16.4 Types of Circuits

We use electric circuits for thousands of things, from flashlights to computers, cars, and satellites. There are two basic ways circuits can be built to connect different devices. These two types of circuits are called *series* and *parallel*. Series circuits have only one path for the current. Parallel circuits have branching points and multiple paths for the current.

VOCABULARY

series circuit - an electric circuit that has only one path for current.

What is a series circuit?

A series circuit has one path

A **series circuit** contains only one path for electric current to flow. This means the current is the same at all points in the circuit. All the circuits you have studied so far have been series circuits. For example, two D-cells and three identical bulbs connected in a loop form a series circuit because there is only one path through the circuit (Figure 16.16). The current is the same in each bulb, so they are equally bright.

A series circuit has only one path for the current, so the current is the same at any point in the circuit.

Series circuit in holiday lights

If there is a break at any point in a series circuit, the current will stop everywhere in the circuit. Inexpensive strings of holiday lights are wired with the bulbs in series. The bulbs are rated for 2.5 volts each, and with 50 of them wired in series, the string runs well when plugged into a 120-volt outlet. Manufacturers and marketing specialists like to work with nice round numbers. With 50 bulbs in a strand that is plugged into a 120-volt outlet, each bulb will get (120/50) 2.4 volts. This works just fine, even though the bulbs are rated at 2.5 volts each. If you remove one of the bulbs from its socket, the whole string of mini bulbs will go out. However, if a bulb's filament burns out, but the bulb is still in the socket, the string will stay lighted. How does this work? Modern 2.5-volt mini bulbs have a special backup wire to carry the current when a filament breaks (Figure 16.17). As long as the burned-out bulb is still in the socket, the series circuit will not be broken because the current can travel through the backup wire (often called a shunt).

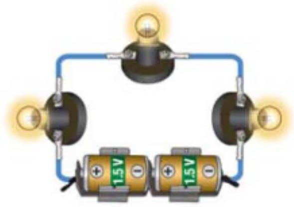


Figure 16.16: *A series circuit.*

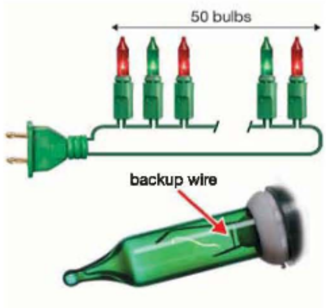


Figure 16.17: *A strand of 50 mini bulbs has a backup wire inside. If the filament burns out, current can flow through the backup wire, and the rest of the bulbs in the strand can stay lit.*

Current and resistance in a series circuit

Using Ohm's law You can use Ohm's law to calculate the current in a circuit if you know the voltage and resistance. If you are using a battery, you know the voltage from the battery. If you know the resistance of each device, you can find the total resistance of the circuit by adding up the resistance of each device.

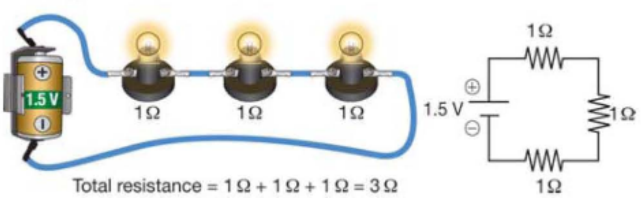
Adding resistances Adding resistances is like adding pinches to a hose (Figure 16.18). Each pinch adds some resistance. The total resistance is the sum of the resistance from each pinch. To find the total resistance in a series circuit, you add the individual resistances.

ADDING RESISTANCES IN A SERIES CIRCUIT

$$R_{total} = R_1 + R_2 + R_3 + \ldots$$

Total resistance (Ω) — Individual resistances (Ω)

Ignoring resistance from wires in simple circuits Everything has some resistance, even wires. However, the resistance of a wire is usually so small compared with the resistance of light bulbs and other devices that we can ignore the resistance of the wire in the simple circuits we build and analyze.



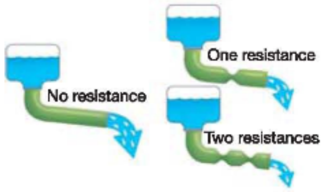


Figure 16.18: *Adding resistance in a circuit is like adding pinches in a hose.*

SCIENCE FACT

Why aren't birds electrocuted?

