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WELCOME, ELECTRICITY & MAGNETISM ENGINEER!

ARE YOU READY TO ENGINEER WITH INVISIBLE FORCES?

Plan → Build → Test → Measure → Improve



Electricity and magnetism are working all around you. Electricity lights homes, powers computers, and operates machines. Magnets help speakers produce sound, motors create motion, and cranes lift heavy metal objects.

But how does electrical energy travel through a system? Why does a device work only when its circuit is complete? How can an invisible magnetic field guide direction? Can electricity be used to create a magnet? How can magnetic forces lift objects or make a machine spin? These are the kinds of questions that electrical and mechanical engineers investigate. In this book, you will build working systems that allow you to observe, test, control, and apply these invisible forces. You will:

- 💡 Explore how electrical energy flows through a complete circuit.
- 🧭 Investigate how magnetic fields can provide direction.
- 🧲 Discover how electric current can create a controllable magnet.
- 🏗️ Apply electromagnetism inside a useful lifting system.
- ⚙️ Transform electrical energy into spinning motion.

Each project begins with a challenge. You will plan a first design, build and test it, collect evidence about its performance, and decide how the system can be improved.

YOUR ELECTRICITY & MAGNETISM ENGINEERING MISSION

Complete all five engineering projects and discover how engineers transfer electrical energy, control magnetic forces, and produce useful work. During your mission, you will:

1. Create Electric Flow

Explore how a power source, conducting path, and output device work together inside a complete electrical system.

2. Detect Magnetic Fields

Investigate how magnetic materials respond to Earth's magnetic field and how invisible forces can be used to determine direction.

3. Control Magnetism

Discover how electric current flowing through a coil can produce a magnetic field that can be switched on, switched off, and adjusted.

Design a Magnetic Compass

Get ready to think like an engineer and build your own **direction-detection system using magnetism!**

In this activity, you will design and build a simple magnetic compass using a magnetized needle and a floating platform. Instead of using electricity, you will use **Earth's natural magnetic field** to create a system that can detect direction — just like real engineers and explorers have done for centuries.

When the needle is magnetized, it becomes a temporary magnet. As it floats freely, it will align with Earth's magnetic field and point in a consistent direction.



? What problem are we solving?

People often need to find direction when roads, signs, or electronic tools are unavailable. Hikers, sailors, pilots, explorers, and rescue teams all depend on reliable ways to stay oriented and travel safely. Engineers use direction-detection systems to:

✓ identify North, South, East, and West
✓ support navigation on land, at sea, and in the air
✓ provide a backup when GPS or electronic devices are unavailable
✓ help maps, vehicles, and navigation tools stay correctly oriented

A magnetic compass solves this problem by detecting Earth's invisible magnetic field. Its magnetized needle turns until it aligns in a consistent North–South direction.

💡 Engineering Challenge

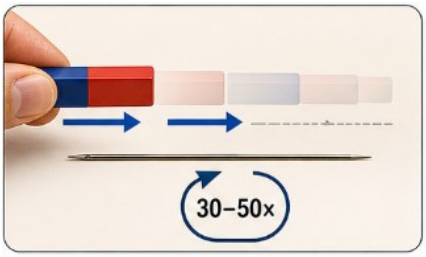
How can you design a stable magnetic compass that uses Earth's magnetic field to detect a consistent North–South direction?

🌎 Where do we see this in real life?

