Electromagnetism

A massive junk heap sits, a mixture of trash and valuable materials. A giant magnet pulls steel scraps out for recycling. How do you unstick the steel from a powerful magnet? The solution is a temporary magnet that you can turn on and off.

The Discovery of Electromagnetism

The battery was the first source of electric current. It was invented by Alessandro Volta (1745–1827) in 1800. The D-cell we use today is a direct result of Volta's discovery.

The magnetic property of steel and iron makes these metals the easiest materials to separate from the solid waste stream. Millions of tons of steel are diverted from trash to reuse each year, pulled from scrap heaps by powerful electromagnetic cranes.

Hans Christian Ørsted (1777–1851) was a Danish physics professor in the late 1700s. He was fascinated by Volta's battery. Ørsted conducted many experiments with electric current.

In 1820, Ørsted was demonstrating that electric current makes wires hot. When he closed the electric circuit, the needle of a compass on the lecture table rotated. Some people think that Ørsted had planned to show the relationship between electric current and magnetism that day. Others think it was just a lucky accident. We will never know for sure.

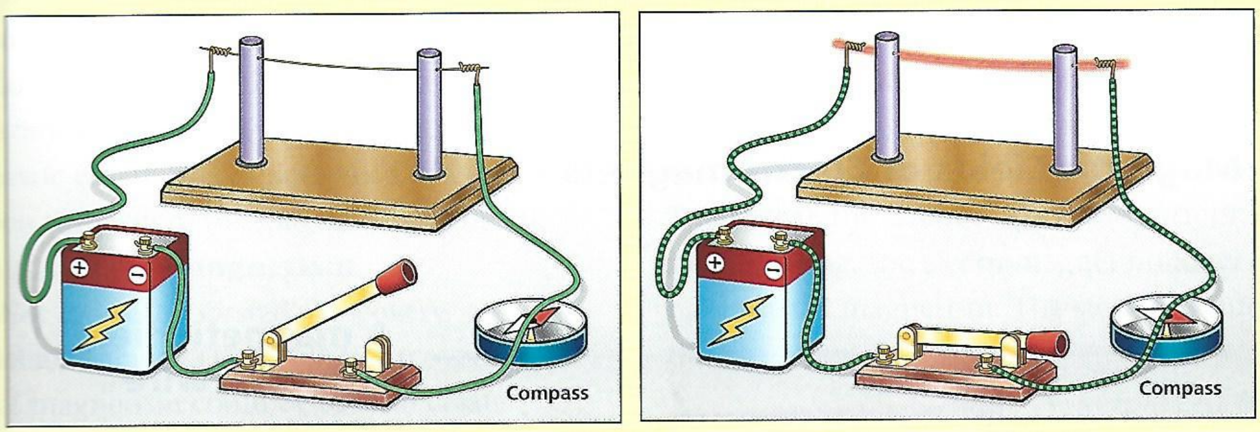
Here is what might have happened. Ørsted had a thin wire connected to a battery and a switch. A compass needle was right under one of the wires forming the circuit.

When Ørsted closed the circuit to deliver electric current to the thin wire, the needle rotated.

When Ørsted made this discovery, he conducted more experiments. Four months later, he wrote about his findings. He concluded that a flow of electric current produces a magnetic field.

This important discovery resulted in hundreds of inventions in the years that followed. One was the **electromagnet**, a magnet that can be turned on and off.

The Discovery of Electromagnetism



Whether by accident or by design, Ørsted discovered the relationship between electricity and magnetism. Both are caused by the electromagnetic force.