If high-voltage wires are so dangerous, how can birds sit on them without being instantly electrocuted? First, the bird's body has a higher resistance than the electrical wire. The current tends to stay in the wire because the wire is an easier path.

The most important reason, however, is that the bird has both feet on the same wire. That means the voltage is the same on both feet, and no current flows through the bird.

Solving Problems: Current in a Series Circuit

A series circuit contains a 12-V battery and three bulbs with resistances of 1 Ω, 2 Ω, and 3 Ω. What is the current in the circuit (Figure 16.19)?

1. Looking for: You are asked for the current in amps.

2. Given: You are given the voltage in volts and resistances in ohms.

3. Relationships: $R_{tot} = R_1 + R_2 + R_3$

Ohm's law: $I = V/R$

4. Solution: $R_{tot} = 1\ \Omega + 2\ \Omega + 3\ \Omega = 6\ \Omega$

$I = (12\ V)/(6\ \Omega) = 2\ A$

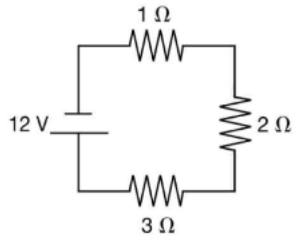


Figure 16.19: *What is the current in the circuit?*

Your turn...

a. A string of five lights runs on a 9-V battery. If each bulb has a resistance of 2 Ω, what is the current?

b. A series circuit operates on a 6-V battery and has two 1-Ω resistors. What is the current?

c. A string of 50 mini-bulbs is wired in series. Each bulb has a resistance of 7 Ω. The string is plugged into a 120-V outlet. How much current does the string of lights draw?

SOLVE FIRST LOOK LATER

a. 0.9 A

b. 3 A

c. 0.3 A

Energy and voltage in a series circuit

Energy changes forms Energy cannot be created or destroyed. The devices in a circuit convert electrical energy into other forms of energy. The rate of energy transfer that takes place is called *power*, measured in watts. Each device requires power to work properly, so the power carried by the current is reduced. As a result, the *voltage in the circuit is lower after each device that uses power*. This is known as the **voltage drop**. The voltage drop is a reduction of electrical potential across an electrical device that has current flowing through it.

Charges lose their energy Consider a circuit with three bulbs and two batteries (illustration C below). The voltage is 3 volts, which means that each amp of current leaves the battery carrying 3 watts. Each bulb changes one third of the power into light and heat. Because the first bulb uses 1 watt, the voltage drops from 3 volts to 2 volts as the current flows through the first bulb. Remember, the current in a series circuit is the same everywhere! As power gets used, voltage drops.

Voltage If the three bulbs are identical, each gives off the same amount of light and heat. Each uses the same amount of power. A meter will show the voltage drop from 3 volts to 2 volts to 1 volt, and finally down to 0 volts after the last bulb. After passing through the last bulb, the current returns to the battery where it is given more power and the cycle starts over.

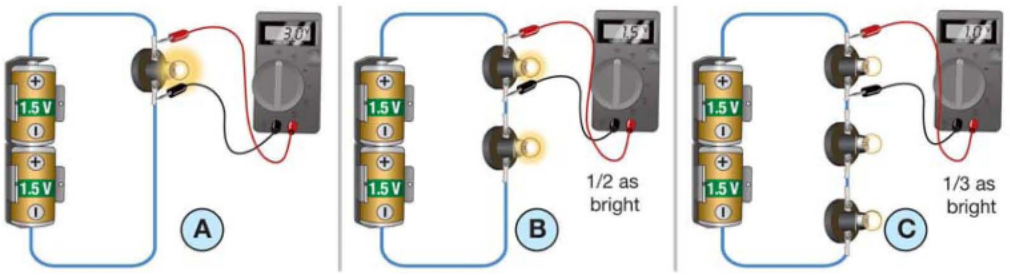
VOCABULARY

voltage drop - the reduction of electrical potential across an electrical device that has current flowing through it.

STUDY SKILLS

Voltage in a Series Circuit

To remember how voltage works in a series circuit, think of the word *share* (series/share). If circuit components are wired in series, the components *share* the total voltage available.