This same idea is used in many real systems:

🧭 Navigation compasses used by hikers and explorers
🗺️ Map-reading and outdoor navigation systems

🧲 Step 2 — Magnetize the Needle

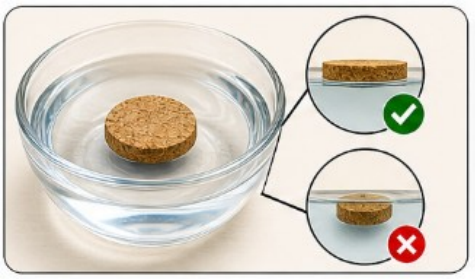


→ Take your magnet
→ Stroke the needle from one end to the other in **one direction only**
→ Lift the magnet away after each stroke
→ Start again from the same end each time
→ Repeat **30–50 times**

One stroke means moving the magnet from one end of the needle to the other once

👉 **Do not rub the magnet back and forth. Stroking in one direction helps turn the needle into a temporary magnet.**

🧭 Step 3 — Prepare the Floating Base



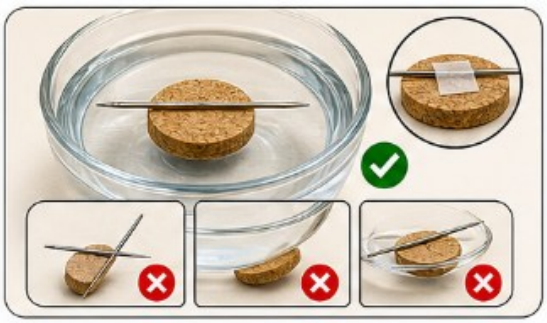
→ Cut a small piece of cork or craft foam
→ Make it large enough to hold the needle
→ Keep it small enough to float freely
→ Place that piece in the bowl of water to check that it **floats flat**

👉 If it sinks, use a lighter or thicker material

👉 The floating base allows the needle to turn freely with very little friction.

👉 ***"The base must float freely in the center without touching the bowl."***

🔧 Step 4 — Place the needle



→ Carefully place the needle **on top of the floating piece**
→ Lay it flat across the center (not sticking out too far)
→ If it slides off, use a **very small piece of tape** to hold it

👉 Important:

The needle should **not touch the water directly**

The needle should **not touch the bowl**. The base must float freely without getting stuck

🧭 Step 5 — Create the Compass Circle

→ Place the empty bowl upside down on the paper and trace around its rim.
→ Remove the bowl and mark the center of the circle.

How It Works (Science Background)

Your Compass is a System

Your compass is a simple **magnetic detection system** made of:

👉 Magnetized Needle 👉 Floating Base 👉 Earth's Magnetic Field

All parts must work together to detect direction.

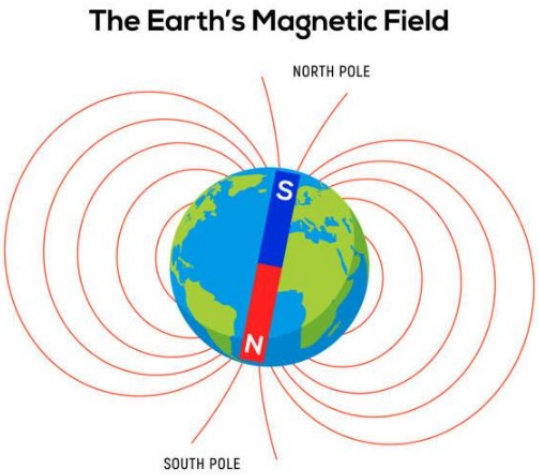
Earth is a Giant Magnet

Earth produces a magnetic field that behaves somewhat like the field around a giant magnet:

✓ A **North magnetic pole**
✓ A **South magnetic pole**

Around Earth, there is an invisible region called a **magnetic field**.

👉 This field exists everywhere around us, even though we cannot see it.