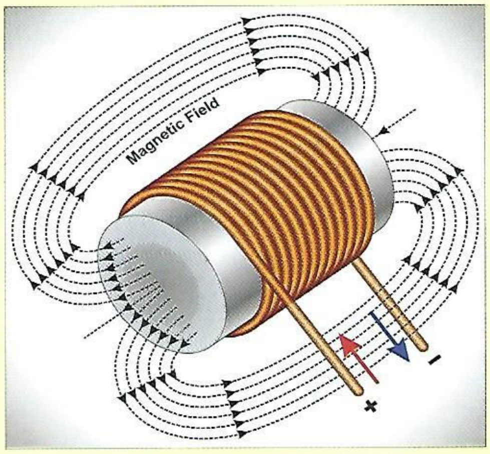
Electromagnetism

The wire you have been using to make circuits is made of copper. Copper is not magnetic. There is no magnetic field around a copper wire. You can confirm or prove this by bringing a compass close to a copper wire. The compass needle does not move.

Things change when you connect a copper wire to a source of electricity, such as a D-cell. While electric current flows through the wire, a magnetic field surrounds it. When you bring a compass close to the wire, the compass needle rotates slightly. When you break the circuit, the magnetic field disappears. The compass needle points north again.

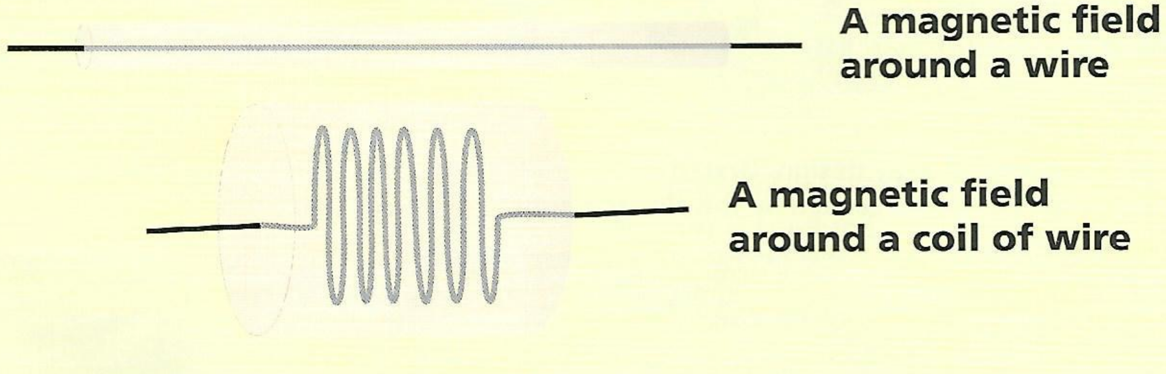
The magnetic field around a wire that has electric current flowing through it may not be very strong. But if you put two magnetic fields together, the magnetism becomes stronger. That is what happens when you coil up a wire. The magnetic field around each loop of wire adds to the fields from other loops. The greater the number of loops, the stronger the total magnetic field is.

Electric Current and Magnetic Field



Copper itself is not magnetic. But the flow of electric current through a copper wire creates a magnetic field around the wire.

Magnetic Fields of Electromagnets



Increasing the number of coils or loops of wire increases the strength of the magnetic field.

Steel is the world's most recycled material, more than paper, plastic, glass, and aluminum combined. Yesterday's cars and toasters may be tomorrow's bridges and skyscrapers.

What happens when the coil wraps around a steel **core**, like a rivet? The strong magnetic field induces magnetism in the steel. The steel becomes a temporary magnet as long as the electric circuit is complete. And when you open the switch, the magnetism turns off. This is **electromagnetism**.

Not long after Ørsted's discovery, Michael Faraday (1791–1867) discovered that magnetism could be used to create electric current. From then on, it was clear that one force was behind both magnetism and electricity. That force is the **electromagnetic force**.

Now you know how metal objects can quickly be sorted for recycling. Strong electromagnets are used in recycling centers for separating some metals (mostly iron and steel) from other scrap metal. Aluminum cans, for example, are left behind because they are not attracted to magnets. Turn on a large electromagnet over a junk heap, and watch as it lifts steel parts from the pile. Move the electromagnet over your collection bin. Then break the circuit. When the current stops flowing, the electromagnet no longer has induced magnetism. The steel falls into the bin below.

Think Questions

1. What was Ørsted's historic discovery?
2. How do you make an electromagnet?
3. How do you think you could make an electromagnet stronger?

