating. This is why parallel circuits are commonly used in lighting and vehicle electrical systems — one failed component doesn't shut everything down.

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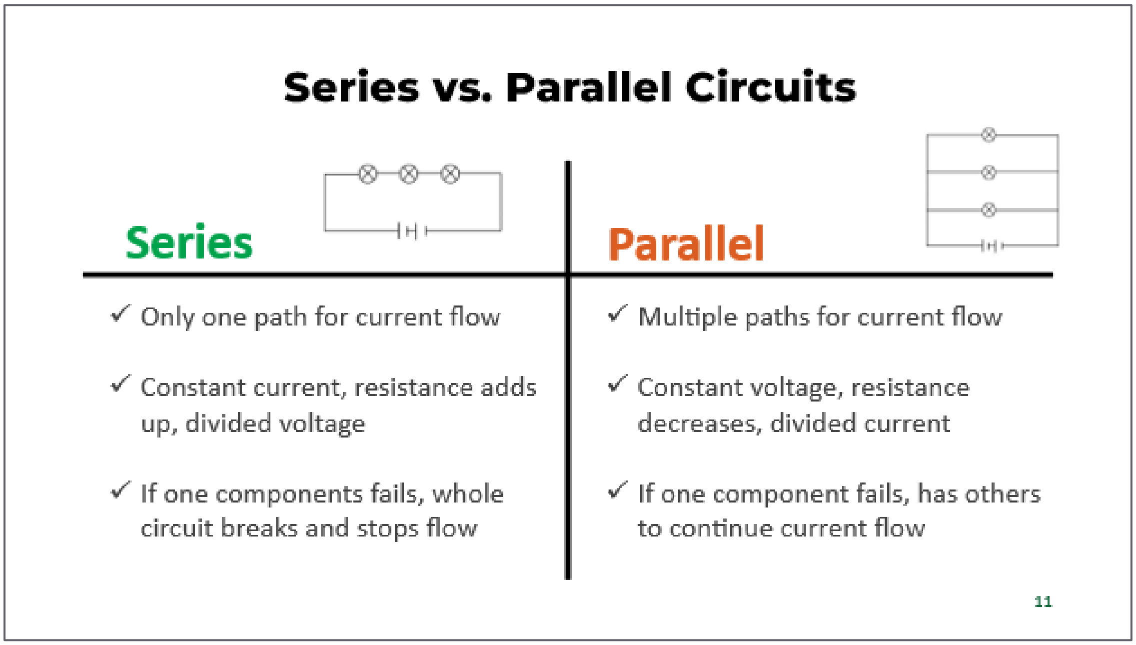

Notes:

- **Series**:
  - In a series circuit, there is only one path for current to flow, so the same current moves through every component in the circuit.
  - As you add more components, the total resistance increases and the voltage is shared across them- and if one component fails, the entire circuit opens and current stops everywhere.
- **Parallel**:
  - In a parallel circuit, there are multiple paths for current, which gives the current more than one way to flow through the system.
  - Each branch receives the same voltage, but the current divides between paths, and if one component fails, the rest of the circuit can continue to operate.

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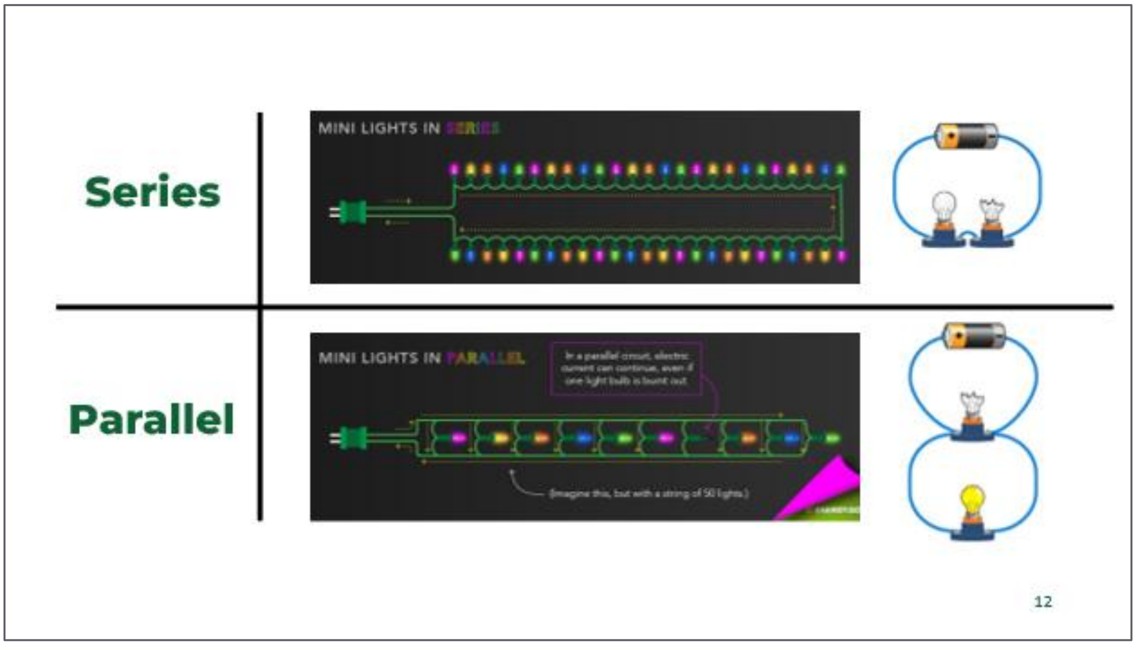

Notes:

- The slide shows a few visual examples of series and parallel circuits.
- On the top row, we have a series circuits. In the holiday light example, if one light goes out then all lights (loads) will go out.
- On the bottom row, we have parallel circuits. If one light goes out the others will remain lit.
- Modern holiday lights usually use a parallel circuit. This way, one light going out does not affect the rest of the string.
- Other instances, as with fire alarms, the use of series circuits is needed. This way if an alarm is triggered in one room of a school for instance, they all go off, giving people time to evacuate safely.

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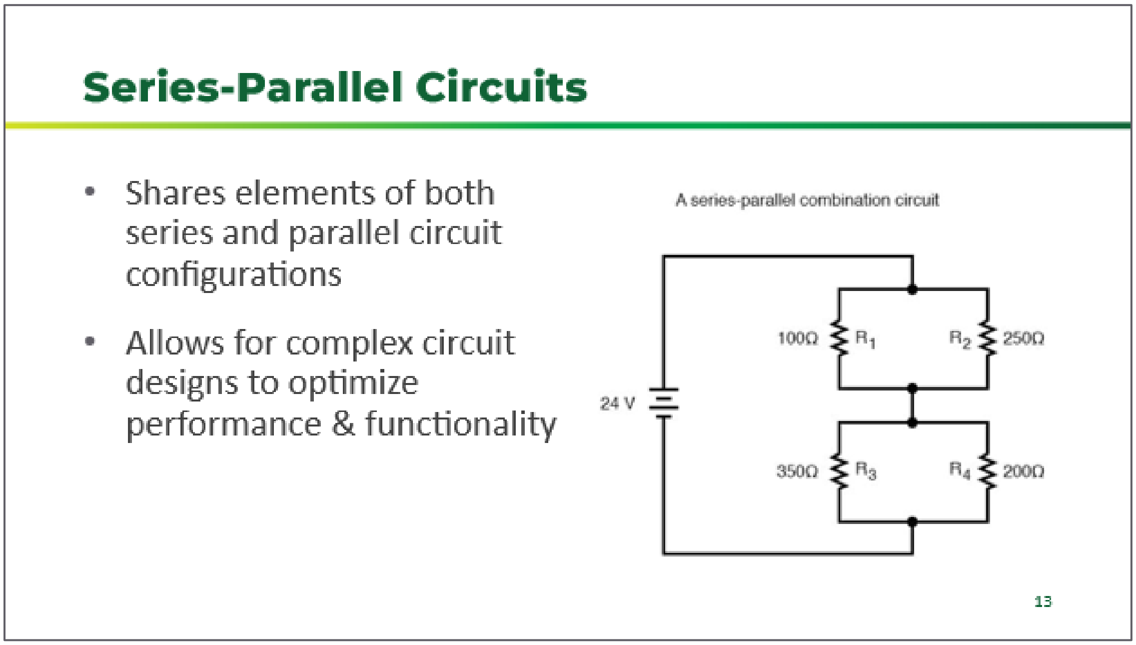
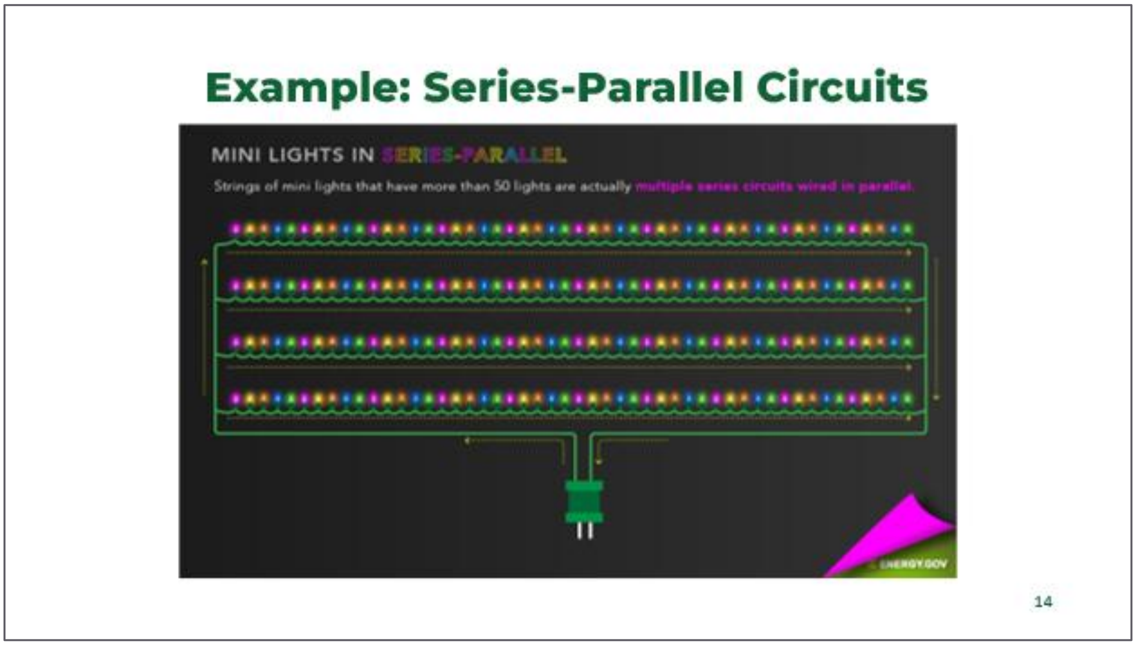


Notes:

- A **series-parallel circuit** is a combination of both series and parallel connections within the same circuit.
- Some components are arranged in a single path, while others have multiple pathways for current to flow.
- When examining a series-parallel circuit, it helps to look at one section at a time. Identify which portions act as a series circuit, and which parts act like parallel circuits. Then apply the same rules.
- If a component fails, it depends on where the failure occurred.
- A failure in a series section can stop current to all components downstream. However, a failure in a parallel branch may only affect that path; the rest of the circuit may continue to allow current to flow.



Notes:

- The slide shows a real-world example of a **series-parallel circuit** using holiday or mini lights.
- Each individual section of lights is wired **in series** — meaning within that small section, current flows through each bulb one after another.
- Then, those series sections are connected **in parallel** to each other.
- So, what does that mean functionally?
    - Within each small section (series), **voltage** is divided across the bulbs.
    - Across the larger branches (parallel), each section receives the same source **voltage**.
    - **Current** divides between the parallel branches.
- This design balances efficiency and reliability. If one entire series section fails, the other parallel branches can still operate.
- However, within a single series section, if one bulb opens (depending on the design) it may affect that entire section.

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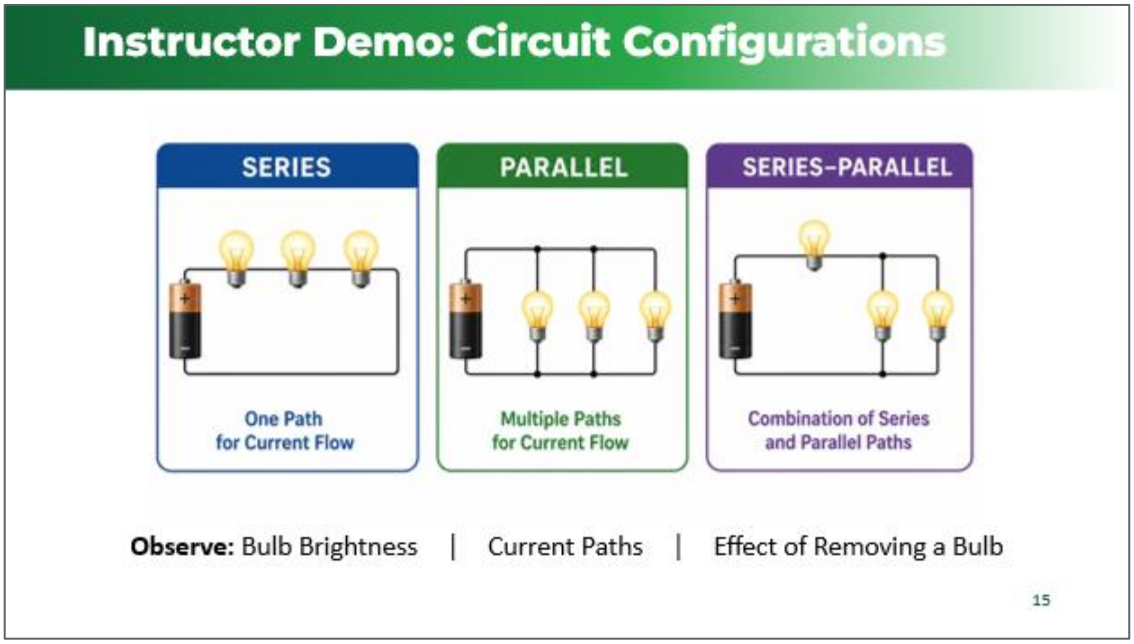

Notes:

- Watch your instructor demonstrate how to configuration each of the type of circuits.
- Series Circuit
  - What do you think will happen when power is applied?
  - What happens if one bulb is removed?
  - Remember: **In a series circuit, current has only one path. If any component opens, the entire circuit stops working.**
- Parallel Circuit
  - How do you think this circuit will behave differently?
  - What happens when one bulb is removed?
  - Remember**: Parallel circuits provide multiple current paths. A failure in one branch does not stop current flow through the others.**
- Series-Parallel
  - Would you classify this circuit as series or parallel?
  - What do you think happens when one bulb is removed?
  - Remember: **Series-parallel circuits combine characteristics of both circuit types. The effect of a failure depends on where the component is located within the circuit.**
- Now after the full demonstration, discuss with your instructor the following debrief questions:

- Which circuit provided only one path for current flow?
- Which circuit continued operating after a bulb was removed?
- Why are parallel circuits commonly used in electrical systems?
- How might these circuit configurations appear in transit vehicles and facilities?

Finally, one key takeaway:
Series circuits have one path, parallel circuits have multiple paths, and series-parallel circuits combine both. Understanding these configurations helps technicians troubleshoot electrical systems more effectively.

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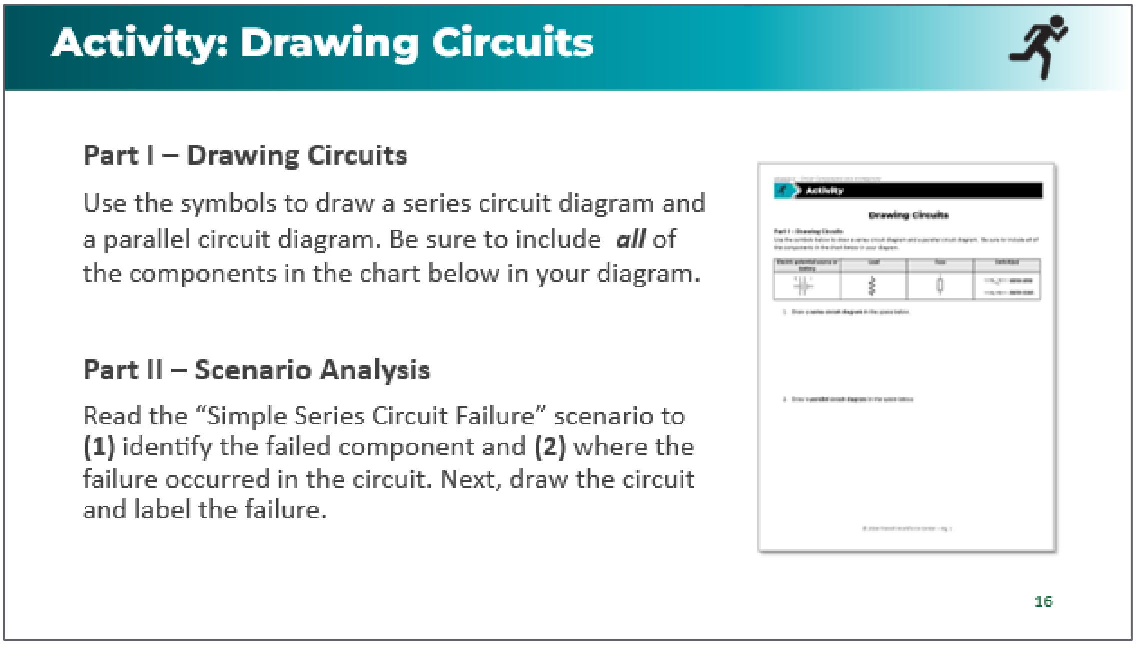
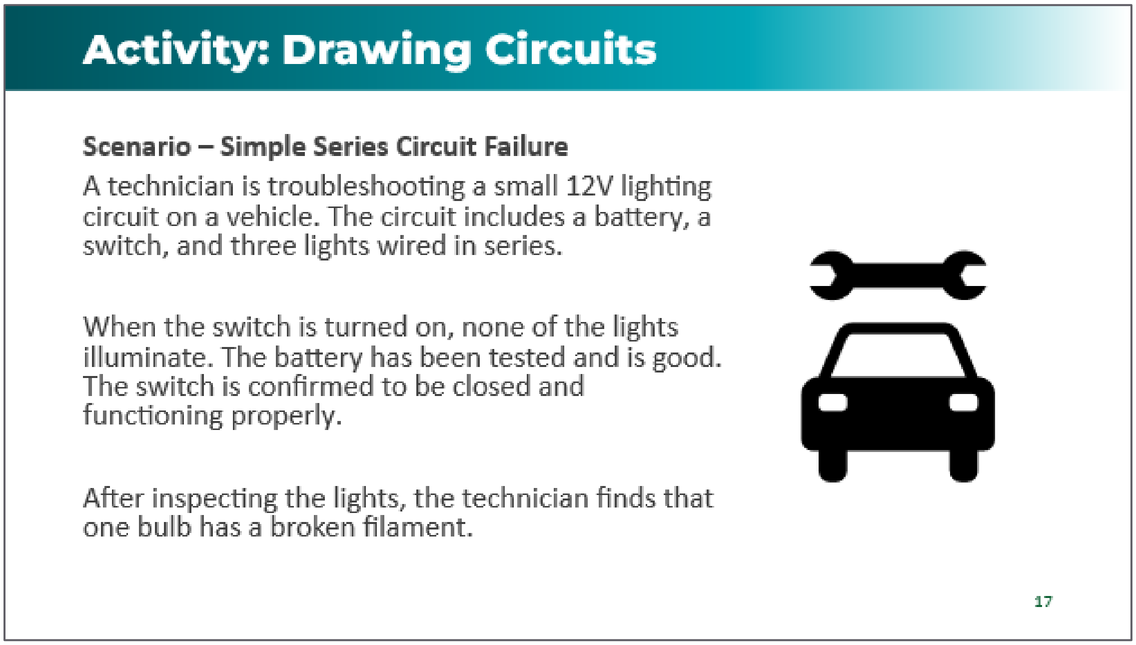

Activity: Drawing Circuits
Part I – Drawing Circuits
Use the symbols to draw a series circuit diagram and a parallel circuit diagram. Be sure to include ***all*** of the components in the chart below in your diagram.
Part II – Scenario Analysis
Read the "Simple Series Circuit Failure" scenario to **(1)** identify the failed component and **(2)** where the failure occurred in the circuit. Next, draw the circuit and label the failure.
Activity
Drawing Circuits
16



Notes:

Helpful information:

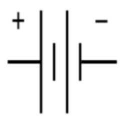
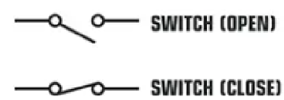
- Series circuits are useful in alarm circuits because any break or open in the circuit stops current flow and triggers an alarm condition. In these systems, the loss of power or current is what signals the problem.
- Parallel circuits are useful when multiple devices need to operate from one power source. Because current has multiple paths to flow, one device can fail while the others continue operating. This is common in house wiring and other systems where you do not want one failed load to shut down the entire circuit.
- Series-parallel circuits combine features of both series and parallel circuits. These are very common in bus, shop, and signal systems because they allow electrical systems to be designed for different operating needs.

Activity

Drawing Circuits

Part I – Drawing Circuits

Use the symbols below to draw a series circuit diagram and a parallel circuit diagram. Be sure to include all of the components in the chart below in your diagram.

Electric potential source or battery	Load	Fuse	Switch(es)
			

1. Draw a **series circuit diagram** in the space below.

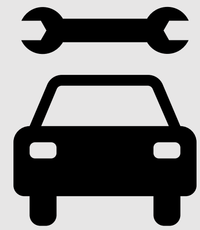
2. Draw a **parallel circuit diagram** in the space below.

Part II – Scenario Analysis

Read the "Simple Series Circuit Failure" scenario to **(1)** identify the failed component and **(2)** where the failure occurred in the circuit. Next, draw the circuit and label the failure.

Simple Series Circuit Failure

A technician is troubleshooting a small 12V lighting circuit on a vehicle. The circuit includes a battery, a switch, and three lights wired in series.



When the switch is turned on, none of the lights illuminate. The battery has been tested and is good. The switch is confirmed to be closed and functioning properly.

After inspecting the lights, the technician finds that one bulb has a broken filament.

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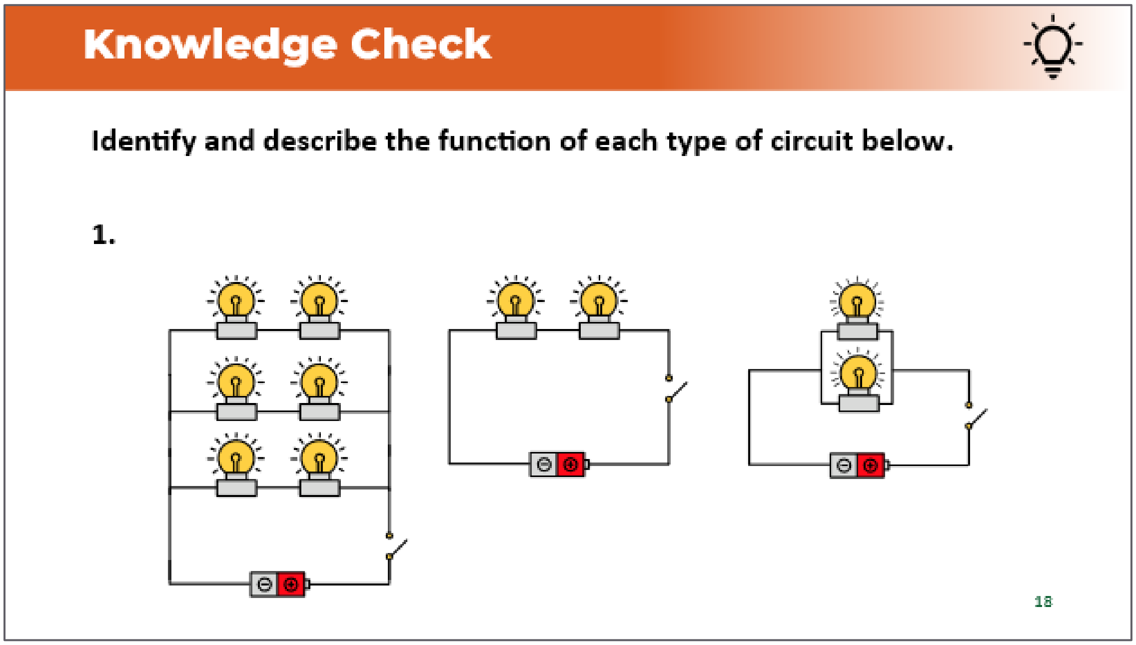

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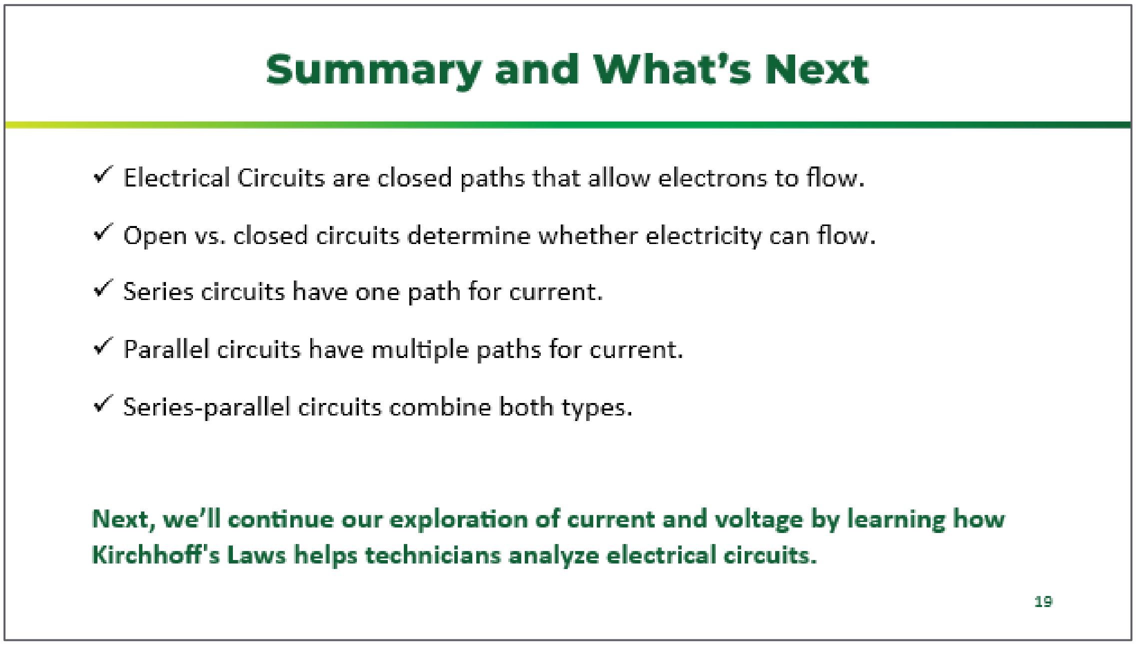
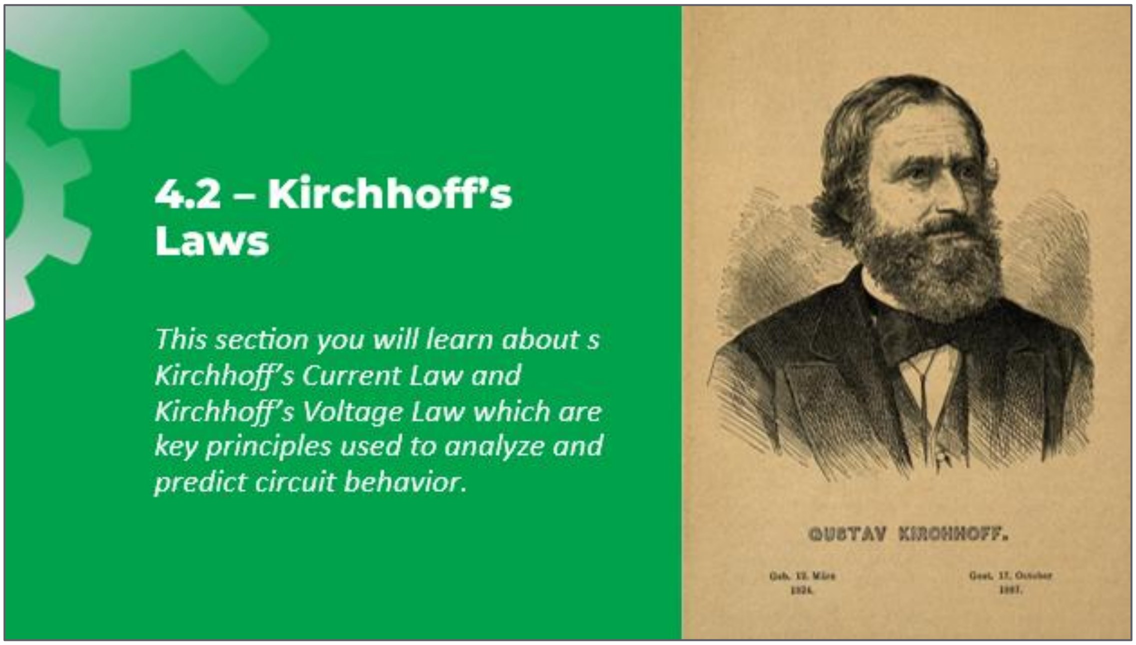
- Series-parallel circuits combine features of both series and parallel circuits. These are very common in bus, shop, and signal systems because they allow electrical systems to be designed for different operating needs.



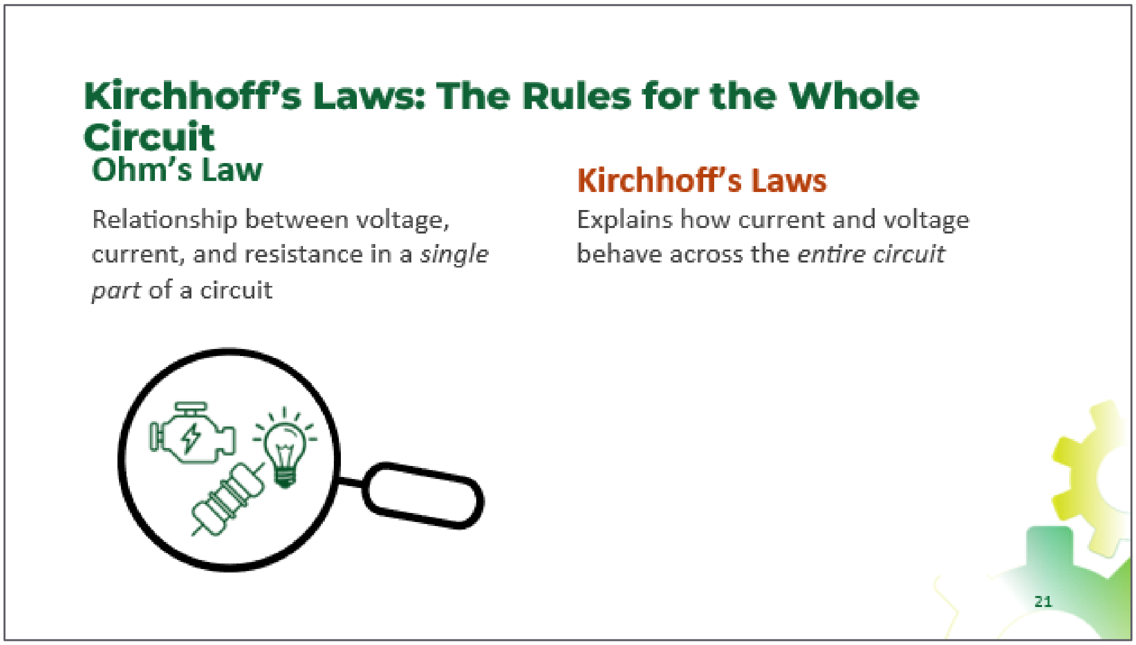
Notes:

- An electrical circuit is a **closed path** that allows electrons to flow.
- Whether a circuit is **open or closed** determines if current can move through the system.
- We discussed how **series circuits** have only one path for current — meaning one break stops everything.
- We also covered **parallel circuits**, which provide multiple paths — so one branch can fail without shutting down the entire system.
- And finally, we looked at **series-parallel circuits**, which combine both configurations. These are common in real-world systems, especially in transportation and facility electrical systems.
- Before we move on…
  - In a series circuit, what happens if one component fails?
  - In a parallel circuit, what electrical value stays the same across each branch?
- **The key takeaway**: Understanding circuit architecture helps you predict how a system will behave — and how it will fail.
- **Next , we'll continue our exploration of current and voltage by discussing Kirchoff's Laws. Then, we'll review the components that move, control, and power a circuit.**



Notes:

- This section you will learn about Kirchhoff's Current Law and Kirchhoff's Voltage Law which are key principles used to analyze and predict circuit behavior.



Notes:

- You've learned that **Ohm's Law** explains the relationship between voltage, current, and resistance in a *single* part of a circuit.
- Think of Ohm's Law *like zooming in* with a magnifying glass. We're looking at **one** resistor, one light, one motor, etc.
- **Kirchhoff's Laws** *zoom back out*. They explain how current and voltage behave across the **entire circuit** — how everything connects and stays balanced.
- Without Kirchhoff's Laws, we can't analyze complex circuits, especially series-parallel systems.
- So now it's shifting from component-level thinking to system-level thinking.

