SUPERCHARGED SCIENCE

Unit 11: Magnetism

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Appropriate for Grades:
Lesson 1 (K-12), Lesson 2 (K-12)
Duration: 10-25 hours, depending on how many activities you do!

Why does a magnet stick to your fridge and not your soda can, even though *both* are magnetic? (No kidding!) And why is if that when you run magnets down a metal ramp, they defy gravity and slow to a stop? And how come the grapes from your lunchbox twist around to align with magnets, even though there's no iron inside a grape? There's got to be a reason behind this madness, and that’s what we’re about to uncover.

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Key Vocabulary

If an **atom** has more electrons spinning in one direction than the other, that atom has a magnetic field. Atoms are made of a core group of neutrons and protons with an electron cloud circling the nucleus.

The **Earth** has a huge magnetic field and a weak magnetic force. The magnetic field probably comes from the moving electrons in the currents of the Earth's molten core. The Earth has a north and a south magnetic pole which is different from the geographic north and south poles.

Electricity is a flow of electrons. A flow of electrons creates a magnetic field. Magnetic fields can cause a flow of electrons and, thus, electricity.

Electrons can have a "left" or "right" spin in addition to "going around" the nucleus. Electrons technically don't orbit the core of an atom. They pop in and out of existence. However, they do tend to stay at a certain distance from a nucleus. This area that the electron tends to stay in is called a shell. The electrons move so fast around the shell that the shell forms a balloon-like ball around the nucleus.

A **field** is an area around an electrical, magnetic, or gravitational source that will create a force on another electrical, magnetic, or gravitational source that comes within the reach of the field. In fields, the closer something gets to the source of the field, the stronger the force of the field gets. This is called the inverse square law.

Magnetic fields are created by electrons moving in the same direction. A magnetic field must come from the north pole of a magnet and go to its south pole (or atoms that have turned to the magnetic field.) Iron and a few other types of atoms will turn to align themselves with the magnetic field. Compasses turn with the force of the magnetic field.

If an object is filled with atoms that have an abundance of electrons spinning in the same direction, and if those atoms are lined up in the same direction, that object will have a **magnetic force**.

Magnetism is caused by moving electrons and, thus, electricity is moving electrons. Electricity causes magnetism. Moving magnetic fields can cause electrons to move. Therefore, electricity can be caused by a moving magnetic field.

All magnets have two **poles** and are called dipolar. The two poles of a magnet are called north and south poles, and the magnetic field comes from a north pole and goes to a south pole. Opposite poles will attract one another while like poles will repel one another.

Unit Description

Did you know that if you cut a magnet in half to try to separate the north from the south pole you'll wind up with two magnets, each with their own north and south poles? Turns out that the poles are impossible to separate!

Why does a magnet stick to your fridge and not your soda can, even though both are magnetic? (No kidding!) And why is it that when you run magnets down a metal ramp, they defy gravity and slow to a stop? And how come the grapes from your lunchbox twist around to align with magnets, even though there's no iron inside a grape? There's got to be a reason behind this madness. Would you like to find out what it is with me?

Now that you've spent a few lessons learning about the strange world of the atom (Units 3 & 8), it's time to discover which part of the atom is responsible for magnets and magnetic fields.

Objectives

Lesson 1: Magnets

What IS magnetism, anyway? You can feel how two north sides of a magnet push against each other, but what IS that invisible force, and why is it there? And how come magnets stick to the fridge but not a soda can? We're about to dive deep into the mysterious world of magnetism. Although scientists are still trying to puzzle out some of its secrets, I'm going to get you up to speed on what they do know today. Are you ready?

You can get started by watching this video and afterward either read more about it or start your experiments!

Highlights

- Magnetic fields are created by electrons moving in the same direction.
- Electrons can have a “left” or “right” spin.
- If an atom has more electrons spinning in one direction than in the other, that atom has a magnetic field.
- If an object is filled with atoms that have an abundance of electrons spinning in the same direction, and if those atoms are lined up in the same direction, that object will have a magnetic force.
- There’s still a lot about fields that is unknown. Fields are an exciting area of physics where a lot is still left to be discovered.
- A field is an area around a electrical, magnetic, or gravitational source that will create a force on another electrical, magnetic, or gravitational source that comes within the reach of the field.
- In fields, the closer something gets to the source of the field, the stronger the force of the field gets. This is called the inverse square law.
- A magnetic field must come from a north pole of a magnet and go to a south pole of a magnet (or atoms

that have turned to the magnetic field).

- Magnets are called dipolar which means they have two poles, and all magnets have two poles.
- The two poles of a magnet are called north and south poles.
- The magnetic field comes from a north pole and goes to a south pole.
- Opposite poles will attract one another. Like poles will repel one another.
- Iron and a few other types of atoms will turn to align themselves with the magnetic field.
- The Earth has a huge magnetic field.
- The Earth has a weak magnetic force.
- The Earth's magnetic field probably comes from the moving electrons in the currents of the Earth's molten core.
- The Earth has a north and a south magnetic pole which is different from the geographic north and south poles.
- Compasses turn with the force of the magnetic field.
- Over time, iron atoms will align themselves with the force of a magnetic field.

Objectives

Lesson 2: Electromagnetism

This is one of the most important scientific discoveries of all time: moving magnets create electricity. Before this, people thought of electricity and magnetism as two separate things. When scientists realized that not only were they linked together, but that one causes the other, then the physics really started to fly!