Electromagnetic Engineering

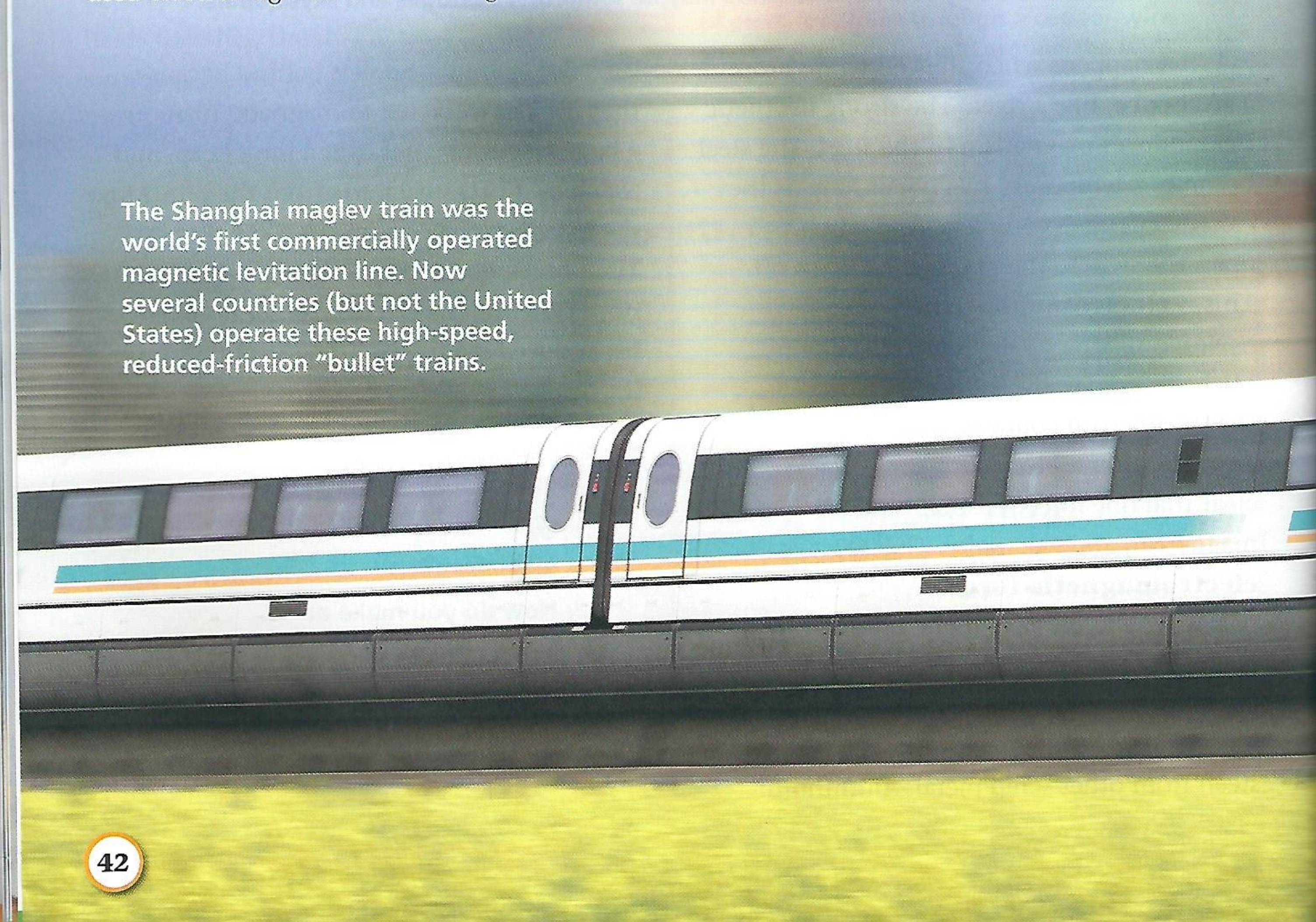
This train is off the tracks. As it moves, it hovers just above the tracks.