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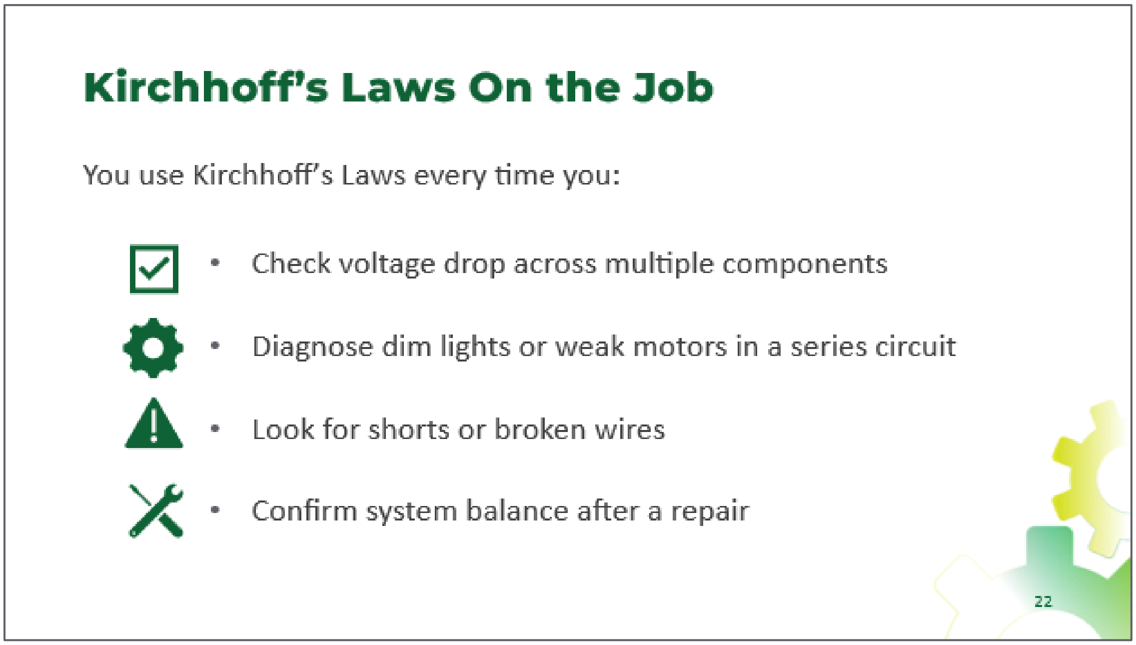
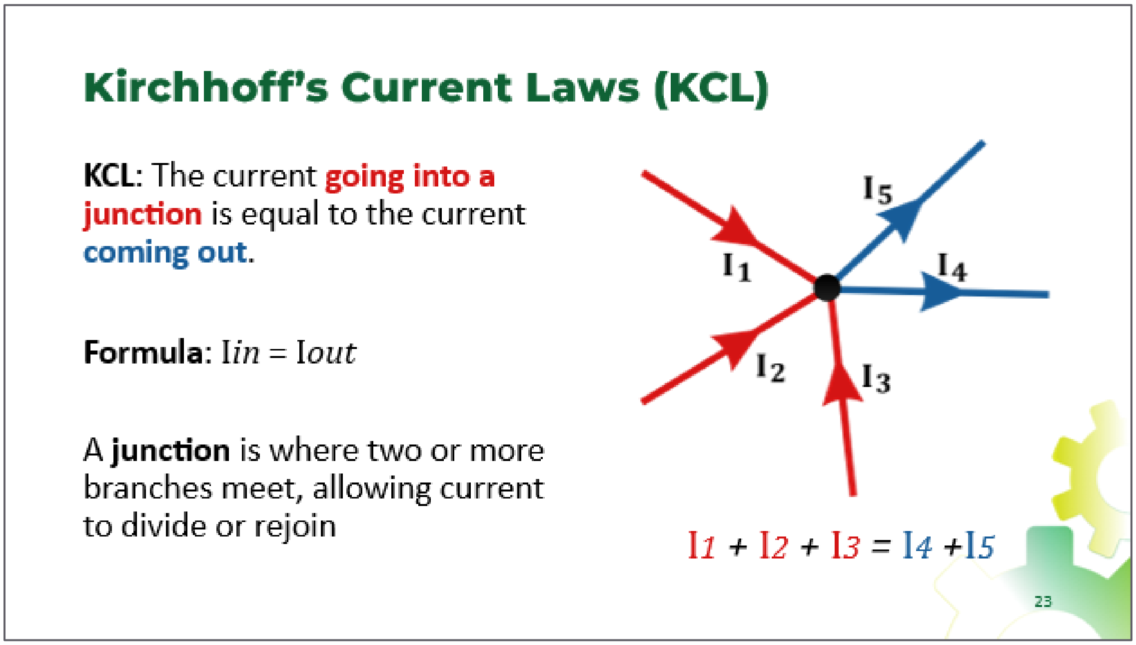


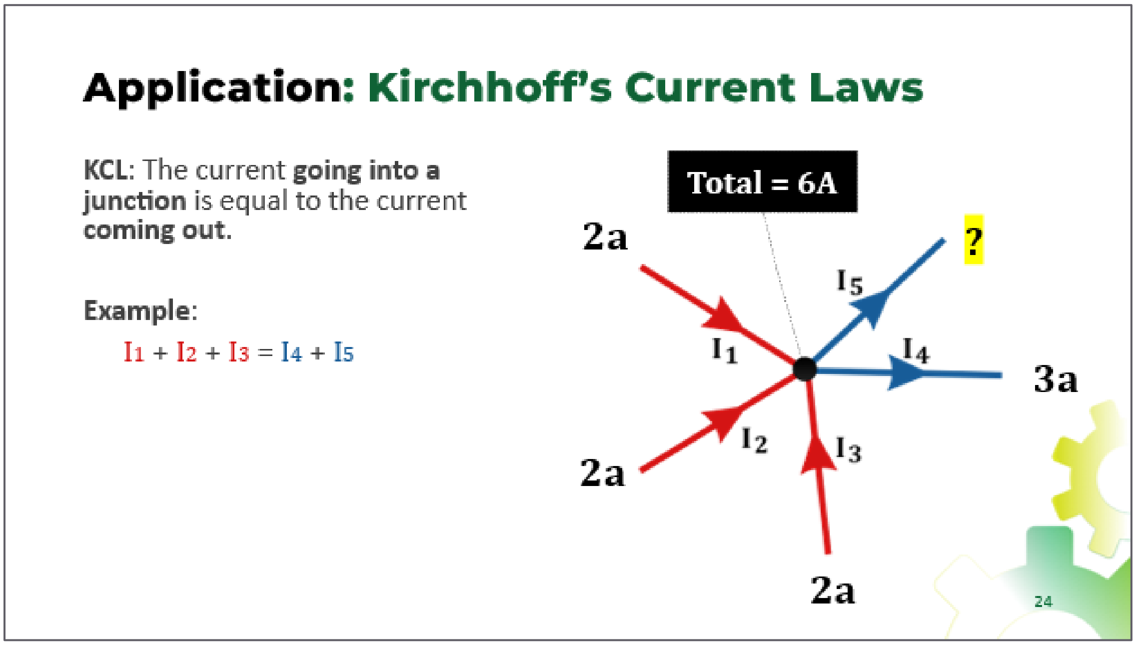
Notes:

- Kirchhoff's Laws are important because it isn't just theory. This is exactly what you do when you troubleshoot.
- You use Kirchhoff's Laws any time you:
    - Check voltage drop across multiple components
    - Diagnose dim lights or weak motors in a series circuit
    - Look for shorts or open connections
    - Confirm the system is balanced after a repair
- You might not call it "Kirchhoff's Law" at work — but when you expect voltage to add up or current to split correctly, that's Kirchhoff.
- If voltage or current doesn't balance, something is open, shorted, loose, or corroded. That imbalance is your diagnostic clue.



Notes:

- Kirchhoff's Laws help us understand how current and voltage behave in electrical circuits, especially when things get more complex with multiple branches or loops.
- **Kirchhoff's Current Law**, referred to as **KCL** for short, states that the current going into a **node** (or **junction**) is equal to the current coming out.
  - In other words, current flowing *into* the circuit is equal to the current flowing *out of* the circuit.
- A **junction** is a point in an electrical circuit where two or more conductors or branches meet, allowing current to split into different paths or combine back together.
  - Think of it like traffic at an intersection- what goes in must come out.
- All the current flowing into that junction point must flow out through the available paths.
  - Current doesn't pile up or disappear at a junction; it splits up depending on the load and circuit design.
- That junction is also where different paths can lead into separate loops, and each of those loops still follows Kirchhoff's Voltage Law.
- Even though the current divides at the junction, the voltage remains constant at these junctions. Circuits design may also be a factor.



Notes:

- Remember, KCL tells us that the total current entering a junction equals the total current leaving. What goes in must come out!
- This is especially helpful when analyzing complex circuits—instead of trying to follow every path, you can focus on the junction and use KCL to find missing values.
- For example, if you have five wires meeting at a node and you know the current in four of them, you can calculate the fifth by making sure the total in equals the total out.
- Take a look at the example on the slide:
  - We know that the junction is **6A**.
  - That means the current **coming in** (red arrows) equals **6A.**
- According to KCL, the current **coming out** (blue arrows) also needs to equal **6A.** So, if I4 is 3A, what does I5 equal?
- We know this is correct because we have 6A coming in and 6A going out. Think of it like balancing the flow of traffic at an intersection.

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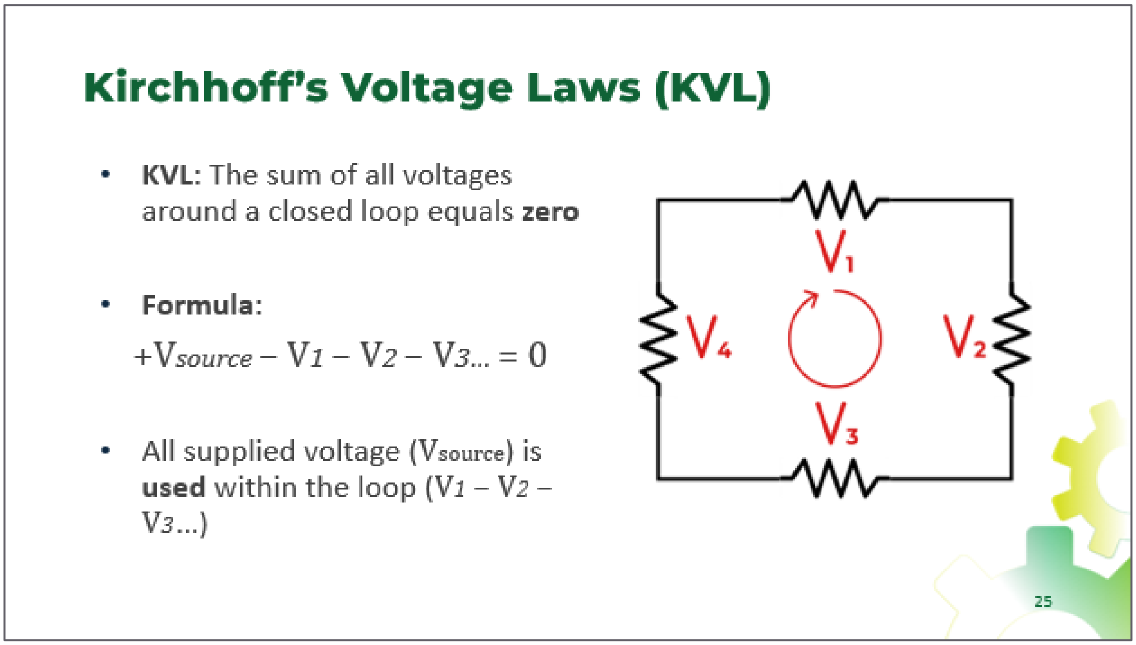
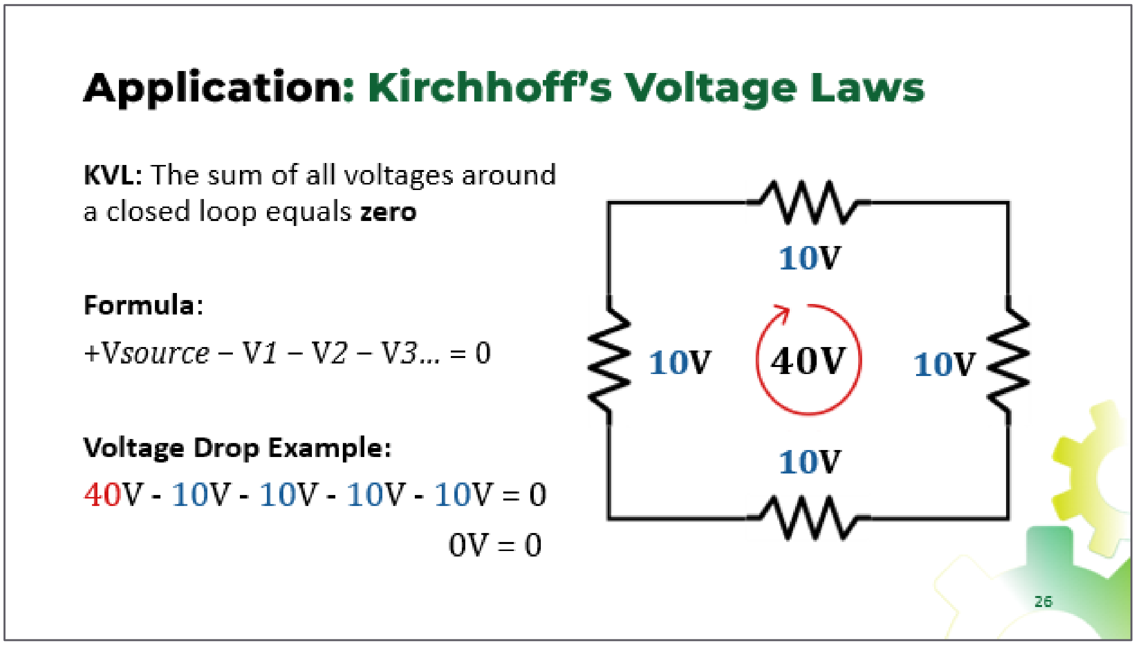


Notes:

- **Kirchhoff's Voltage Law**, referred to as KVL, states that the sum of all voltages around a closed loop equals **zero**. What that means practically is this:
  - Any voltage supplied by the source must be completely accounted for within the loop.
  - As current moves through the circuit, each component uses some voltage.
  - By the time you return to the source, all the voltage has been "used" or dropped across the components.
- You can think of this like an energy accounting system. Whatever energy the source provides must be fully spent across the resistors, lights, motors, or other loads in that loop.
- If the numbers don't add up, something is wrong. It could be a bad connection, incorrect measurement, or a hidden fault.
- Kirchhoff's Laws, both Voltage and Current, are foundational tools for analyzing and troubleshooting circuits, especially those with multiple loops or branches.
- Once you understand the logic, they become powerful diagnostic tools in real-world systems. **Additional Video**: https://www.youtube.com/watch?v=ZDoyIghUI44



Notes:

- Again, Kirchhoff's Voltage Law tells us that the sum of all voltages around a closed loop must equal **zero**.
- This principle is used to find unknown voltages in a circuit by making sure that all the voltage supplied is completely used up by the components in the loop—nothing extra, nothing missing.
- For example, if you have a loop with one voltage source and several resistors, KVL allows you to calculate the voltage drop across each resistor. It's like making sure every dollar you spend adds up exactly to the amount of money you had at the start.
- In any circuit, a **voltage drop across a component** represents the amount of voltage that component uses. (Remember voltage drops are considered negative voltage)
- According to Kirchhoff's Voltage Law, the sum of all voltage drops in a closed loop must equal the source voltage — so when we add them algebraically around the loop, the total equals zero.
- In this example, we have a 40-volt source and four resistors of equal resistance connected in series.
    - Because the resistors are equal, the voltage divides evenly across them.
- If 40 volts is supplied to the circuit and there are four equal resistors, how much voltage will each resistor drop?

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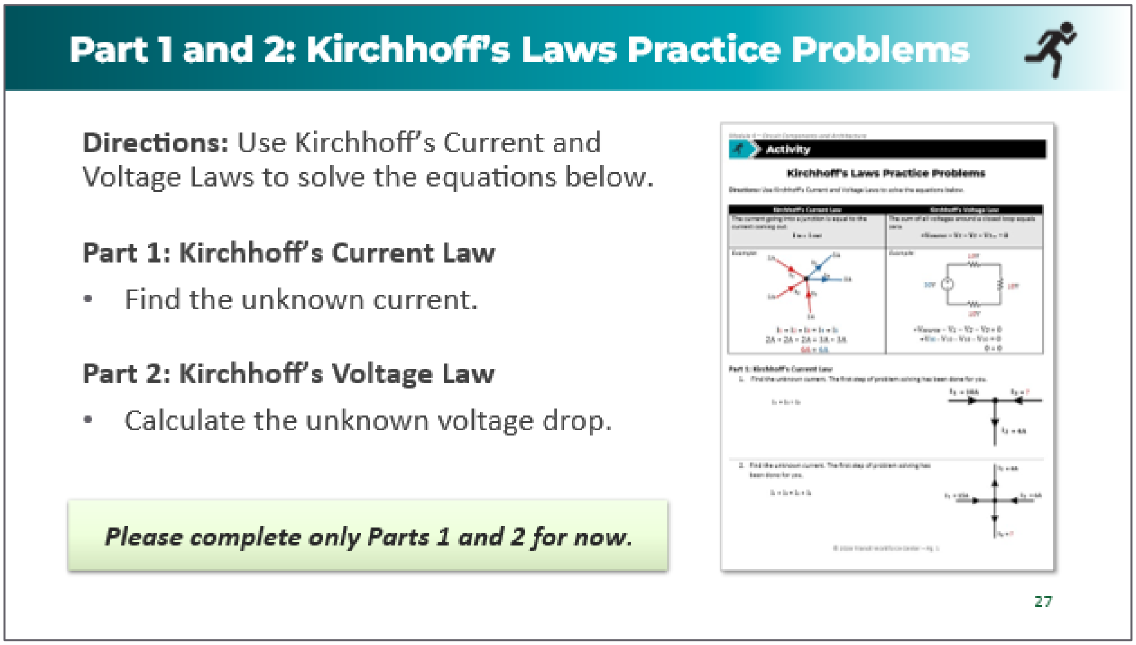
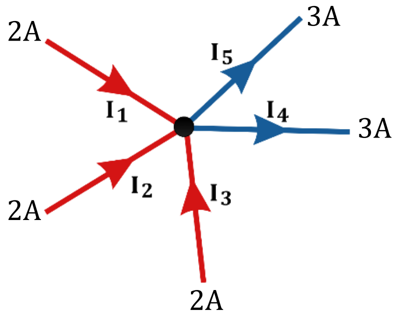
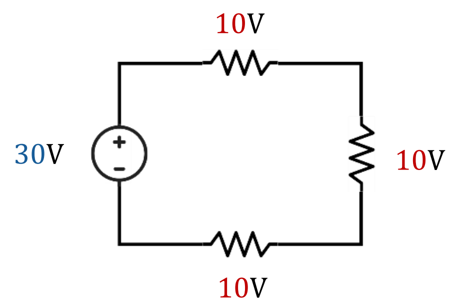

Part 1 and 2: Kirchhoff's Laws Practice Problems
Directions: Use Kirchhoff's Current and Voltage Laws to solve the equations below.
Part 1: Kirchhoff's Current Law
• Find the unknown current.
Part 2: Kirchhoff's Voltage Law
• Calculate the unknown voltage drop.
Please complete only Parts 1 and 2 for now.
Activity
Kirchhoff's Laws Practice Problems
27

Activity

Kirchhoff's Laws Practice Problems

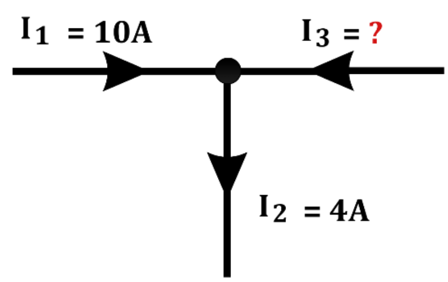
Directions: Use Kirchhoff's Current and Voltage Laws to solve the equations below.

Kirchhoff's Current Law	Kirchhoff's Voltage Law
The current going into a junction is equal to the current coming out. $I_{in} = I_{out}$	The sum of all voltages around a closed loop equals zero. $+V_{source} - V_1 - V_2 - V_3 ... = 0$
Example:  $I_1 + I_2 + I_3 = I_4 + I_5$ $2A + 2A + 2A = 3A + 3A$ $6A = 6A$	*Example:*  $+V_{source} - V_1 - V_2 - V_3 = 0$ $+V_{30} - V_{10} - V_{10} - V_{10} = 0$ $0 = 0$

Part 1: Kirchhoff's Current Law

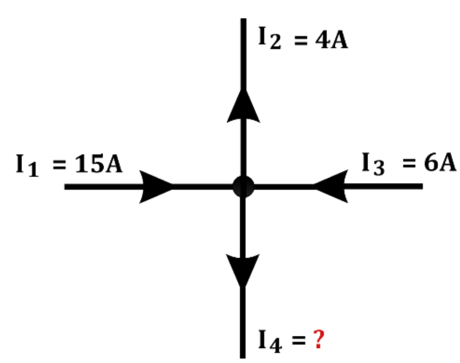
1. Find the unknown current. The first step of problem solving has been done for you.

$I_1 + I_3 = I_2$

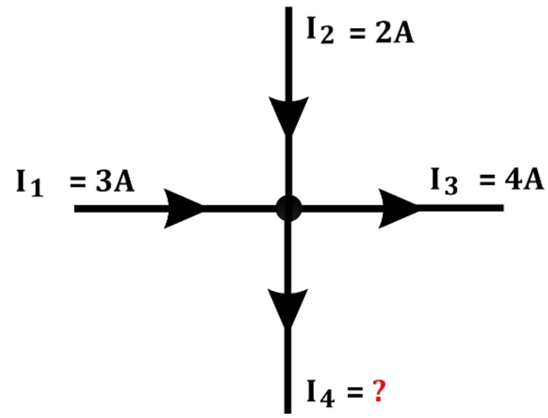


2. Find the unknown current. The first step of problem solving has been done for you.

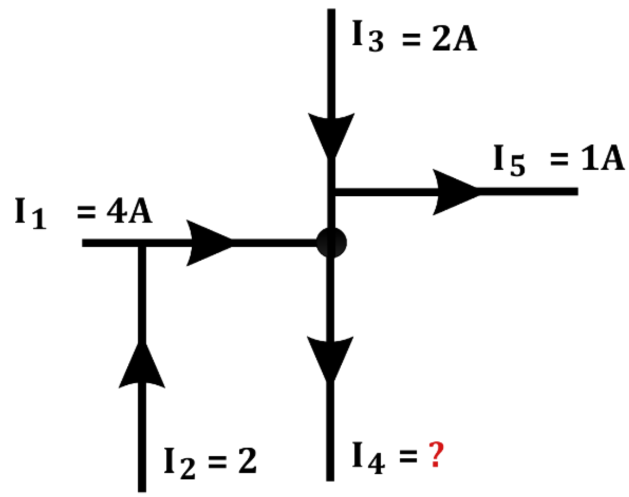
$I_1 + I_3 = I_2 + I_4$



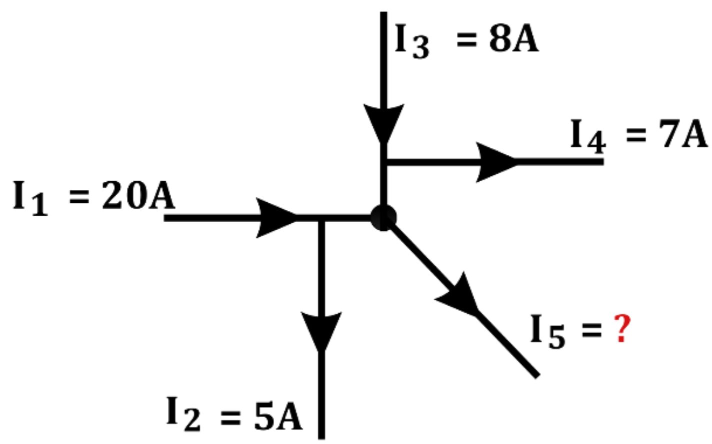
3. Find the unknown current.



4. Find the unknown current.

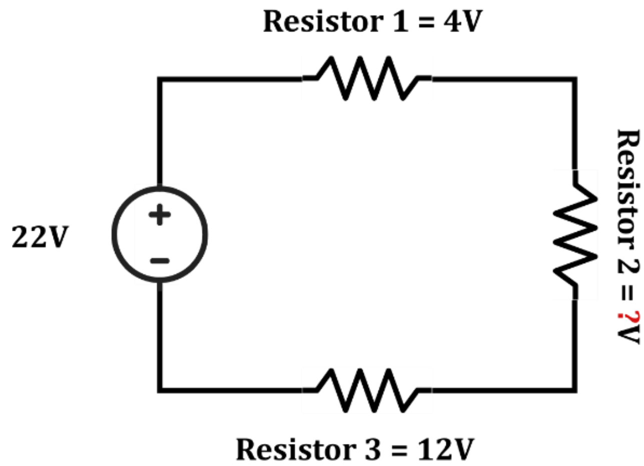


5. Find the unknown current.



Part 2: Kirchhoff's Voltage Law

6. Calculate the unknown **voltage drop** across Resistor 2.



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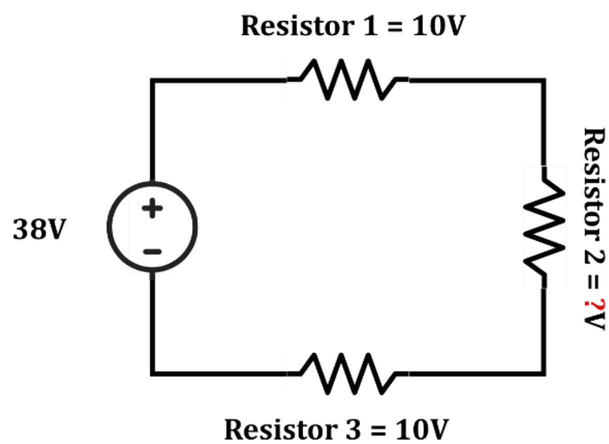
7. Calculate the unknown **voltage drop** across Resistor 2.



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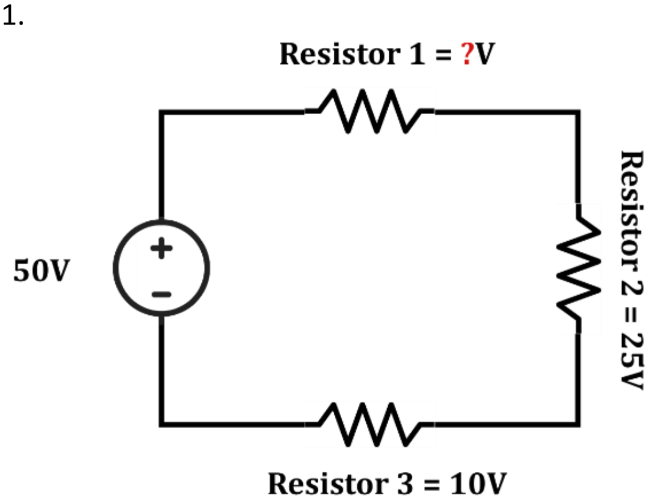
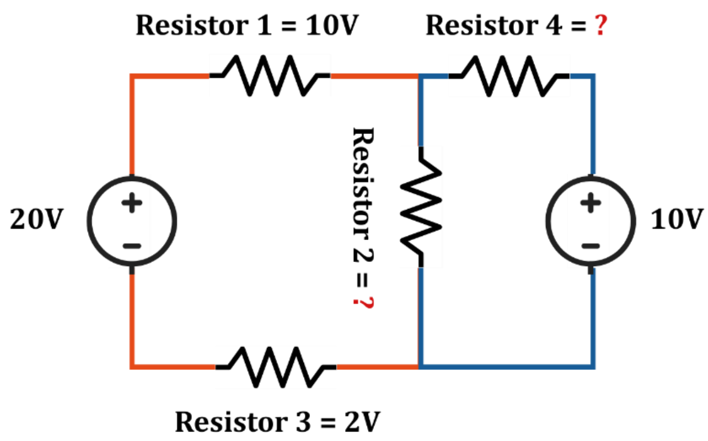
8. Calculate the unknown **voltage drop** across Resistor 1.



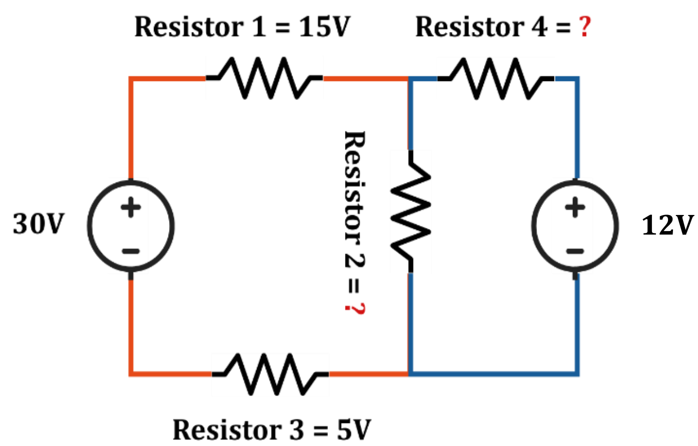
9. Calculate the unknown **voltage drop** across Resistor 2 and 4. First, calculate the voltage drop in the **orange** circuit. Next, solve the voltage drop in the **blue** circuit. The first step in the equation has been done for you.

+Vsource − V1 − V2 − V3 = 0



10. Calculate the unknown **voltage drop** across Resistor 2 and 4. First, calculate the voltage drop in the **orange** circuit. Next, solve the voltage drop in the **blue** circuit. The first step in the equation has been done for you.

+Vsource − V1 − V2 − V3 = 0



Part 3: Write Your Own Equations

- Using the diagrams below, write two practice problems using Kirchhoff's Current Law and two practice problems using Kirchhoff's Voltage Law.
- Give your paper to a partner and have them solve your equations.
- Get your paper back from your partner and check their work.

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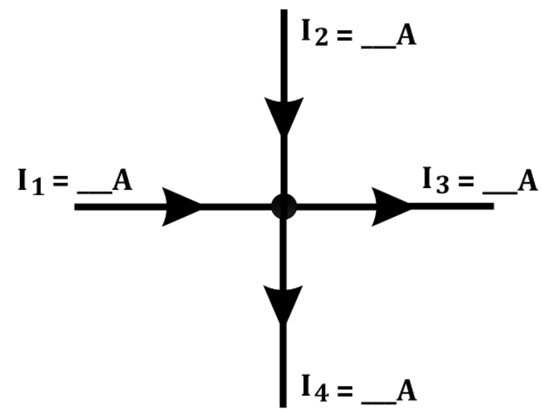
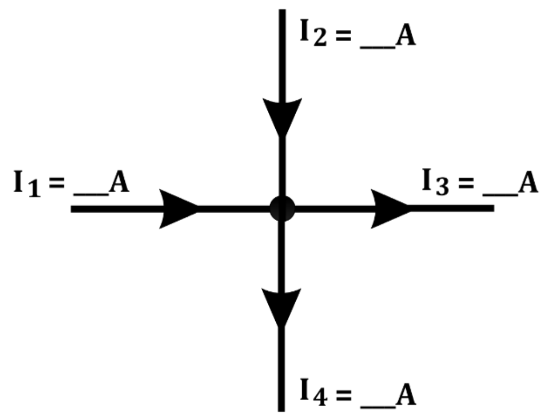
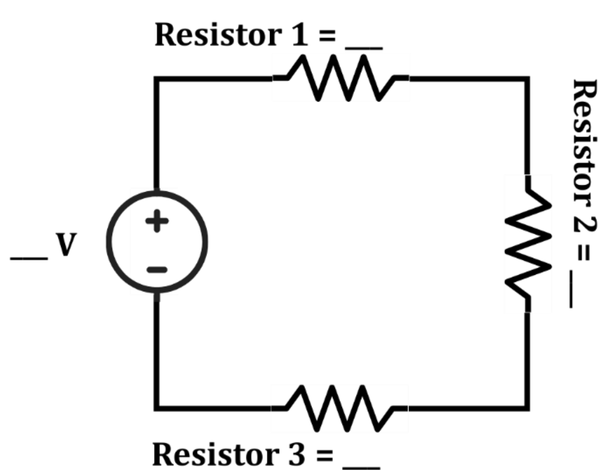
11. **KCL** Practice Problem - Find the **unknown current**.



12.**KCL** Practice Problem - Find the .