Voltage drops and Ohm's law

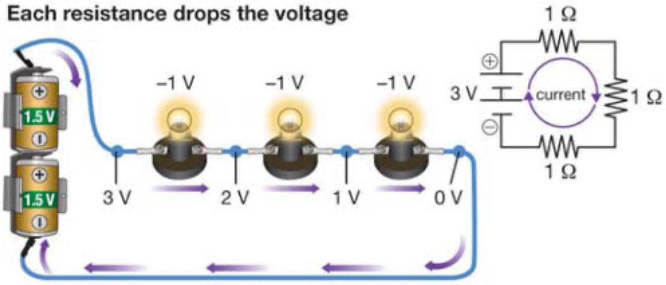
Voltage drops Each separate bulb or resistor creates a voltage drop. The voltage drop across a bulb is measured by connecting an electrical meter's leads at each side of the bulb (Figure 16.20). The greater the voltage drop, the greater the amount of power being used per amp of current flowing through the bulb.

Ohm's law The voltage drop across a resistance is determined by Ohm's law in the form $V = IR$. The voltage drop (V) equals the current (I) multiplied by the resistance (R) of the device. In a series circuit, the current is the same at all points, but devices might have different resistances. In the circuit below, each bulb has a resistance of 1 ohm, so each has a voltage drop of 1 volt when 1 amp flows through the circuit.

Energy conservation The law of conservation of energy applies to a circuit. Over the entire circuit, the power used by all the bulbs must equal the power supplied by the battery. This means the total of all the voltage drops must add up to the battery's voltage. This rule is known as **Kirchhoff's voltage law**, named after German physicist Gustav Robert Kirchhoff (1824–1887).

Applying Kirchhoff's law In the circuit below, three identical bulbs are connected in series to two 1.5-volt batteries. The total resistance of the circuit is 3 ohms. The current flowing in the circuit is 1 amp ($I = 3\text{ V} \div 3\ \Omega$). Each bulb creates a voltage drop of 1 volt ($V = IR = 1\text{ A} \times 1\ \Omega$). The total of all the voltage drops is 3 volts, which is the same as the voltage of the battery.

Each resistance drops the voltage



VOCABULARY

Kirchhoff's voltage law - the total of all voltage drops in a series circuit must equal the voltage supplied by the battery.

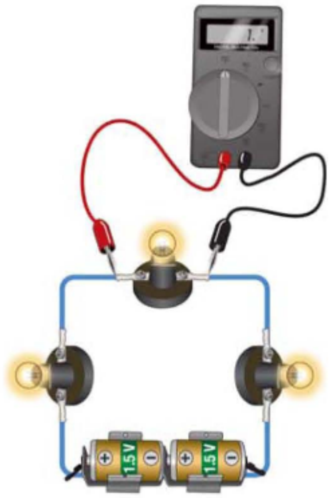


Figure 16.20: *A multimeter can be used to measure the voltage drop across a bulb in a circuit.*

Finding voltage drops

Ohm's law is especially useful in series circuits where the devices do *not* have the same resistance. A device with a larger resistance has a greater voltage drop. However, the sum of all the voltage drops must still add up to the battery's voltage. The example below shows how to find the voltage drops in a circuit with two different light bulbs.

Solving Problems: Voltage in a Series Circuit

The circuit shown at the right (Figure 16.21) contains a 9-V battery, a 1-Ω bulb, and a 2-Ω bulb. Calculate the circuit's total resistance and current. Then find each bulb's voltage drop.

1. Looking for: You are asked for the total resistance, current, and voltage drops.

2. Given: You are given the battery's voltage and the resistance of each bulb.

3. Relationships: Total resistance in a series circuit: $R_{tot} = R_1 + R_2$

Ohm's law: $I = V/R$ or $V = IR$

4. Solution: Calculate the total resistance: $R_{tot} = 1\ \Omega + 2\ \Omega = 3\ \Omega$
Use Ohm's law to calculate the current:
$I = (9\ \text{V})/(3\ \Omega) = 3\ \text{A}$
Use Ohm's law to find the voltage drop across the 1 Ω bulb:
$V = (3\ \text{A})(1\ \Omega) = 3\ \text{V}$
Use Ohm's law to find the voltage drop across the 2 Ω bulb:
$V = (3\ \text{A})(2\ \Omega) = 6\ \text{V}$

Your turn...

a. The battery in Figure 16.21 is replaced with a 12-V battery. Calculate the new current and the voltage drops across the bulbs.

b. A 12-V battery is connected in series to a 1-Ω bulb and a 5-Ω bulb. What is the voltage drop across each bulb?