What the Needle Does

When you magnetize the needle: 👉 It becomes a **temporary magnet**

This means:

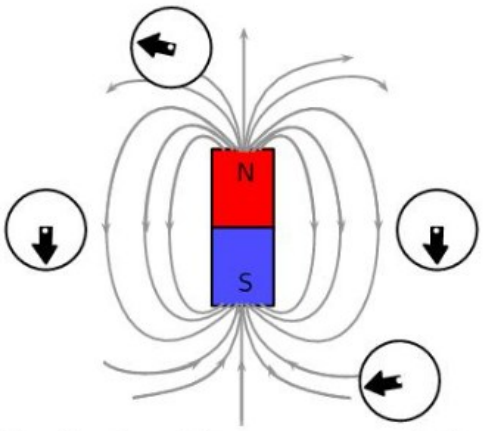
One end becomes **North-seeking**

The other end becomes **South-seeking**

When placed on a floating base:

✓ The needle is free to move
✓ It reacts to Earth's magnetic field
✓ It turns until it lines up with the field

👉 This is called **alignment**

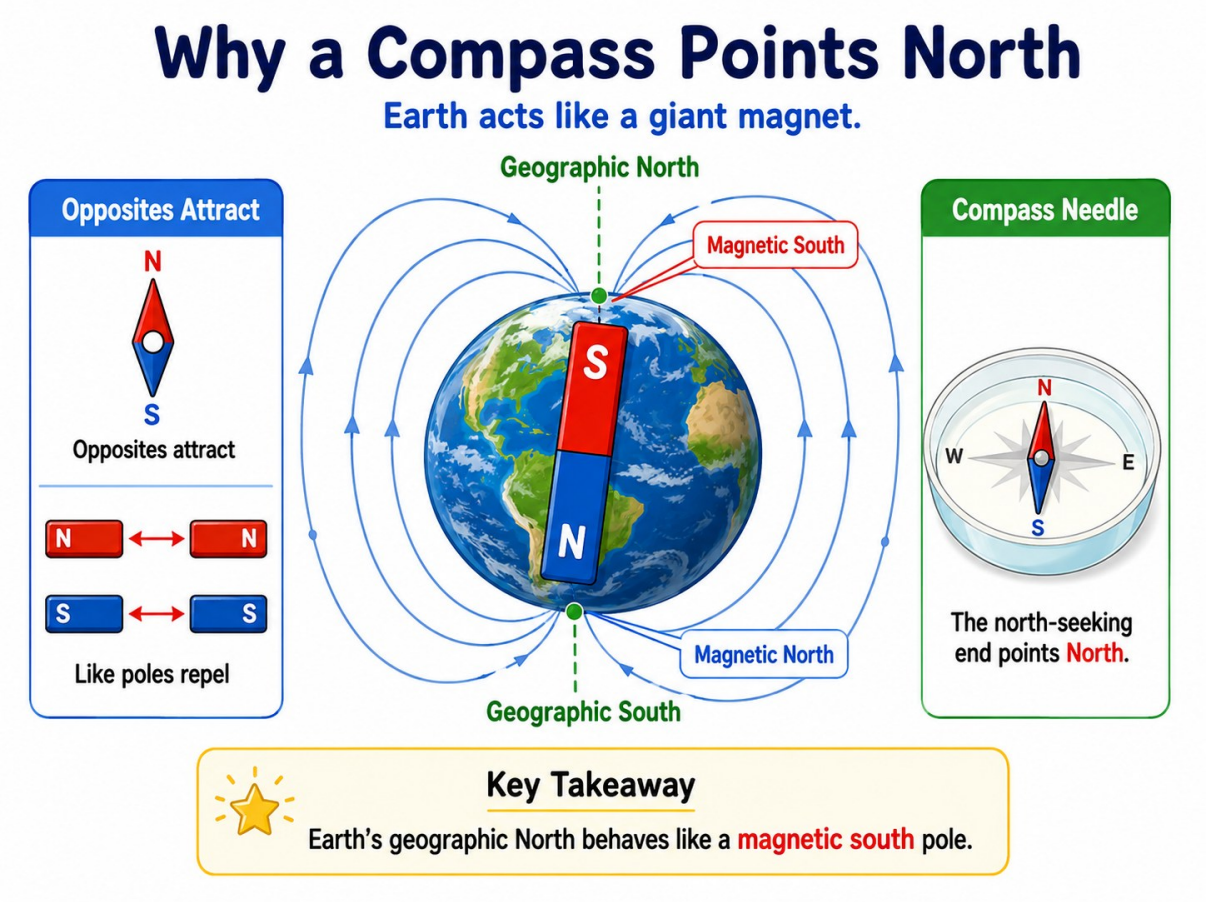


The direction of the compass arrow is the same as the direction of the magnetic field

Why the Needle Turns

Earth's magnetic field creates a turning effect on the magnetized needle.