13.**KVL** Practice Problem - Calculate the unknown **voltage drop.**



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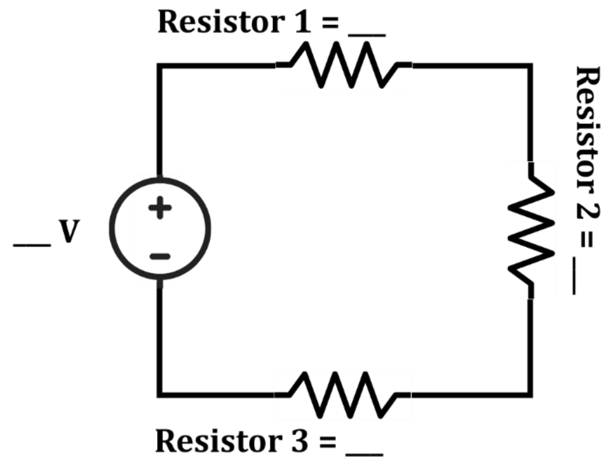
14. **KVL** Practice Problem - Calculate the unknown **voltage drop.**

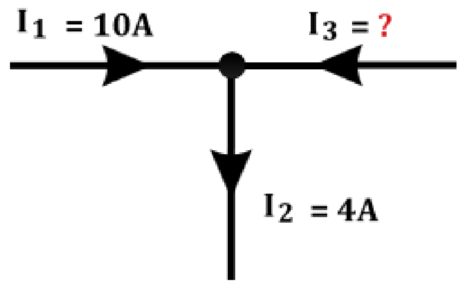


Question 1

1. Find the unknown current. The first step of problem solving has been done for you.

Solution:

$I_1 + I_3 = I_2$



Check:

$I_1 + I_3 = I_2$

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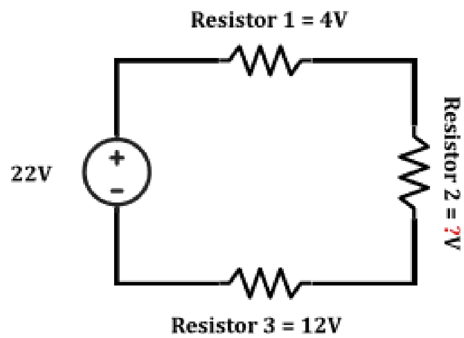
Question 6

6. Calculate the unknown **voltage drop** across Resistor 2.



Solution:

+Vsource – V1 – V2 – V3 = 0

Check:

+Vsource – V1 – V2 – V3 = 0

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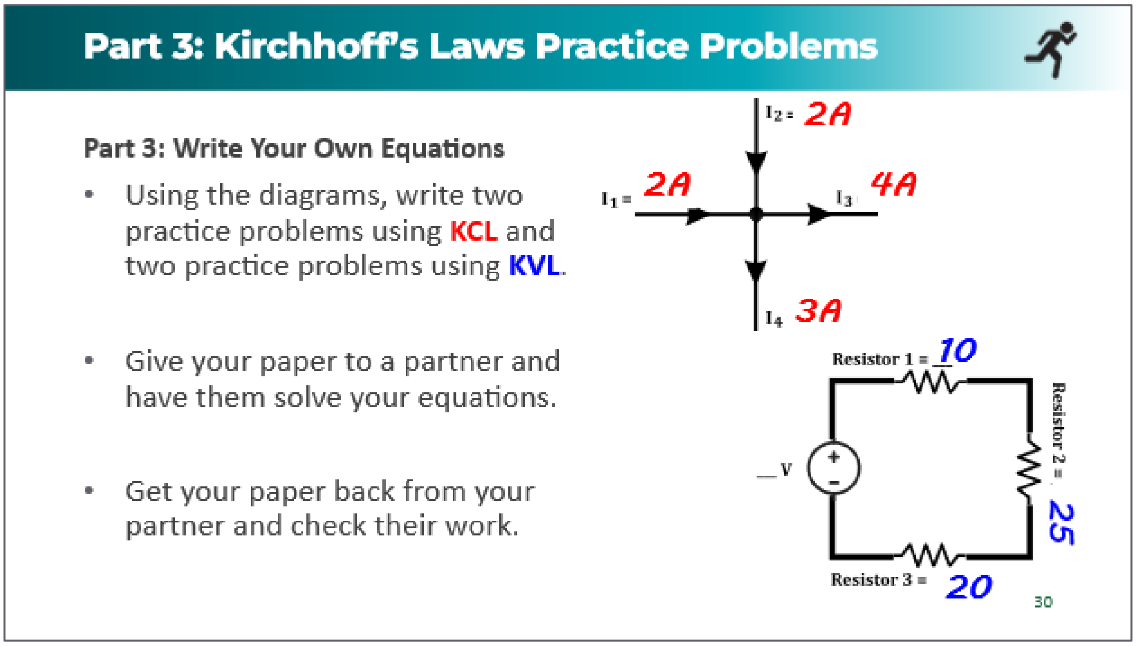

Notes:

- Use the following questions to debrief:
  1. *Were you able to solve your partner's problems? If not, where did you make an error?*
  2. *What was the easiest part of this activity? What was the most challenging?*

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Knowledge Check

According to Kirchhoff's Current Law, ____________________.

A. The current going into a junction is equal to the current coming out.

B. Voltage across a component equals the current flowing through it multiplied by its resistance.

C. The sum of all voltages around a closed loop equals zero.

D. The current will be removed from the circuit.

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Knowledge Check

According to Kirchhoff's Voltage Law, the sum of all voltages around a closed loop in a circuit must be ____________.

A. Equal to the highest voltage in the loop

B. Greater than the battery voltage

C. Less than the sum of voltage drops

D. Equal to zero

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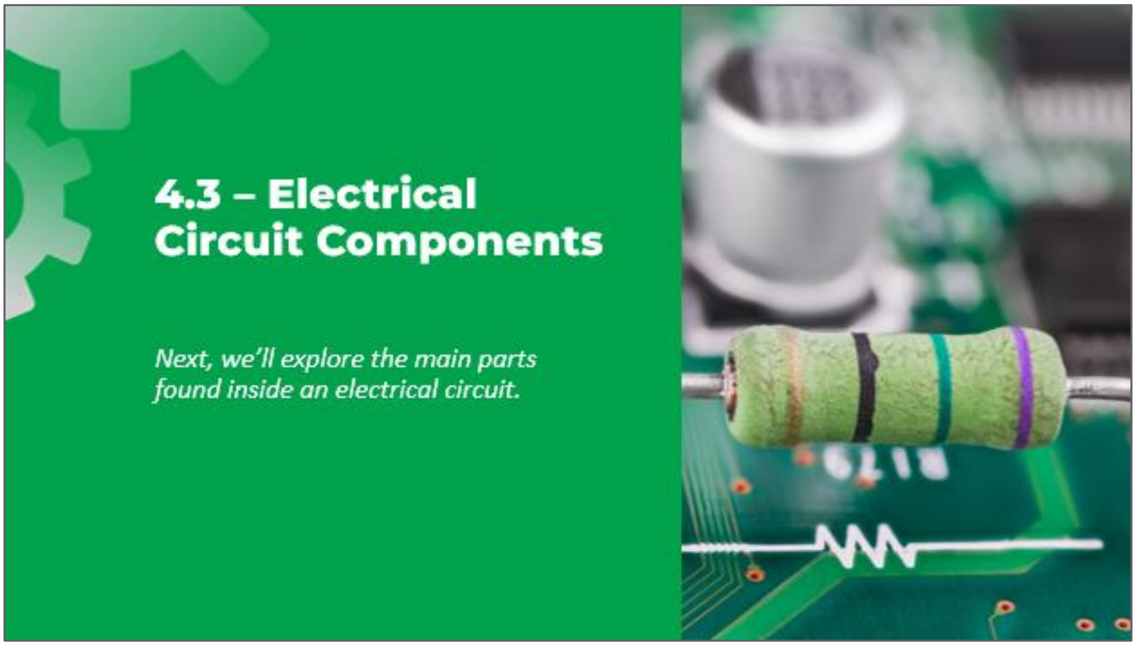

Notes:

- Next, we'll explore the main parts found inside an electrical circuit.

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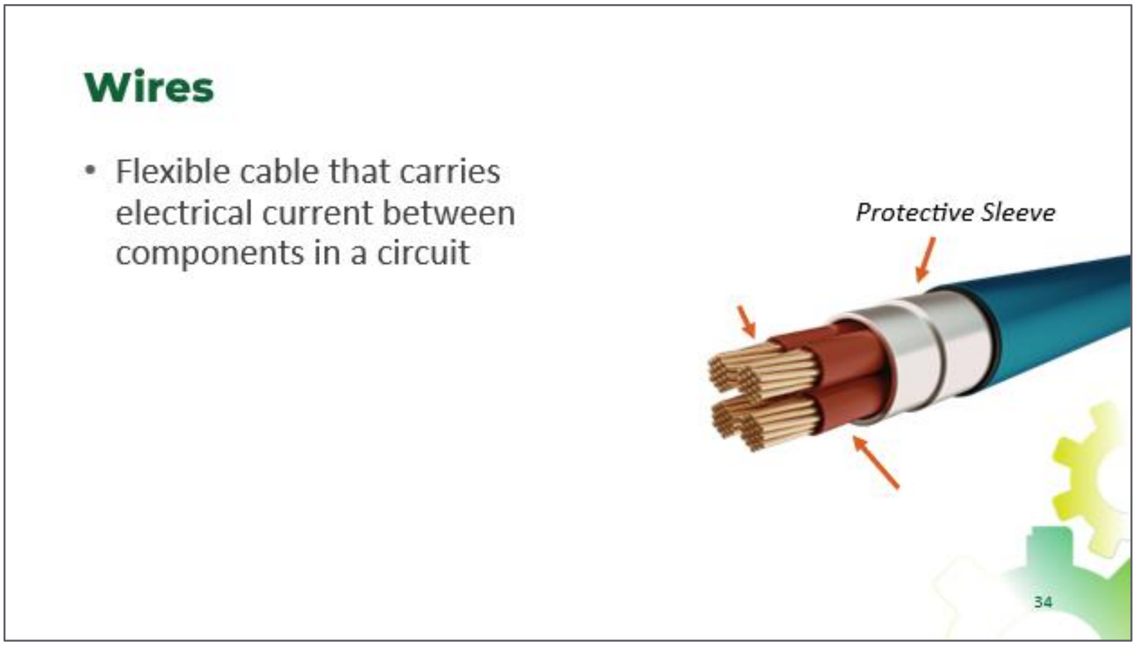
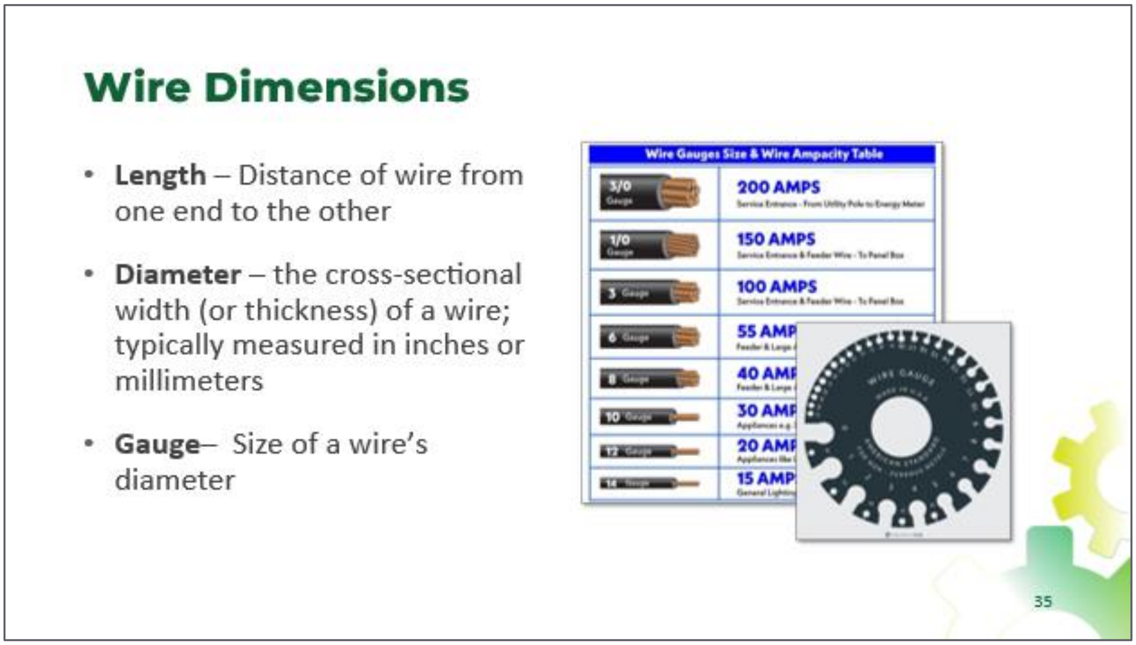


Notes:

- When we talk about wires, we need to discuss two terms we learned about in previous modules: **conductor** and **insulator**.
- A **wire** is a flexible cable that serves as the pathway to carry an electrical current and allows flow between components in a circuit.
- If you look at the image on the slide, it shows a common cable breakdown of several parts of an individual strand of wire.
- Wires can either act as either:
    - a **conductor** which allows electricity flow easily like metals like copper, aluminum, steel, and high-strength alloys.
    - or **insulator** which resists or blocks flow of electricity like rubber or plastic.
- If conductors carrying electrical current were not insulated and came into contact with the ground, the electricity would take an unintended path straight to the ground.
- This is because electricity always looks for the easiest path to return to its source, and the ground often provides a low-resistance route.

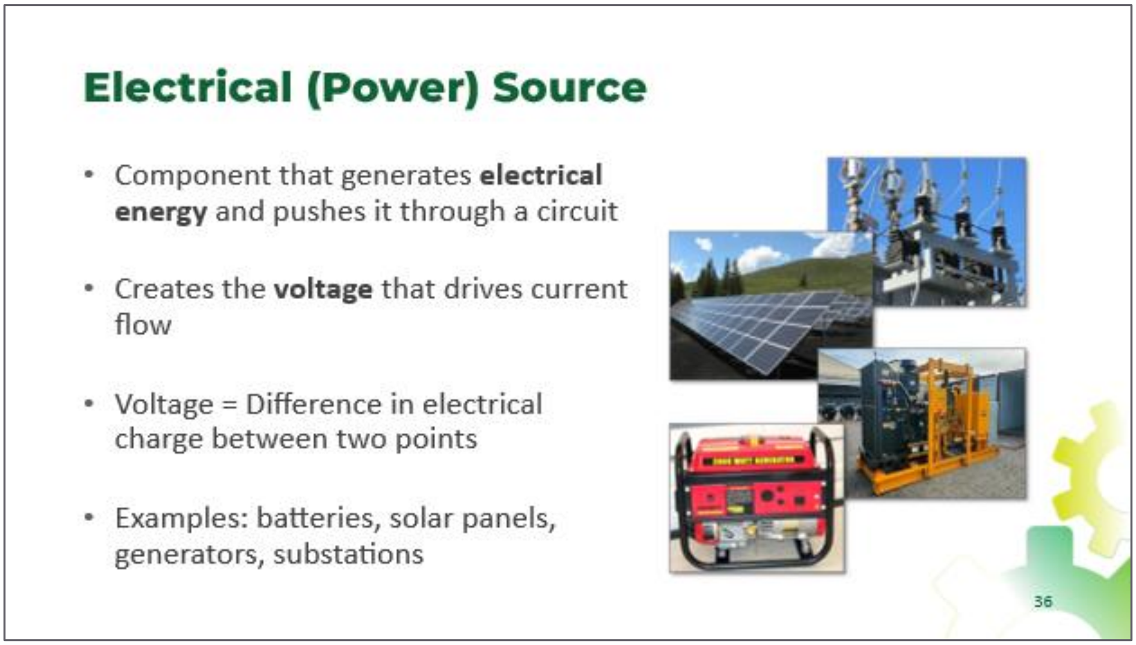
Wire Gauges Size & Wire Ampacity Table

Wire Gauge	Ampacity	Application
3/0 Gauge	200 AMPS	Service Entrance - From Utility Pole to Energy Meter
1/0 Gauge	150 AMPS	Service Entrance & Feeder Wire - To Panel Box
3 Gauge	100 AMPS	Service Entrance & Feeder Wire - To Panel Box
6 Gauge	55 AMPS	Feeder & Large Appliance Wire
8 Gauge	40 AMPS	Feeder & Large Appliance Wire
10 Gauge	30 AMPS	Appliances e.g. Dryer, Air-conditioning, Water Heater
12 Gauge	20 AMPS	Appliances like Laundry, Bathroom & Kitchen Circuits
14 Gauge	15 AMPS	General Lighting, Fans & Outlet / Receptacle Circuits



Notes:

- **Wire length** is the distance of wire from one end to the other.
  - Electrical wire can come in rolls or on spools. Lengths of wire vary from standard cuts of 50, 100, 250, 500 and 1,000 feet, but can be special ordered for specific lengths.
- **Wire gauge** is the size of a wire's diameter.
  - The size of wires affect the amount of electricity that can flow and how safely.
  - The smaller the number of the wire, the bigger the gauge will be.
- **Wire diameter** is the cross-sectional width (or thickness) of a wire and is typically measured in inches or millimeters.

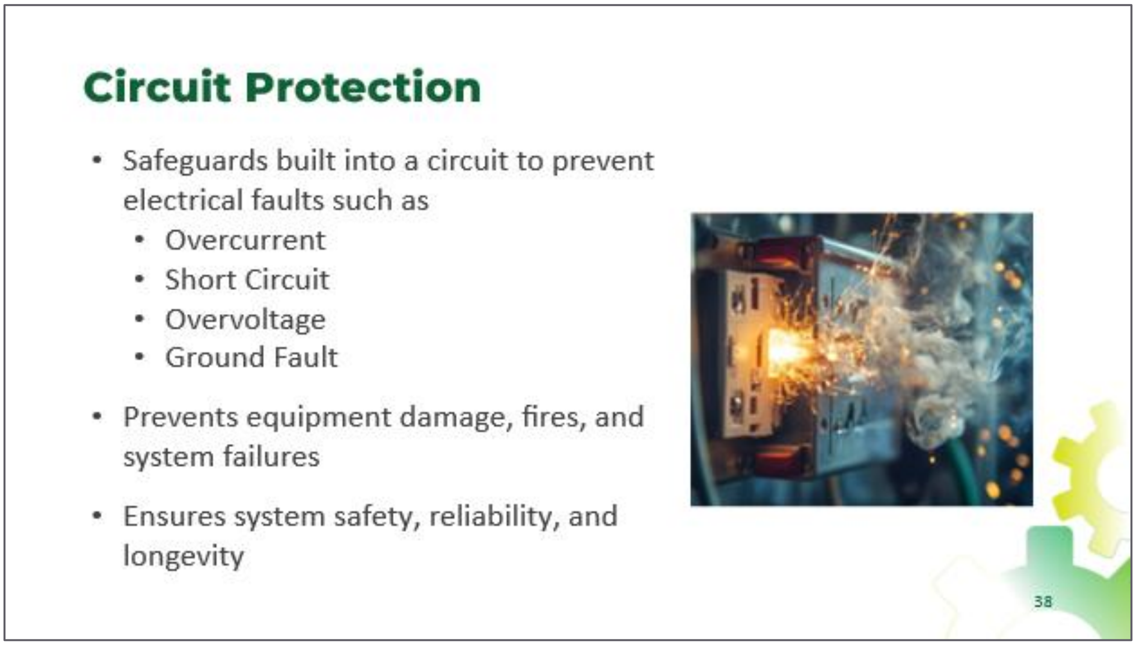


Notes:

- A **power source** is the component that generates electrical energy and pushes it through a circuit.
    - More specifically, electric current consists of free electrons moving through a conductor.
    - As those electrons move from atom to atom, they transfer energy through the circuit.
- So, what does a power source actually do?
    - It creates **voltage** — the electrical pressure that drives current through the system.
- Voltage is the difference in electrical charge between two points. Without that difference in charge, electrons would not move.
- As we continue through this module, you'll see that voltage works together with two other key elements: **current and resistance**. Those relationships are critical to understanding circuit behavior.
- **Common power sources include:**
    a) Batteries (AA, coin cells, solar storage batteries)
    b) Solar panels, which convert sunlight into electrical energy
    c) Generators, often used as backup power
    d) Electrical substations, which distribute power across larger systems
- Every circuit must have a source — without it, there is no energy to move.

Notes:

- A **load** is any component within a circuit that uses electricity to carry out work.
- In other words, a load converts energy into a functional form or task, like producing heat, light or movement (motion).
- Besides the examples shown here on the slide, can you think of any additional examples?
- Examples include: lightbulbs (incandescent, LED), motors and traction motors, resistors, TVs, air conditioners & fans, kitchen appliances, etc.



Notes:

- **Circuit protection** refers to the safeguards built into an electrical system to detect and prevent faults.
- Faults include things like:
    a) **Overcurrent** occurs when current exceeds the rated limit of the circuit. This can overheat wires and components.
    b) A **short circuit** happens when current finds an unintended low-resistance path — often bypassing the load. This can cause a rapid surge in current.
    c) **Overvoltage** is a voltage spike that exceeds the system's design limits. This can damage sensitive electronics.
    d) A **ground fault** occurs when current unintentionally flows to ground, often due to damaged insulation or wiring.
- Electrical systems are designed to operate within specific limits. When those limits are exceeded, damage can occur — sometimes very quickly.
- Circuit protection helps prevent: Equipment damage, fires, system failures, safety hazards
- It also improves system reliability and extends the life of components.

Notes:

- A **fuse** is a one-time safety device that breaks the circuit when the current exceeds a safe level making it a simple and effective way to protect equipment.
- There are several types of fuses used in DC circuits, including:
  a) Blade fuses – commonly found in automotive systems.
  b) Cartridge fuses – used in a variety of industrial and residential settings.
  c) High-speed fuses – designed to protect sensitive electronic components by reacting quickly to overcurrent.
- Some of the advantages of using fuses are that they're simple, low-cost, and reliable.
- They also help protect with electrical damage, short circuiting, voltage, overcurrent and blow outs, reducing fire hazards/risk, wire degradation.
- A main drawback is that once a fuse blows, it has to be replaced, as it's designed for one-time use only.

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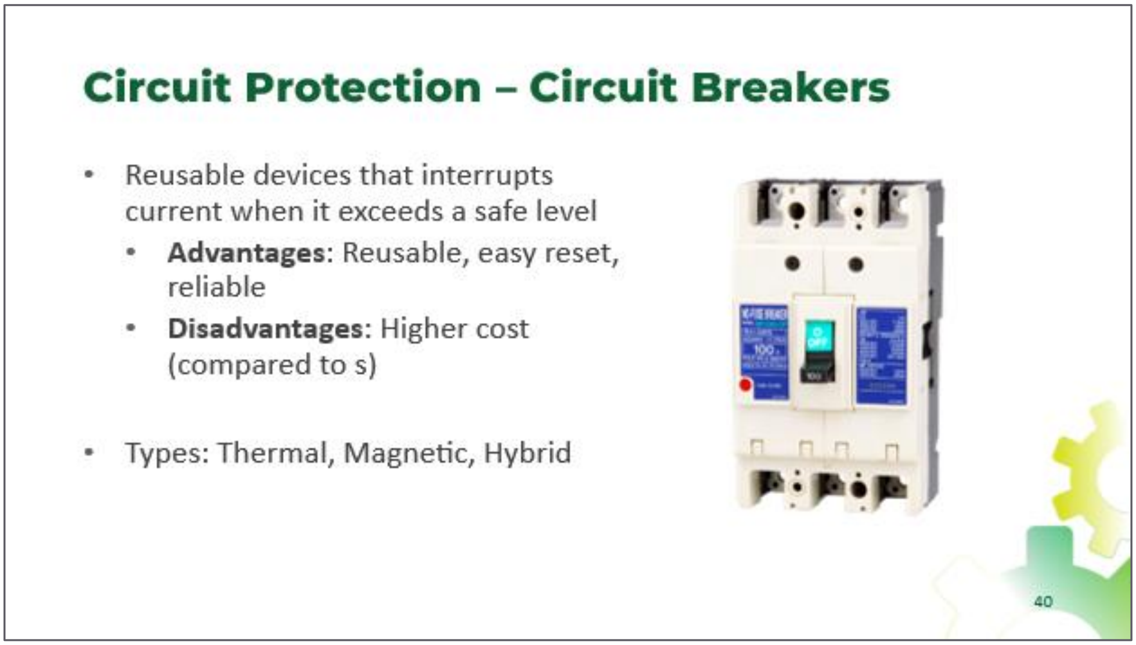

Notes:

- **Circuit breakers** are devices that interrupt current when it surpasses a level that is safe. Like fuses, circuit breakers offer protection against overcurrent.
- However, unlike fuses, circuit breakers are reusable devices that stop the flow of electricity when the current exceeds safe limits—they can be reset rather than replaced.
- Some key advantages of circuit breakers are that they're reusable, easy to reset, and very reliable.
- The main disadvantage is cost—they tend to be more expensive than fuses up front.
- In DC systems, common types of circuit breakers include:
  a) Thermal breakers – which trip when heat from excessive current builds up.
  b) Magnetic breakers – which use a magnetic field to quickly interrupt current during a surge.
  c) Hybrid (thermal-magnetic) breakers – combine both mechanisms for more effective protection.

Knowledge Check

Which of the following describes what wire gauge is?

A. A flexible cable that serves as the pathway to carry electrical current

B. Distance of the wire from one end to the other

C. Cross -sections width (thickness)of the wire

D. The size of a wire's diameter

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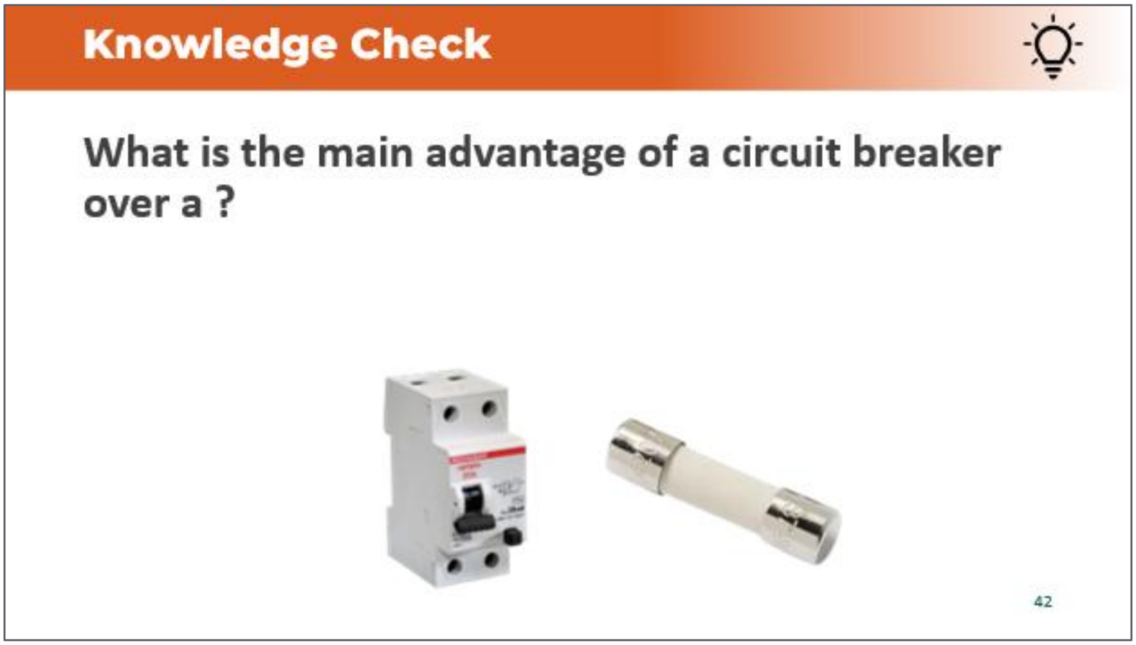
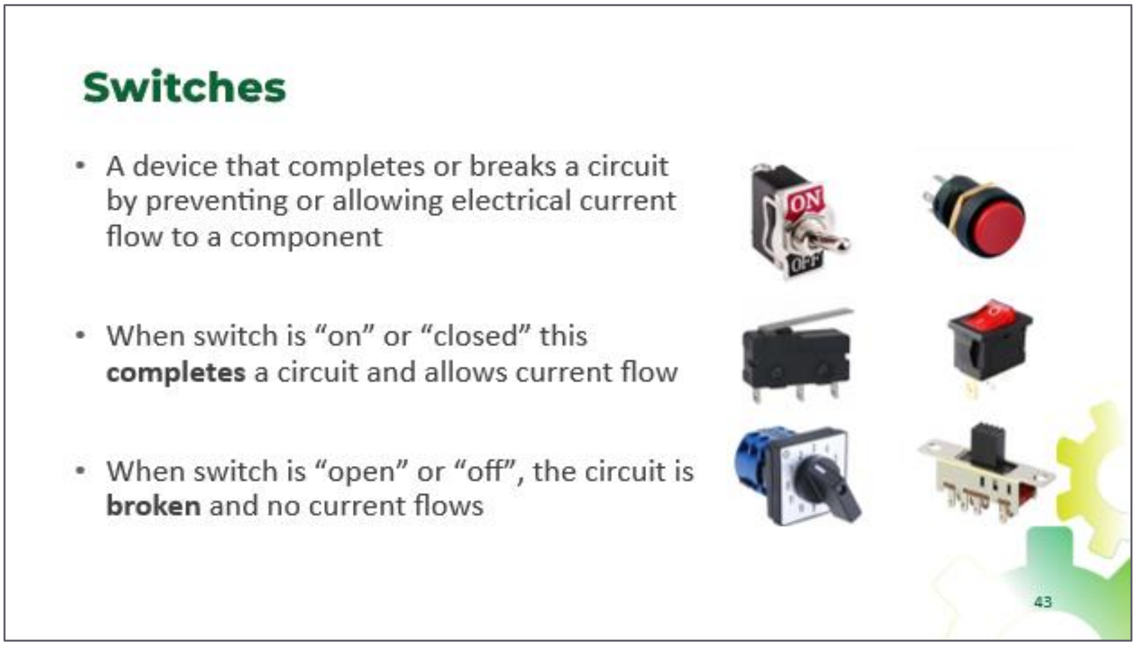
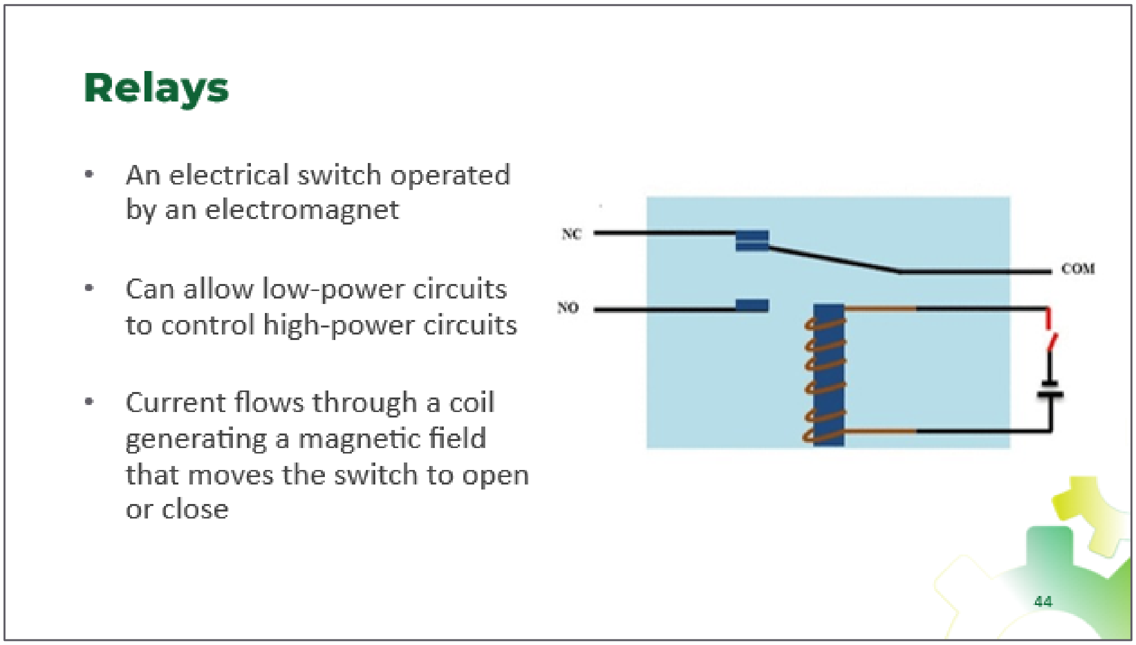

Knowledge Check
What is the main advantage of a circuit breaker over a ?
42



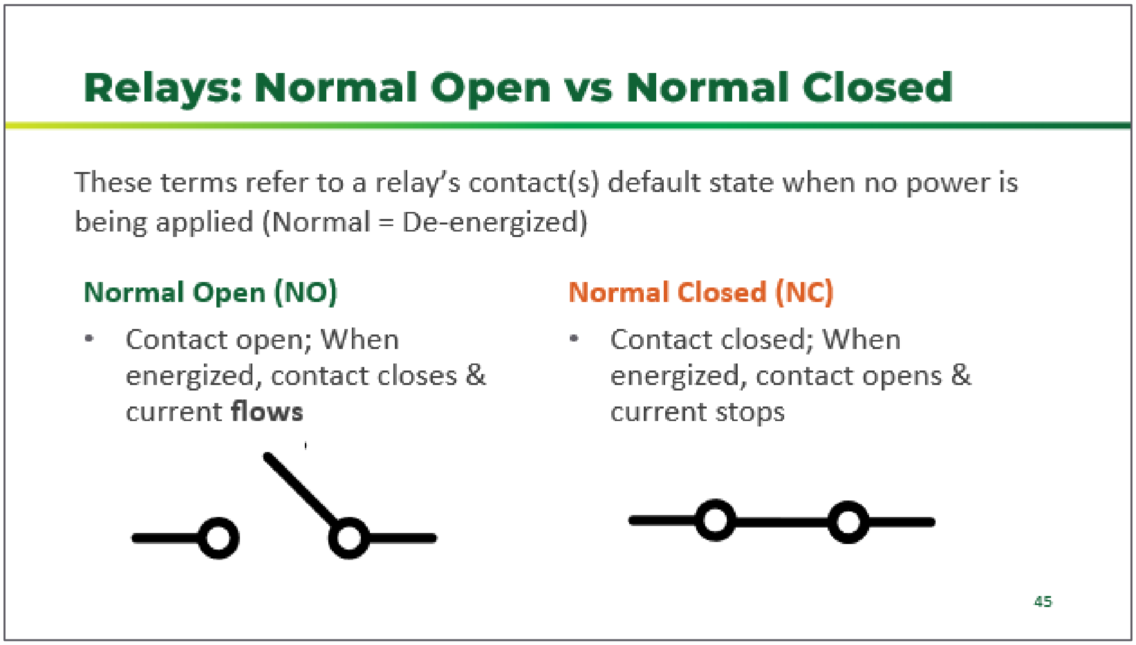
Notes:

- A **switch** is a device that completes or breaks a circuit by preventing or allowing electrical current flow to a component.
  - When a switch is "on" or "closed" this completes a circuit and allows current flow.
  - When a switch is "open" or "off", the circuit is broken which stops the flow of current.
- A switch gives us control over electricity, allowing current to flow only when it's needed and stopping it when it is not needed.
- Some of the key switches shown in the picture are: Toggle, Push button, Rotary, etc.
- Do you know any other examples of switches?