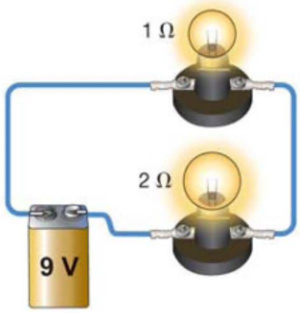


Figure 16.21: *What is the circuit's total resistance and current? What is each bulb's voltage drop?*

SOLVE FIRST LOOK LATER

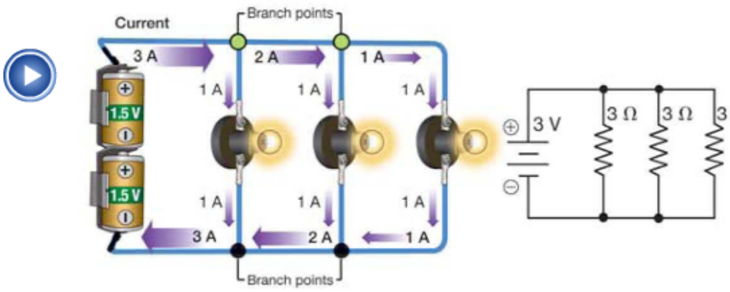
a. 4 A, 4 V drop across the 1-Ω bulb, 8 V drop across the 2-Ω bulb

b. 2 V, 10 V

What is a parallel circuit?

Parallel branches It would be a big problem if your refrigerator shut off whenever you switched off the overhead kitchen light! This is why houses are wired with parallel circuits instead of series circuits. Parallel circuits provide each device with a separate path back to the power source. This means each device can be turned on and off independently from the others. A **parallel circuit** is a circuit with more than one path for the current. Each path in the circuit is sometimes called a *branch*. The current through a branch is also called the *branch current*. The current supplied by the battery in a parallel circuit splits at one or more branch points.

Example: Three bulbs in parallel All of the current entering a branch point must exit again. This rule is known as **Kirchhoff's current law** (Figure 16.22). For example, suppose you have three identical light bulbs connected in parallel as shown below. The circuit has two branch points where the current splits (green dots). There are also two branch points where the current comes back together (black dots). You measure the branch currents and find each to be 1 amp. The current supplied by the battery is the sum of the three branch currents, or 3 amps. At each branch point, the current entering is the same as the current leaving.



VOCABULARY

parallel circuit - an electric circuit with more than one path or branch.

Kirchhoff's current law - states that all of the current entering a circuit branch must exit again.

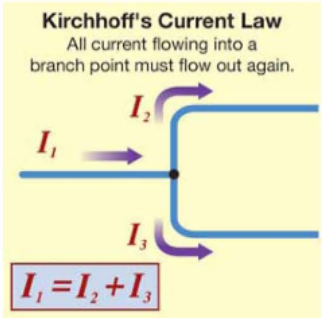


Figure 16.22: *All the current entering a branch point in a circuit must also exit the branch.*

Voltage and current in a parallel circuit

Each branch has the same voltage The voltage in a circuit is the same anywhere along the same wire. This is true as long as the resistance of the wire itself is very small compared to the rest of the circuit. If the voltage is the same along a wire, then the *same voltage appears across each branch of a parallel circuit.* In other words, each branch of a parallel circuit sees the total voltage available for the circuit. This is true even when the branches have different resistances (Figure 16.23). Both bulbs in this circuit get 3 volts from the battery since each is connected back to the battery by wires without any other electrical devices in the way.

Advantages of parallel circuits Parallel circuits have two big advantages over series circuits.

1. Each device in the circuit has a voltage drop equal to the full battery voltage.
2. Each device in the circuit can be turned off independently without stopping the current in the other devices in the circuit.

Parallel circuits in homes Parallel circuits need more wires to connect, but are used for most of the wiring in homes and other buildings. Parallel circuits allow you to turn off one lamp without all of the other lights in your home going out. They also allow you to use many appliances at once, each at full power.