👉 The needle rotates until it aligns with Earth's magnetic field, and the turning effect becomes balanced



👉 *"Earth's geographic North behaves like a magnetic South pole, which is why the needle points toward it."*

🛠️ Improve Your Design

Engineers improve navigation systems by changing one feature, testing again, and comparing the results with evidence. Choose one level—or complete all three.

● LEVEL 1 — CHANGE THE NUMBER OF MAGNET STROKES

🔧 **Challenge:** Test how the number of magnet strokes affects compass performance.

Compare: ✓ needle magnetized with 20 strokes; ✓ needle magnetized with 50 strokes.

☑ Stroke the needle in the same direction each time. Keep the same needle, magnet, floating base, bowl, water level, and testing location.

☑ First, test the needle after 20 strokes. Then add 30 more strokes for a total of 50, and test again.

☑ After 20 total strokes, complete three settling tests. Then add 30 more strokes for 50 total and complete three more tests.

🔧 Troubleshooting

🚧 Problem	🔧 What You Can Do
⚠️ Needle does not point in a clear direction	✓ Magnetize the needle again using one-direction strokes ✓ Use 30–50 strokes ✓ Try a stronger magnet
⚠️ Needle sinks	✓ Use a larger or thicker floating base ✓ Use cork or foam instead of paper ✓ Make sure the needle is resting on top of the base
⚠️ Floating base tips over	✓ Center the needle on the base ✓ Use a flatter base ✓ Use a smaller piece of tape
⚠️ Compass gets stuck near the bowl edge	✓ Gently move the base back to the center ✓ Use a larger bowl ✓ Make sure the base is not touching the side
⚠️ Needle spins or moves too much	✓ Wait for the water to become still ✓ Avoid bumping the table ✓ Wait until all ripples have stopped before testing
⚠️ Needle points toward a strange direction	✓ Move magnets away ✓ Move metal objects away ✓ Keep magnets, steel objects, speakers, and electronic devices away during testing
⚠️ Compass circle does not match the needle	✓ Wait until the needle stops moving ✓ Use a phone compass, physical compass, or the marked North reference ✓ Rotate the paper compass circle so N matches the north-pointing end
⚠️ Compass works sometimes, but not always	✓ Re-magnetize the needle ✓ Check that the base floats freely ✓ Test again in a calm location
⚠️ The needle does not match the North–South line on the paper	✓ Confirm which end was marked as north-seeking ✓ Check the compass circle using a real compass ✓ Remove nearby magnets or steel objects ✓ Remagnetize the needle

REFLECT & EXPLAIN

① **System Pathway**: Which pathway best describes the magnetic-compass system?

☐ A. Magnetize Needle → Float Freely → Align with Earth's Magnetic Field → Detect Direction
☐ B. Water Moves → Needle Sinks → Magnetism Stops → Direction Disappears
☐ C. Compass Circle → Magnet Creates Water → Needle Produces Electricity
☐ D. Floating Base → Bowl Turns → Needle Becomes Heavier → North Changes

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② **Why does the magnetized needle turn and settle in a consistent direction?**

☐ A. It aligns with Earth's magnetic field.
☐ B. The water pulls the needle toward North.
☐ C. The compass circle pushes the needle.
☐ D. Gravity makes one end of the needle point North.

---

③ **Magnetizing the Needle**: Why is the magnet stroked along the needle in one direction?

☐ A. To help magnetic regions inside the steel align
☐ B. To make the needle heavier
☐ C. To heat the needle so it floats
☐ D. To remove all magnetism from the needle

---

④ **Match Each Part to Its Function**: Write the correct letter beside each part.