Notes:

- A **relay** is an electromechanical switch operated by an electromagnet, which can allow low-power circuits to control high-power circuits.
- As current flows through a coil it generates magnetic field, and if it moves through a switch it opens or closes the circuit.
- Applications of relays include:
  - Controlling high-current devices (motors, lights, heating elements).
  - Isolating low-power control systems from high-power circuits (for safety).
  - Automotive systems, industrial machinery, home appliances.
- In transit, you may see an electromagnet at work when doors in a bus open. To open the doors, an electrical signal is sent to a relay, which in turn sends electrical current to activate lights in the stepwell to provide better illumination.
  - When the doors close, the signal is interrupted, which then extinguishes the step lights. This is done automatically without driver intervention.



Notes:

- Relay contact positions: The terms Normally Open (NO) and Normally Closed (NC) refer to the default state of a relay's contacts when **no power** is applied to the coil.
  - "Normal" simply means the relay is **de-energized**.
- When the relay's coil becomes energized, the contacts **switch** from their normal state to the opposite state. That switching action allows connected circuits to open or close. So, a relay is essentially an electrically controlled switch.
- A **Normally Open** contact does **not** allow current to flow when the relay is at rest. When the coil is energized, the contact closes and allows current to pass.
  - Think of it like a push-button light switch that only works while you are pressing it.
  - No power to the coil → circuit open.
    Power applied → circuit closes.
- A **Normally Closed** contact allows current to flow when the relay is at rest. When the coil is energized, the contact opens and interrupts current flow. A good example is a refrigerator light switch.
  - The light is on by default. When the door closes (activating the switch), the circuit opens and the light turns off.
  - You'll also see this logic used in emergency alarm circuits
- Some relays control *more than one* circuit at the same time.
- A **double-pole** relay controls two separate circuits independently.
- A **triple-pole** relay controls three separate circuits.
- Each circuit has its own set of contacts, but all are controlled by the same coil. This allows one control signal to switch multiple circuits simultaneously.

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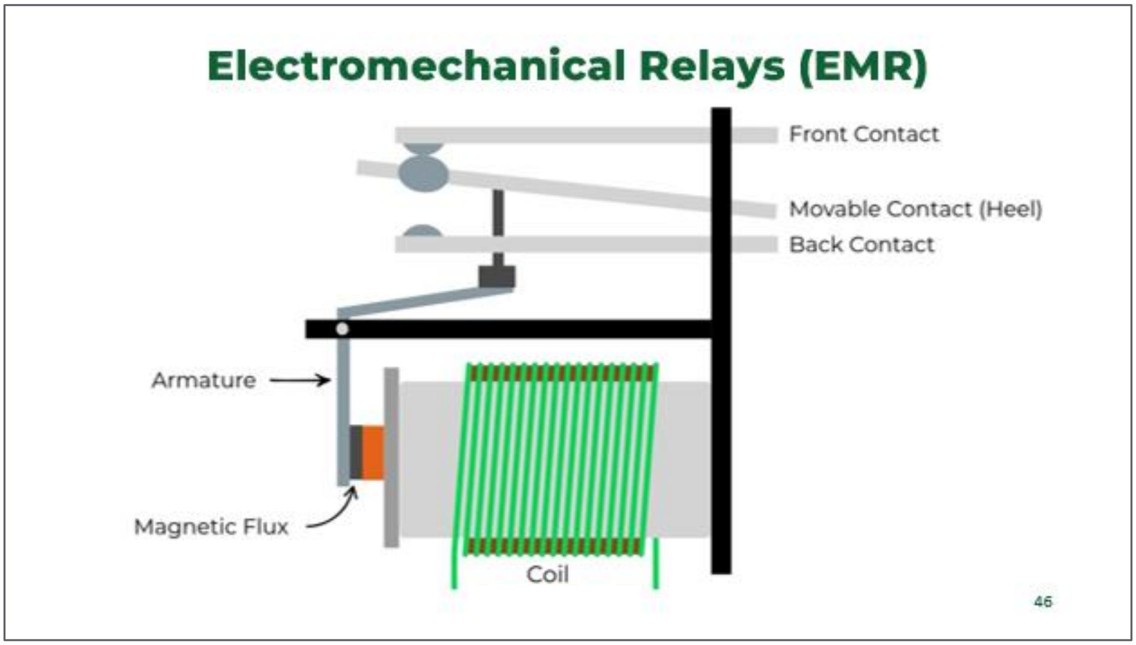

Notes:

- There are several kinds of relays.
- On the slide is a standard type Electromechanical Relays (EMRs) which uses physical moving contacts and a coil to switch circuits.
- Applications for EMRs include industrial machines, automotive systems, appliances.

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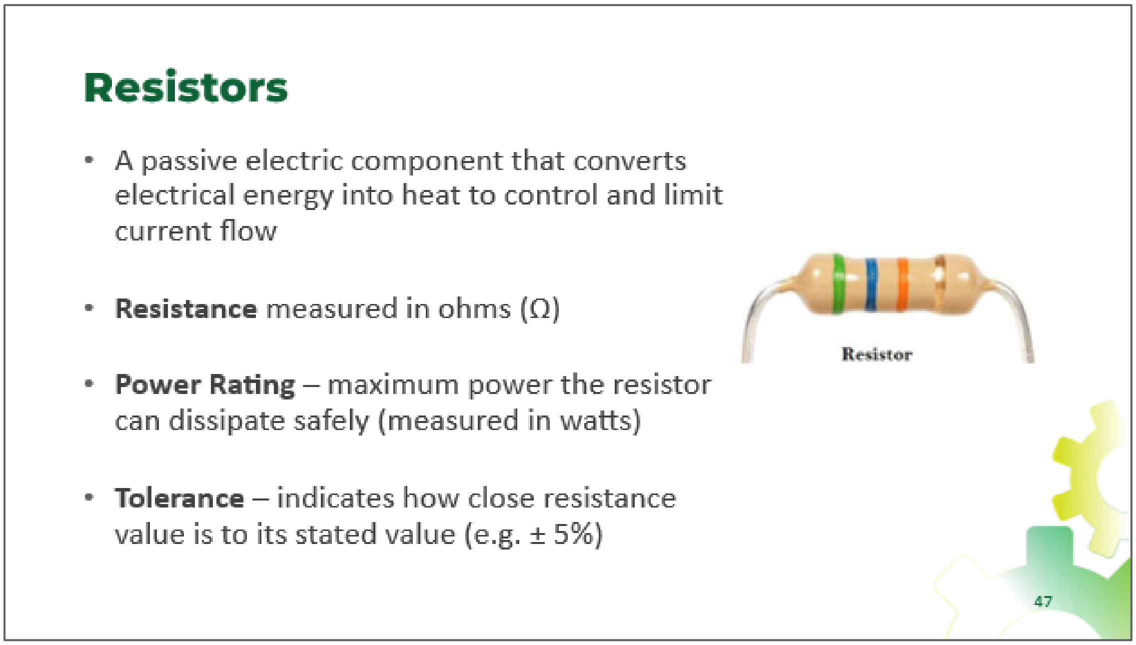
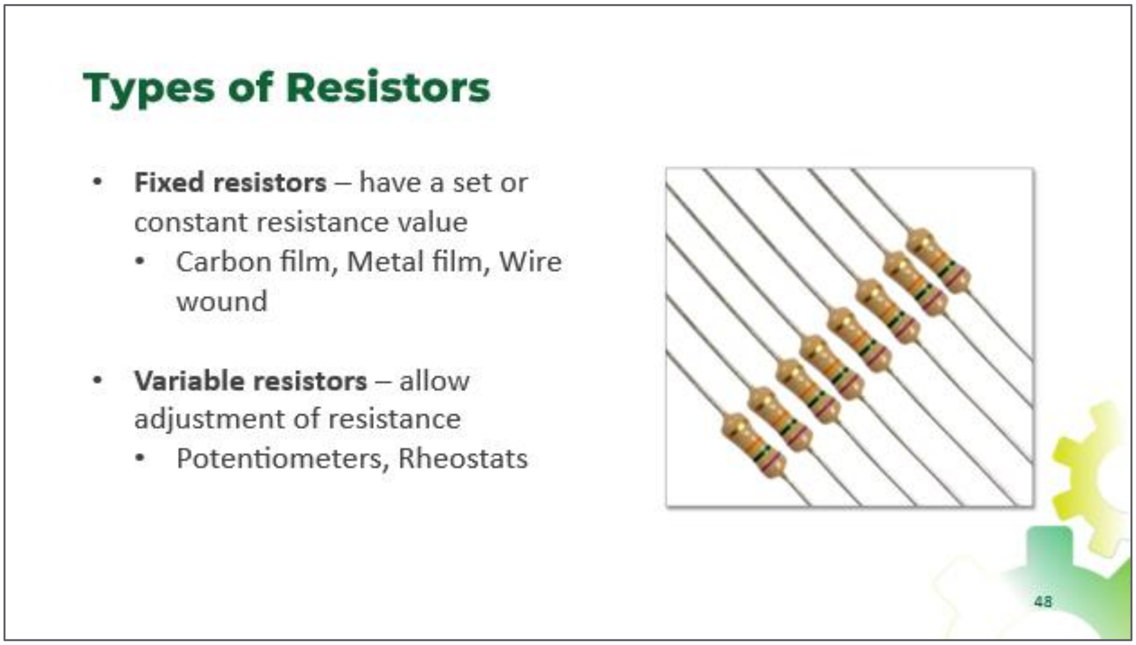


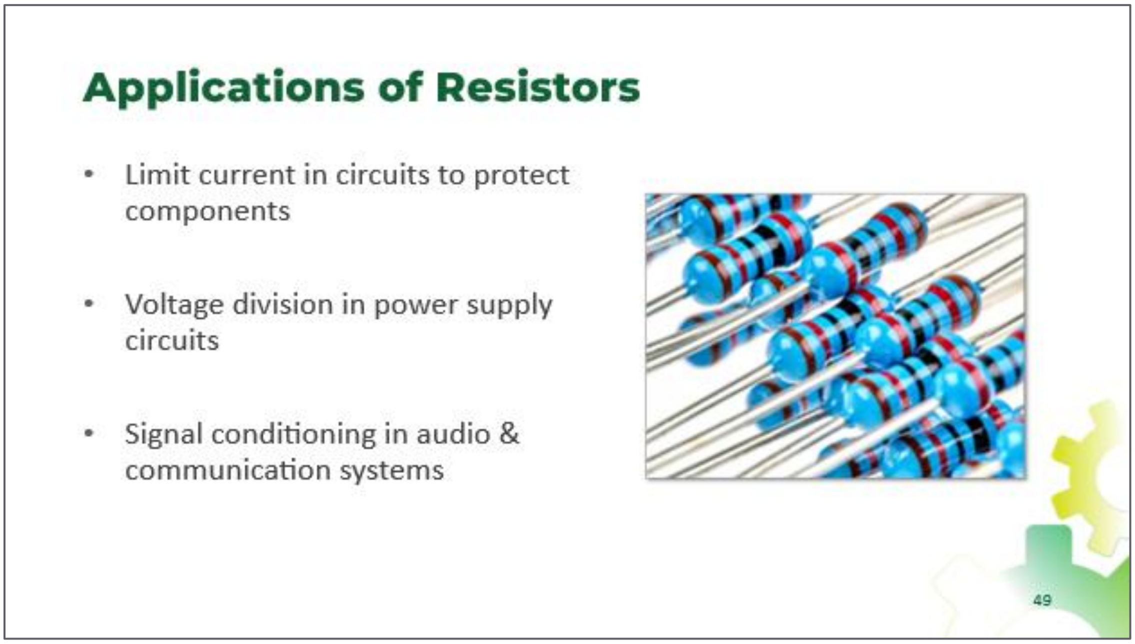
Notes:

- A **resistor** is a basic, passive component with two terminals. It is designed to help control the flow of current by providing resistance.
- This helps protect components, manage voltage drops, and helps to keep equipment operating smoothly.
- It works by converting electrical energy into heat, which helps limit and control the flow of current.
- Resistors are essential for:
  - Controlling current levels
  - Adjusting signal strength
  - Safely ending (terminating) transmission lines
- A few key terms to know:
  - **Resistance** (R) is measured in ohms (Ω)—it tells us how much the resistor resists current.
  - **Power rating** is how much power (in watts) the resistor can handle without overheating.
  - **Tolerance** tells us how close the actual resistance value is to what's printed on the label—like plus or minus (±) 5%.



Notes:

- Two common types of resistors are fixed resistors and variable resistors.
- **Fixed resistors** have a set or constant resistance value that does not change during normal operation.
    - They are used when a circuit needs a consistent, predictable amount of resistance to control current.
    - Types include carbon film, metal film, wire wound.
- **Variable resistors** will come with multiple terminals (or sliding terminals) and will allow for the resistance to be adjusted in the electrical circuit.
    - They are commonly used to fine-tune circuit behavior.
    - Types include potentiometers, rheostats.



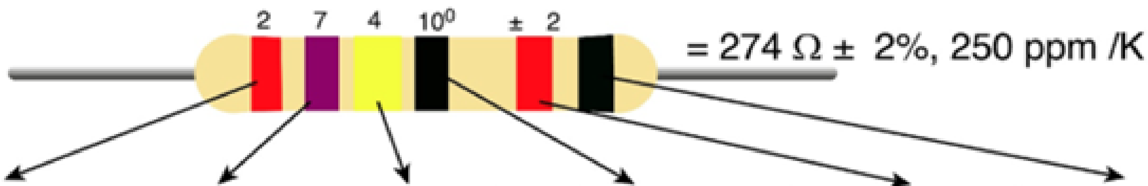
Notes:

- Applications of Resistors can include:
    - Limiting current in circuits to protect components
    - Voltage division in power supply circuits
    - Signal conditioning in audio & communication systems

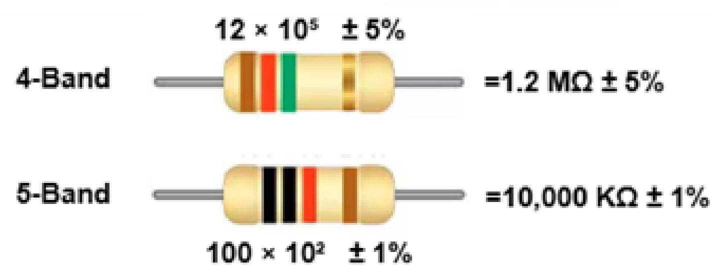
Resource

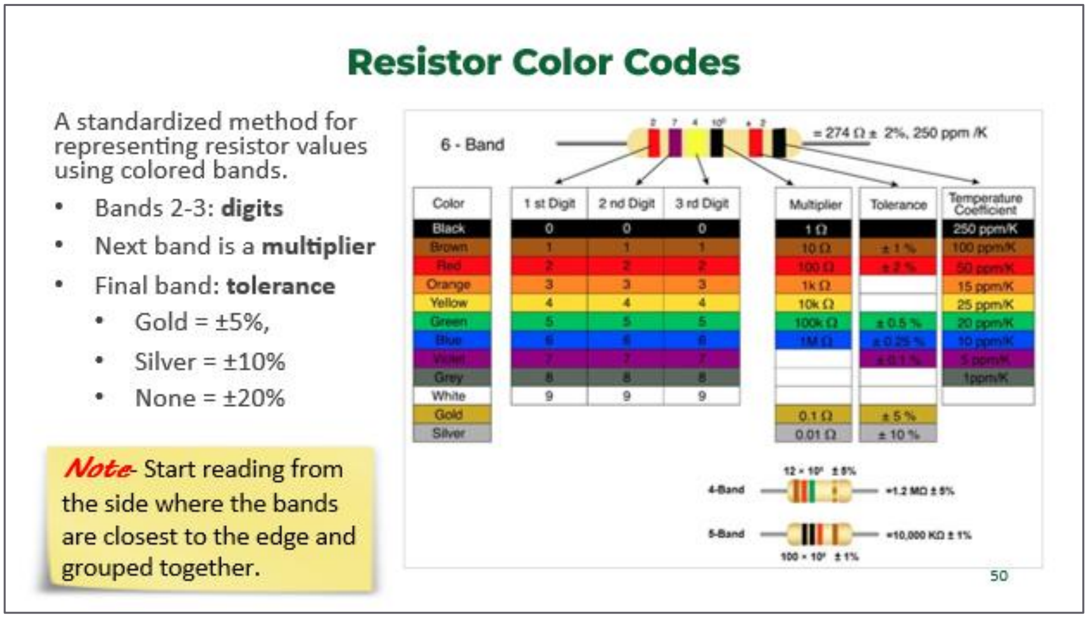
Resistor Color Code Chart

6 - Band



Color	1 st Digit	2 nd Digit	3 rd Digit	Multiplier	Tolerance	Temperature Coefficient
Black	0	0	0	1 Ω		250 ppm/K
Brown	1	1	1	10 Ω	± 1 %	100 ppm/K
Red	2	2	2	100 Ω	± 2 %	50 ppm/K
Orange	3	3	3	1k Ω		15 ppm/K
Yellow	4	4	4	10k Ω		25 ppm/K
Green	5	5	5	100k Ω	± 0.5 %	20 ppm/K
Blue	6	6	6	1M Ω	± 0.25 %	10 ppm/K
Violet	7	7	7		± 0.1 %	5 ppm/K
Grey	8	8	8			1ppm/K
White	9	9	9			
Gold				0.1 Ω	± 5 %	
Silver				0.01 Ω	± 10 %	





Notes:

- **Resistor color codes** are a standardized way to label resistor values without printing numbers.
- Instead, resistors use colored bands to show their resistance and tolerance.
- Each color stands for a number — starting with black for 0, brown for 1, all the way up to white for 9.
- Most resistors have four or five bands.
  - The first two or three bands give you the digits, the next band is a multiplier, and the final band tells you the tolerance, or how much the actual resistance might vary from the stated value.
- For tolerance:
  - Gold means ±5%
  - Silver means ±10%
  - If there's no tolerance band, that means ±20%
- So, how do you know which side to start reading form? Start reading from the side where the bands are closest to the edge and grouped together.

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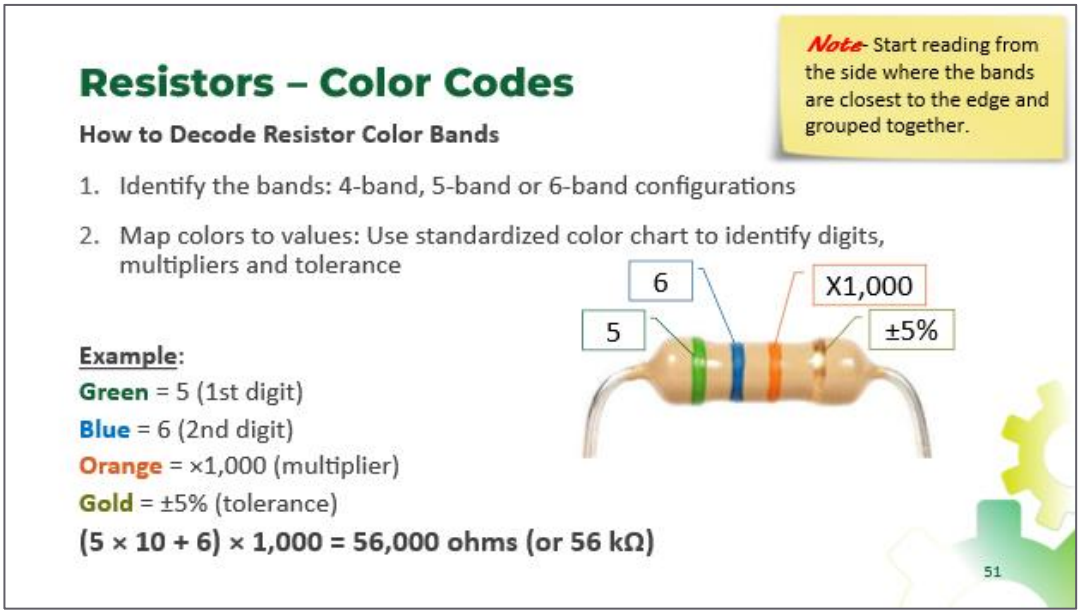

Notes:

- To decode a resistor color band, first identify the band configuration.
- Next, map colors to values using the standardized color chart to identify digits, multipliers and tolerance.
    - Green = 5 (1st digit)
    - Blue = 6 (2nd digit)
    - Orange = ×1,000 (multiplier)
    - Gold = ±5% (tolerance)
    - *(5 × 10 + 6) × 1,000 = 56,000 ohms (or 56 k Ω)*

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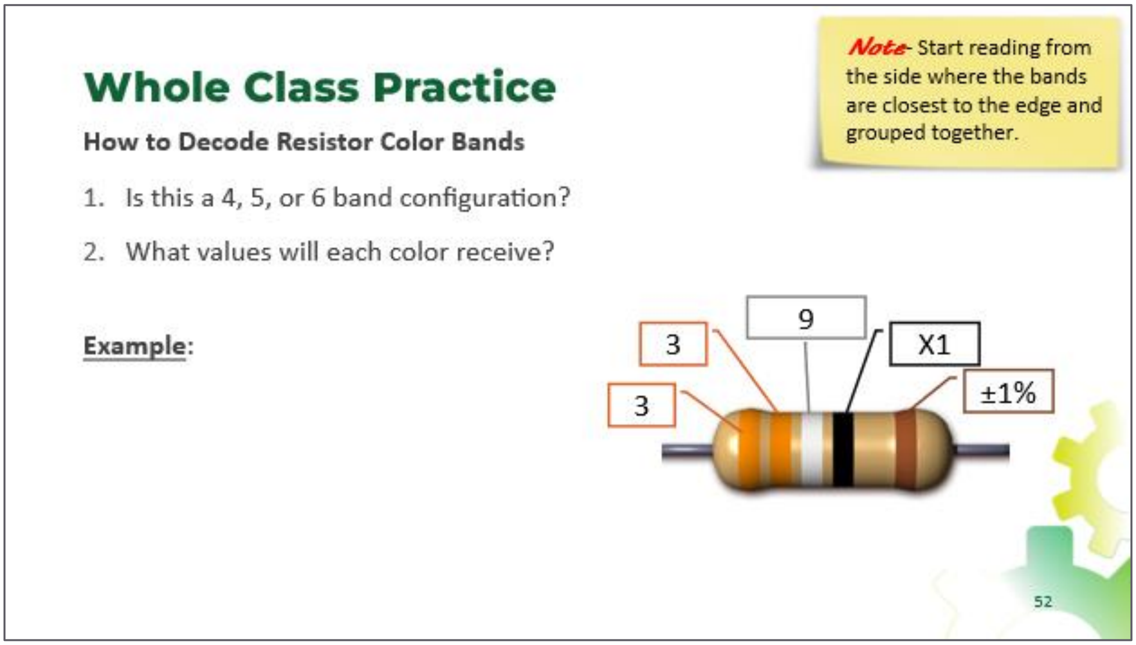


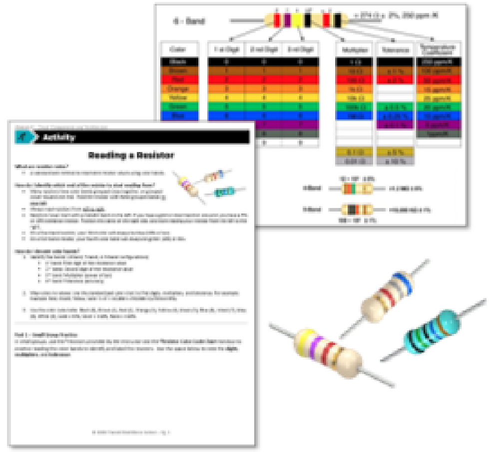
Notes:

- Let's decode this resistor to determine the resistance.
  1. First, identify the bands. Is this a 4, 5, or 6 band configuration?
  2. Next, map the color values. What number will each color receive?
  3. So, what will the equation be?
  4. Calculating the final answer, which is:

Activity: Reading a Resistor

Part 1: In **small groups**, use the **resistors** provided by the instructor and the **Resistor Color Code Chart** handout to identify each resistor by reading its color bands. Use the space below to record the digits, multiplier, tolerance, and final resistance value.

Part 2: **On your own**, read each resistor and use the space provided to note the digits, multipliers, and tolerance.



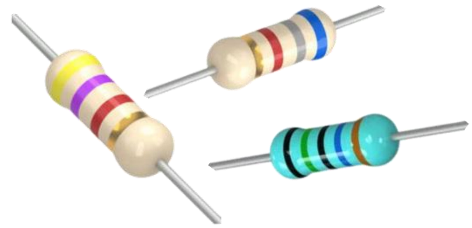
53

Activity

Reading a Resistor

What are resistor codes?

- A standardized method to represent resistor values using color bands.



How do I identify which end of the resistor to start reading from?

- Many resistors have color bands grouped close together, or grouped closer toward one end. Hold the resistor with these grouped bands to your left.
- Always read resistors from left to right.
- Resistors never start with a metallic band on the left. If you have a gold or silver band on one end, you have a 5% or 10% tolerance resistor. Position this band on the right side, and start reading your resistor from the left to the right.
- On a four-band resistor, your third color will always be blue (10^6) or less.
- On a five-band resistor, your fourth color band will always be green (10^5) or less.

How do I decode color bands?

1. Identify the bands: (4 band, 5 band, or 6 band configurations)

   For 4-band resistors
   - 1st band: First digit of the resistance value
   - 2nd band: Second digit of the resistance value
   - 3rd band: Multiplier (power of ten)
   - 4th band: Tolerance (accuracy)

   For 5-band resistors
   - 1st band: First digit of the resistance value
   - 2nd band: Second digit of the resistance value
   - 3rd band: Third digit of the resistance value
   - 4th band: Multiplier (power of ten)
   - 5th band: Tolerance (power of ten)

   For 6-band resistors
   - Same as 5-band plus
   - 6th band: Temperature coefficient (ppm/K)

2. Map colors to values: Use the standardized color chart to find digits, multipliers, and tolerance. For example: Example: Red, Violet, Yellow, Gold → 27 × 10,000 = 270,000 Ω (270 kΩ ±5%).

3. Use the color code table: Black (0), Brown (1), Red (2), Orange (3), Yellow (4), Green (5), Blue (6), Violet (7), Gray (8), White (9), Gold = ±5%, Silver = ±10%, None = ±20%.

Part 1 – Small Group Practice

In small groups, use the [1]**resistors** provided by the instructor and the [2]**Resistor Color Code Chart** handout to identify each resistor by reading its color bands. Use the space below to record the **digits**, **multiplier**, **tolerance**, and final **resistance** value.

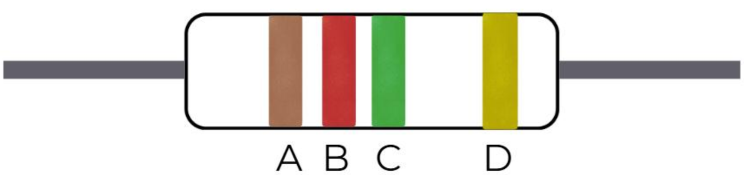
Part 1 Work Space

Part 2 – Independent Practice

On your own, read each resistor and use the space provided to note the digits, multipliers, and tolerance.

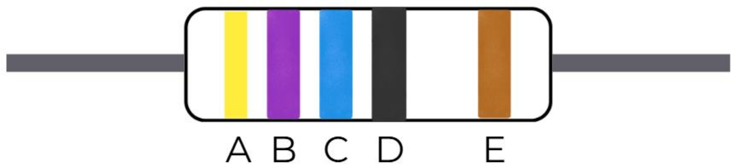
Colors: Brown, black, brown

1. ____



Colors: Brown, red, green, gold

2. ____

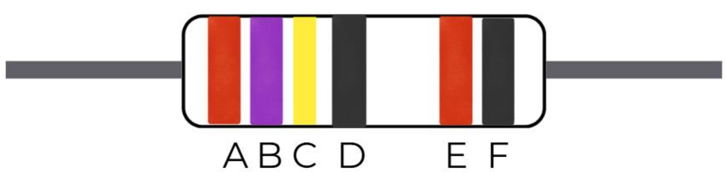


Colors: Yellow, purple, blue, black, brown

3. ____

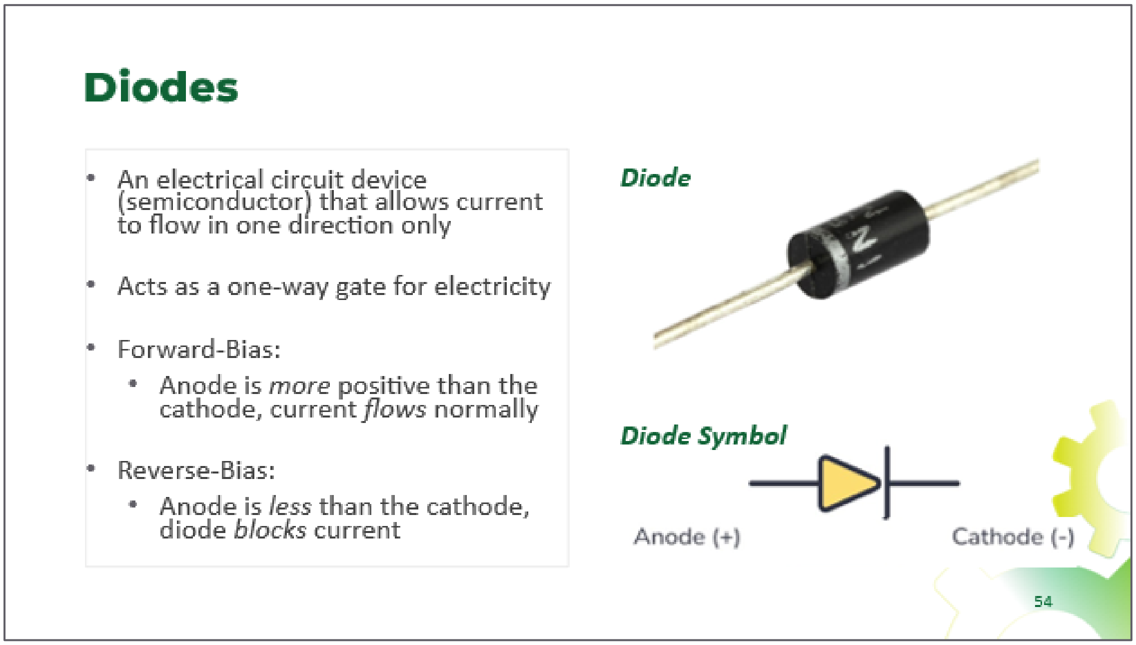
Colors: Orange, yellow, black, green, brown.

4. ____



Colors: Red, purple, yellow, black, red, black.

5. ____



Notes:

- A **diode** is a semiconductor device that allows current to flow in one direction only.
- It acts as a one-way gate for electricity, allowing current to move through the circuit in a single direction while blocking it from flowing in the wrong direction.
- When the diode is **forward biased**, meaning the anode is *more* positive than the cathode, current **flows** normally.
- When the diode is **reverse biased**, meaning anode is *less* positive than the cathode, the diode **blocks** current to protect the circuit and control how electricity moves.

