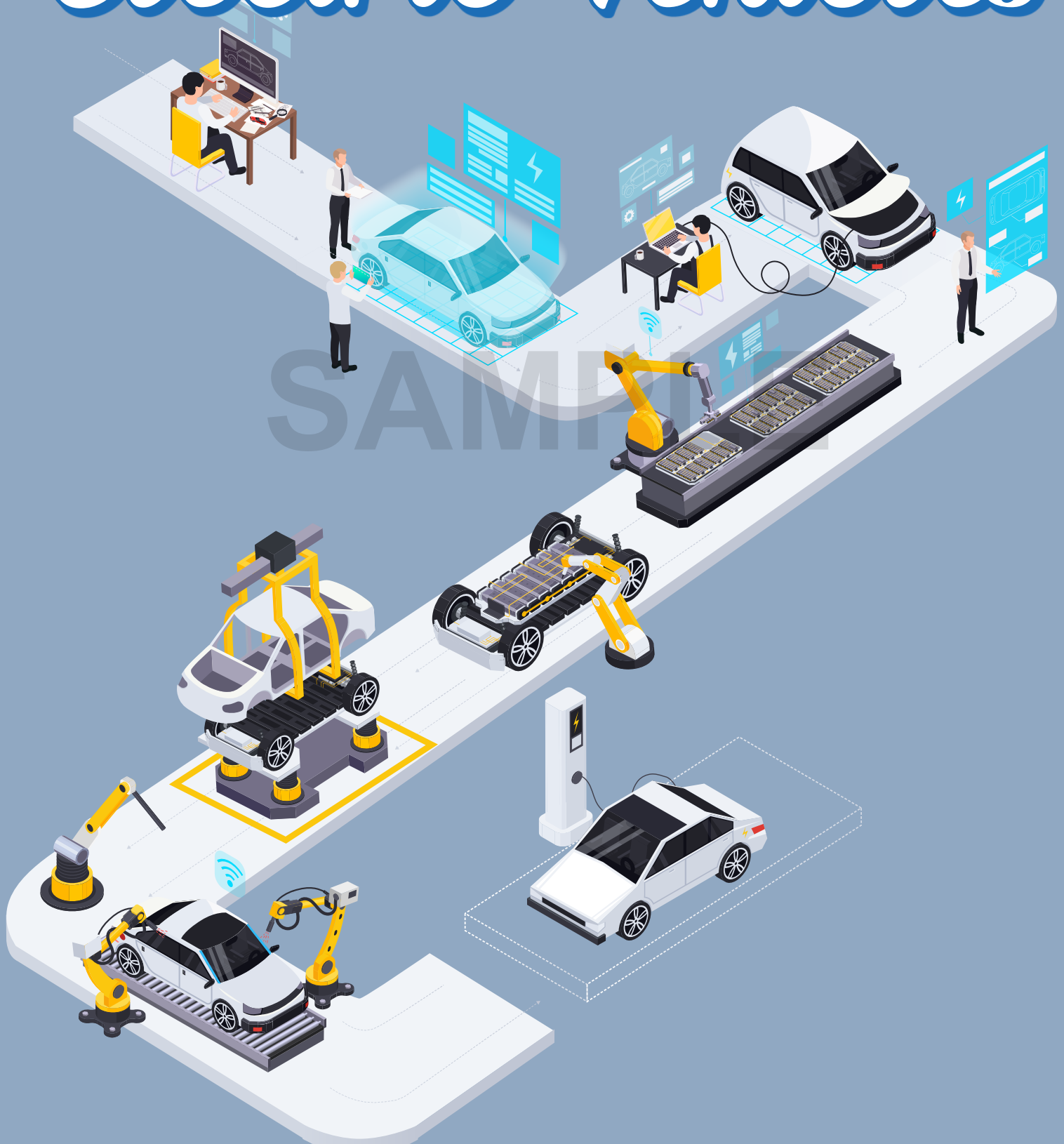


THE SCIENCE & ENGINEERING BEHIND *Electric Vehicles*



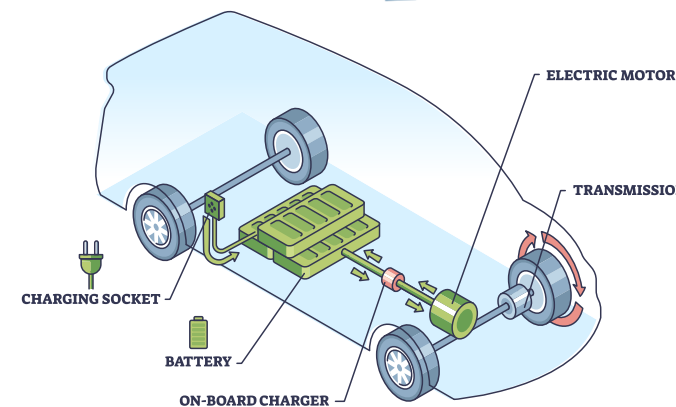
EVS ARE AMAZING!

Have you ever been standing on a sidewalk and had a car glide past you? No rumbling engine. No exhaust pipe puffing smoke. Just a quiet whoosh and it's gone. That was almost certainly an electric vehicle, or EV.

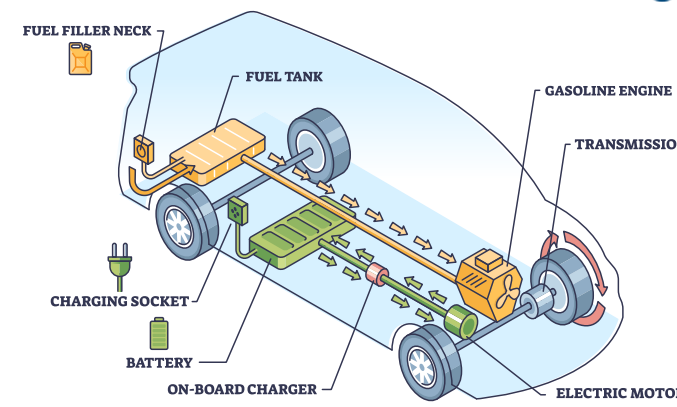
Electric vehicles are cars that run entirely on electricity. Instead of a tank full of gasoline, they carry a large battery pack. Instead of an engine that burns fuel, they use an electric motor. And instead of a trip to the gas station, they recharge at home, or at a charging station, just by plugging them in.

But EVs aren't just quieter than other cars. They are remarkable machines, packed with clever science and brilliant engineering. In this book, you'll discover exactly how they work, from the chemistry inside their batteries to the physics that lets them actually recover energy while braking. By the time you finish, you'll never look at an electric car the same way again.

WHAT KIND OF CAR IS IT?



Electric Vehicles (EVs) run entirely on electricity. Their battery is charged by plugging into a charging station or home outlet. They produce no exhaust at all. This is the type of vehicle this book is all about.



Hybrid Vehicles use both a gasoline engine and an electric motor. They switch between the two depending on driving conditions. The battery charges itself while driving, and some vehicles can be plugged in to charge.

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A History of Batteries, Motors & EVs	8
Inside an EV Battery.....	10
Charging Up.....	12
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Regenerative Braking.....	16
Activities.....	18

DID YOU KNOW?

A gasoline-powered car has more than 2,000 moving parts in its engine and drivetrain. An electric vehicle has far fewer moving parts, which means less can wear out or break.

WHAT IS ENERGY?