Part	Answer	Function
1. Magnetized needle	___	A. Shows North, South, East, and West
2. Floating base	___	B. Provides the field that guides the needle's alignment
3. Earth's magnetic field	___	C. Turns and aligns with the magnetic field
4. Compass circle	___	D. Supports the needle and allows low-friction movement

---

⑤ **A young engineer tested the compass three times. What was the average settling time?**

Trial	Trial 1	Trial 2	Trial 3
Settling Time	8 s	10 s	6 s

☐ A. 6 seconds ☐ B. 8 seconds ☐ C. 10 seconds ☐ D. 24 seconds

---

⑥ **Analyze the Core Test Results:** Which conclusion is best supported?

Trial	Settling Time	Consistent Trial?	Stability Score
Trial 1	9 s	Yes	4/5
Trial 2	7 s	Yes	5/5
Trial 3	13 s	No	2/5

🧲 Create a Powerful Electromagnet

Get ready to think like an engineer and build a magnetic system that you can switch on, test, and improve!

In this activity, you will create an electromagnet by sending an electric current through a coil of wire wrapped around a metal core. Unlike a permanent magnet, an electromagnet works only when current flows through the circuit. This means its magnetic effect can be turned on and off, controlled, and changed through design.

You will test how well your electromagnet attracts metal objects, collect evidence about its strength, identify problems, and improve the system to make its magnetic effect more useful and reliable.



❓ What problem are we solving?

Many machines need a magnetic force only at certain times. A permanent magnet is always magnetic, so it cannot easily be switched off or adjusted. Engineers need magnetic systems that can be activated when needed, controlled during operation, and turned off when the task is complete. Electromagnets help solve this problem. Engineers use them to:

✓ lift, hold, and release metal objects
✓ control locks, switches, relays, and machines
✓ produce sound and motion in speakers and motors
✓ change magnetic strength by adjusting the electrical system

An electromagnet combines an electrical circuit with a magnetic output, allowing engineers to control an invisible force and use it to perform useful work.

💡 Engineering Challenge

How can you design and build a controllable electromagnet that uses electric current to attract and lift metal objects reliably?

Picking Up Objects

The magnetic field pulls metal objects (like paper clips) toward the nail

✓ More wire coils → stronger magnet ✓ Better connections → stronger current
✓ Stronger current → stronger magnetic field

Energy Transfer

In your system, energy is not just moving — it is being **changed into a different form**:

👉 The battery supplies electrical energy to the circuit. Electric current flowing through the coil creates a magnetic field. The field magnetizes the nail, allowing it to attract and lift metal objects. Some electrical energy is also transformed into heat in the wire and battery.