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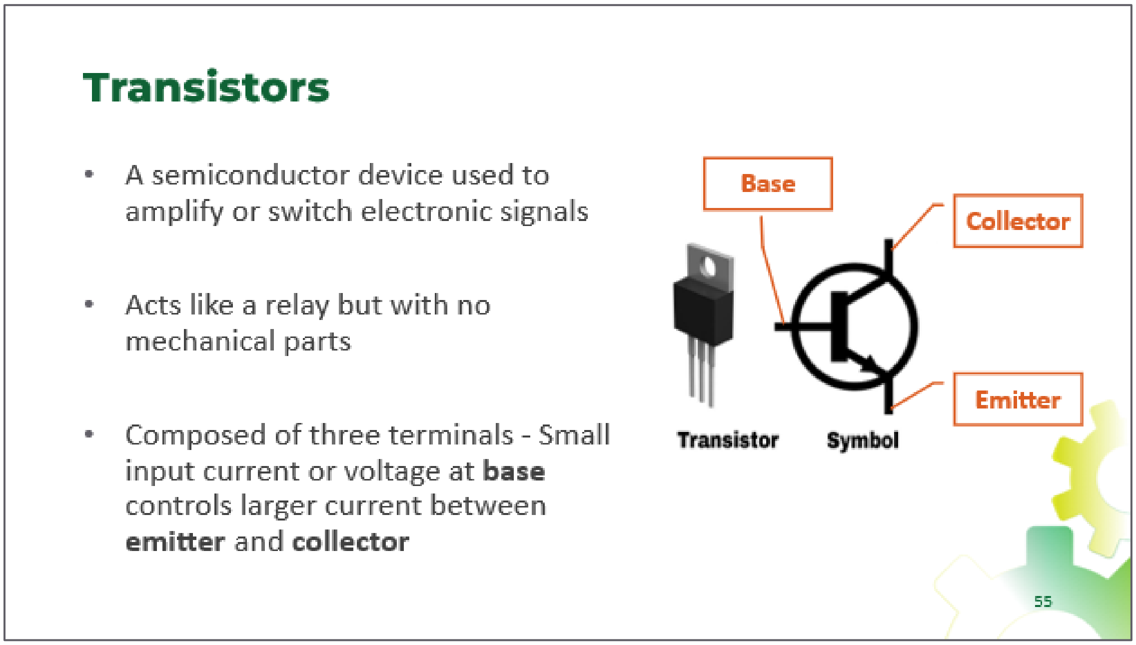
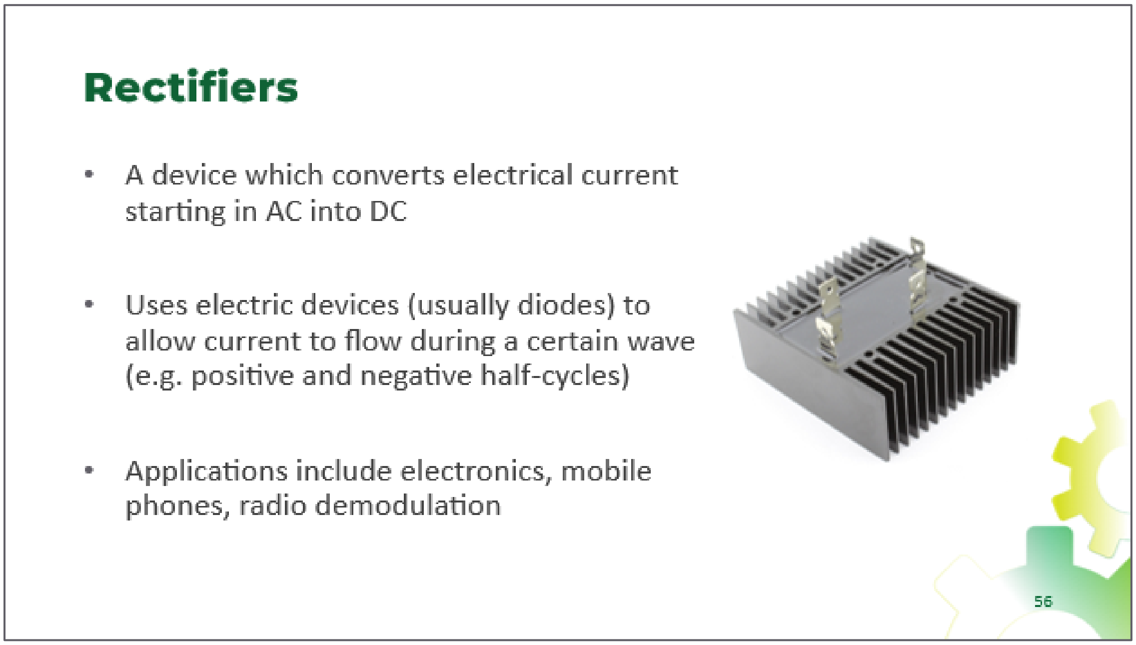


Notes:

- A **transistor** is a semiconductor device used to amplify or switch electronic signals.
- When you apply voltage to the base it is like operating the relay coil, then power can flow from the collector to the emitter.
- Advantage is no mechanical parts so there is little to no wear.
- They act as an electronic switch/signal amplifier in circuits.
- Transistors are composed of three parts: **Emitter**, **Base**, and **Collector**.
- There will be a small input current or voltage at base controls larger current between emitter and collector.



Notes:

- A **rectifier** is a device which converts electrical current starting in AC into DC.
- They use electric devices (usually diodes) to allow current to flow during a certain wave (e.g. positive and negative half-cycles).
- Applications include electronics, cell phones, and radio demodulation.

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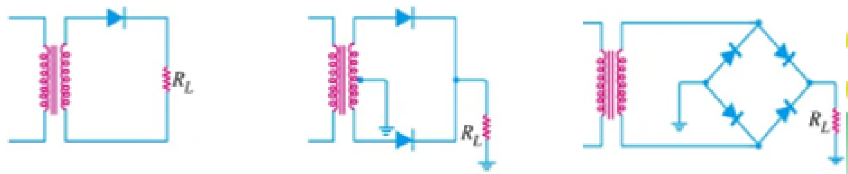
Types of Rectifiers

Three Primary Types: Half-wave, Full-wave, Full-wave bridges

Feature	Half-Wave	Full-Wave	Bridge Rectifier
Diodes	1	2	4
Efficiency	Low	High	High



Notes:

- Now let's look at the three primary types of rectifiers, which are devices used to convert alternating current (AC) into direct current (DC). The three main types are half-wave rectifiers, full-wave rectifiers, and bridge rectifiers.
- The **half-wave rectifier**.
  - A half-wave rectifier uses one diode. It allows only one half of the AC waveform to pass through while blocking the other half.
  - Because only half of the waveform is used, the output DC is less efficient and more uneven.
- The **full-wave rectifier**.
  - A full-wave rectifier uses two diodes and a center-tapped transformer.
  - Instead of using only half of the AC signal, it converts both halves of the waveform into DC, which results in higher efficiency and a smoother output than the half-wave design.
- The **bridge rectifier**.
  - A bridge rectifier uses four diodes arranged in a bridge configuration.
  - This design also converts both halves of the AC waveform, but it does so without needing a center-tapped transformer.
  - Because of this configuration, bridge rectifiers are very common in power supplies and electronic devices.

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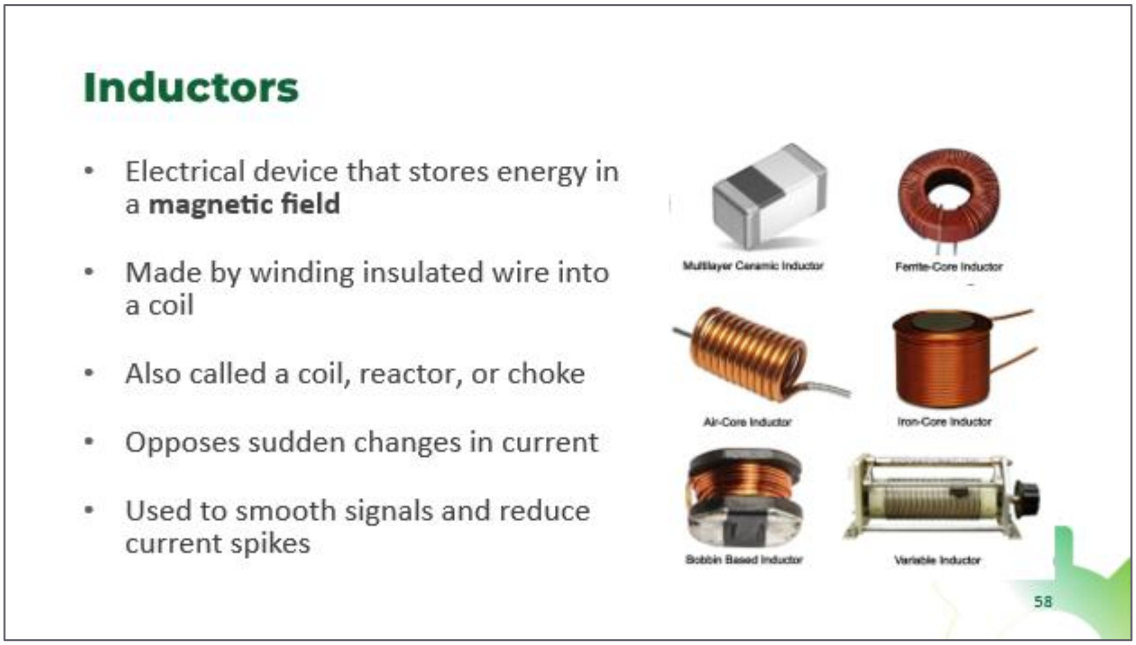

Notes:

- An **inductor** is an electrical device that stores energy in a magnetic field.
- Unlike a capacitor (which stores energy in an electric field) an inductor stores energy *magnetically*.
- Inductors are typically made by winding insulated wire into a coil.
- When current flows through that coil, it creates a magnetic field around it.
  - That magnetic field is where the energy is temporarily stored.
- You may also hear inductors referred to as a **coil**, a **reactor**, or a **choke**, depending on the application.
- One of the most important functions of an inductor is that it resists sudden changes in current.
- When current tries to increase or decrease quickly, the inductor reacts by opposing that change.
- This makes inductors useful for:
  - Smoothing electrical signals
  - Reducing electrical noise
  - Limiting sudden current spikes
- In power systems and electronics, inductors help stabilize circuits and protect components from abrupt current changes.
- Inductors have little to no effect on DC and do have many functions in AC circuits.

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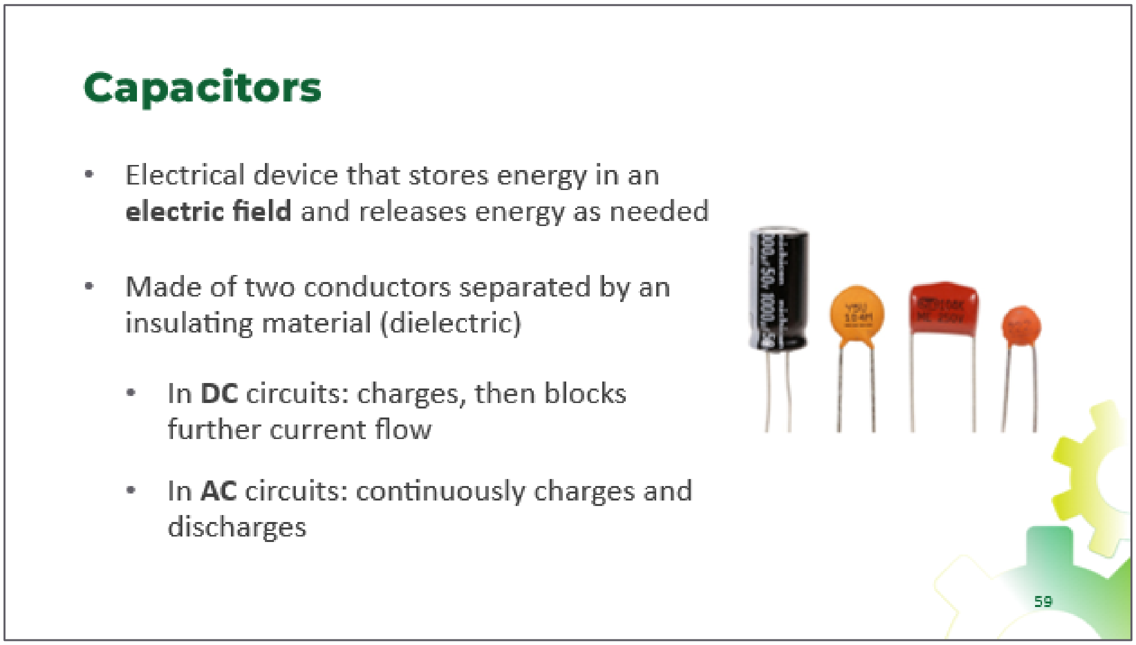
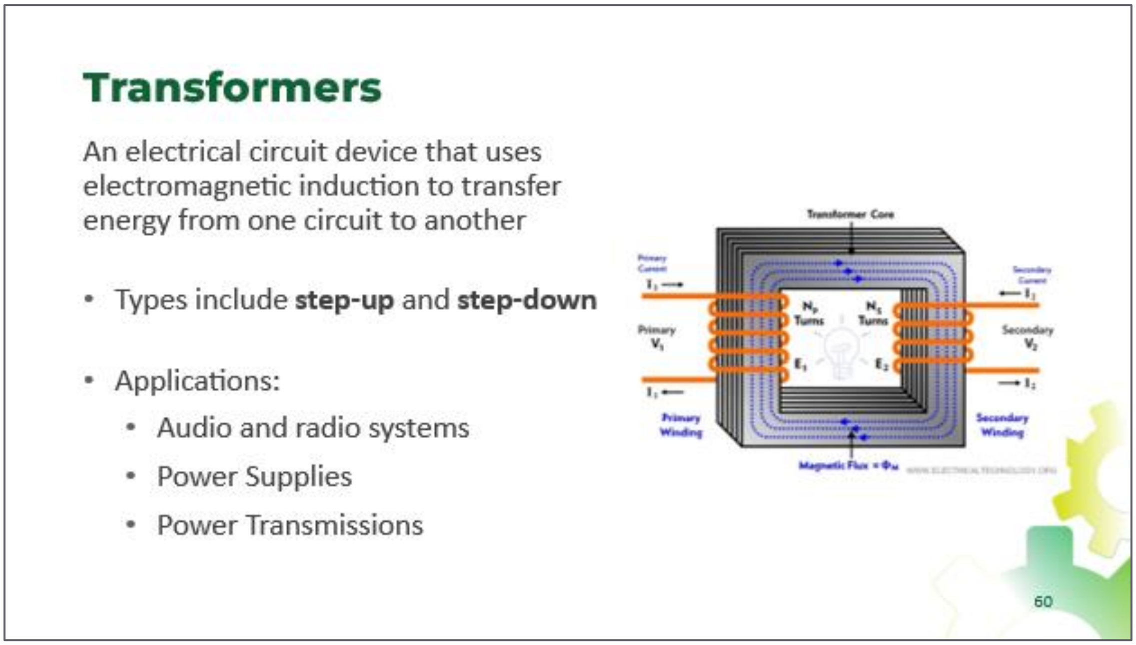


Notes:

- A **capacitor** is an electrical device that stores energy in an electric field.
- It consists of two conductive plates separated by an insulating material called a dielectric.
- When voltage is applied, the capacitor stores energy by building up an electric charge between the two plates. That stored energy can then be released back into the circuit when needed.
- In a **DC circuit**, a capacitor will charge up to the applied voltage and then block further current flow once it is fully charged.
- In an **AC circuit**, the voltage is constantly changing direction. Because of that, the capacitor continuously charges and discharges, allowing energy to keep moving through the circuit.
- Capacitors are commonly used for:
    - Smoothing voltage
    - Filtering noise
    - Stabilizing power supplies
    - Timing and signal processing applications



Notes:

- **Transformers** are an electrical circuit device that uses electromagnetic induction to transfer energy from one circuit to another.
- The primary types include step-up and step-down transformers.
- A **step-up transformer** is designed to increase the voltage from primary to secondary.
- A **step-down transformer** is designed to decrease the voltage from primary to secondary.
- Applications for a transformer can include:
  - Audio and radio systems
  - Power Supplies
  - Power Transmissions

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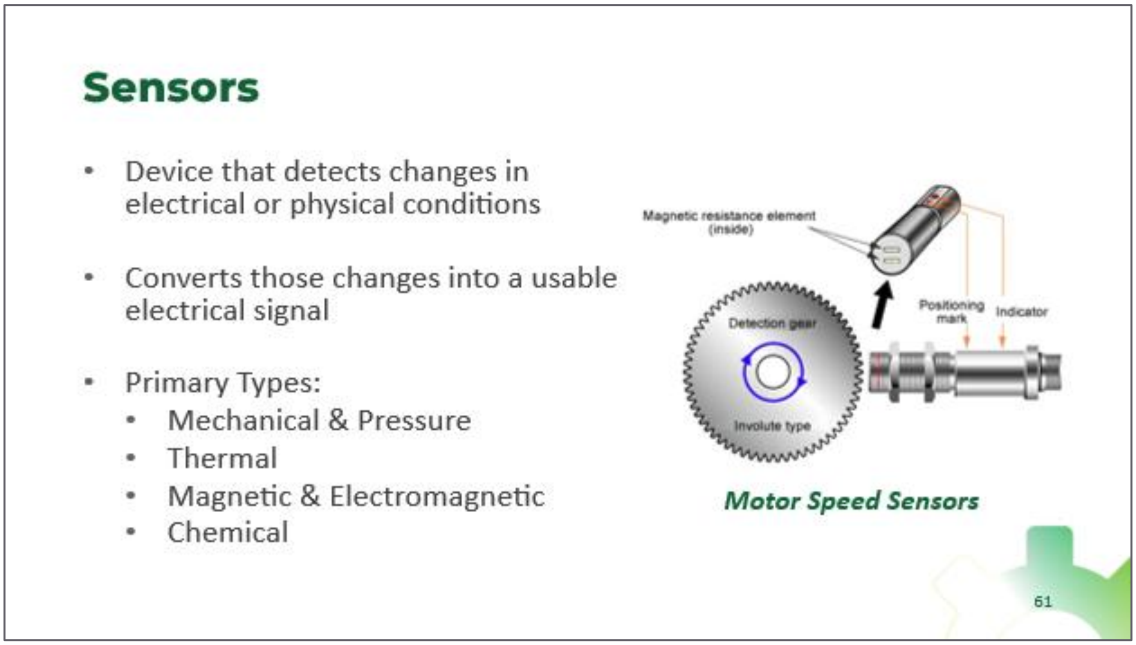
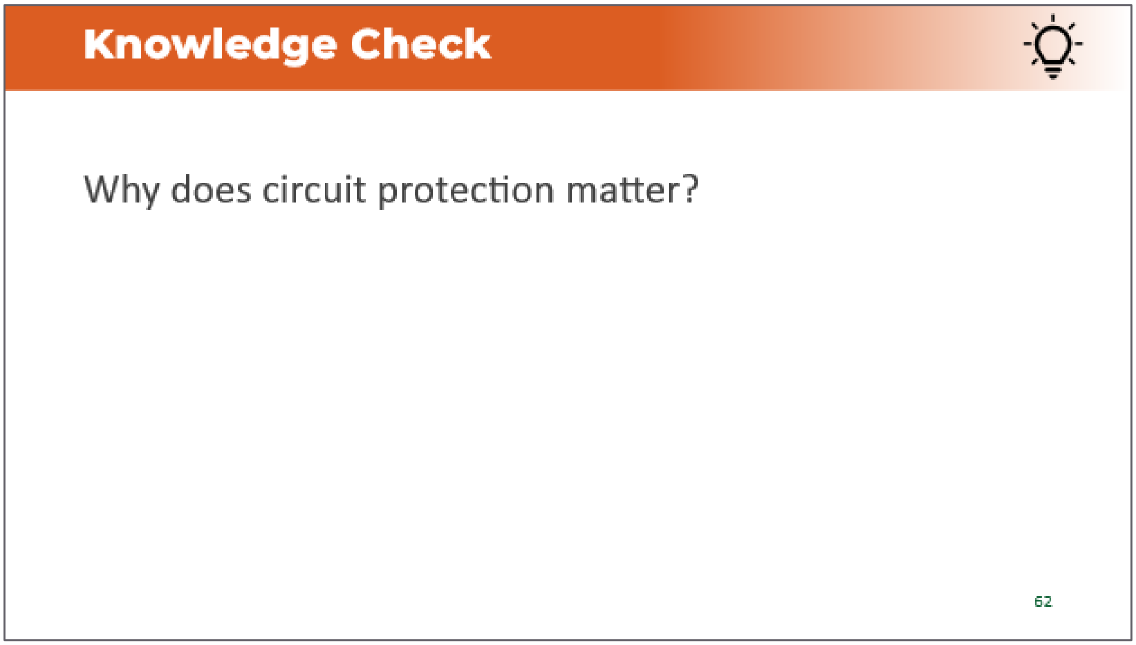
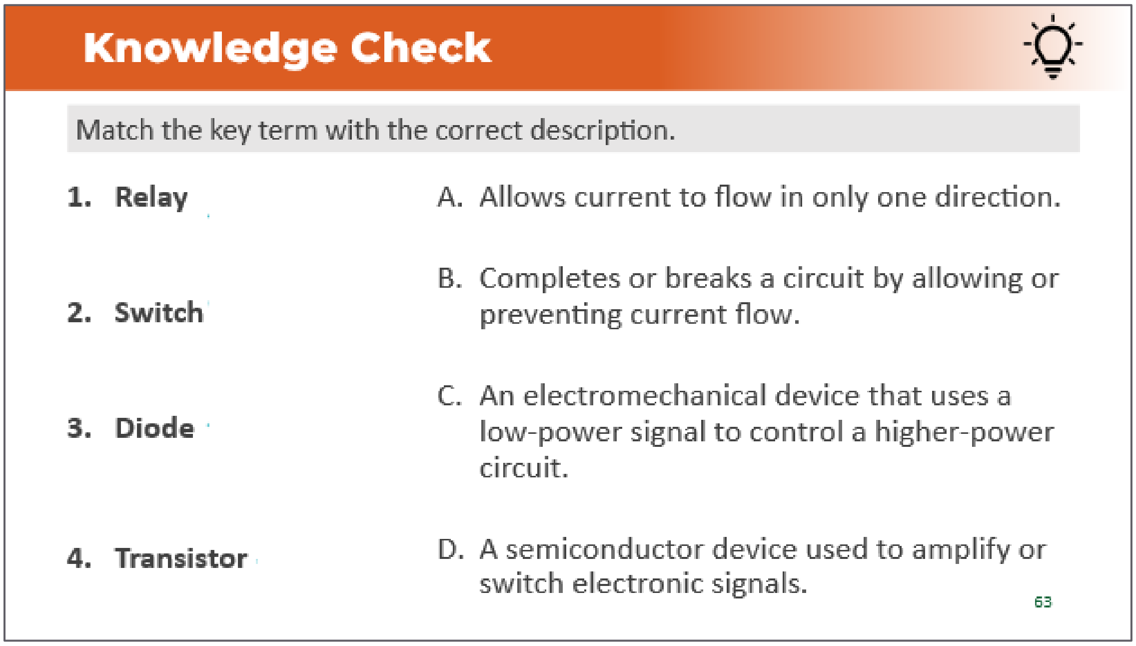


Notes:

- A **sensor** is a device that detects changes in conditions — such as motion, temperature, pressure, light, or electrical fields — and converts that change into a usable **electrical signal**.
- In simple terms, a sensor takes a physical event and turns it into information a circuit or control system can understand.
- For example:
  - A temperature sensor detects heat and converts it into a voltage signal.
  - A pressure sensor detects force and converts it into an electrical output.
  - A magnetic sensor detects movement or position and generates a signal.
- Sensors are critical in modern electrical and transportation systems because they allow systems to monitor, adjust, and respond automatically.

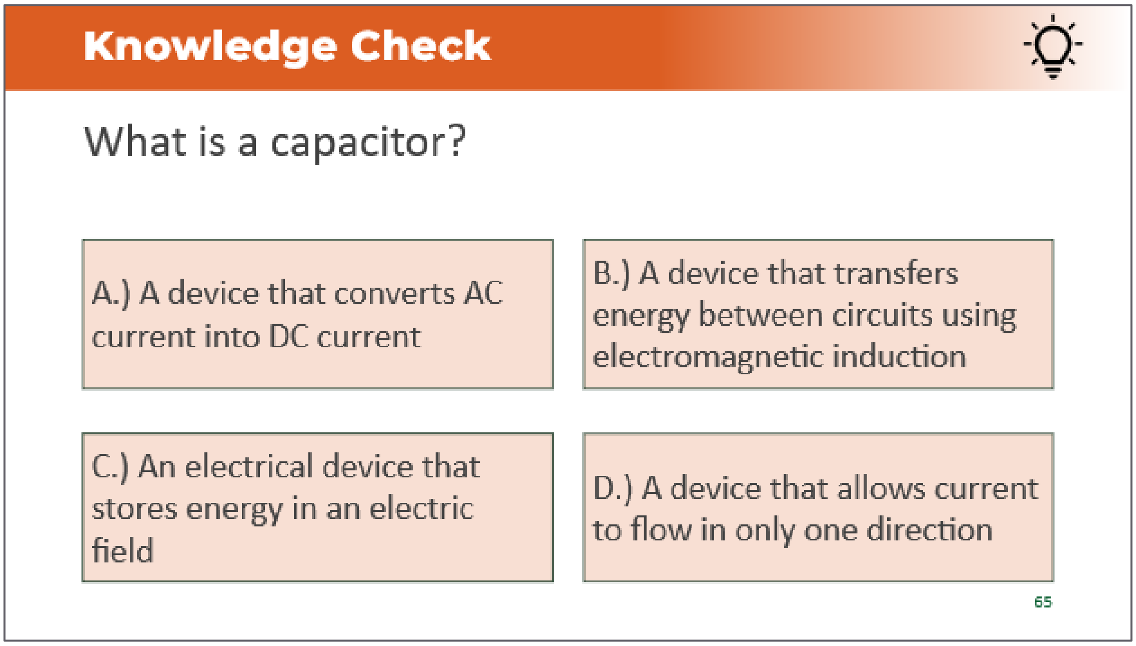

Knowledge Check
Why does circuit protection matter?
62

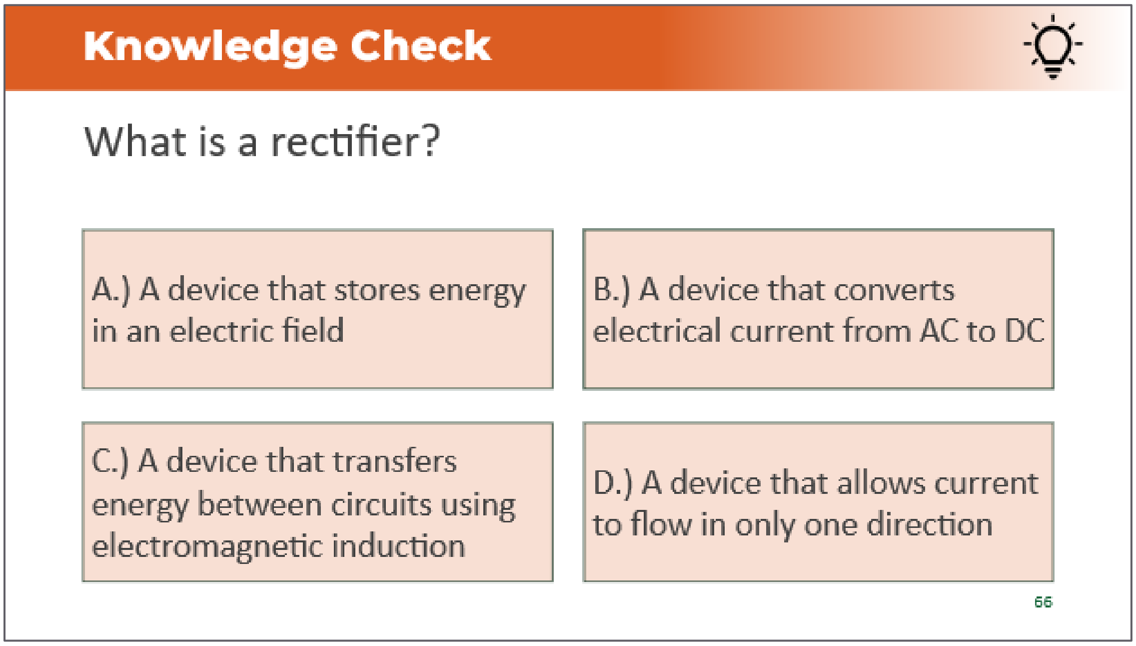

Knowledge Check
Match the key term with the correct description.
1. Relay
2. Switch
3. Diode
4. Transistor
A. Allows current to flow in only one direction.
B. Completes or breaks a circuit by allowing or preventing current flow.
C. An electromechanical device that uses a low-power signal to control a higher-power circuit.
D. A semiconductor device used to amplify or switch electronic signals.
63

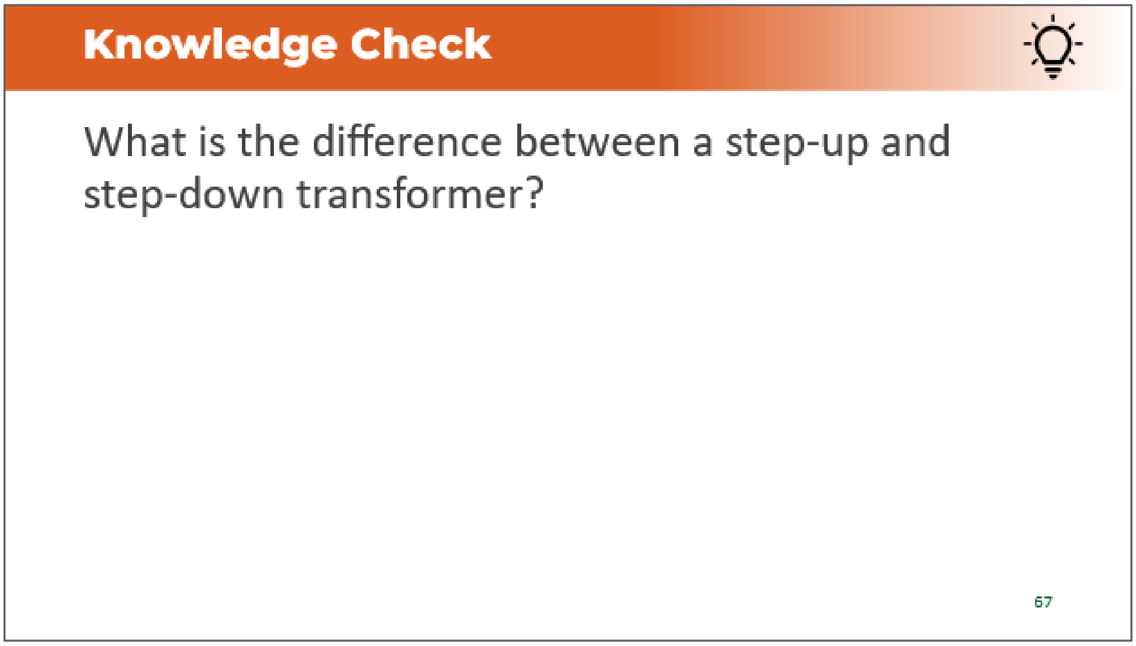
Knowledge Check

Walk us through reading a resistor using the image below.
Calculate the final resistance.

64


Knowledge Check
What is a capacitor?
A.) A device that converts AC current into DC current
B.) A device that transfers energy between circuits using electromagnetic induction
C.) An electrical device that stores energy in an electric field
D.) A device that allows current to flow in only one direction
65


Knowledge Check
What is a rectifier?
A.) A device that stores energy in an electric field
B.) A device that converts electrical current from AC to DC
C.) A device that transfers energy between circuits using electromagnetic induction
D.) A device that allows current to flow in only one direction
66

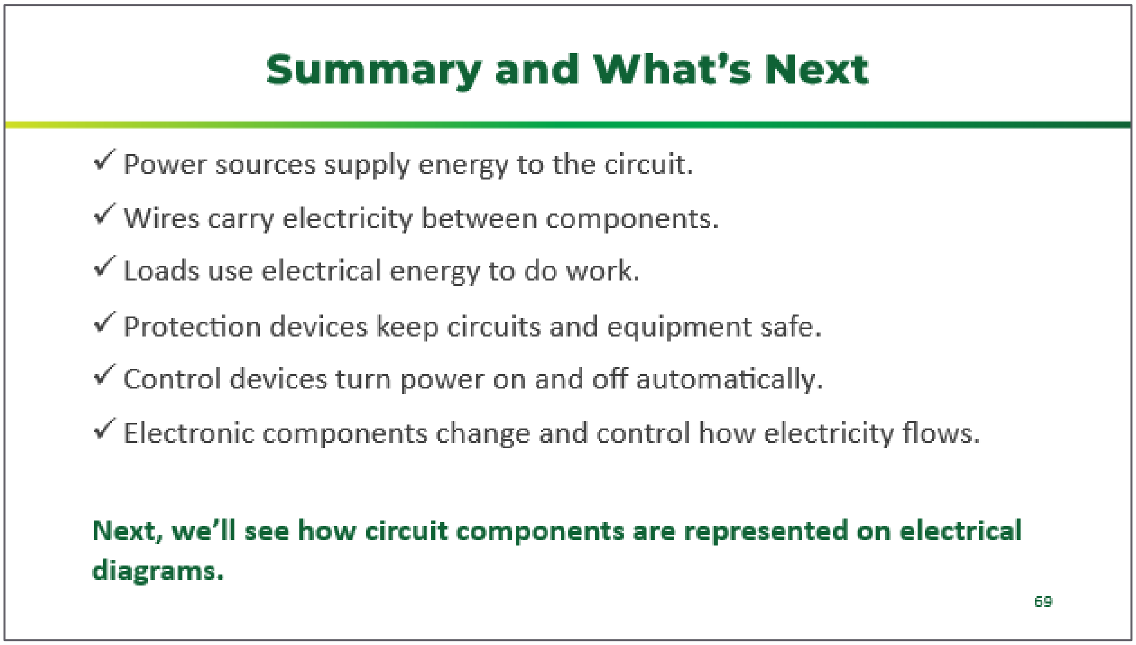

Knowledge Check
What is the difference between a step-up and step-down transformer?
67

Knowledge Check

A ___________ is a device that detects changes in conditions such as motion, temperature, pressure, light, or electrical fields and converts that change into a usable electrical signal.