Before we can understand electric vehicles, we need to understand energy. Energy is what makes things move, light up, heat up, and work. Cars need energy to drive. Lights need energy to shine. Even your own body needs energy to run, jump, and think.

Energy comes in many different forms. One of the most important things about energy is that it can change from one form into another. It can't be created from nothing, and it never disappears. It just transforms.

Inside an electric vehicle, energy changes form several times before the car moves even one inch. That chain of transformations is one of the most fascinating things about how EVs work.

TWO BASIC TYPES OF ENERGY



Potential Energy is stored energy – energy that is waiting to be released. A battery sitting on a shelf has potential energy stored in its chemicals. A stretched rubber band has potential energy stored in its shape. An apple held up in the air has potential energy stored in its position. The moment something changes – the battery connects to a circuit, the rubber band is released, the apple falls – that stored energy is released and gets to work.



Kinetic Energy is the energy of movement. Any object that is moving has kinetic energy. A rolling ball has kinetic energy. A spinning motor has kinetic energy.

THE THREE FORMS OF ENERGY IN AN EV

Every time an electric vehicle drives down the road, energy takes three forms. Each form is a step in the journey from a parked car to a moving one.



Chemical energy is energy stored inside the chemicals in the battery, a type of potential energy, waiting and ready. Think of it like the energy stored in the food you eat before your body uses it. The battery holds this chemical energy until the car is switched on.



Electrical energy is energy carried by moving electrons. When the car turns on, a chemical reaction inside the battery releases the stored energy and sends electrons flowing through the car's wires and circuits. Now the energy is on the move.

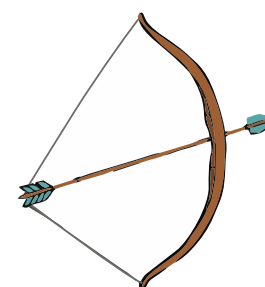
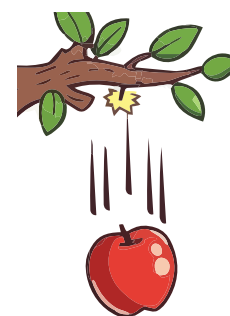
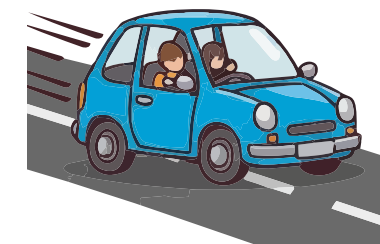


Mechanical energy is the energy of motion, a type of kinetic energy. When the electrical energy reaches the motor, the motor spins. The spinning shaft turns the wheels, and the car moves. Stored chemical energy has become motion.

Three forms of energy. One smooth, quiet ride.

SORT IT OUT

Write the name of the type of energy represented underneath the image. Is it **potential energy** or **kinetic energy**?



(Answers on back cover)

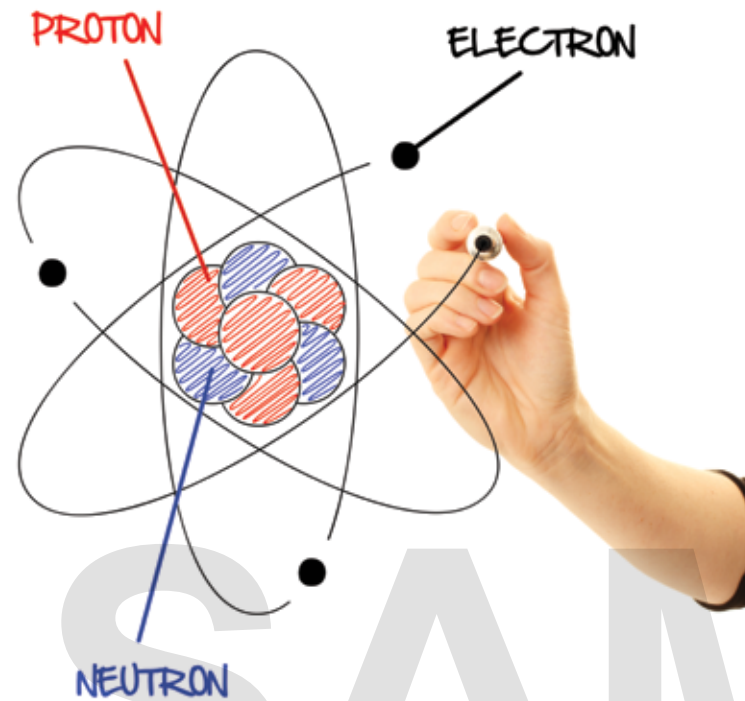
WHAT IS ELECTRICITY?

EVERYTHING IS MADE OF ATOMS

To really understand how an electric vehicle works, you need to understand what electricity actually is.

Everything in the universe, every rock, every drop of water, every piece of metal, and every part of your body, is made of tiny particles called atoms. Atoms are far too small to see, even with a powerful microscope. And inside each atom are even tinier particles: protons, neutrons, and electrons.

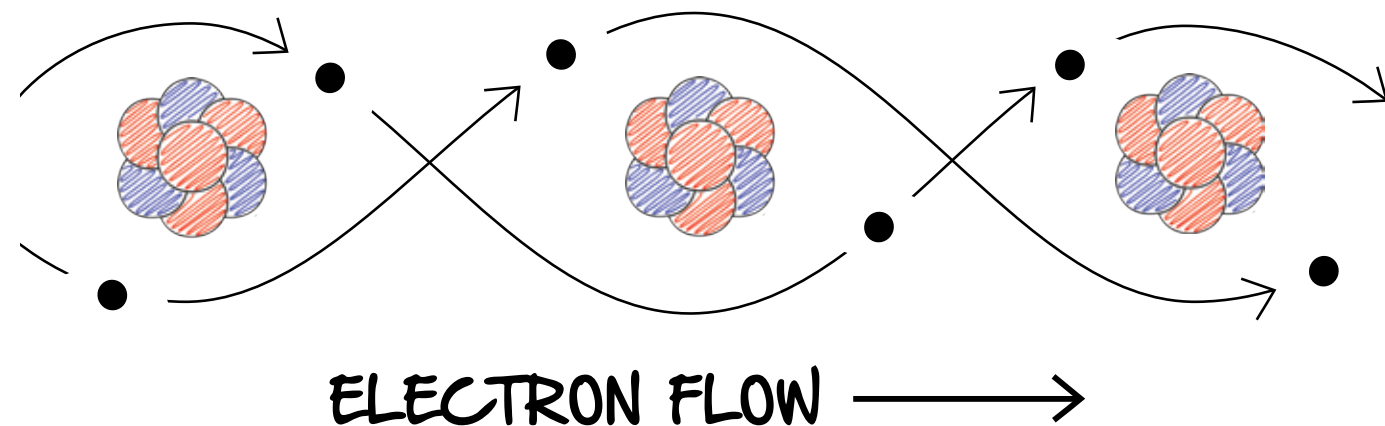
Protons and neutrons are packed tightly in the center of the atom, called the nucleus. Electrons orbit around the outside, and are the key to electricity.



ELECTRONS ON THE MOVE

Electrons are constantly moving around their atoms. In some materials, electrons are loosely attached and can escape from one atom and jump to the next. When huge numbers of electrons jump from atom to atom in the same direction, that moving flow of electrons is called electric current. And electric current is electricity.