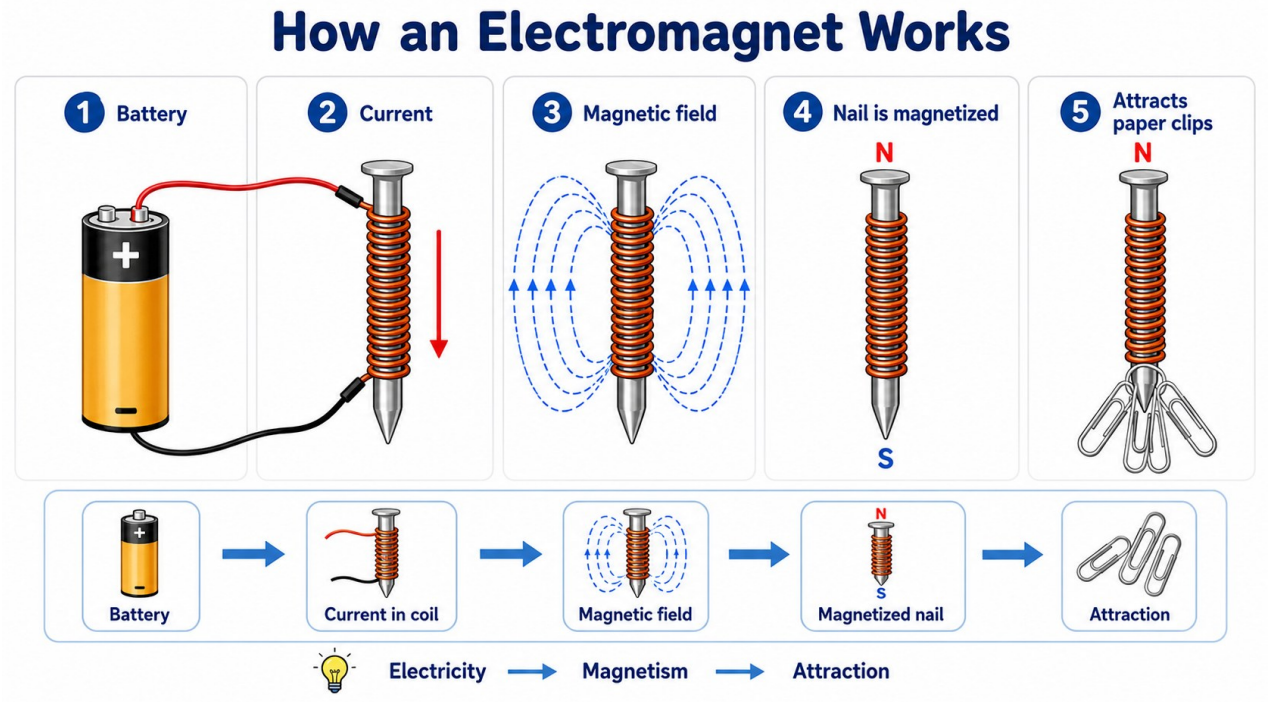
💡 **Electrical energy from the battery produces a magnetic field that can exert forces on magnetic materials. Engineers use this idea to create systems that move, lift, hold, and control objects using electromagnets**

Engineer Insight

Engineers use electromagnets in real systems:

- Cranes lifting metal
- Electric door locks
- Speakers and motors
- Maglev trains

👉 **They control electricity to control magnetism**



🔴 LEVEL 3 — ADD A SWITCH

🔧 **Challenge:** Add a simple switch that controls when the electromagnet turns on and off.

Build a switch using cardboard, two paper clips, and a folded strip of aluminium foil.

→ Attach two paper clips to the cardboard with a small gap between them.

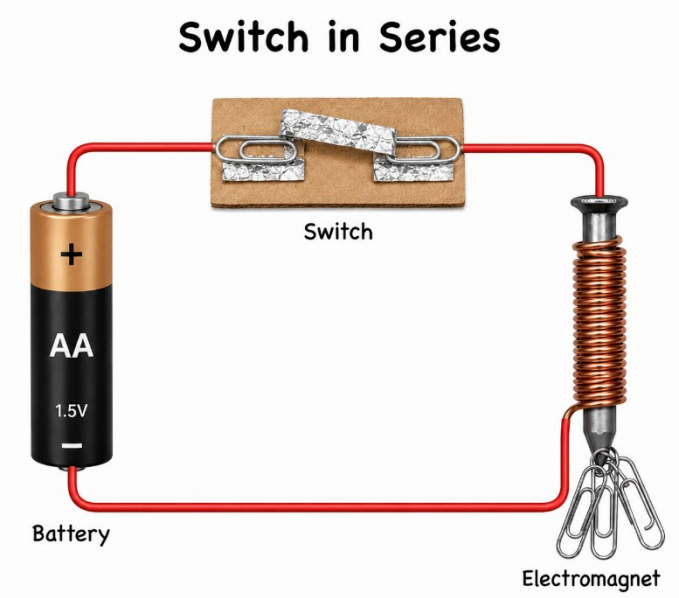
→ Connect one paper clip to the battery.