A train can travel more than 400 kilometers (km) per hour. It is propelled by electromagnetic force. How did the first electromagnets develop into an electromagnetic train?

Communicating with Electromagnets

Countless scientists and engineers have used electromagnets in their designs. Some designs use simple electromagnets combined with other components to transmit messages.

In 1835, Samuel F. B. Morse (1791–1872) used an electromagnet, a switch, and a battery to send a long-distance message. Long wires ran to an electromagnet far away. When the sender pressed a switch to complete the circuit, the receiver's electromagnet attracted a piece of steel and made a loud click. Those



The Shanghai maglev train was the world's first commercially operated magnetic levitation line. Now several countries (but not the United States) operate these high-speed, reduced-friction "bullet" trains.

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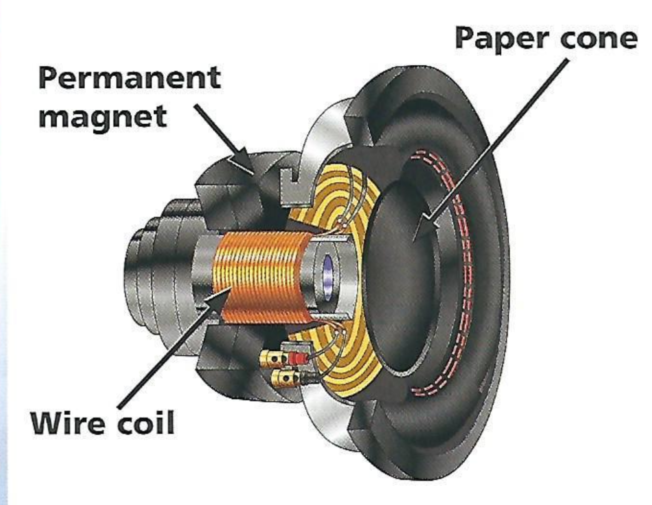
first clicks announced the invention of the telegraph.

Electromagnets are essential in the telephone, too. Alexander Graham Bell (1847–1922) invented the telephone in 1876. To hear sounds over a phone, you need a speaker to convert electric signals into sound vibrations. Most speakers have a coil of wire attached to a paper cone. The coil of wire is near a permanent magnet. When electric signals pass through the coil, the electromagnetic field of the coil interacts with the permanent-magnet field. This makes the paper cone vibrate, creating sound waves in the air. Headphones and earbuds work much the same way, but use much smaller magnets and coils of wire.

The telegraph key is a switch that opens and closes a long-distance electric circuit, transmitting signals—the dots and dashes of a coded alphabet—by wire.



Speakers come in all shapes and sizes, from compact earbuds to stadium loudspeakers. All use electromagnets to change electric energy into sound energy.

Microphones convert sound into electric signals. Some music-recording microphones use electromagnets. For example, a dynamic microphone acts like a speaker in reverse. Instead of a paper cone, a dynamic microphone has a disk. A coil of wire attached to the disk sits in the field of a permanent magnet. When the sound waves make the disk vibrate, the coil vibrates in the magnetic field, generating electric vibrations.

Other Designs That Use Electromagnets

Model railroads sometimes use electromagnets for switching tracks. Tiny electric **motors** physically move the track. Electric motors are related to electromagnets, as you will see later in this course.