Materials that allow electrons to flow freely are called **conductors**. Copper wire is one of the best conductors, which is why most electrical wires are made of copper. Materials that block the flow of electrons are called **insulators**, like the plastic coating around a wire that keeps the electricity safely inside.



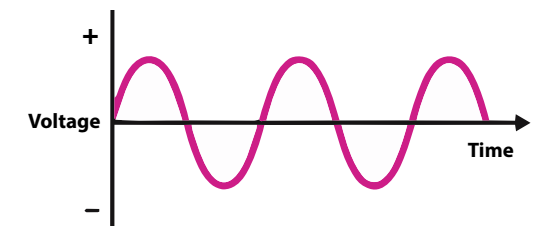
TWO KINDS OF ELECTRIC CURRENT: AC AND DC

Not all electric current flows the same way. There are two types, and electric vehicles use both.

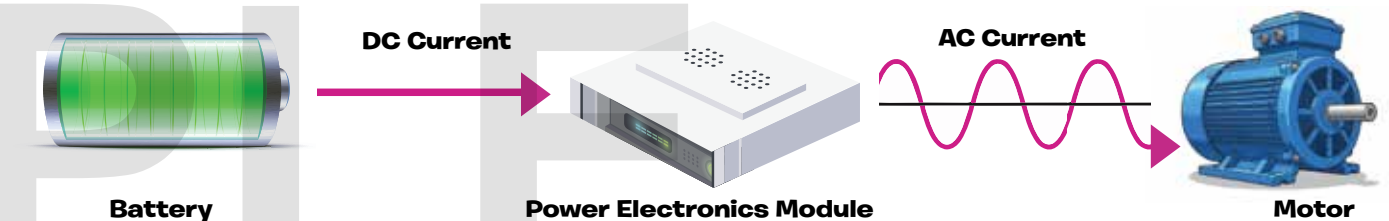
Direct Current (DC) flows in one direction only, like water flowing one way through a pipe. Batteries produce DC. The battery pack in an EV delivers DC energy.



Alternating Current (AC) switches direction back and forth very rapidly. AC is better for traveling long distances through power lines, which is why it's used in the electric grid.



Here's the clever part: an EV battery delivers DC, but the electric motor runs better on AC. So the car uses a component called a **power electronics module** to convert DC from the battery into AC for the motor.



THE FLOW OF ELECTRICITY

One way to think about electricity is to compare it to the way that water flows through pipes:

Electrons are the tiny charged particles that carry electrical energy, like individual droplets of water.

Electric Current is the flow of many electrons moving together, like the stream of water from a running faucet.

Voltage is the force that pushes the electrons through the wire, like the water pressure in a pipe.

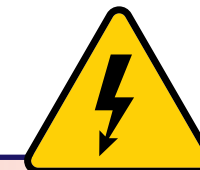
Resistance is the way a material slows down the flow of electrons, like a narrow pipe slowing the water moving through it.

DID YOU KNOW?

Your body is a conductor. About 60-65% of your body is made of water, and water conducts electricity well.

If a person comes into contact with electricity, it can flow through their body and cause a shock, injury, or even death.

This is why you should always be careful around electricity and never touch electrical equipment with wet hands.



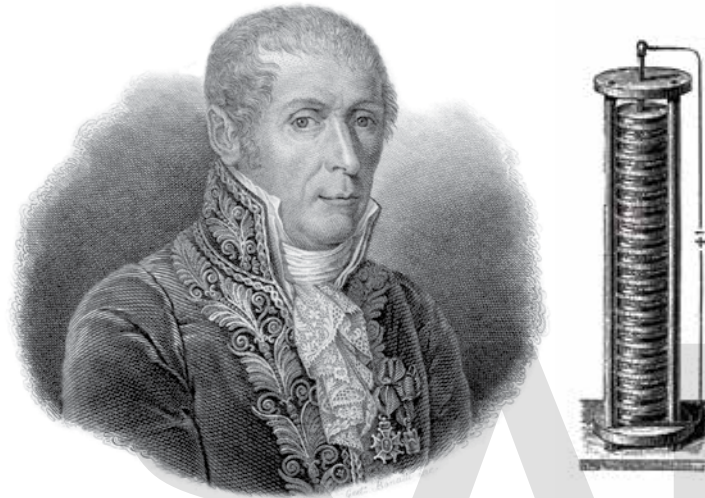
A HISTORY OF BATTERIES, MOTORS & ELECTRIC VEHICLES

Big Ideas Have Long Histories.

Electric vehicles feel like a modern invention, but the science behind them has been building for more than 200 years. Batteries, electric motors, and the first electric cars all have roots going back to the 1800s.

1800 – Volta's First Battery

Italian scientist Alessandro Volta built the very first true battery in 1800: a stack of metal discs that could produce a steady flow of electricity. Before Volta, scientists could only make brief sparks of static electricity. Volta's battery was different. It could deliver electricity in a steady, controlled way, again and again. Volta showed that electricity could be put to work, and that idea led to everything else on this timeline.



1900-1915 – Early Electric Cars

In the early 1900s, electric cars were actually more popular than gasoline-powered ones. They were quiet, smooth, and easy to operate. Many city dwellers, especially doctors making house calls, preferred them. These early EVs used lead-acid batteries and simple electric motors, and they could travel reasonable distances around town.

1901-1914 –

Edison's Better Batteries

Thomas Edison spent years working to build a better battery for electric vehicles. He believed that improving battery technology was the key to making EVs practical for everyday use. His work on nickel-iron batteries contributed to the understanding of how to store more energy in a smaller, lighter package.



1800

TODAY

1830s-1840s –

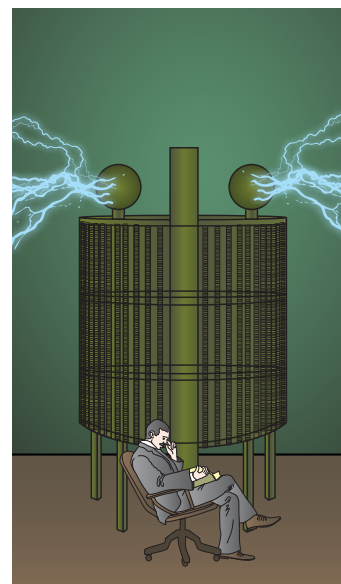
The First Electric Motors

During the 1830s and 1840s, inventors in the United States and Europe built the first working electric motors. These devices could convert electrical energy into mechanical motion. At the time, this was astonishing. These early motors were the direct ancestors of the motors that power electric vehicles today.

Late 1800s –

Tesla and Alternating Current

Nikola Tesla helped develop the AC power system and invented the AC induction motor. AC could travel much longer distances through wires than the direct current (DC) that came before. This made it possible to build large power plants and send electricity to homes and businesses across entire cities. Tesla's work laid the foundation for the electrical grid and for the charging stations that would one day power electric vehicles.



Today – The Modern Electric Vehicle

Today's electric vehicles combine everything these inventors discovered: powerful lithium-ion batteries that store enormous amounts of energy, highly efficient electric motors that instantly convert electricity to motion, and systems like regenerative braking that recover energy that would otherwise be wasted. Modern EVs can travel hundreds of miles on a single charge, and they're only getting better.

INSIDE AN EV BATTERY

Batteries come in all sizes.

Someone in your home probably charged a phone today. It took a little while, and then the battery icon turned green and the phone was ready to go. Simple, right?