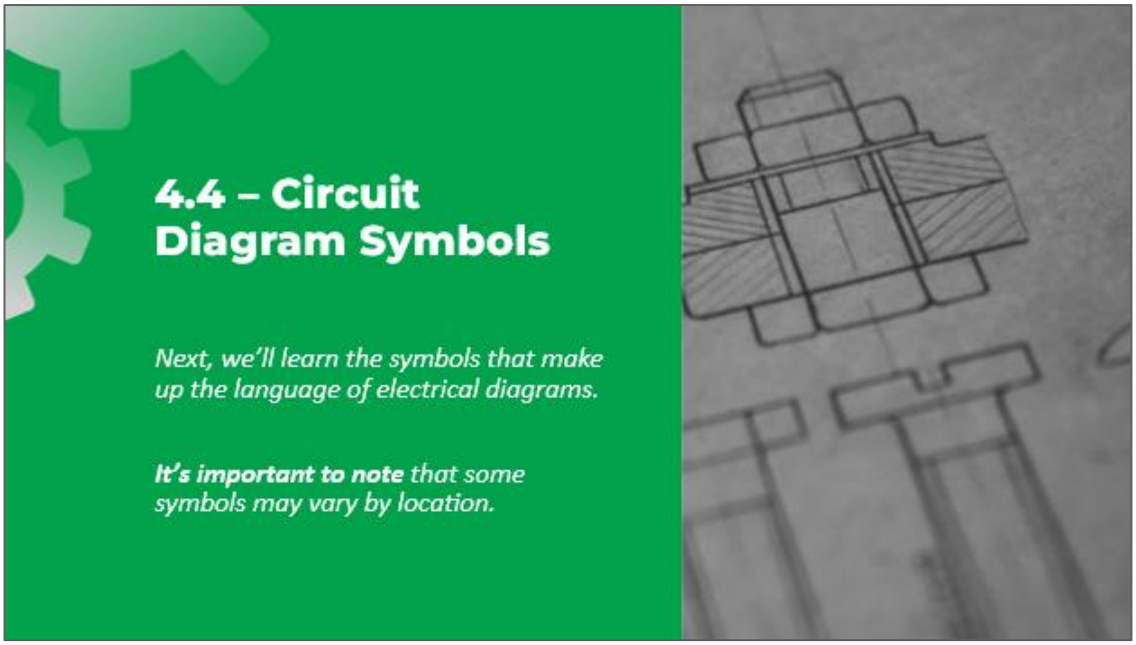
A.) Relay	B.) Electromagnet
C.) Transformer	D.) Sensor

68



Notes:

- We started by looking at **power sources**, which supply the energy that moves through a circuit.
- We discussed how **wires** act as the pathway, carrying electrical current between components.
- Then we looked at **loads**, which use electrical energy to perform work — whether that's producing light, motion, or heat.
- We also covered **protection devices**, which safeguard circuits and equipment from faults like overcurrent or short circuits.
- Next, we explored **control devices**, which allow circuits to turn on and off automatically.
- And finally, we introduced **electronic components** that regulate and shape how electricity flows through a system.
- **The key takeaway is this**: Every electrical system is made up of components that generate, carry, control, protect, and use electrical energy. Now that we understand the function of these parts, the next step is learning how they are represented visually.
- **Next, we'll see how circuit components are represented on electrical diagrams.**



Notes:

- Now that you know the parts of a circuit, let's see how those parts are shown on electrical diagrams.

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Why Electrical Symbols Matter

Electrical Diagrams use **symbols** instead of pictures.

Symbols are a shared language that technicians use to show:

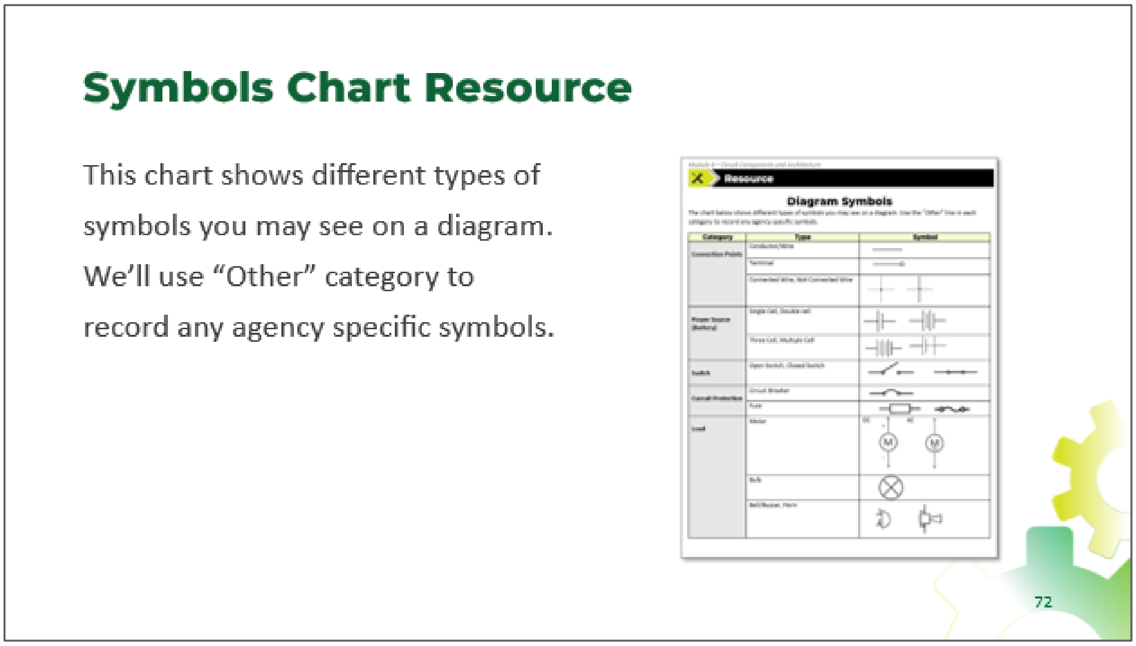
- Type of component
- Connection
- How electricity moves through the system

Learning symbols allows you to read any electrical diagram, even if you've never seen that system before.

71

Notes:

- Electrical Diagrams use **symbols** instead of pictures.
- Think of symbols like road signs. You don't need a picture of a stop sign to know what it means, the shape and color tell you what to do.
- Electrical symbols work the same way. Once you know them, you can look at any diagram and understand what parts are in the circuit and how they're connected.
- Symbols are a shared language that technicians use to show the type of component, their connection within the system, and how electricity moves through the system.
- Learning symbols allows you to read any electrical diagram, even if you've never seen that system before.



Notes:

- The Symbols Chart in your Participant Resource Guide will be a useful reference in this part of the lesson as we review diagram symbols.
- At times, you may need to add some agency specific symbols in the "Other" category on page two of the chart.

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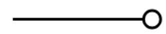
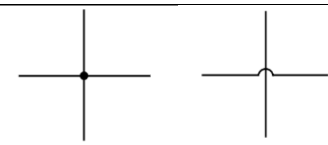
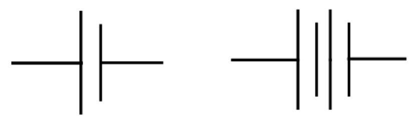
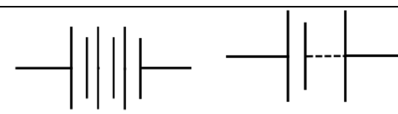
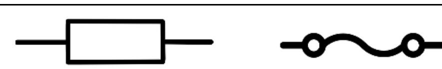
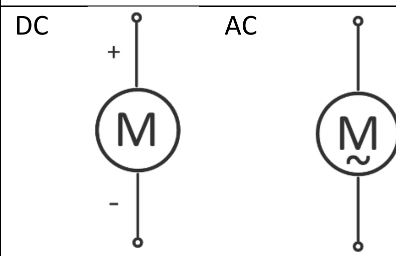
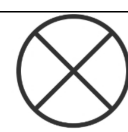
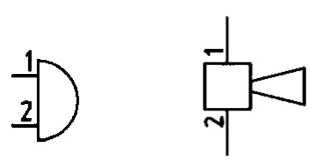
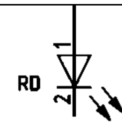
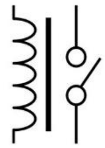
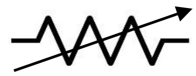
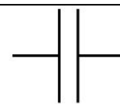
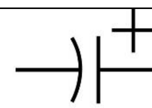
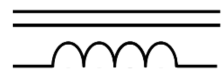
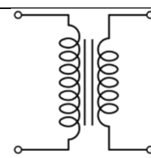
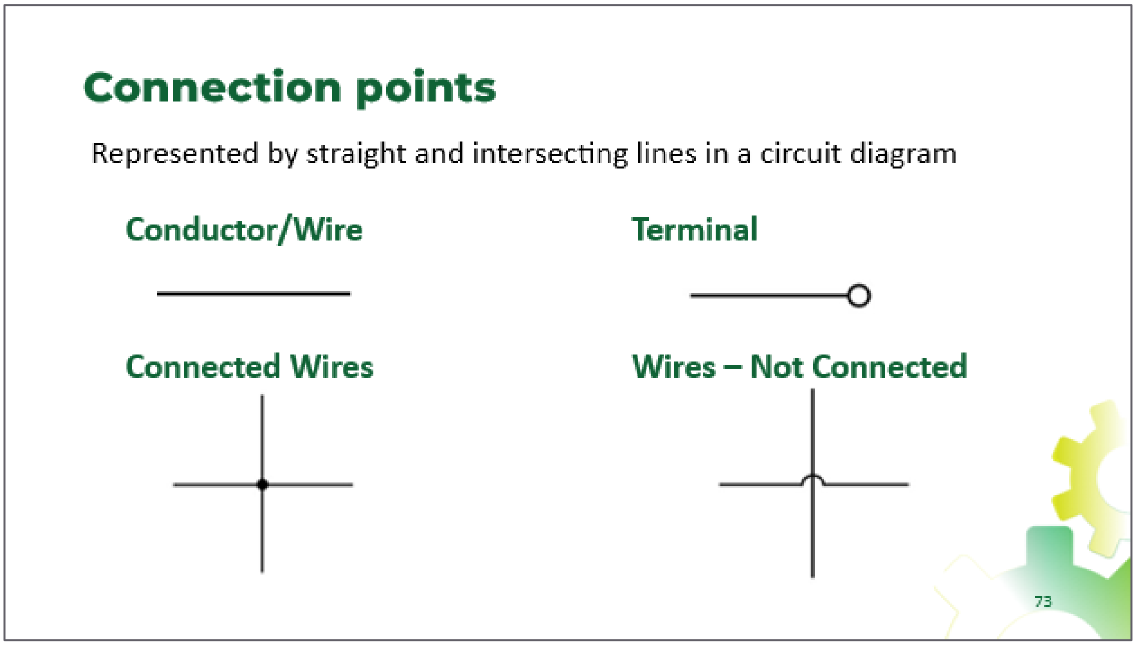
Resource

Diagram Symbols

The chart below shows different types of symbols you may see on a diagram. Use "*Other*" category to record any agency specific symbols.

Category	Type	Symbol
Connection Points	Conductor/Wire	
	Terminal	
	Connected Wire; Not Connected Wire	
Power Source (Battery)	Single Cell, Double cell	
	Three Cell, Multiple Cell	
Switch	Open Switch, Closed Switch	
Curcuit Protection	Circuit Breaker	
	Fuse	
Load	Motor	
	Bulb	
	Bell/Buzzer, Horn	

	LED Lamb, Incandescent Lamp	 
Diode	Standard diode	
Relay	Common Relay Symbol	
Resistor	Resistor, Variable Resistor	 
Capacitor	Standard Capacitor	 
Inductor	Air Core, Iron Core	 
	Ferrite Core, Variable Core	 
Transformer	Standard transformer	
	Other:	
OTHER		



Notes:

- In schematics, connections are shown using straight lines to represent conductors or wires.
- A simple straight line represents a **conductor** — the pathway for current to travel.
- A **terminal** is shown as a line ending in a small circle. That circle indicates a connection point where a wire connects to a device or component.
- When wires are **connected**, you will see a solid dot at the intersection. That dot indicates an electrical connection — current can flow between those conductors.
- When wires are **not connected**, one wire will typically "jump" over the other using a small arc. That shows the wires cross visually, but they are not electrically connected.
- This distinction is critical when reading diagrams. Missing or misreading a connection dot can completely change how a circuit functions.

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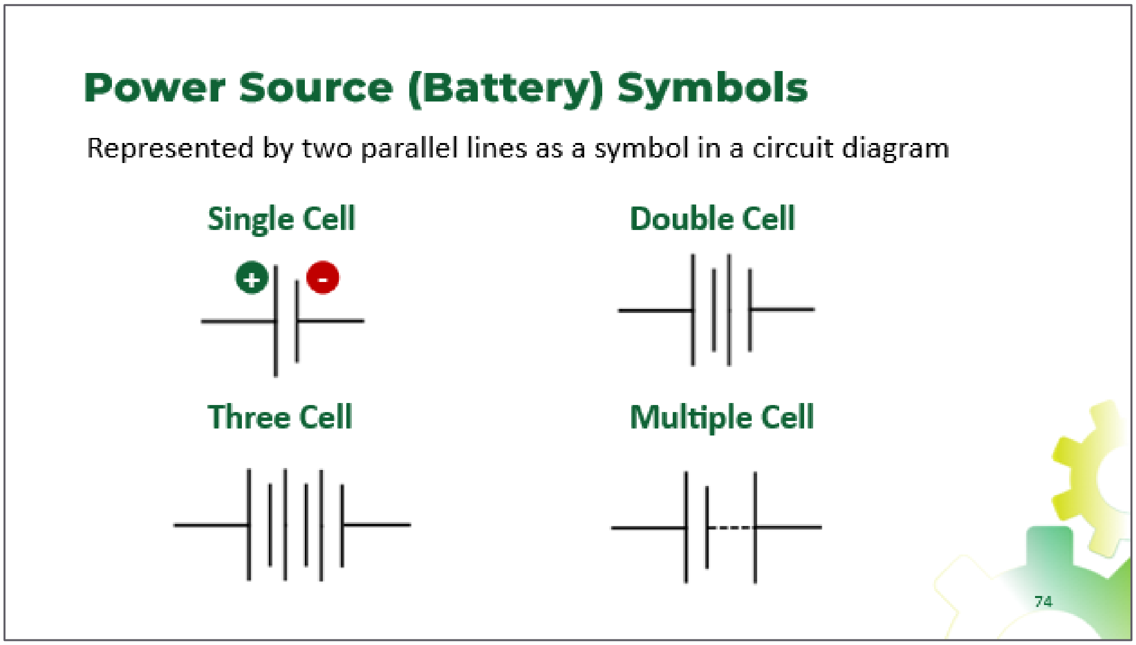

Notes:

- A battery or DC power source is shown using **two parallel lines**.
  - One line is longer, and one line is shorter.
- The **longer line represents the positive terminal**, and the **shorter line represents the negative terminal**.
  - That length difference is important — it tells you polarity.
- There are a few types of batteries represented on this slide:
- **Single Cell** - A single cell has one long line and one short line. This represents one voltage source — like a single battery cell.
- **Double Cell** - A double cell symbol shows two sets of long and short lines. Each pair represents another cell added in series. More cells mean higher total voltage.
- **Three Cell** - With three sets of long and short lines, you have three cells in series. Each additional cell increases the total voltage supplied to the circuit.
- **Multiple Cell** - The multiple-cell symbol is often simplified with dashed or abbreviated lines. Instead of drawing every cell individually, the diagram shows that there are multiple cells connected in series. This keeps complex diagrams cleaner while still communicating that multiple voltage sources are present.

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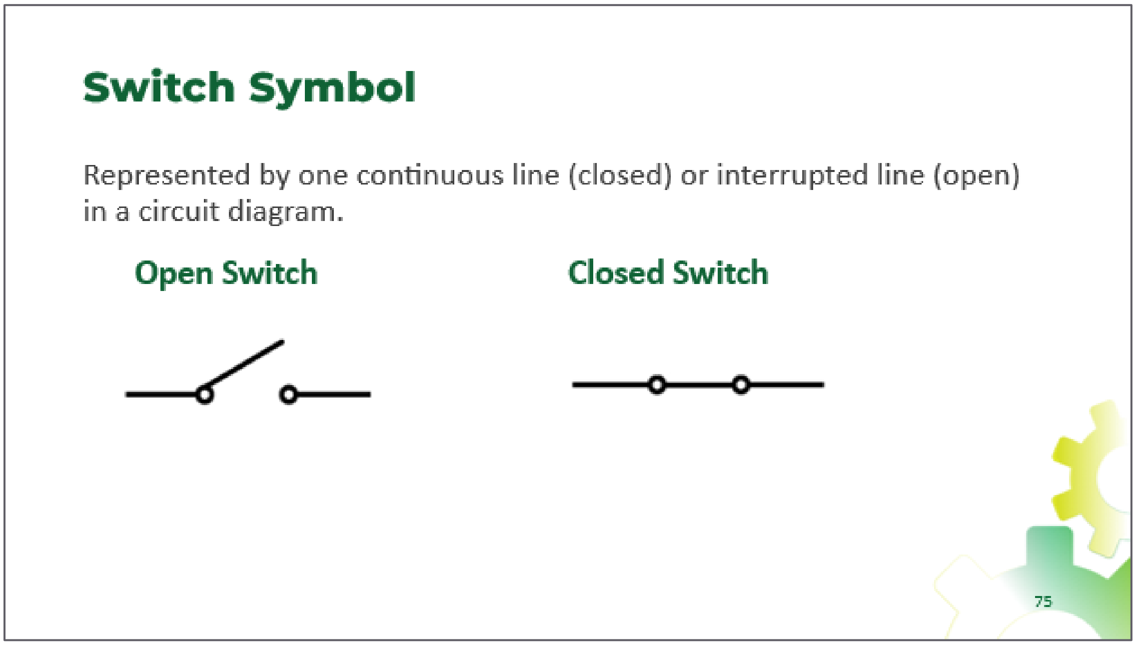

Notes:

- A switch is shown as either a continuous line or an interrupted line, depending on its position.
- An **open switch** is shown with a gap in the line. That gap indicates the circuit is broken, and current cannot flow.
- When a switch is open, the path is interrupted — just like turning a light switch off.
- A **closed switch** is shown as a continuous line. This means the circuit path is complete, and current is allowed to flow.
- When a switch is closed, electricity can move through the circuit and power the load.
- There are other examples that may be specific depending on the setup of a circuit. On the right you will see two agency specific switch symbols used at CATS (Charlotte Area Transit System).

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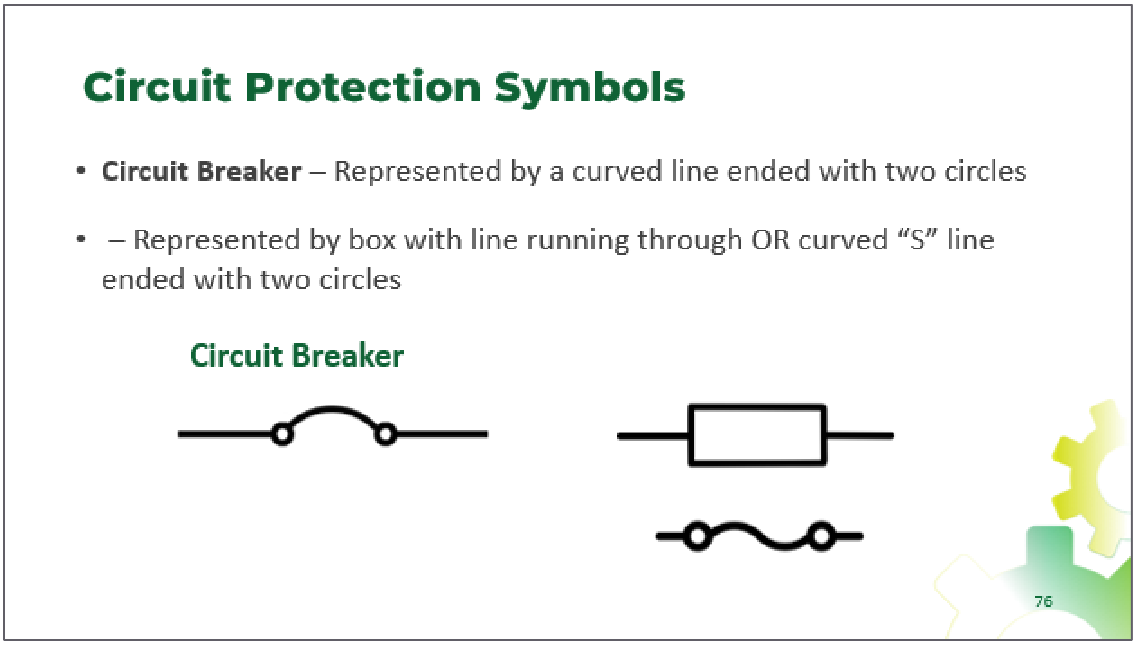

Notes:

- Now let's look at how circuit protection devices are represented on electrical diagrams.
- First, the **circuit breaker** symbol is:
    - A circuit breaker is typically shown as a curved line between two connection points, often ending in small circles.
- This symbol represents a protective device that can open the circuit automatically if current exceeds a safe limit.
- Unlike a , a circuit breaker can usually be reset after the fault is cleared.
- Next, the symbol. May be represented in one of two common ways:
    - A rectangular box with a line running through it or a curved "S" shaped line between two connection points
    - Both symbols represent a device designed to protect the circuit from overcurrent.
- When excessive current flows, the element melts, permanently opening the circuit.
- Unlike a breaker, a must be replaced after it operates.

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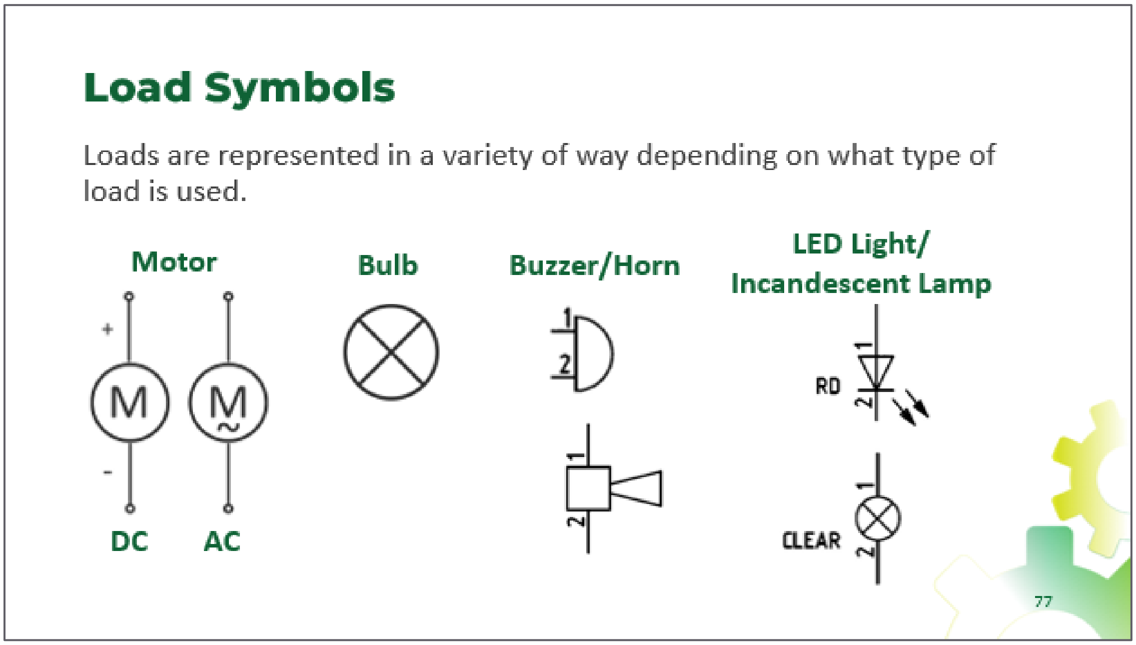

Notes:

- Next, Now let's look at how loads are represented on electrical diagrams.
- Loads can appear in different forms depending on what the circuit is powering. The symbols may vary slightly depending on the agency or application, but the core representations remain consistent.
- **Motors (DC and AC)**
  - The symbols shown here represent both DC motors and AC motors.
    - DC voltage is commonly supplied by batteries or DC power supplies.
    - AC voltage typically comes from wall outlets in homes and facilities.
  - On schematics, DC motors are usually marked clearly, and AC motors may include a small sine wave symbol to indicate alternating current.
- **Light Bulb**
  - In this module, we'll often focus on a basic load like a light bulb.
  - The standard symbol for a bulb is a circle with an "X" inside.
  - This represents a simple resistive load that converts electrical energy into light and heat.
- **Buzzer or Horn**
  - The buzzer or horn symbol represents an audible load — something that produces sound. These are common in alarms, signaling systems, and warning circuits.
- **LED / Incandescent Lamp**
  - LEDs have a distinct symbol showing a diode with arrows pointing outward, representing light emission.
  - An incandescent lamp uses the circular "X" symbol, similar to a general bulb.
  - The labels may indicate color, such as RD for red or CLEAR for standard incandescent.

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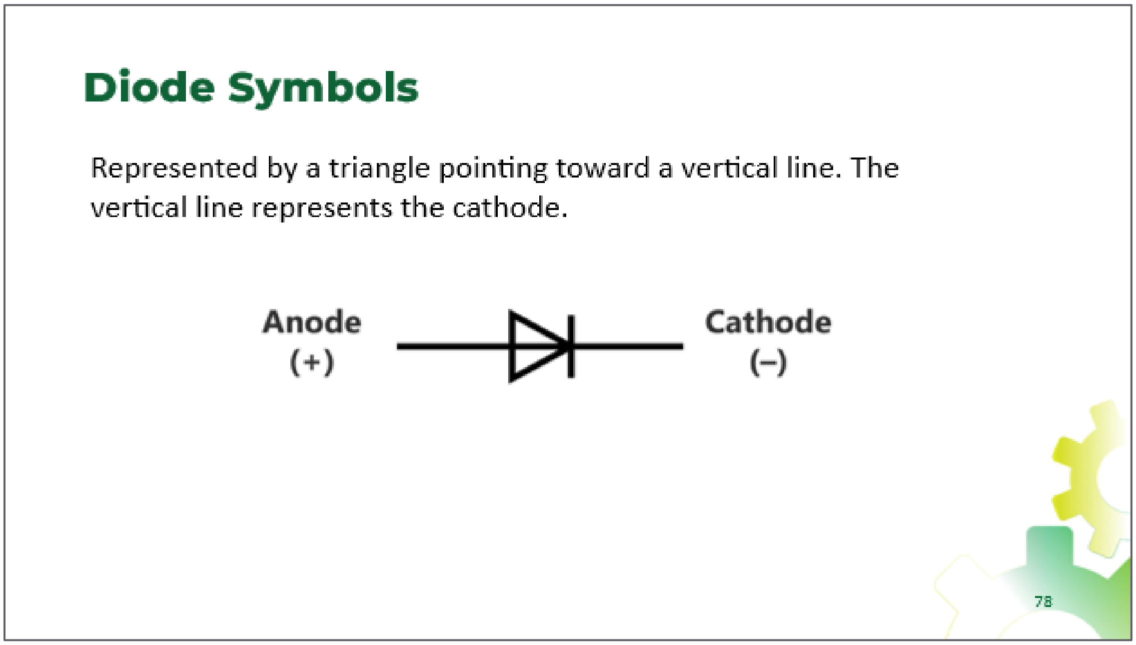
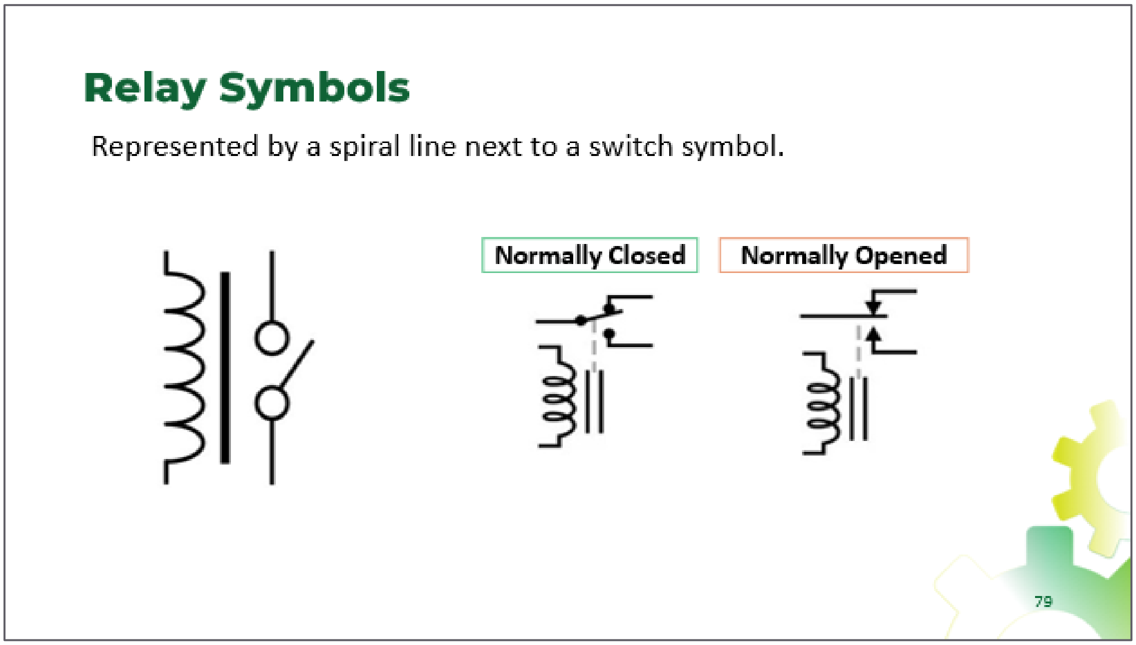


Notes:

- The symbol for a **diode** is a triangle pointing toward a vertical line. The triangle represents the anode, and the vertical line represents the cathode.
- On a schematic, the diode symbol shows the direction conventional current is allowed to flow — from anode to cathode.
- Diodes control and protect circuits by allowing current to flow in one direction while blocking reverse current.
- When you see a diode symbol, pay close attention to its orientation, especially during troubleshooting, because current can only flow in one direction.



Notes:

- What symbol do you see here that we have already talked about?
- A relay symbol typically consists of two main parts:
  - A **coil**, shown as a spiral or curved line.
  - One or more **switch contacts**, shown using standard switch symbols.
- The coil represents the electromagnet inside the relay.
- When current flows through the coil, it creates a magnetic field. That magnetic field mechanically moves the switch contacts.

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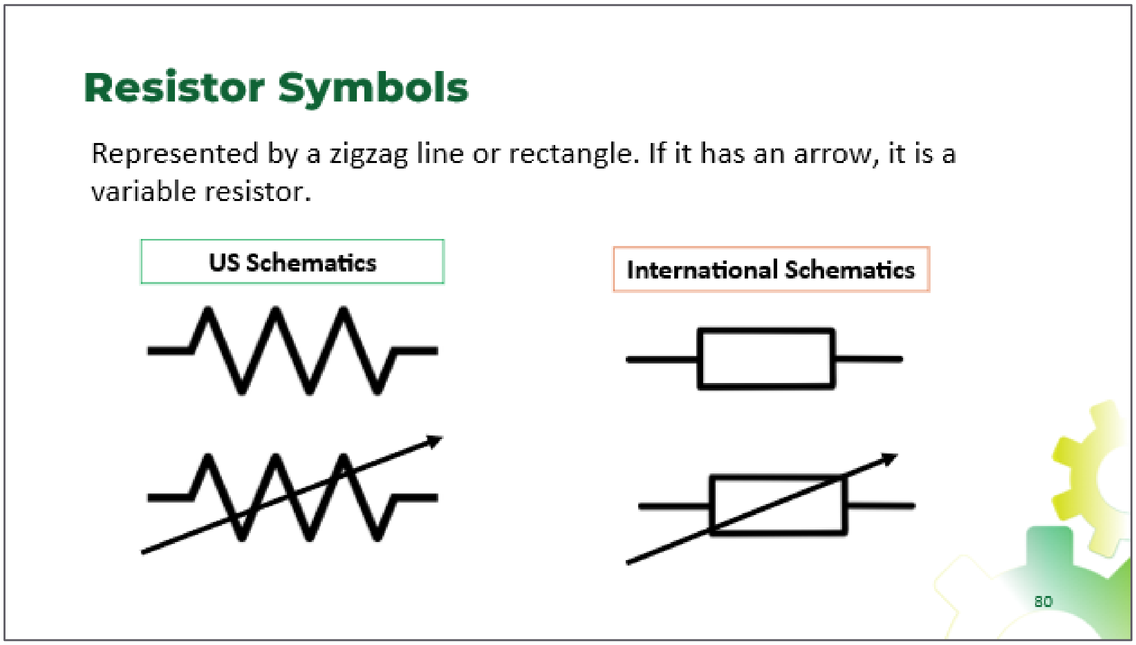

Notes:

- Resistors are typically shown in one of two standard formats.
  - The first is a **zigzag line**. This is the common symbol used in many U.S. schematics.
  - The second is a **rectangle**. This version is often used in international or IEC-style diagrams.
- Both symbols represent the same component — a fixed resistor.
- A **variable resistor** will have an **arrow crossing the resistor symbol**, which indicates it is adjustable.
- The arrow represents the movable contact that changes the resistance value.
- Variable resistors are used when you need to adjust current or voltage levels in a circuit — for example, in volume controls or tuning circuits.