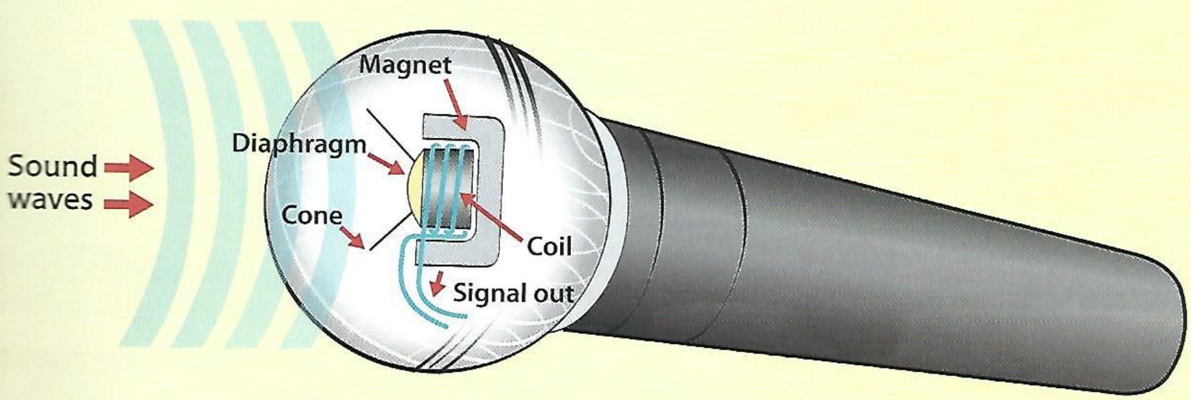
Induction heating uses electromagnets. An induction stovetop stays cool on its surface and heats only pans made of iron or steel. When the iron pan is on the stove, the stove converts electric current into thermal energy to heat the pan. Induction heating is also used in manufacturing and medical treatments.

An induction stovetop is safe to touch while cooking. The burner heats your pot but not your palm.

Take Note

Why do you think the induction stove heats only pans containing iron?

Dynamic Microphone



Dynamic microphones use electromagnets to change sound to electricity. The current can then be sent to an amplifier to be changed back to (louder) sound. Or it can flow to a recording device to be stored.