Current in branches Because each branch in a parallel circuit has the same voltage, the current in a branch is determined by the branch resistance and Ohm's law, $I = V/R$ (Figure 16.24). The greater the resistance of a branch, the smaller the current. Each branch works independently, so the current in one branch does not depend on what happens in other branches.

Total current The total current in a parallel circuit is the sum of the currents in each branch. The only time branches have an effect on each other is when the total current is more than the battery or wall outlet can supply. A battery has a maximum amount of current it can supply at one time. If the branches in a circuit try to draw too much current, the battery voltage will drop and less current will flow.

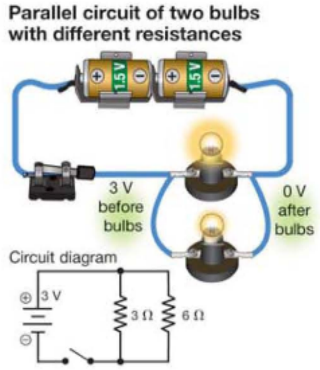


Figure 16.23: *The voltage across each branch of a parallel circuit is the same.*

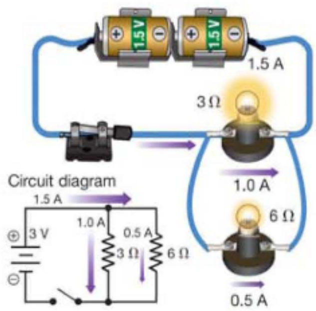


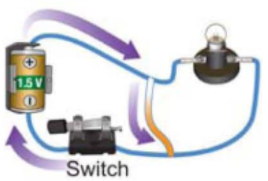
Figure 16.24: *The current in each branch might be different.*

Calculating current and resistance in a parallel circuit

More branches mean less resistance With parallel circuits, adding a resistor in parallel provides another independent path for current. More current flows for the same voltage so the total resistance is *less*.

Example of a parallel circuit Compare the series and parallel circuits in Figure 16.25. All bulbs are identical and have a resistance of 2 ohms. In the series circuit, the current is 6 amps ($I = V/R$ = 12 V ÷ 2 Ω = 6 A). In the parallel circuit, the current is 6 amps *in each branch*. The total current, therefore, is 12 amps. So what is the total resistance of the parallel circuit? Ohm's law solved for resistance is $R = V \div I$. The total resistance of the parallel circuit is the voltage (12 volts) divided by the total current (12 amps), which equals 1 ohm. The resistance of the parallel circuit is *half* that of the series circuit!

Short circuits



If too much current flows through too small a wire, the wire will overheat and might melt or start a fire. A **short circuit** is a parallel path in a circuit with very low resistance. A short circuit can be created accidentally by making a parallel branch with a wire. A plain wire might have a resistance as low as 0.001 ohm. Ohm's law tells us that with a resistance this low, 1.5 volts from a battery results in a (theoretical) current of 1,500 amps! A short circuit is dangerous because currents this large can melt wires.

Circuit safety in homes Appliances and electrical outlets in homes are connected in many parallel circuits. Each circuit has its own fuse or circuit breaker that stops the current if it exceeds the safe amount, usually 15 or 20 amps. If you turn on too many appliances in one circuit at the same time, the circuit breaker or fuse cuts off the current. To restore the current, you must first disconnect some or all of the appliances. Then, either flip the tripped circuit breaker (in newer homes) or replace the blown fuse (in older homes). Fuses are also used in car electrical systems and in electrical devices such as televisions.

VOCABULARY

short circuit - a branch in a circuit with zero or very low resistance.

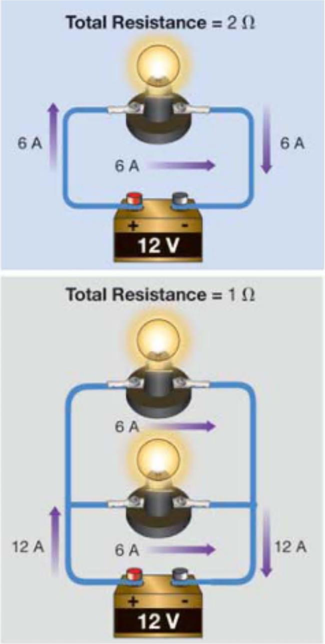


Figure 16.25: *The parallel circuit has twice the current and half the total resistance of the series circuit.*

Solving Problems: Current in a Parallel Circuit

All of the electrical outlets in Jonah's living room are on one parallel circuit. The circuit breaker cuts off the current if it exceeds 15 A. Will the breaker trip if he uses a light (240 Ω), a radio (150 Ω), and an air conditioner (10 Ω)?