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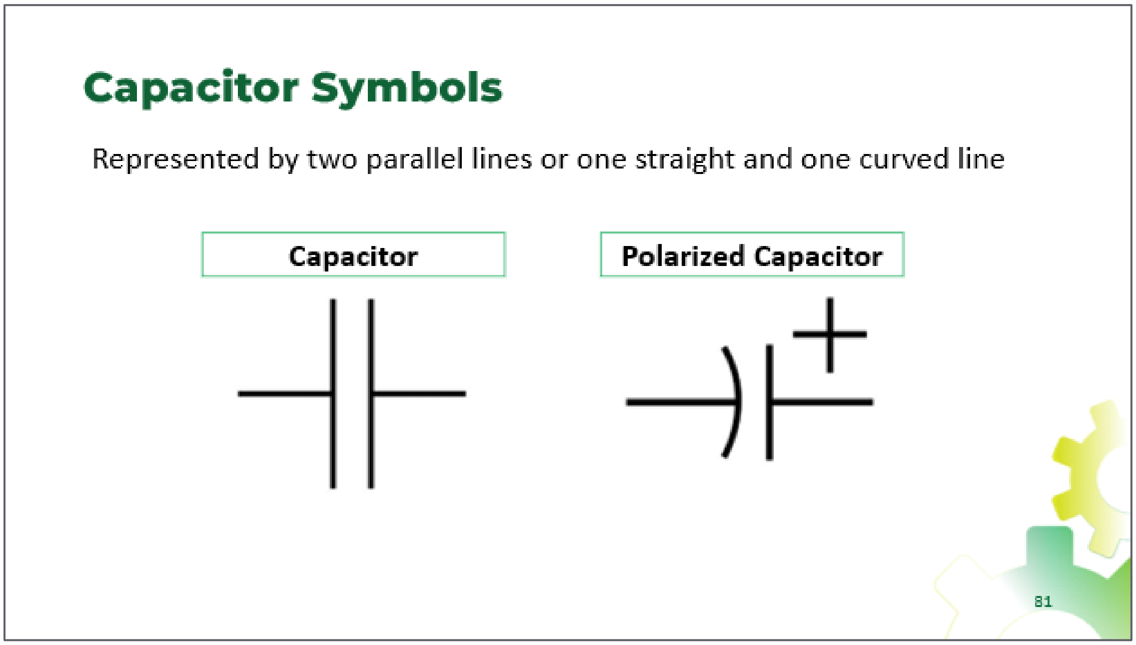

Notes:

- The symbol for a capacitor is shown as **two parallel lines**. Those lines represent the two conductive plates inside the device.
- Sometimes, you'll see one straight line and one curved line.
  - This typically represents a **polarized capacitor**, where orientation matters. The curved plate often indicates the negative side, and you may see a plus sign marking the positive terminal.
  - As mentioned earlier in the module, the function of a capacitor is to **store and release electrical energy**.
- Capacitors store energy in an electric field created between those two plates.
- When reading a schematic, the **capacitance value** listed next to the symbol tells you how much energy the capacitor can store and release at a given voltage.
- Understanding this relationship helps you predict how the capacitor will behave in a circuit.

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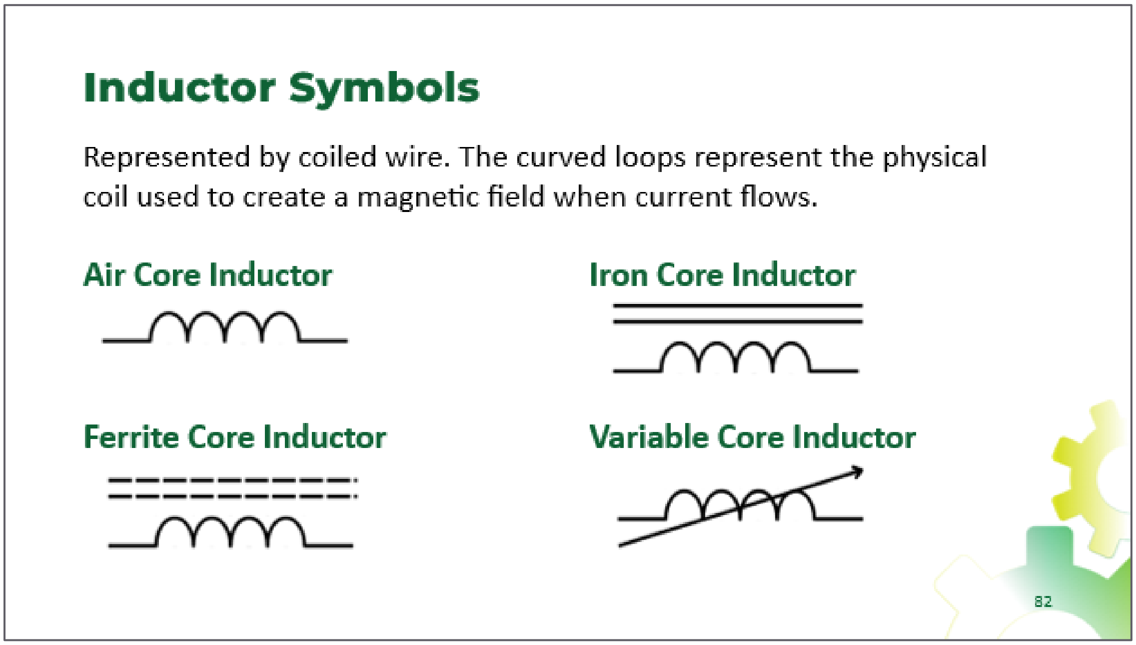

Notes:

- The symbol for an inductor is a **coiled wire**. The curved loops represent the physical coil used to create a magnetic field when current flows.
- As mentioned earlier in the module, the primary function of an inductor is to **store energy in a magnetic field**.
- When current flows through the coil, a magnetic field forms around it. That magnetic field is where the energy is temporarily stored.
- This slide shows a few different types of inductors.
- **Air Core Inductor**
  - The basic inductor symbol — just the **coil** — usually represents an air core inductor.
  - This means there is no magnetic core material inside the coil. The magnetic field is created in open air.
  - Air core inductors are common in high-frequency applications.
- **Iron Core Inductor**
  - When you see **solid parallel lines** next to the coil, that indicates an iron core inductor.
  - The solid lines represent a ferromagnetic core placed inside the coil.
  - Adding an iron core increases the inductance by strengthening the magnetic field.
- **Ferrite Core Inductor**
  - If the parallel lines appear **dashed**, that typically represents a ferrite core.
  - Ferrite materials are commonly used in electronics because they perform well at higher frequencies and reduce energy losses.
- **Variable Core Inductor**
  - If an adjustable core, which allows the inductance value to be changed.
  - These are often used in tuning circuits, such as radios or signal processing systems.

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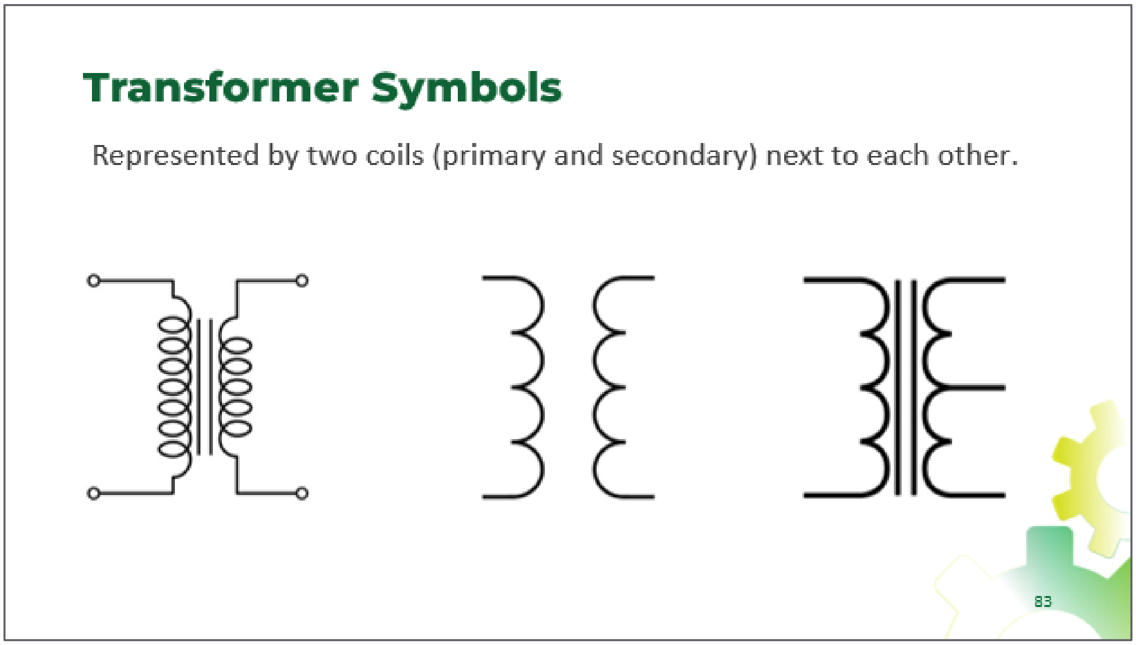

Notes:

- A **transformer** symbol consists of two coils placed next to each other.
- One coil represents the primary winding, and the other represents the secondary winding.
- The key idea is that these two coils are magnetically coupled but not electrically connected.
- Energy is transferred from the primary to the secondary through electromagnetic induction.
- Sometimes you'll see the two coils drawn without any lines between them.
- Other times, you'll see parallel vertical lines between the coils.
- Those lines represent a magnetic core — usually iron — that helps strengthen and guide the magnetic field between the windings.
- So then:
  - Two coils side-by-side = transformer
  - Lines between them = magnetic core

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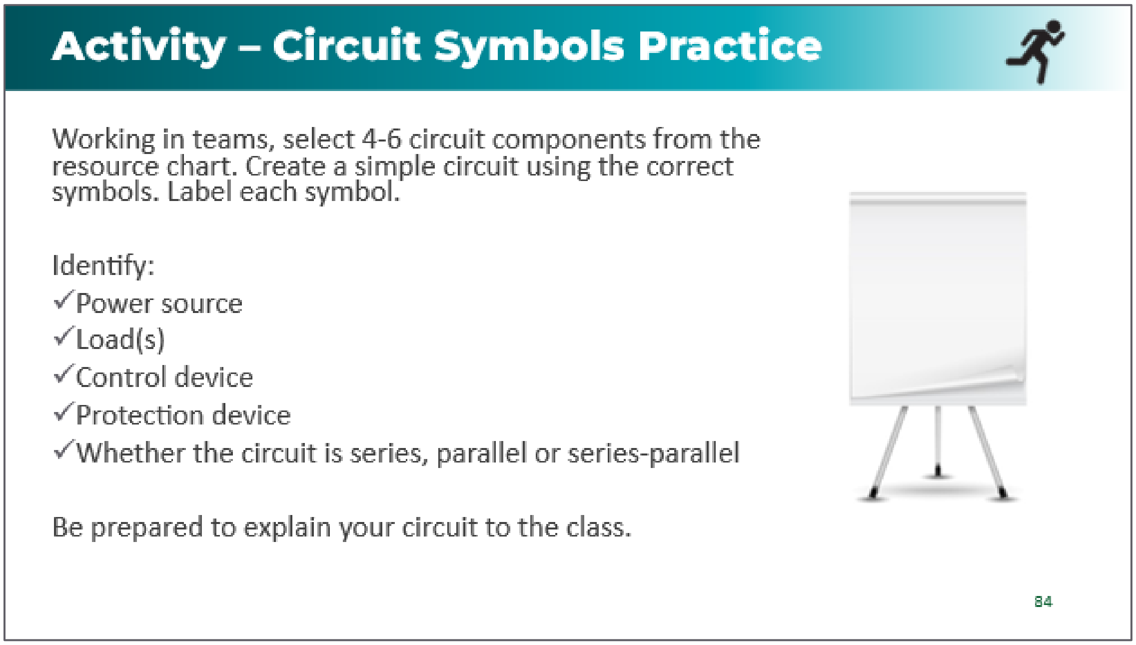


Notes:

- After the activity, answer the following debrief questions:
    - Which symbols appeared most frequently in your circuits?
    - How did you determine whether your circuit was series, parallel, or series-parallel?
    - Why is it important for technicians to use standardized symbols instead of drawings or pictures?
    - How do symbols make electrical diagrams easier to read and troubleshoot?

Key Takeaway:
Electrical symbols provide a standardized language that allows technicians to quickly understand, communicate, and troubleshoot electrical circuits regardless of the equipment or manufacturer.

Knowledge Check

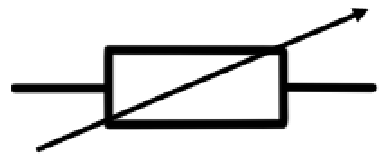
What does this image represent?

A. Variable resistor

B. Transformer

C. Inductor

D. Diode



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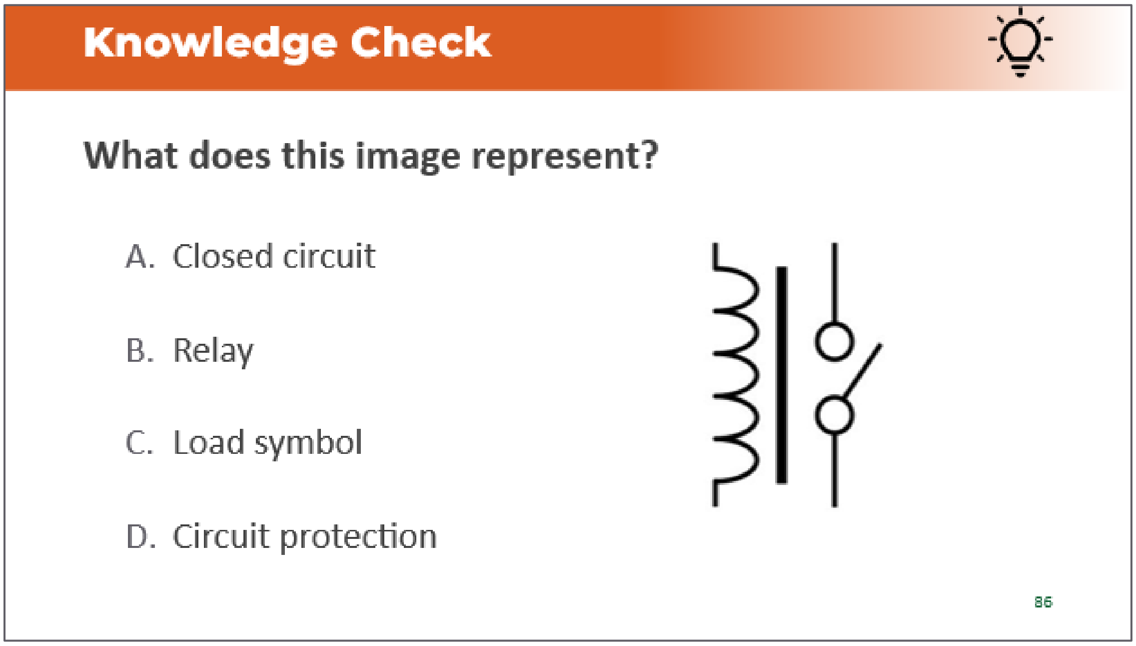
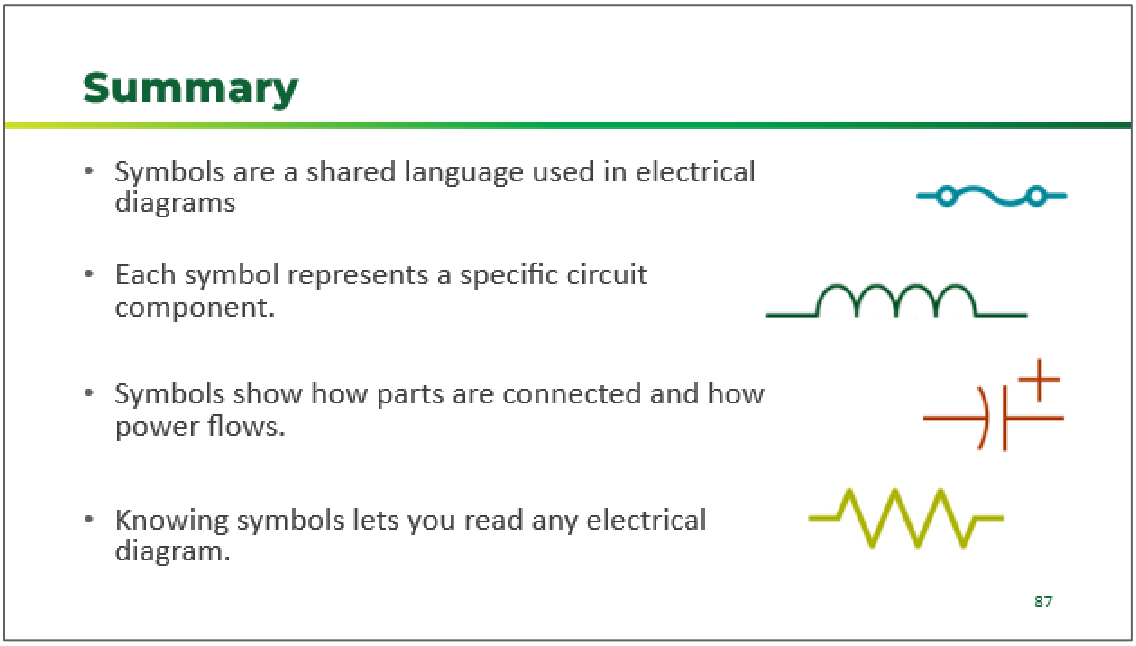

Knowledge Check
What does this image represent?
A. Closed circuit
B. Relay
C. Load symbol
D. Circuit protection
86

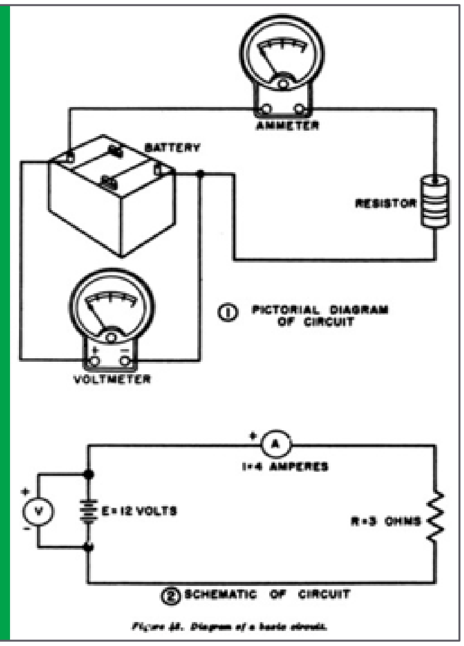


Notes:

- Symbols are a shared language used in electrical diagrams. No matter the system, these symbols allow technicians, engineers, and electricians to communicate clearly.
- Each symbol represents a specific circuit component. When you see a symbol, you should immediately recognize the type of device and its function.
- Symbols don't just show components — they show how parts are connected and how power flows through the system.
- Once you understand the symbols, you can read and interpret electrical diagrams with confidence.
- That ability is critical for troubleshooting, installation, and system analysis.
- As we move forward, we'll begin applying these symbols in full diagrams so you can practice identifying components and understanding how entire systems operate.

4.5 – Electrical Circuit Diagrams

Now that we've learned the common electrical symbols used in schematics, let's see how those symbols are combined to create electrical circuit diagrams.



Notes:

- Now that we've learned the common electrical symbols used in schematics, let's see how those symbols are combined to create electrical circuit diagrams.

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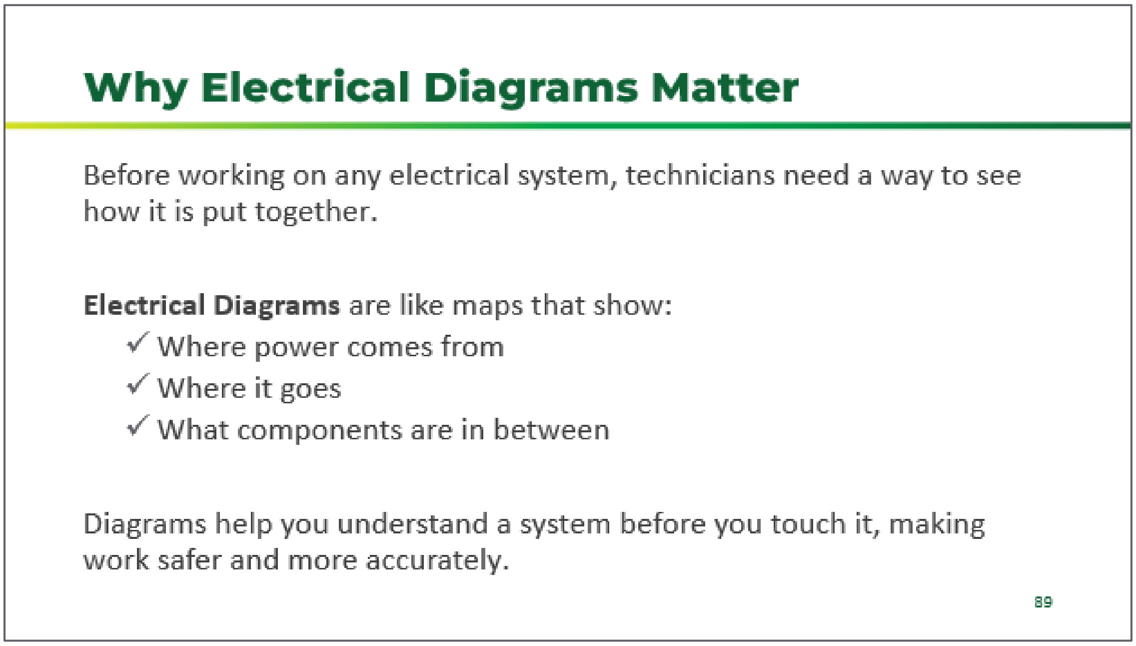
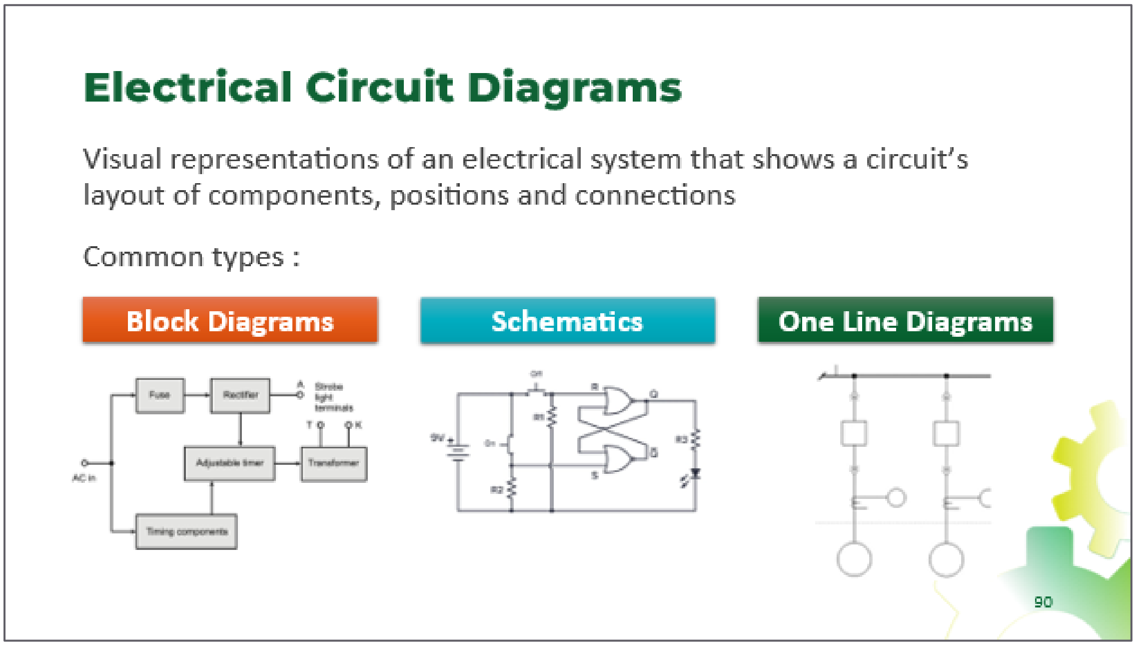


Notes:

- You will not yet be using diagrams to fix things, that comes later after more advanced training. Right now, diagrams help to guide your understanding.
- You will learn about where power comes from, where it goes, and what components are used in the different systems we will discuss.
- A common question you might ask is: What is this system made of and how is it connected?
- Understanding a system before you even tough it, will help improve your safety, communication, and understanding what you're looking at when you open a cabinet or panel.
- Electrical diagrams are similar to maps. They are a visual representation of an electrical system, usually with a map or drawing that shows a circuit's layout of components, positions and connections.



Notes:

- Before a technician works on a system, they need a way to see how it's put together.
- Electrical diagrams show where power comes from, where it goes, and what's in between.
- An **electrical circuit diagrams** are visual representations of an electrical system, usually with a map or drawing that shows a circuit's layout of components, positions and connections.
- Primary types of electrical circuit diagrams can include the following:
  - Block diagrams
  - Schematics
  - One-line diagrams (also called single-line diagrams)

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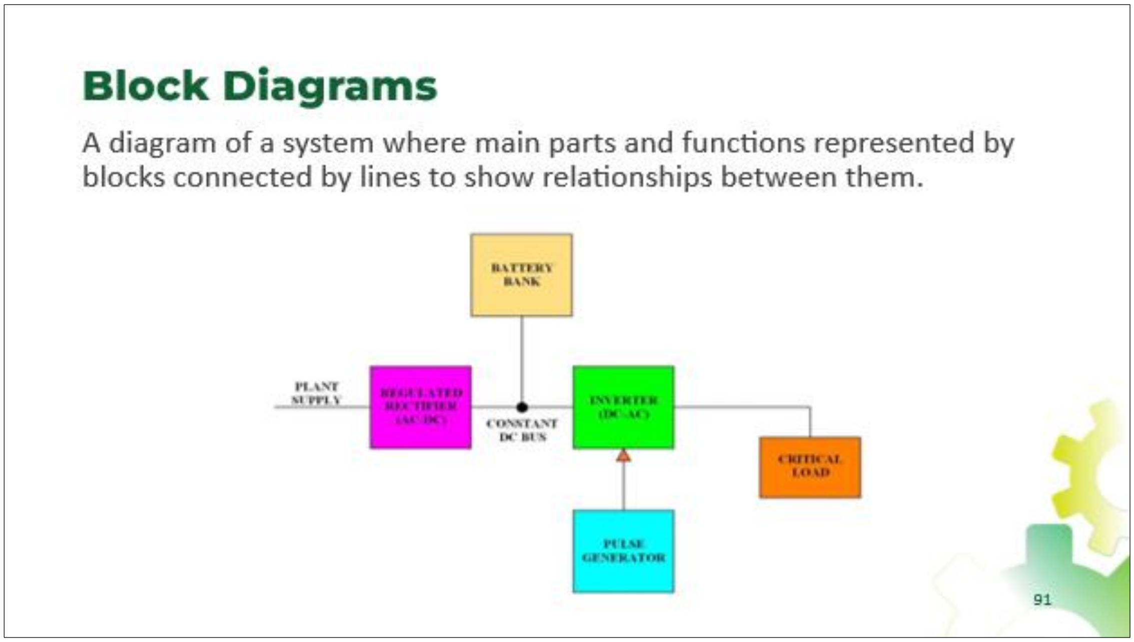

Notes:

- A **block diagram** is a diagram of the system in which the principal parts or functions are represented by blocks connected by lines that show the relationships of the blocks.
- You should consider the block diagram a more general, less detailed description of the electrical system that is aimed more at understanding the overall concepts and less at understanding the details of circuit operation.

- What does it help you do?

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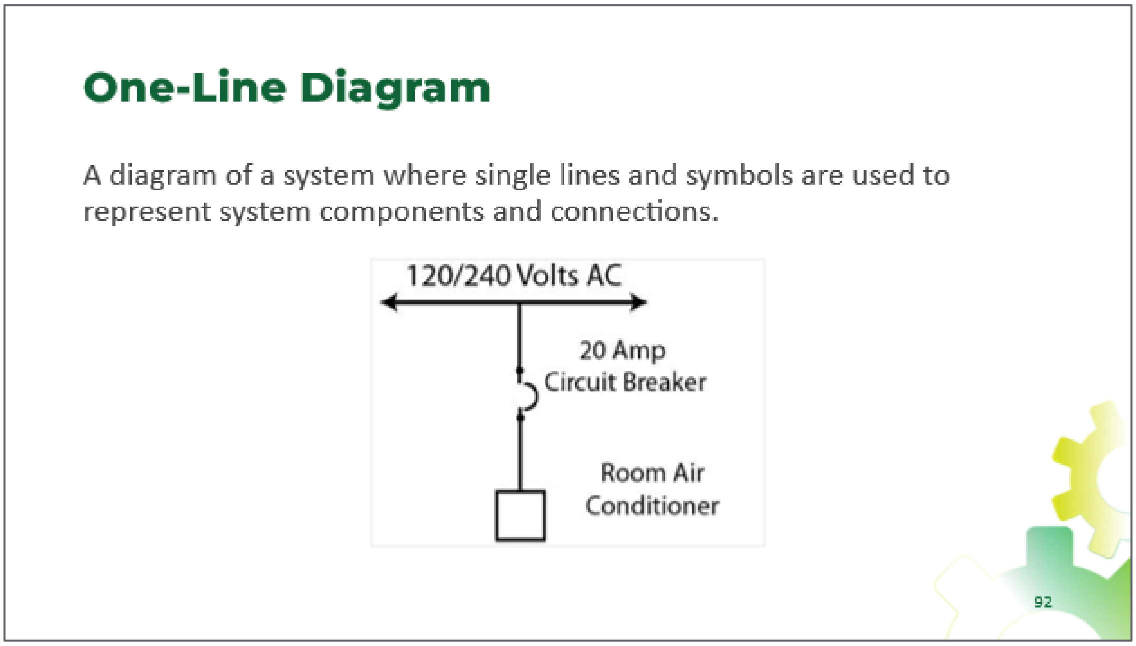
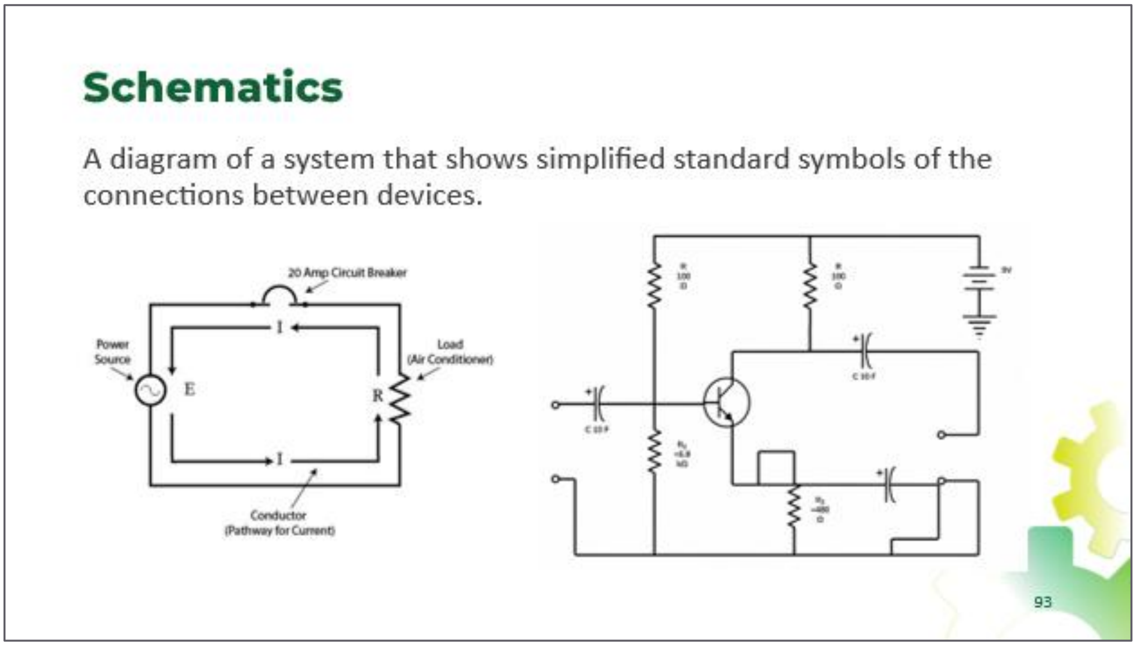


Notes:

- A **one-line diagram** also known as a single-line diagram is a simplified notation for representing an electrical system.
- The one-line diagram is similar to a block diagram except that electrical elements such as switches, circuit breakers, transformers, and capacitors are shown by standardized schematic symbols.
- A one-line diagram uses simple symbols and a single line to show how major electrical components are connected.
- These diagrams focus on the overall flow of power, rather than showing detailed wiring.
- You can familiarize yourself with the electrical system by using these simple, no-frills diagrams.