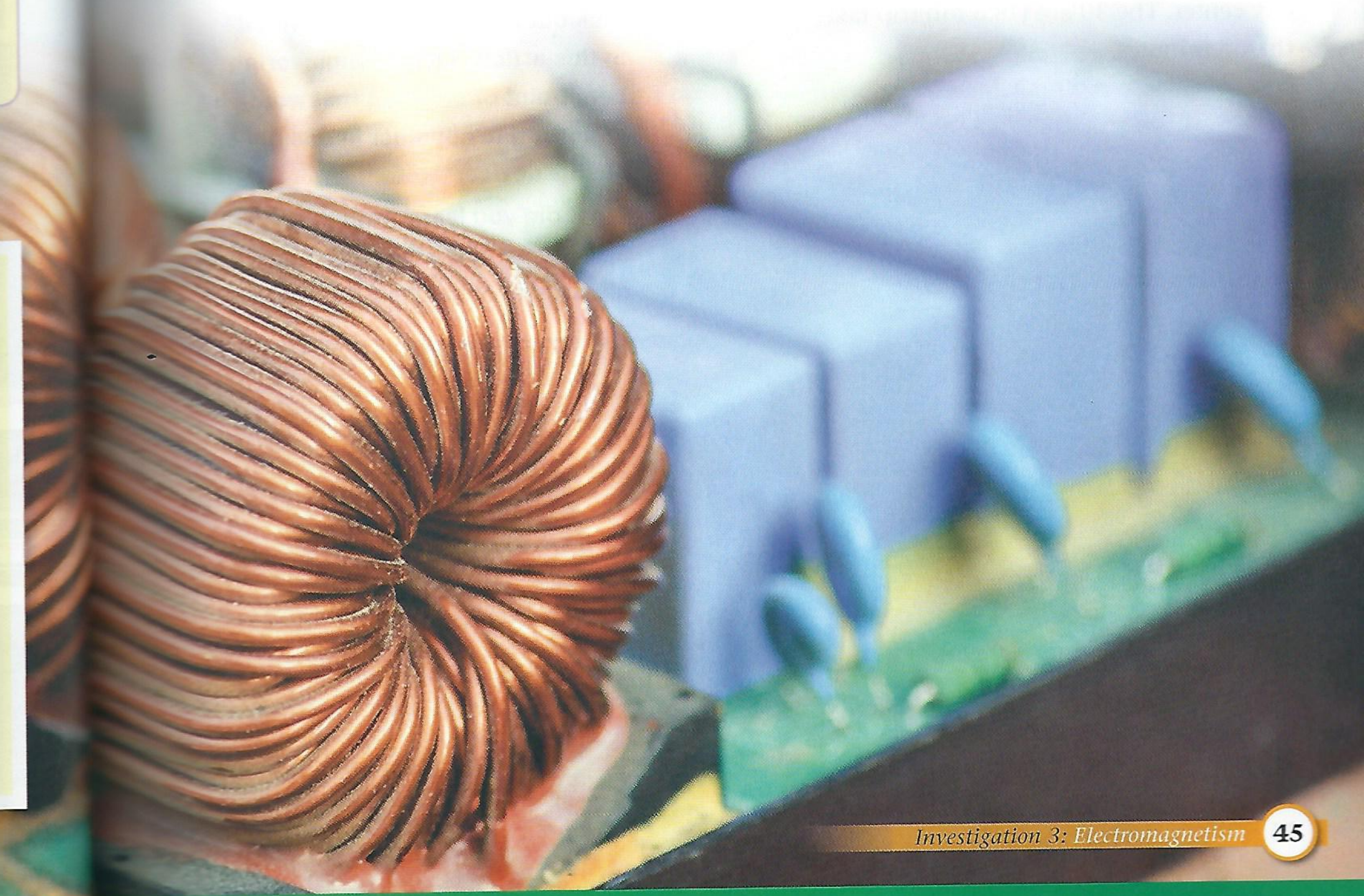
Modifications to Electromagnets

How can you make an electromagnet stronger? One way, which you may have figured out, is to have more coils of wire. The more wire you wrap around the core, the stronger the magnetism.

Another way to make an electromagnet stronger is to increase the amount of electric current flowing through the wire. You used one D-cell for your electromagnet. Two D-cells in a series circuit increases the magnetism a lot. What if you had ten D-cells in series? Or a giant car battery? Now we're talking about some strong magnetism!

A third way to make an electromagnet stronger is to wrap thicker wire around the core. Thicker wire can conduct more current. The thicker the wire is, the stronger the magnetic field, and the stronger the electromagnet.

Electromagnets have two important features that permanent magnets lack: Their magnetism can be turned on and off, and their magnetic fields can be strengthened with more coils and thicker wires.