But what was actually happening inside that battery? And why does a phone battery seem to hold less and less charge the older it gets?

The answers lie in chemistry. And once you understand the chemistry of the battery in a phone, you'll understand the battery in an electric vehicle, because they work in exactly the same way.

WHAT IS A LITHIUM-ION BATTERY?

The batteries in phones, laptops, and electric vehicles are called lithium-ion batteries. To understand the name, let's break it down.

Lithium is a real element, a soft, silvery metal found in nature. An **ion** is an atom that is carrying an electric charge. When a lithium atom loses one of its electrons, it becomes a **lithium ion**, a tiny, positively charged particle.

The Cathode is the positive side of the cell. It's made of a lithium metal oxide. When the battery is in use, lithium ions travel from the anode toward the cathode – like cars leaving a parking garage and driving across town to a different one.

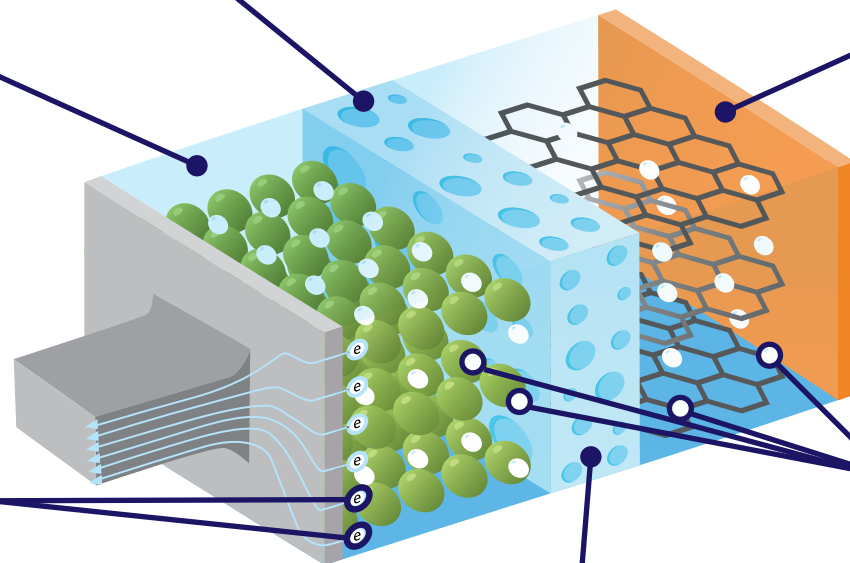
Electrons – when the battery is being used, these particles flow out, through the external circuit, to power the connected device. When the battery is charging, electrons flow in, from the power source, to recharge the battery.

The Separator is a thin physical barrier between the anode and cathode. It makes sure they never accidentally touch each other directly. If they did, it would cause a short circuit – a sudden, uncontrolled release of energy as dangerous heat. The separator keeps the system safe while still allowing ions to pass through.

The Anode is the negative side of the cell. It's made of graphite – the same material that makes up the lead in your pencil. When the battery is fully charged, lithium ions are packed between the layers of graphite in the anode, like cars filling up every space in a parking garage.

Lithium Ions – these charged lithium ions are the messengers that carry energy back and forth inside the battery. Their movement is what makes the whole system work.

The Electrolyte is a liquid or gel that sits between the anode and cathode. The electrolyte lets ions through, but it blocks electrons. The electrons are forced to travel the long way around – through the wires and circuits of your phone or car. That long detour through the circuits is exactly what powers everything. The screen lighting up, the motor spinning, the music playing – it's all powered by electrons making that journey.



FROM PHONE TO VEHICLE

The phone in your pocket and the EV in the driveway use the same basic lithium-ion technology. The difference is scale.

Your phone contains a single small battery cell. An EV battery pack contains hundreds or thousands of cells, grouped into modules, which are assembled into the full pack. The pack sits flat underneath the floor of the car.



HOW USING THE BATTERY WORKS

Here's a way to picture what happens inside a battery. The lithium ions are like kids being driven to school: home is the anode, school is the cathode. They travel to school when the battery is being used, and back home when it's charging.

Discharging: Heading to School

When you use a phone or EV, the battery starts discharging. The lithium ions leave home (**the anode**) and travel through the electrolyte (**the road**) to school (**the cathode**), like kids heading off for the day. Similarly, electrons flow out through the external circuit, powering your device. When all the ions have arrived at school, there are no more electrons to push through the circuit. The battery is empty.



Charging: Returning Home

When you plug in a phone or an EV, electricity flows back into the battery and reverses the trip. The lithium ions travel from school (**the cathode**) back home (**the anode**), each one returning to its own parking spot. When every ion is back home in its spot, the battery is fully charged and ready for another day.



Why Does Your Battery Get Weaker Over Time?

Home has only so many parking spots, and parking goes smoothly when ions come home a few at a time.

But when a battery is drained all the way to empty, every single ion has left for school. The moment you charge it back up, they all rush home at once, and the driveway gets jammed. In that big crowded rush, some ions can't park properly and get stuck, blocking their spot for good. They can never make the trip again.



After many of these all-at-once rushes, more and more spots end up blocked. With fewer spots to come home to, fewer ions can make the journey, so the battery holds less and less energy. That's why a phone battery holds less charge after a year, and why many EV owners try to keep their battery between about 20% and 80% for everyday driving, so the ions come home in smaller, calmer groups instead of one giant jam.



CHARGING UP

Filling Up – With Electricity.

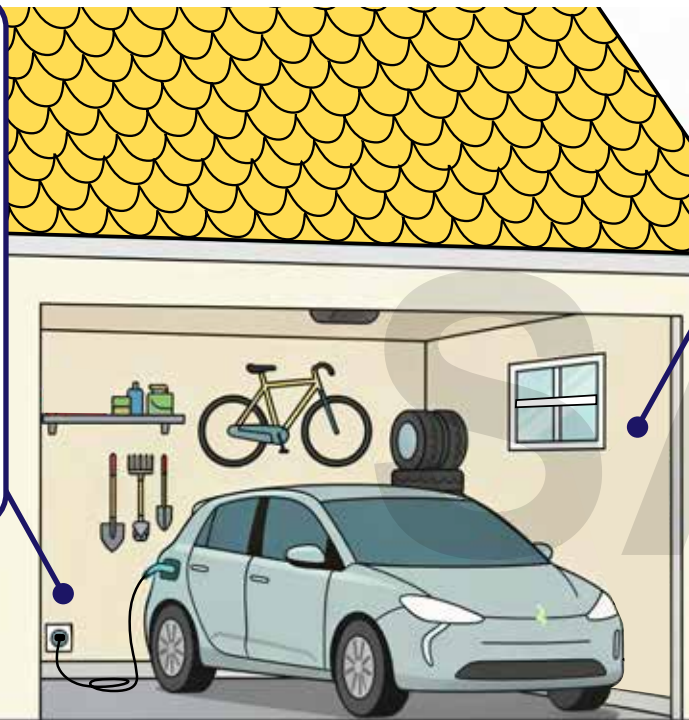
A gasoline car pulls up to a pump, the driver squeezes a handle, and in a few minutes the tank is full. An electric vehicle works differently. Most EV owners charge their car overnight at home, waking up every morning to a full battery, the same way you wake up to a fully charged phone.

But not all chargers are alike. The type of charger you use determines how quickly that battery fills up – and there's some interesting science behind the differences.