→ Connect the other paper clip to the electromagnet.

→ Attach one end of the foil strip to the first paper clip.

→ Lower the foil to touch the second paper clip and close the circuit.

→ Lift the foil away to open the circuit.



→ Place the switch **in series**, so all the current passes through it before reaching the electromagnet.

→ Keep the same battery, nail, coil design, paper clips, and testing method.

🧪 Test and Measure

Trial	Switch Closed: Magnet On?	Switch Open: Magnet Off?	Paper Clips Lifted	Control Successful?
1	Yes / No	Yes / No	_____	Yes / No
2	Yes / No	Yes / No	_____	Yes / No
3	Yes / No	Yes / No	_____	Yes / No

☑ A successful control trial means the closed switch turns the electromagnet on, the open switch turns it off, and the electromagnet lifts at least one paper clip.

⊙ **Successful control trials**: _____ out of 3

Control Reliability = Successful Control Trials ÷ 3 × 100

⊙ **Control reliability**: _____ %

🧠 What's Happening?

A switch controls whether the circuit pathway is complete.

⚡ Build a Spinning Electric Motor System

Get ready to think like an engineer and build your own working machine that **creates motion using electricity and magnetism**!

In this activity, you will design and build **a simple electric motor system** that spins using magnetic forces. Instead of just creating magnetism or controlling it, you will use it to produce continuous motion — just like real machines do.

Using simple materials, you will create a wire coil, connect it to a battery, and place it in a magnetic field. When electric current flows through the wire, it creates a magnetic field. This field interacts with a permanent magnet, producing a force that causes the coil to spin.



👉 **This is how real engineering systems work: They don't just create forces — they use them to produce motion.**

❓ What problem are we solving?

Many machines need parts to rotate repeatedly and reliably. Fans move air, pumps move water, power tools turn blades and bits, washing machines rotate drums, and electric vehicles use motors to turn their wheels. Electricity can supply energy, but electrical energy does not create useful motion by itself. Engineers must design a system that uses electricity and magnetic forces to produce controlled rotation.

💡 Engineering Challenge

How can you design and build a simple electric motor that starts easily and spins smoothly, continuously, and reliably using electricity and magnetism?

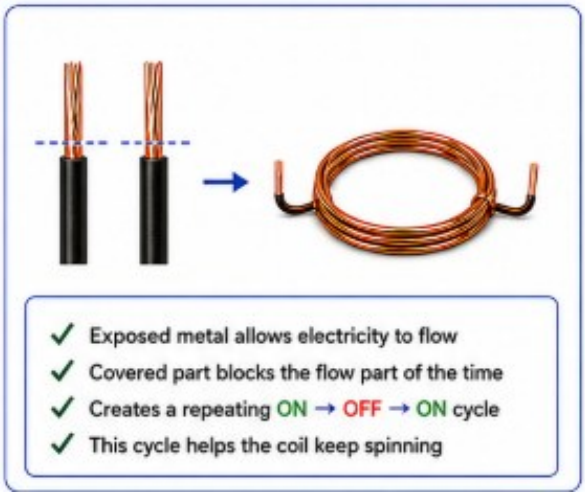
🌎 Where do we see this in real life?

This same idea is used in many real engineering systems:

- 🌀 Electric fans and cooling systems
- 🚙 Electric vehicles and motors
- 🧺 Washing machines and appliances
- 🔧 Power tools and machines

👉 **In all these systems**: Electric current flows → magnetic field is created → forces interact → motion is produced

🔌 Step 3 — Prepare the Wire Ends



→ Use sandpaper or a scraping tool
→ Remove the coating from the wire ends **carefully**
👉 The wire is coated with a thin invisible insulation layer
⚠️ Important: On **each wire end**, remove the coating from **only the top half**
👉 Leave the **bottom half still covered**
👉 Make sure both ends are prepared the **same way**
👉 The exposed (shiny) side should face **upward** when the coil is placed on the supports. When coil rotates:

Exposed side contacts support → current flows → coil becomes magnetic → magnetic push
Coated side contacts support → current stops → coil's magnetic field becomes very weak → coil coasts

🧲 Step 4 — Set Up the Magnetic Field



→ Place the magnet flat on top of the battery and centered directly under the coil.
→ Attach it to the battery using tape if needed

👉 The magnet creates the external magnetic field

🏗️ Step 5 — Build the Supports



→ Bend each paper clip into a curved "U" shape
→ Attach one paper clip to each end of the battery
👉 These act as:
✓ supports for the coil
✓ electrical contact points

🔄 Step 6 — Assemble the Motor

→ Place each end of the coil into the paper clip supports
→ Make sure:
✓ the coil spins freely
✓ the coil sits above the magnet
✓ the wire ends touch the paper clips
👉 Adjust height so the coil is close to the magnet but not touching

REFLECT & EXPLAIN — ANSWER KEY

ACTIVITY 1 — CIRCUIT SYSTEM

① **A** ② **A** ③ **A** ④ **Matching:** 1–C 2–D 3–A 4–B
⑤ **A**. Two batteries in series produced a brighter output: **5/5 compared with 3/5**. Both setups remained steady for 10 seconds.
⑥ **A; Reliability = C — 67%** (The circuit worked successfully in Trials 1 and 3. Reliability = 2 ÷ 3 × 100 = **67%)**
⑦ **B**. Keep the same bulb and wires and change only the number of batteries.
⑧ **A**. Connect the switch in series so opening it breaks the pathway and stops current.
⑨ **Correct checks:** ✓ Check whether the pathway forms a complete loop. ✓ Check whether the wire ends touch the battery and bulb terminals.
⑩ **Suggested Response**: The battery supplies **electrical energy**. When the battery, wires, bulb, and closed switch form a **complete pathway**, **current flows** through the circuit and the bulb produces **light**. Opening the switch breaks the pathway and turns the bulb off.

ACTIVITY 2 — MAGNETIC COMPASS

① **A** ② **A** ③ **A** ④ **Matching:** 1–C 2–D 3–B 4–A
⑤ **B — 8 seconds** (Average = (8 + 10 + 6) ÷ 3 = **8 seconds)**
⑥ **A**. Trial 2 settled fastest at **7 seconds**, returned to the same direction, and earned the highest stability score of **5/5**.
⑦ **B**. Use the same needle, magnet, floating base, and bowl, but change only the number of magnet strokes.
⑧ **Cork Base**. The cork base: settled faster: **8 seconds instead of 12 seconds**; returned to the same direction; earned a higher stability score: **5/5 instead of 3/5**.
⑨ **Correct changes:** ✓ Move the floating base to the centre, so it does not touch the bowl. ✓ Rebalance the needle and floating base.
⑩ **Suggested Response**: The **magnetized needle** rotates freely and responds to **Earth's magnetic field**. It turns until it can **align** approximately along the **North–South** direction, allowing the compass to indicate direction.

ACTIVITY 3 — POWERFUL ELECTROMAGNET

① **A** ② **A** ③ **A** ④ **Matching:** 1–B 2–C 3–A 4–D
⑤ **B — 9 paper clips** (Average = (6 + 9 + 12) ÷ 3 = **9 paper clips)**
⑥ **A**. Trials 1 and 3 successfully held their loads and had reliable connections. Trial 2 lifted fewer paper clips, did not hold them for five seconds, and had an unreliable connection.
⑦ **B**. Keep the nail, battery, paper clips, and testing method the same and change only the number of wire coils.
⑧ **40-Coil Design**. It: lifted an average of **10 instead of 5 paper clips**; lifted a maximum of **13 instead of 7**; succeeded in **3/3 instead of 2/3 trials**.
⑨ **Correct changes:** ✓ Tighten and secure the battery connections. ✓ Check that the exposed wire ends make firm metal-to-metal contact.