Superconducting Magnets

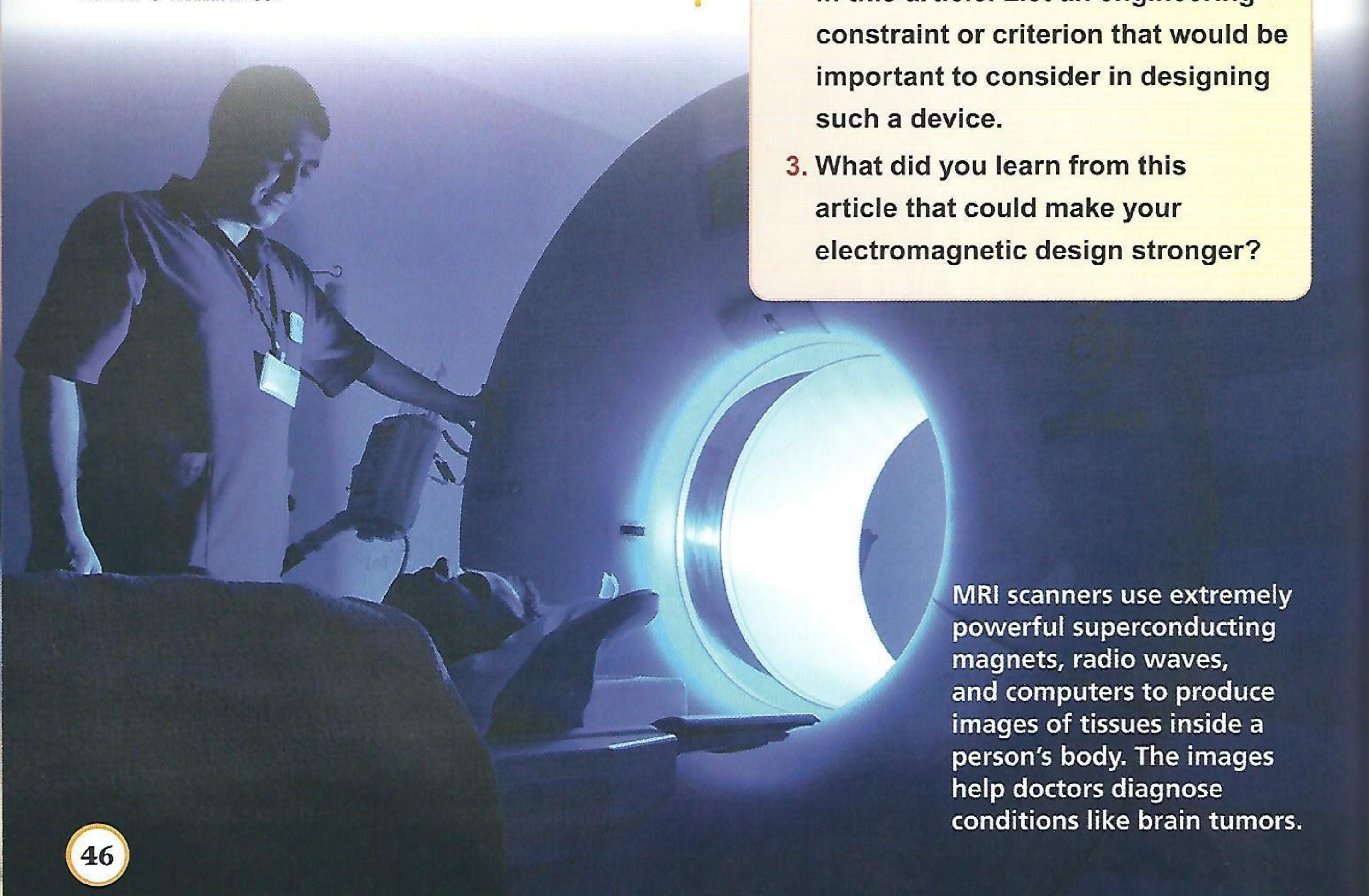
Some of the strongest electromagnets, called superconducting magnets, are cooled to reach maximum strength. Their coils of wire are cooled to extremely low temperatures, about –269 degrees Celsius (°C). Supercooled wires can conduct much larger electric currents than ordinary wire. This allows them to create intense magnetic fields. These magnets are efficient to operate, because no energy is lost heating the wire. Magnetic resonance imaging (MRI) machines in hospitals use such magnets.

Superconducting magnets can be strong enough to lift a whole train above its tracks. The Shanghai **maglev** train is a high-speed magnetic-levitation train. It carries passengers from the airport in Shanghai, China, to the city center. The 30 km (18.6 mi) trip takes less than 8 minutes.

The term *maglev* combines the words *magnetic* and *levitation*. Electromagnetic force levitates the cars between 8 and 12 millimeters (mm) above the track. The levitating cars do not have friction with the track. The cars still have friction with air, however. This air resistance is called **drag**. An aerodynamic design minimizes drag. Once the train levitates, superconducting electromagnets alternately push and pull the train along the track, faster and faster. The Shanghai maglev train reaches speeds over 500 km per hour (300 mph). Without friction on the tracks, the ride is extremely smooth.

Think Questions

1. **How has use of electromagnetic technology changed over the years?**
2. **Pick out three devices described in this article. List an engineering constraint or criterion that would be important to consider in designing such a device.**
3. **What did you learn from this article that could make your electromagnetic design stronger?**



MRI scanners use extremely powerful superconducting magnets, radio waves, and computers to produce images of tissues inside a person's body. The images help doctors diagnose conditions like brain tumors.