THREE LEVELS OF CHARGING

Level 1 – Home Outlet

A Level 1 charger simply plugs into a regular wall outlet, the same kind you'd use for a phone charger. It delivers alternating current (AC) at low power. This is the slowest way to charge an EV, adding roughly 3-5 miles of driving range per hour of charging. It works well overnight for drivers who don't travel far each day.



Level 2 – Home or Public Charging Station

A Level 2 charger uses a special higher-power outlet, the kind sometimes used for large appliances. It also delivers AC, but at much higher power, adding 10-30 miles of range per hour. Many EV owners install a Level 2 charger in their garage. You'll also find them in parking garages, shopping centers, and workplaces.

Level 3 – DC Fast Charger

A Level 3 charger skips the car's on-board charger and delivers direct current (DC) straight to the battery. This is the fastest option, adding 100-200 miles of range in just 20-30 minutes. You'll find DC fast chargers at highway rest stops and dedicated charging stations. They're ideal for long road trips when you need to recharge quickly and get back on the road.



SMART CHARGING

We've already learned that letting a lithium-ion battery go to zero can make it weaker over time. Charging it to 100% (especially if it stays at full charge for a long time) can also do long-term damage to the battery. That's why most EVs have a smart charging function. Many owners set it to stop charging at 80% for daily use. Keeping an EV battery between about 20% and 80% reduces wear on the cells and helps the battery last longer.



HOW FAR CAN YOU GO?

The range of an electric vehicle is how far it can travel on one full charge. Several factors affect how much energy the battery uses:



Speed: Driving fast uses more energy. Highway driving typically uses more battery power than city driving.

Temperature: Batteries work best at moderate temperatures. In very cold weather, chemical reactions inside the battery slow down, and the battery can't deliver as much energy. In very hot weather, the battery management system may limit charging to protect the cells.

Hills: Driving uphill requires more energy. (Though some of that energy can be recovered on the way back down – more on that in the regenerative braking section!)

Load: Carrying more weight or running the heater and air conditioning uses extra battery power.

CHARGING MATH CHALLENGES

Challenge 1: An electric car's battery needs 60,000 watt-hours of energy to fully charge. A Level 2 home charger delivers 6,000 watts, which means it puts 6,000 watt-hours of energy into the battery every hour. How many hours will it take to fully charge the car?

$$\frac{\text{Watt-hours to full charge}}{\text{Watts}} = \text{Hours to full charge}$$

Challenge 2: A 25-watt light bulb uses 25 watt-hours of energy every hour it's on. A large EV battery holds 50,000 watt-hours of energy. If you used the EV battery to power just that one light bulb, how many hours would it last?

$$\frac{\text{Battery capacity (watt-hours)}}{\text{Light bulb watt-hours}} = \text{Hours of light}$$

(Answers on back cover)

THE ELECTRIC MOTOR

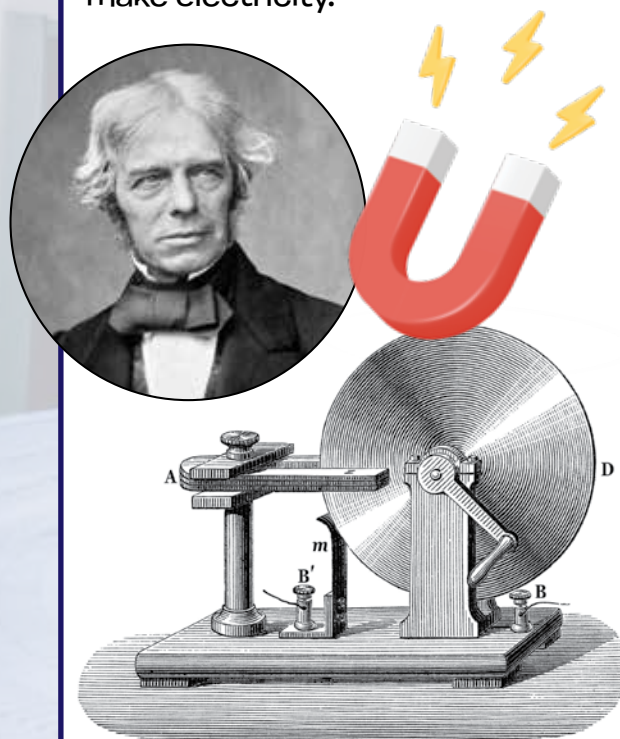
From Electricity to Movement.

The battery stores the energy. The charger fills the battery back up. But how does the energy in that battery actually make a two-ton vehicle move?

The answer is the electric motor, one of the most elegant and efficient machines ever built.

ELECTRICITY & MAGNETISM

In 1831, a scientist named Michael Faraday made a discovery that changed the world. He found that when you move a magnet near a coil of copper wire, it creates an electric current in the wire. Magnetism can make electricity.



But the reverse is also true: when electricity flows through a wire, it creates a magnetic field around that wire. Electricity can make magnetism.

The electric motor uses electricity to create magnetism, and uses that magnetism to produce motion.

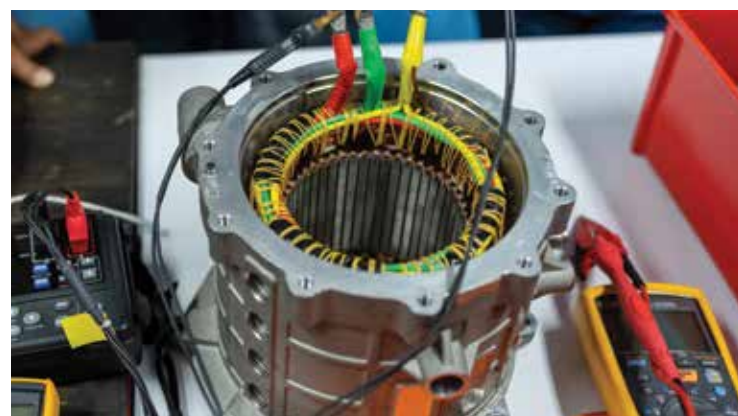
HOW AN ELECTRIC MOTOR WORKS

Inside an electric motor, there are two main parts: a ring of wire coils that stays still, and a set of magnets in the center that can spin.

When electric current flows through the wire coils, it turns them into magnets too. Because magnets push and pull on each other, the coils push and pull on the magnets in the center, and the center starts to spin. The spinning center is attached to a shaft, which connects to the wheels. The shaft spins, the wheels turn, and the car moves.

Here's where AC comes in: the power electronics module sends alternating current to the coils, so the push and pull keeps moving from coil to coil around the ring. The magnets in the center chase that moving push and pull around and around, like a cat chasing a laser dot.

Here's what makes it so clever: by controlling how strong the current is and how fast it switches, engineers can control exactly how fast and how powerfully the motor spins. Press the accelerator gently, and a small current creates a gentle push. Press it firmly, and a larger current creates a powerful surge of acceleration.



INSTANT TORQUE: WHY EVS FEEL SO FAST

Torque is the twisting force that makes the wheels turn. In a gasoline engine, torque builds up gradually as the engine revs up, which is why gas-powered cars sometimes feel like they need a moment to “wake up” before accelerating.