1. Looking for: You are asked whether the current will exceed 15 A.

2. Given: You are given the resistance of each branch and the circuit breaker's maximum current.

3. Relationships: Ohm's law: $I = V/R$

4. Solution: Because the devices are plugged into electrical outlets, the voltage is 120 V for each.
I_{light} = (120 V)/(240 Ω) = 0.5 A
I_{stereo} = (120 V)/(150 Ω) = 0.8 A
I_{AC} = (120 V)/(10 Ω) = 12 A
The total is 13.3 A, so the circuit breaker will not trip.

Your turn...

a. Will the circuit breaker trip if Jonah also turns on a computer (60 Ω)?

b. What is the total current in a parallel circuit containing a 12-V battery, a 2-Ω resistor, and a 4-Ω resistor?

TECHNOLOGY

What if you plug in too many things?

In a parallel circuit, each connection uses as much current as it needs. If you plug in a coffee maker that uses 10 amps and a toaster oven that uses 10 amps, a total of 20 amps needs to come through the wire. If you plug too many appliances into the same outlet, you will eventually use more current than the wires can carry without overheating. On the previous page, you learned how circuit breakers prevent this.

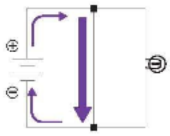
SOLVE FIRST LOOK LATER

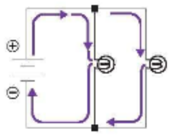
a. Yes. The additional current is 2 A, so the total is 15.3 A.

b. 9 A

Section 16.4 Review

1. What do you know about the current in a series circuit?
2. Three bulbs are connected in series with a battery and a switch. Do all of the bulbs go out when the switch is opened? Explain.
3. What happens to a circuit's resistance as resistors are added in series?
4. A series circuit contains a 9-V battery and three identical bulbs. What is the voltage drop across each bulb?
5. A student builds a series circuit with four 1.5-V batteries, a 5-Ω resistor, and two 1-Ω resistors.
   a. What is the total resistance in the circuit?
   b. Use Ohm's law to find the value of the current in the circuit.
6. What happens to the total current in a parallel circuit as more branches are added? Why?
7. What is the total resistance of two 12-Ω resistors in parallel? What is the total for three 12-Ω resistors in parallel?
8. For each diagram below, label the circuit *series*, *parallel*, or *short circuit*. The arrows show the flow of current. One circuit type is not shown.





9. A circuit breaker in your house is set for 15 A. You have plugged in a coffee maker that uses 10 A. Plugging which of the four items into the same circuit will cause the circuit breaker to trip (because the current is too high)?
   a. a light that uses 1 A
   b. a can opener that uses 2 A
   c. a mixer that uses 6 A
   d. an electric knife that uses 1.5 A

BIOGRAPHY

Lewis Latimer

Photo courtesy of Queens Library

Lewis Latimer was born in Chelsea, Massachusetts, in 1848, six years after his parents escaped from slavery in Virginia.

As a child, Lewis loved to read and draw. When he was sixteen, Lewis joined the U.S. Navy, fighting for the Union in the Civil War. Afterward, he worked in a law office in Boston that specialized in helping people patent their inventions. There he taught himself how to use draftsmen's tools to make scale drawings of machines.

Latimer met Alexander Graham Bell at that office. Working late, Latimer made blueprints and helped Bell file the papers for his telephone patent—just hours before a rival.

A new job as a mechanical draftsman for U.S. Electric Lighting helped Latimer learn about incandescent lighting. Four years later, Thomas Edison hired Latimer as an electrical engineer and patent advisor. Latimer was later invited to join the prestigious research team known as Edison's pioneers. Latimer improved incandescent bulb design by replacing a paper filament with a carbon one. He also wrote the first engineer's handbook on electric lighting.