- What does it help you do?



Notes:

- A **schematic** is a diagram that shows the components of the circuit as simplified standard symbols showing the connections between the devices including power and signal connections.
- The arrangement of the components interconnections on the diagram does not correspond to their physical locations in the finished device.

- What are schematics used for? What does it help you do?
- When have you seen schematics used?
- What does it help you do?

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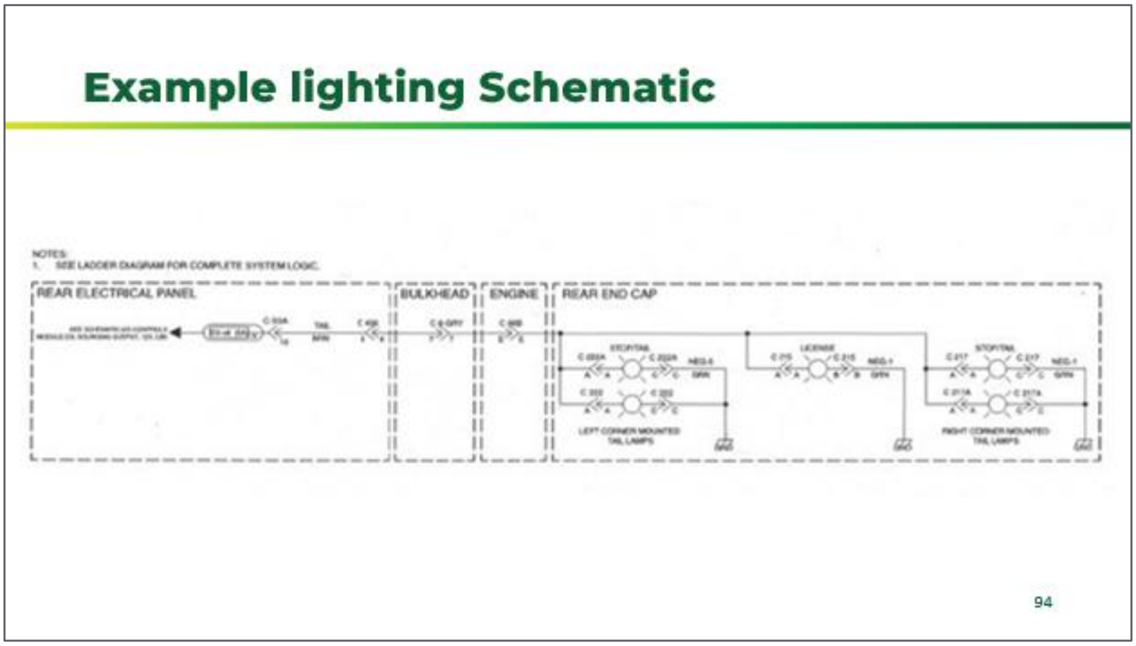

Notes:

- Up to this point, we've been working with simplified circuits to learn how current flows and how components are connected.
- Real-world schematics are more detailed, but they follow the same electrical principles.
- This diagram shows several lighting circuits located at the rear of a bus, including tail lights, stop lights, and license plate lighting.
- Notice that multiple lighting circuits are connected to the same power source while operating independently. This is an example of parallel circuit design.
- Individual lamps within a branch may be connected in a way that creates a series or series-parallel arrangement.
- Understanding series, parallel, and series-parallel circuits helps technicians predict how a system will behave when a component fails.
- For example, if one lighting branch fails, other branches may continue to operate because they have their own current path.
- Technicians use schematics like this to trace power, identify components, and troubleshoot faults efficiently.

- Can you identify any parallel branches in this diagram?
- Why do you think vehicle lighting systems are commonly designed using parallel circuits?
- How would this diagram help a technician troubleshoot an inoperative light?

Key Takeaway:

Although real-world schematics appear more complex than the examples we've practiced, they are built from the same series, parallel, and series-parallel circuit concepts. Understanding those foundational concepts makes larger diagrams much easier to read and troubleshoot.

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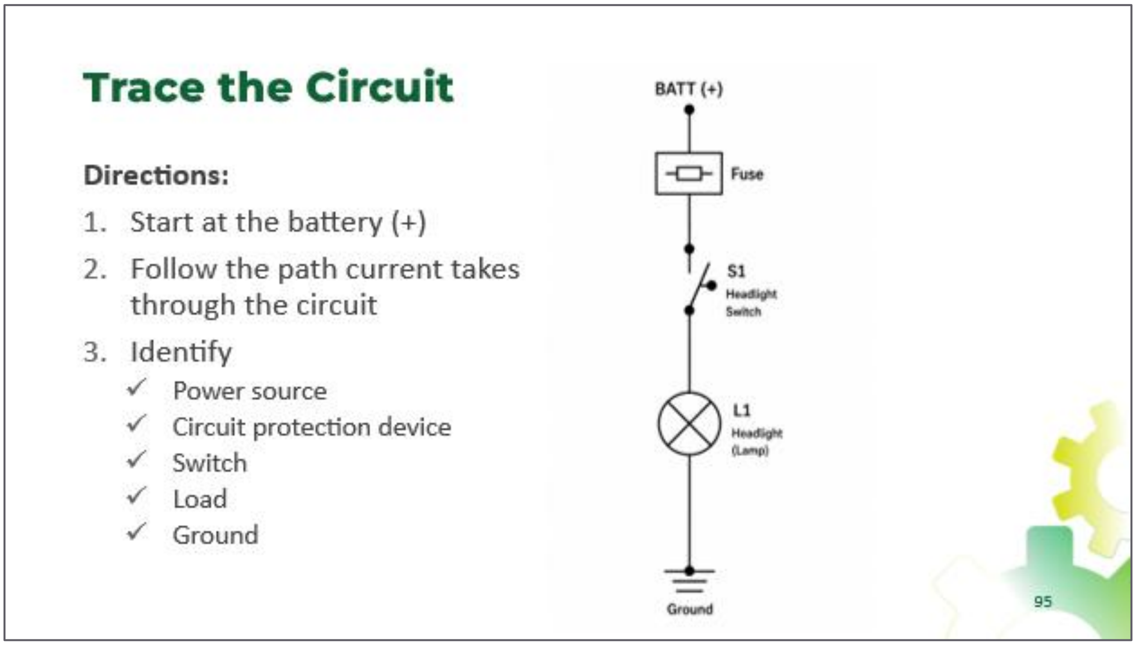
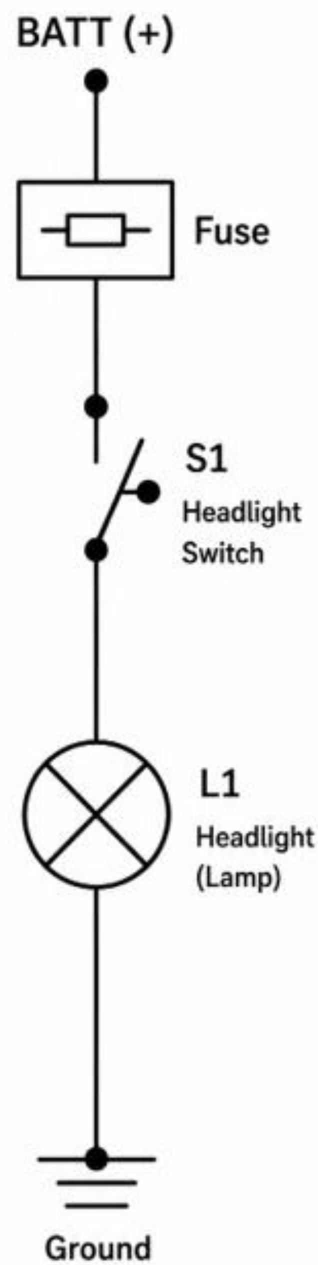


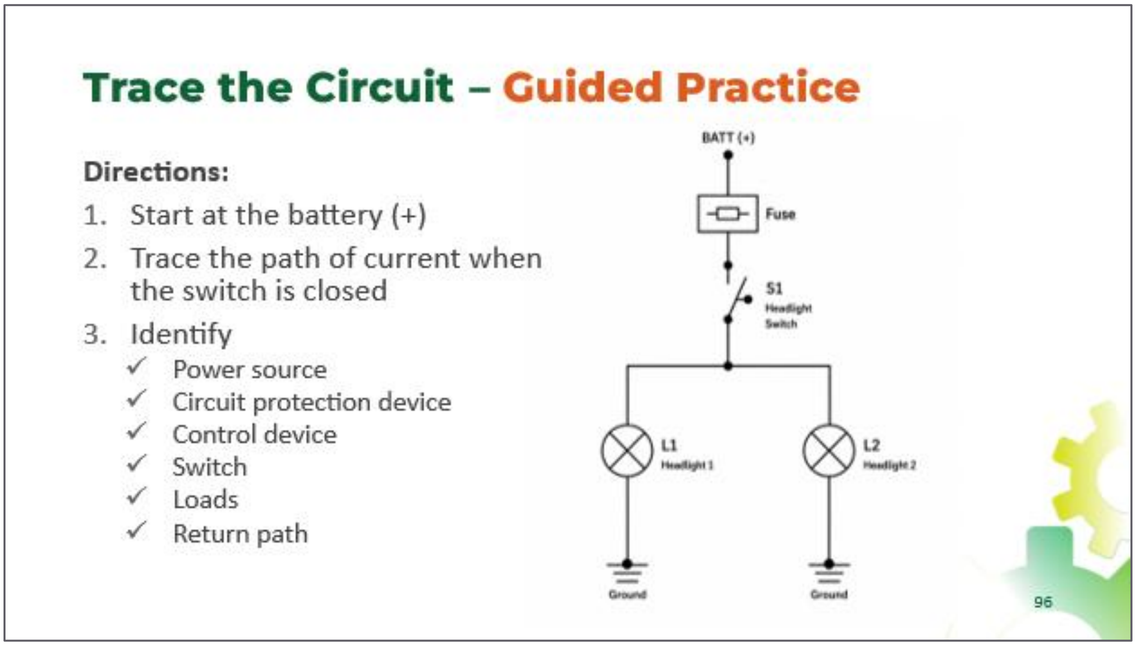
Notes:

- Current leaves the **battery positive terminal**, which serves as the power source for the circuit.
- Current travels through the **fuse**, which protects the circuit from excessive current.
- Current then reaches the **switch (S1)**.
- When the switch is closed, current continues to the **headlight (L1)**.
- The headlight acts as the **load**, converting electrical energy into light.
- Current returns through the **ground path** to complete the circuit.
- When troubleshooting, technicians trace the flow of current from the source to the load and back to the source to identify where the circuit has been interrupted.

- Which component is the power source?
- Which component provides circuit protection?
- Which component controls current flow?
- Which component is the load?

Key Takeaway:
Electrical troubleshooting begins by tracing the path of current through the circuit and identifying where that path is interrupted.


BATT (+)
Fuse
S1
Headlight
Switch
L1
Headlight
(Lamp)
Ground

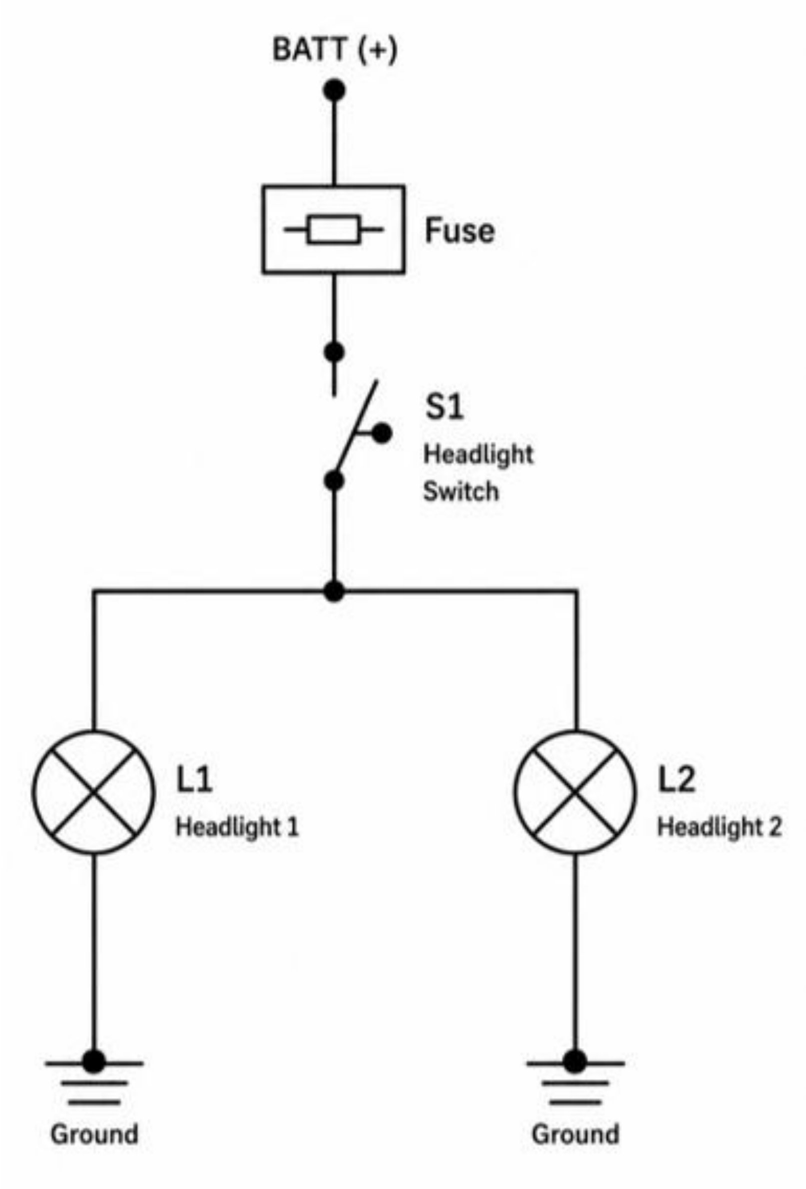


Notes:

- Current leaves the battery positive terminal and travels through the fuse.
- The fuse protects the circuit from excessive current.
- Current reaches switch S1.
- When S1 closes, current can flow into the circuit.
- At the junction, current has two paths available.
- One path supplies Headlight 1 (L1).
- The second path supplies Headlight 2 (L2).
- This is a **parallel circuit** because both loads are connected across the same source voltage.
- After passing through each headlight, current returns to the battery through its ground connection.
- Because the headlights are connected in parallel, each lamp can operate independently of the other.

- Where does current originate?
- What component protects the circuit?
- What component controls current flow?
- What type of circuit is shown?
- Why are there two paths for current?
- What happens when the switch closes?

Key Takeaway:
In a parallel circuit, current has multiple paths. A failure in one branch does not necessarily stop current flow through the remaining branches. This is one reason many vehicle lighting circuits are designed using parallel connections.



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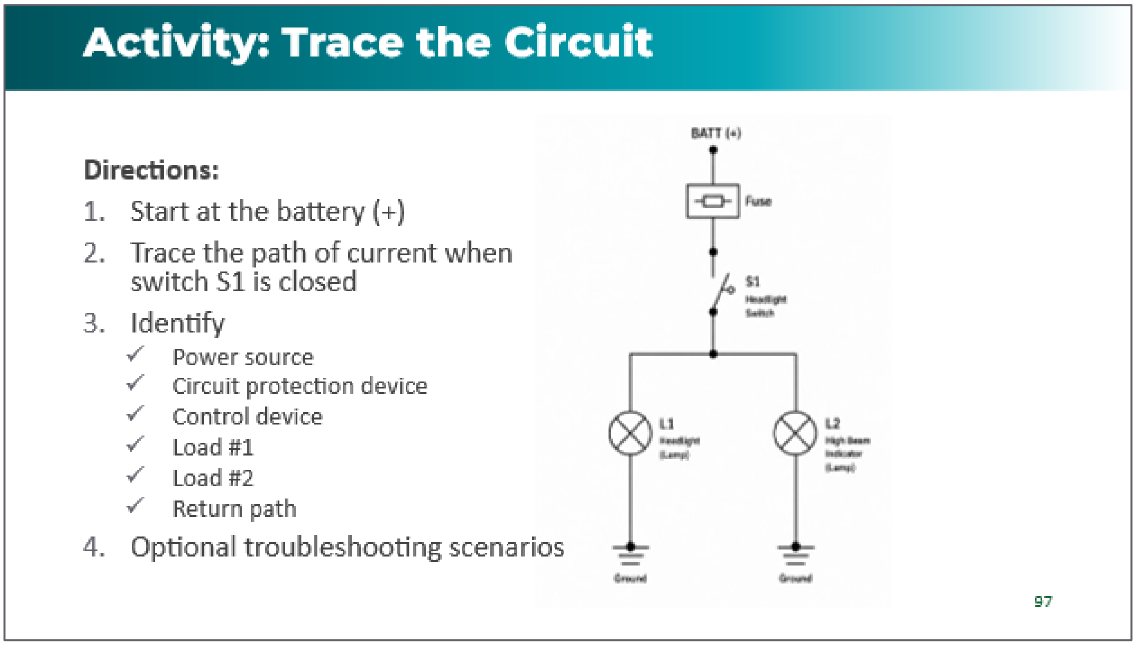

Notes:

Remember the following:

- Begin tracing at the battery positive terminal.
- Follow the complete path of current through each branch of the circuit.
- Consider how current reaches each load and how it returns to the source.
- Understanding current flow is an important troubleshooting skill.
- Think about how a failure in one component would affect the rest of the circuit.

- Which component is the power source?
- Which component provides circuit protection?
- Which component controls current flow?
- What are the two loads?
- What type of circuit is shown?
- Why do both lamps illuminate when the switch closes?

Optional Failure Scenarios:

- What happens if the fuse opens?
- What happens if the switch remains open?
- What happens if the headlight (L1) fails open?
- What happens if the indicator lamp (L2) fails open?
- What happens if the ground connection to L1 is lost?

Key Takeaway:

A parallel circuit provides multiple paths for current flow. A failure in one branch does not necessarily affect the operation of the other branches.

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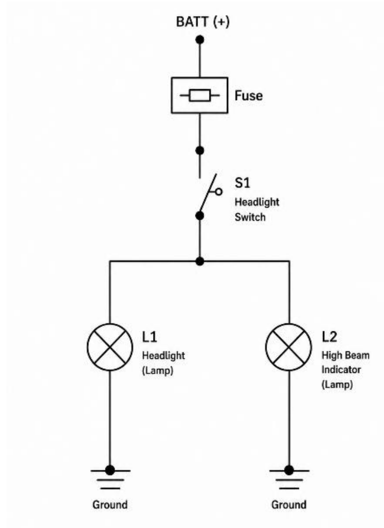
Activity

Trace the Circuit

Directions

1. Start at the battery positive terminal.
2. Trace the path current follows when switch S1 is closed.
3. Label the following components on the diagram:
   - Power Source
   - Protection Device
   - Control Device
   - Load #1
   - Load #2
   - Return Path
4. Answer the questions below.



Enlarged diagram on next page

Questions

Which component provides power to the circuit? ______________________________

Which component protects the circuit from excessive current? ______________________________

Which component controls current flow? ______________________________

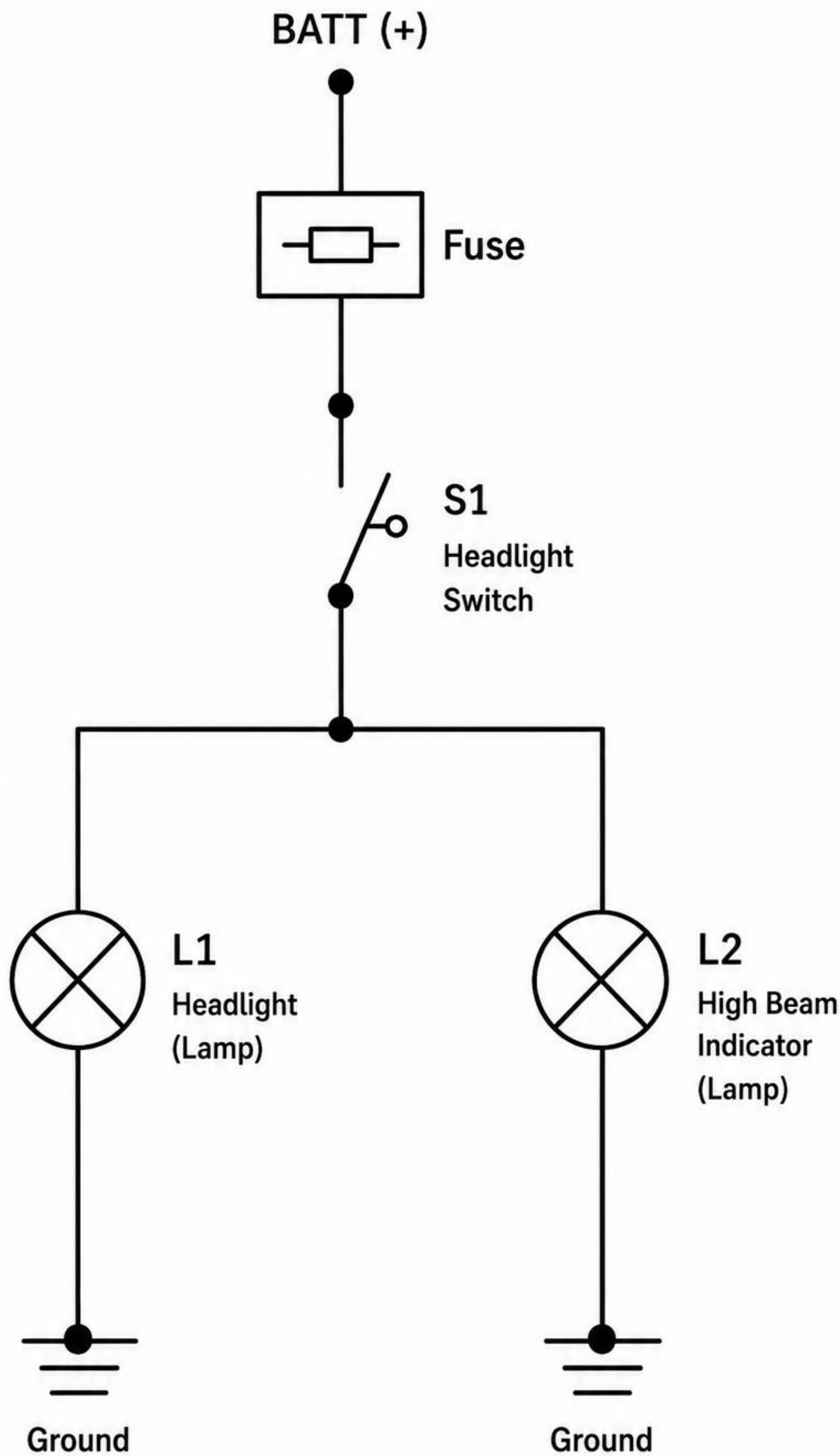
What are the two loads in this circuit? ______________________________

What type of circuit is shown? □ Series □ Parallel

Why do both lamps illuminate when the switch closes? ______________________________

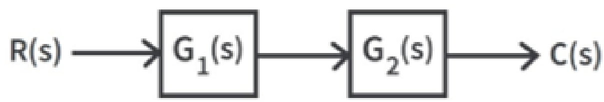
(Optional) Troubleshooting Challenge

Failure Condition	What Happens?
Fuse opens	
Switch remains open	
Headlight (L1) fails open	
Indicator lamp (L2) fails open	
Ground connection to L1 fails	


BATT (+)
Fuse
S1
Headlight
Switch
L1
Headlight
(Lamp)
L2
High Beam
Indicator
(Lamp)
Ground
Ground

Knowledge Check

What does this image represent?



A.) Schematic

B.) One-Line Diagram

C.) Block Diagram

D.) Tempered-Fit Diagram

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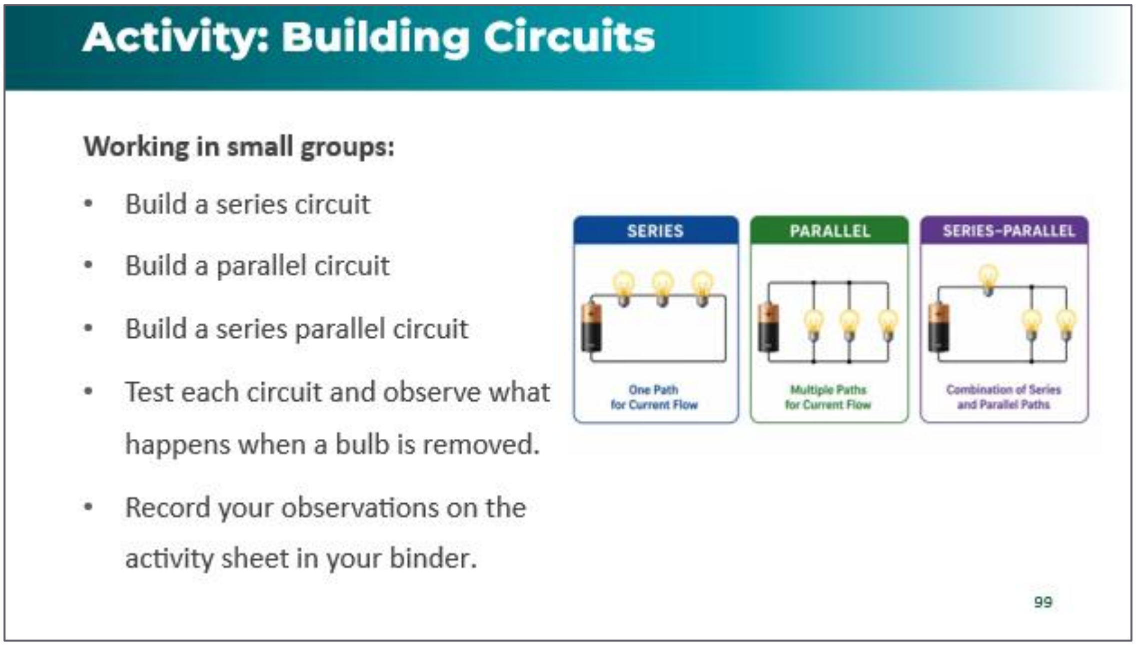

Notes:

Review Questions:

- What characteristics define a series circuit?
- What characteristics define a parallel circuit?
- What makes a circuit series-parallel?
- What happened when a bulb was removed from each circuit?
- Which circuit architecture provides the greatest reliability?
- Why are parallel circuits commonly used in transit vehicles and equipment?

Key Takeaways

- A **series circuit** contains a single path for current flow. If one component fails, the entire circuit is interrupted.
- A **parallel circuit** contains multiple current paths. Components can continue operating even if one branch fails.
- A **series-parallel circuit** combines characteristics of both configurations.
- Understanding circuit architecture is critical when reading diagrams and troubleshooting electrical systems.
- Many transit vehicle electrical systems utilize parallel branches to improve reliability and maintain operation of critical components.

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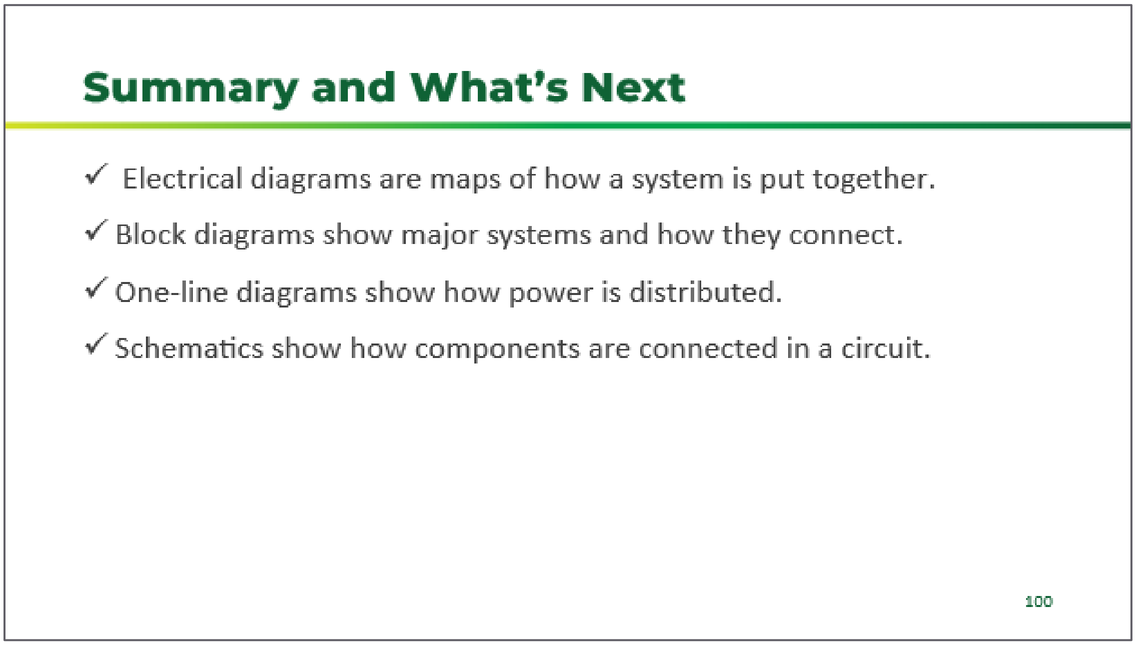

Notes:

- Electrical diagrams are essentially maps. They show how a system is organized and how its parts are connected.
- We discussed **block diagrams**, which give a general, high-level view. They show major systems and how they *connect* to one another, but not the internal details.
- We looked at **one-line diagrams**, which simplify how electrical *power is distributed* throughout a system.
- And we reviewed **schematics**, which show the detailed *connections* between individual components in a circuit.
- Each type of diagram serves a different purpose — from big-picture system layout to detailed troubleshooting.
- The **key takeaway** is this: Understanding what type of diagram you're looking at determines how you interpret the information.
- Now that you understand the different diagram types, the next step is learning the language they use.
- Next, we'll focus on the symbols used to draw and read these diagrams — because being able to recognize symbols is essential for working in the field.

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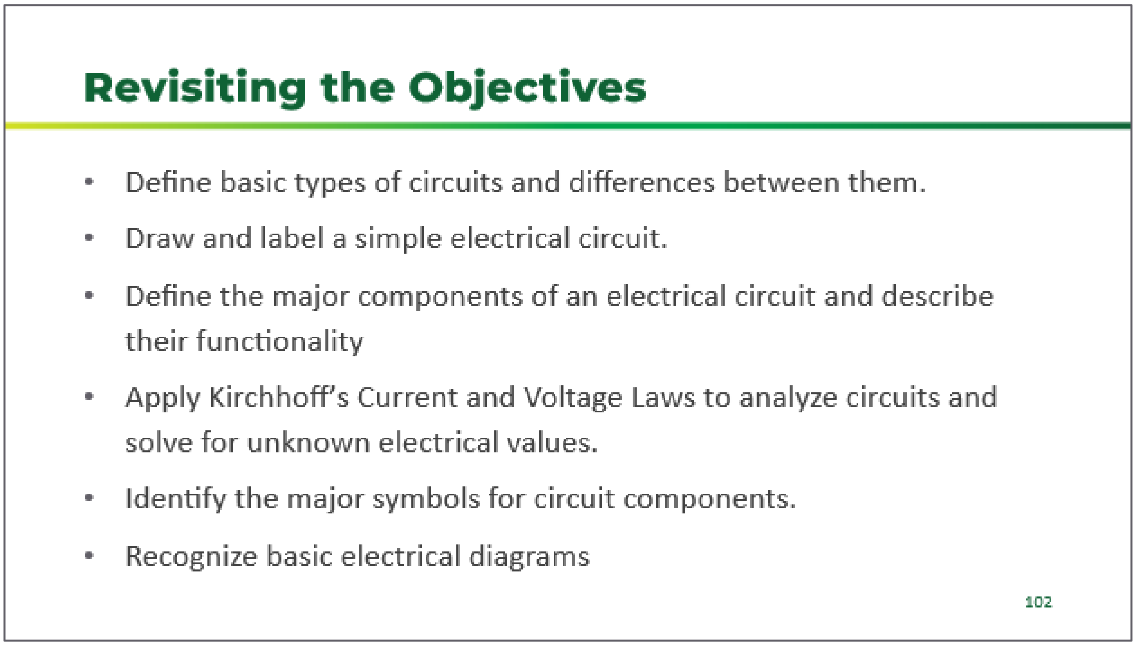
Notes:

- Time for a quiz! Let's see what you have retained from today's lesson.



Notes:

- If you were explaining today's objectives to someone else, how would you summarize what they mean and why they matter?
- Which of today's objectives do you feel most confident about? Which were most challenging? Explain your reasoning.
- Can you give an example of how you could apply one of today's objectives in a real-world situation?