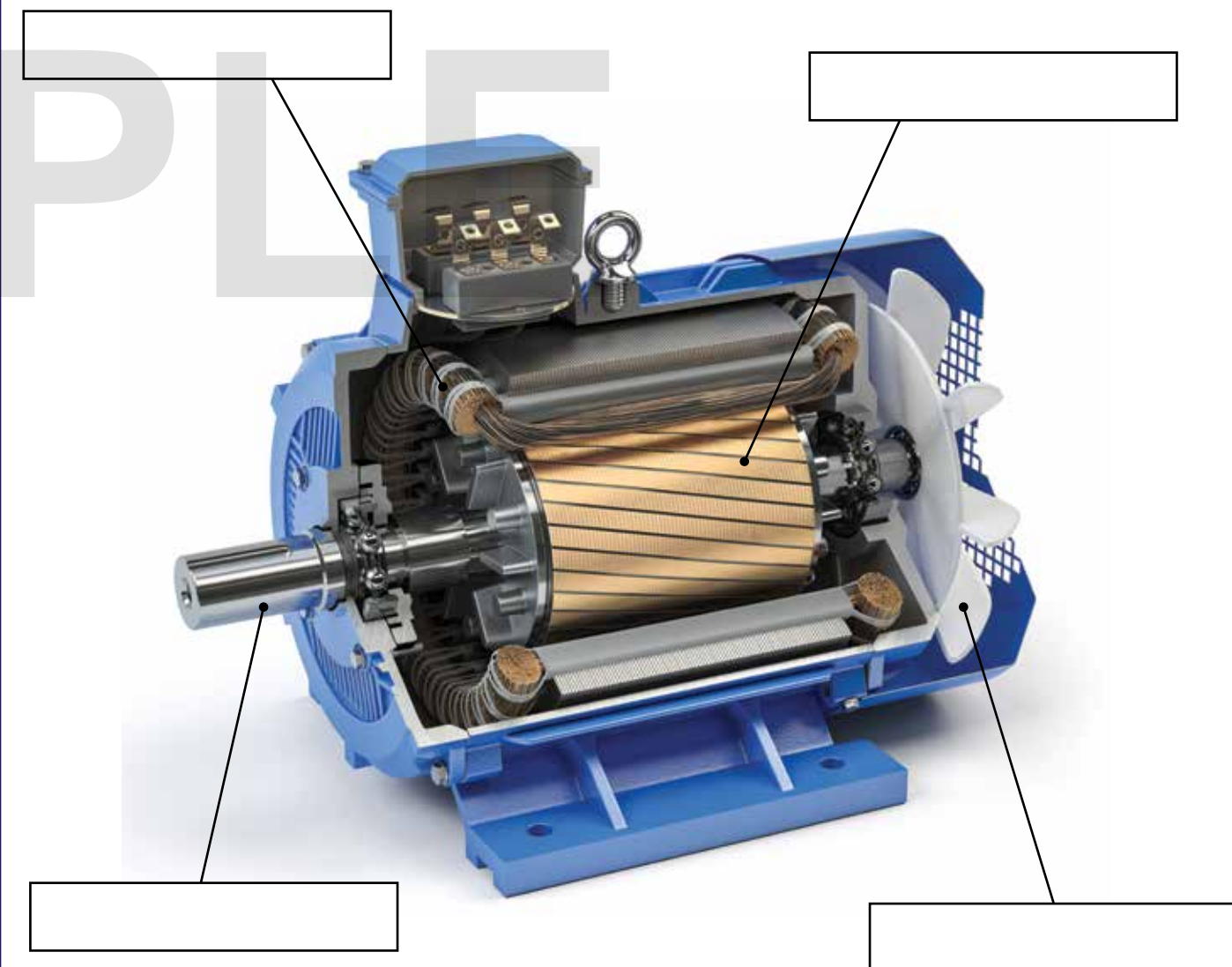
An electric motor produces its full torque instantly, the moment electricity flows through it. There's no revving up, no delay. Press the accelerator and the full force of the motor is immediately applied to the wheels. This is why many drivers describe EVs as feeling surprisingly quick and responsive.

DID YOU KNOW?

Electric motors are efficient! A gasoline engine converts only about 20-40% of the fuel's energy into motion, the rest is lost as heat. An electric motor converts about 85-90% of the electrical energy it receives into motion. Almost nothing is wasted.

LABEL THE MOTOR

Can you figure out which part is which? Fill in the blanks on the diagram with these terms: **Wire Coil, Magnet, Spinning Shaft, Fan.**



(Answers on back cover)

ReGenerative BRAKING: GETTING ENERGY BACK

The Cleverest Trick in the Car.

Every time a vehicle slows down or stops, something has to happen to the energy that was moving it forward. In a gasoline-powered car, that energy is turned into heat through the brake pads, and that heat is wasted and disappears into the air.

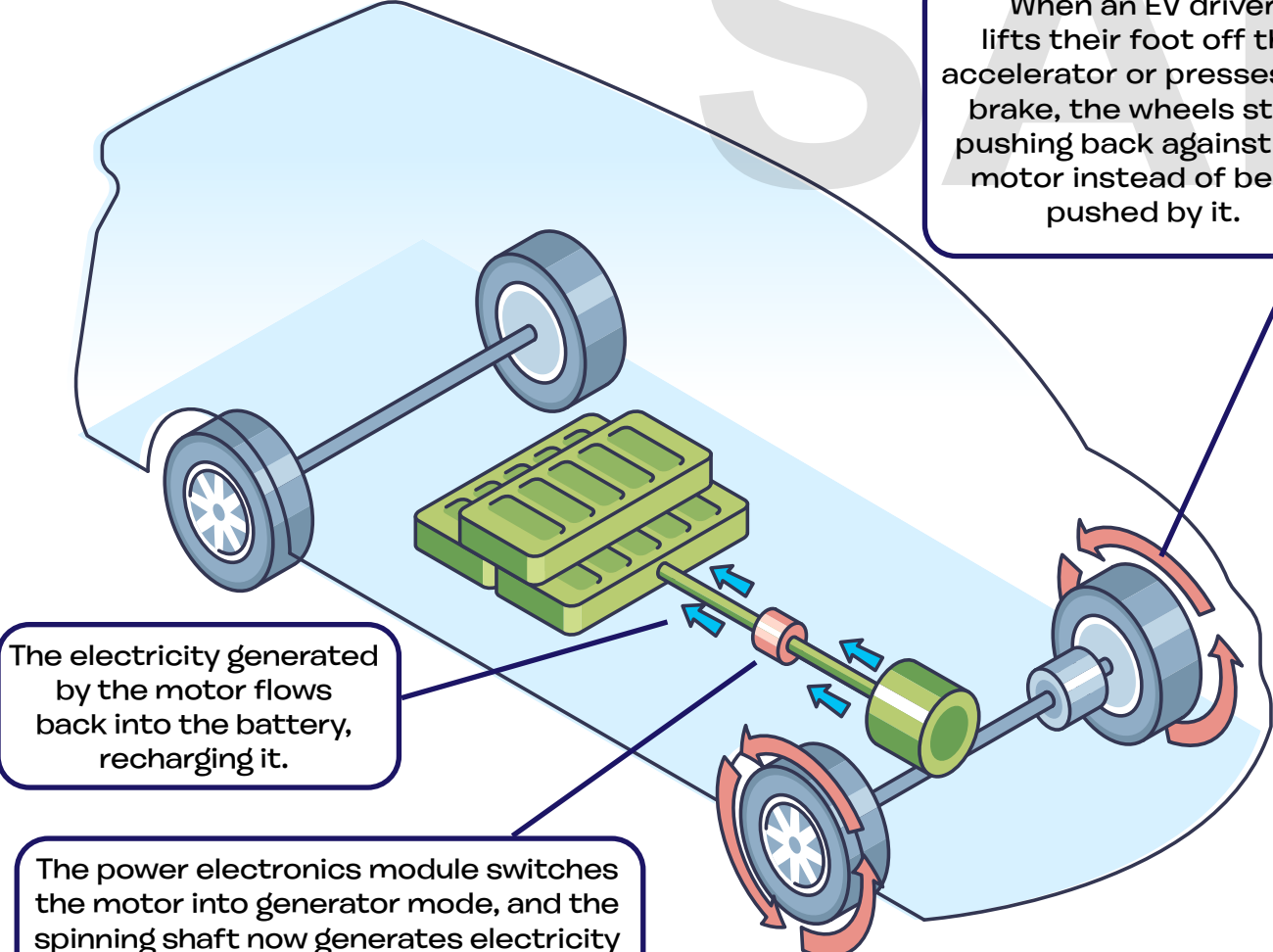
But electric vehicles can do something far more clever. They can catch that energy and put it back in the battery.

This is called regenerative braking, and it is one of the most ingenious pieces of engineering in the entire vehicle.

HOW IT WORKS

Think back to what you learned about Michael Faraday. He discovered that moving a magnet near a coil of wire creates an electric current. Normally, electricity makes the motor's shaft spin. But when the wheels spin the shaft instead, the motor does the reverse: the spinning shaft makes electricity.

When an EV driver lifts their foot off the accelerator or presses the brake, the wheels start pushing back against the motor instead of being pushed by it.



The electricity generated by the motor flows back into the battery, recharging it.

The power electronics module switches the motor into generator mode, and the spinning shaft now generates electricity instead of using it.

ReGenerative BRAKING MATH

An electric car uses 20 kWh of energy to drive a certain distance. Regenerative braking gives back about 15% of the energy used during the trip. How much energy is returned to the battery?

$$\underline{\hspace{2cm}} \times \underline{\hspace{2cm}} = \underline{\hspace{2cm}}$$

kWh of energy used to drive Percent of energy returned kWh of energy returned to the battery

(Answers on back cover)

FILL IN THE BLANK

Use the word bank to complete the sentences below:

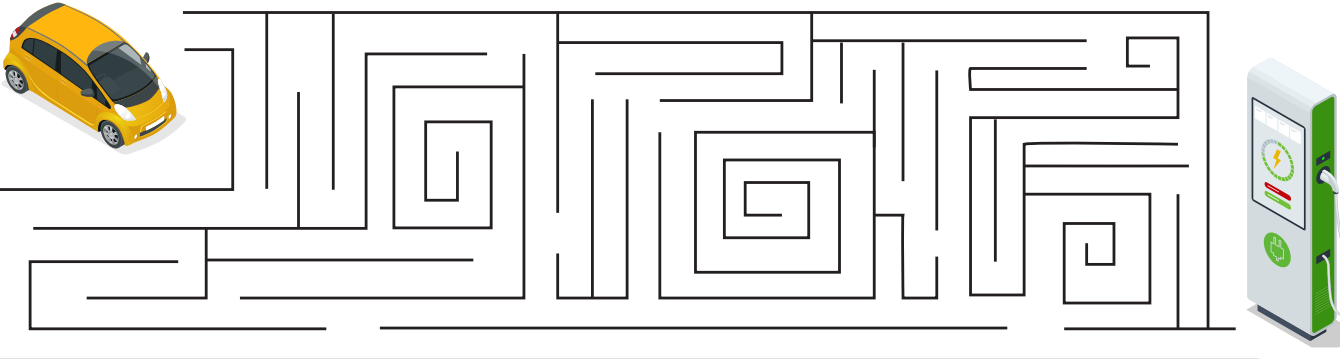
Word Bank: chemical potential / energy / kinetic / electrical / range / heat

1. When a car is moving, it has _____ energy.
2. When the motor captures that motion and sends electricity back to the battery, the energy is then _____ energy.
3. The energy goes back into the car's battery and is stored as _____ energy.
4. This process helps increase the car's driving _____.
5. In a gas-powered vehicle, braking energy is lost as _____.
6. Regenerative braking is most effective in city driving because stopping and starting frequently collects the most _____.

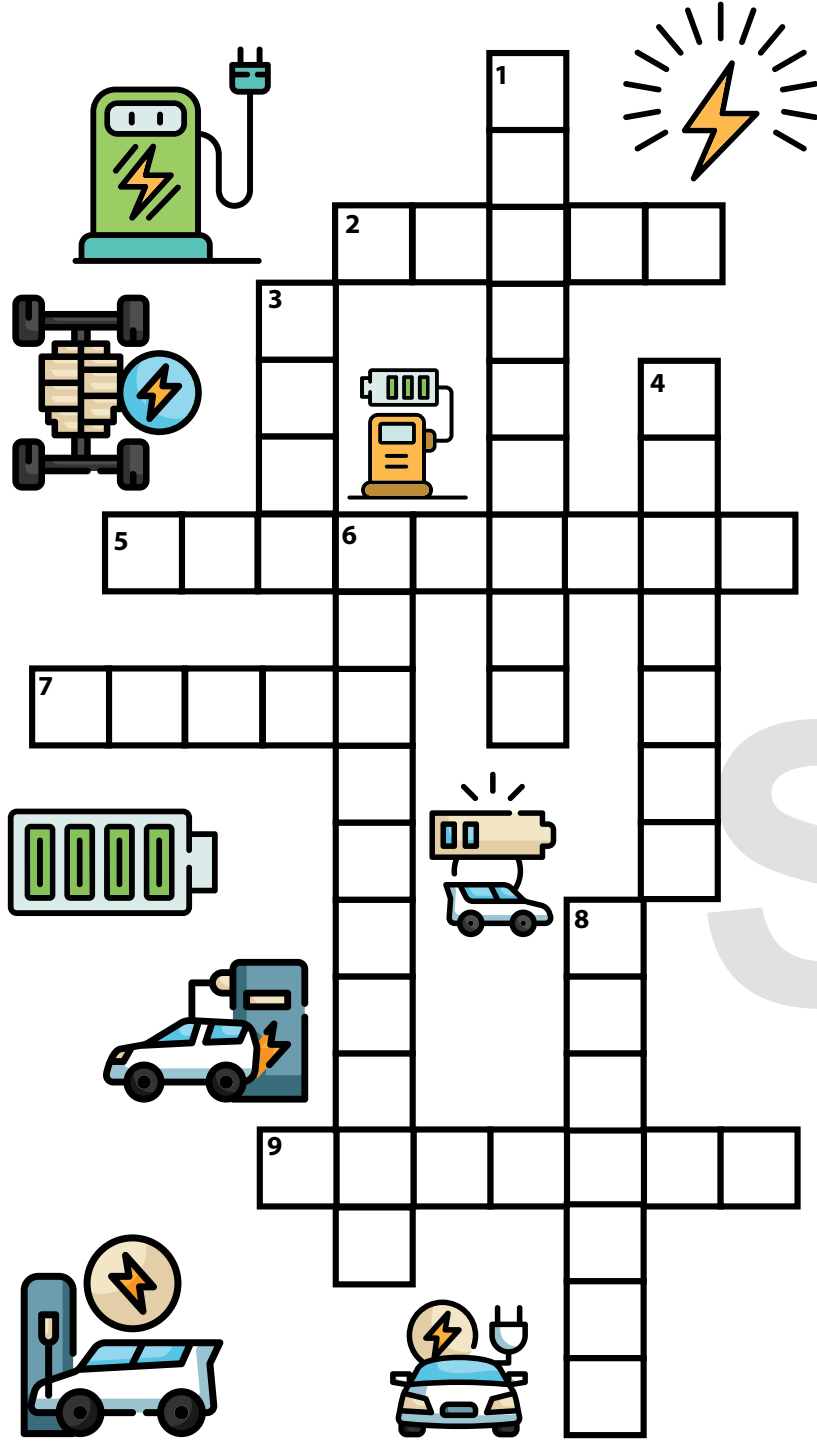
(Answers on back cover)

ReGenerative BRAKING MAZE

Help this EV find its way to the charging station.
Remember, every time you slow down, you get a little energy back!



Let's Review



ACROSS

- 2. How far an electric vehicle can travel on one charge
- 5. The type of energy that is stored for later use
- 7. What the driver does to slow down
- 9. Stores electrical energy as chemical energy

DOWN

- 1. What the motor becomes during regenerative braking
- 3. Gas-powered vehicle brakes turn motion into this wasted energy
- 4. A tool used to fill a battery with electricity
- 6. The type of energy sent back to the battery during regenerative braking
- 8. The energy of movement

ANSWERS

ELECTRICAL	BATTERY	RANGE
GENERATOR	POTENTIAL	KINETIC
CHARGER	HEAT	BRAKE

WORD FIND

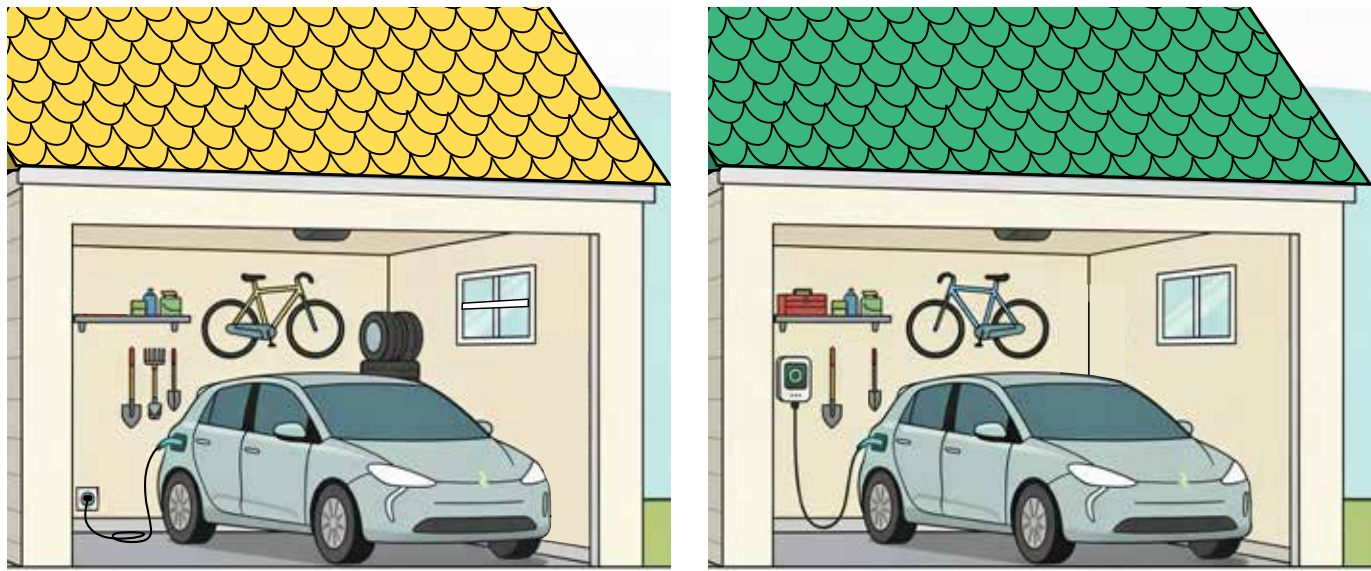
M	O	T	O	R	L	I	O	N	A	G	B
P	V	T	O	R	Q	U	E	K	H	E	A
L	P	E	L	E	C	T	R	I	C	N	T
L	O	A	H	F	I	E	C	N	A	E	T
I	T	N	R	I	R	V	K	E	T	R	E
T	E	O	B	G	C	S	U	T	H	A	R
H	N	D	A	B	U	L	Q	I	O	T	Y
I	T	E	E	T	I	T	E	C	D	O	H
U	I	V	O	L	T	A	G	E	E	R	A
M	A	W	B	E	C	C	H	A	R	G	E
Z	L	W	C	U	R	R	E	N	T	H	A
R	E	G	E	N	E	R	A	T	I	V	E

WORD BANK

- ELECTRIC
- VEHICLE
- BATTERY
- MOTOR
- KINETIC
- POTENTIAL
- REGENERATIVE
- VOLTAGE
- CURRENT
- ANODE
- CATHODE
- LITHIUM
- CHARGE
- GENERATOR
- CIRCUIT
- TORQUE
- ION

SPOT THE DIFFERENCES

Take a look at these EVs charging – can you find all 8 differences?



Resources

U.S. Department of Energy
Alternative Fuels Data Center
afdc.energy.gov

Energy Information Administration Kids Page
eia.gov/kids

Answer Key

Sort It Out – Page 5:



POTENTIAL



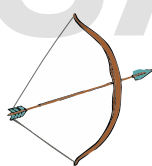
POTENTIAL



KINETIC



KINETIC



POTENTIAL



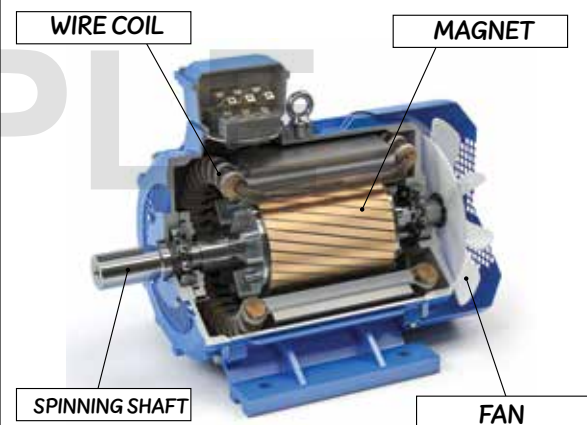
POTENTIAL

Charging Math – Page 13:

Challenge 1: $60,000 \div 6,000 = 10$ hours

Challenge 2: $50,000 \div 25 = 2,000$ hours

Label the Motor – Page 15:



Regenerative Braking Math – Page 17:

$15\% \text{ of } 20 \text{ kWh} = 0.15 \times 20 = 3 \text{ kWh}$

Fill in the Blank – Page 17:

1. When a car is moving, it has KINETIC energy.
2. When the motor captures that motion and sends electricity back to the battery, the energy is then ELECTRICAL energy.
3. The energy goes back into the car's battery and is stored as CHEMICAL POTENTIAL energy.
4. This process helps increase the car's driving RANGE.
5. In a gas-powered vehicle, braking energy is lost as HEAT.
6. Regenerative braking is most effective in city driving because stopping and starting frequently collects the most ENERGY.