In this lesson, we're going to take a closer look at how magnets create electricity by building electromagnets, galvanometers, motors, relays, telegraphs, and speakers. Are you ready?

You can get started by watching this video and afterward either read more about it or start your experiments!

Highlights

- Magnetism is caused by moving electrons.
- Electricity is moving electrons.
- Electricity causes magnetism.
- Moving magnetic fields can cause electrons to move.
- Electricity can be caused by a moving magnetic field.
- Electricity is a flow of electrons.
- A flow of electrons creates a magnetic field.
- Magnetic fields can cause a flow of electrons.
- Magnetic fields can cause electricity.

Textbook Reading

Here's a riddle:

I stick to some things but not to others.
I stick but I'm not sticky.
I attract some things, but push other things away.
If allowed to move, I will always point the same way.
What am I?

Well, since you know the topic of this lesson, this isn't the hardest riddle to solve. I'm a magnet, right? Sure. But take a look at the wacky things a magnet does! It sticks but it's not sticky. It only sticks to certain things, and it pushes some things away. If you hang it from a string or float it in water, it will always point north.

If that's not enough strangeness, magnets can actually create electricity as we'll find out in a later lesson! Wow, what a wacky thing a magnet is! So what is a magnet? What is going on with all those bizarre little shapes that are sticking to my fridge!?

What Causes Magnetism?

Believe it or not, electrons! Those wacky little fellows that we learned about several lessons ago are the

key to magnetism. As you move further and further in your science education, you'll notice that electrons are responsible for a lot of stuff that goes on in science!

More accurately, a majority of electrons moving in a similar direction creates a magnetic field. This is how electromagnets work. Electrons are forced to move through a wire and the moving electrons cause a magnetic field. We'll look deeper into magnetic fields in the next lesson.

Electron Spin

"But how are electrons moving in my magnet on my fridge? It isn't connected to any battery. What's going on there!?! Don't I need electricity to have moving electrons?"

Electromagnets do have electricity flowing through them. Electricity is nothing more than moving electrons, so it's the electricity that causes the magnetic force in electromagnets.

However, most of the magnets you run across are not attached to any form of electricity. So how are the electrons moving?

Electrons move on their own. They move around the nucleus and they spin. It's the electron spin that tends to be responsible for the magnetic field in those "permanent" magnets (the magnets that maintain a magnetic field without electricity flowing).

"But don't electrons always spin? Shouldn't everything be magnetic?"

Yes, electrons are always spinning. The reason some things are magnetic and other things aren't is due to the balance of the spinning electrons.

Electrons are said to spin left or right. It not quite that simple but it makes it easier to think and talk about. Most atoms have a fairly even number of left and right spinning atoms. If there are four spinning left, there are four spinning right. If there are nine spinning right, there are eight spinning left. Since they are fairly balanced, there's no net direction that the electrons are moving in. With no overall direction of movement, there's no magnetic force.

However, there are a few atoms, iron being the most famous, that are not in balance. Iron has four more electrons that spin in one direction than in the other. This excess of same spinning electrons creates a net directional movement and, thus, a magnetic force! Nickel and cobalt are other fairly common magnetic metals.

Atomic Line Up

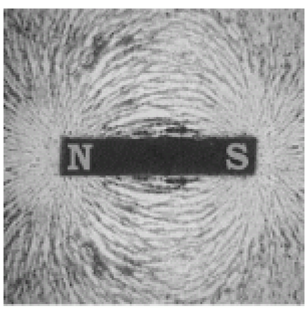
"Aha, so everything that's made of iron is magnetic! Got it."

Well, not so fast. Yes, each iron atom is like a little magnet but not all iron objects have a magnetic field. In fact, most don't. The reason that most objects that have iron in them are not magnetic is because the atoms are all jumbled up.

Imagine I gave you a shoe box filled with small magnets. Since I just threw the magnets in there, they are all jumbled up. Some are facing right, some left, some up and some down. Because of the jumble, the whole box may not have much magnetic force since the magnets inside are all canceling each other out.

Now, imagine what would happen if the magnets inside the box did all face the same way, like if I stuck them all end to end and created a long string of magnets. Now the box would have a very powerful magnetic force, right? This is the difference between an iron nail and a magnet. The nail has iron atoms going all which ways, while the magnet has iron atoms that are fairly lined up. The more lined up the iron atoms are, the stronger the magnetic force.

What's a magnetic field?



Well, I can't tell you. To be honest, nobody can. Magnetic fields, gravitational fields, and electric fields are very mysterious and at this point there are still lots of questions about each one.

A field is an area around an electrical, magnetic or gravitational source that will create a force on another electrical, magnetic, or gravitational source that comes within the reach of the field. (Now you can see why there's still so much mystery about them!)

A gravitational field, for example, comes from a body of some sort. The larger the body is, the greater the force. A planet, for example, is a large body with a large gravitational force. If another body gets within the gravitational field of the planet, it will be affected by the force.

What creates the force? What's pulling or pushing?

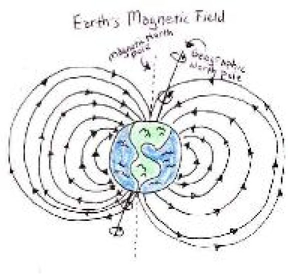
Nobody knows! We just know that it happens.

Another thing about forces is that the farther something gets away from the source, the less and less the force works on that object. A fancy term for this is the inverse square law. Something quite far from the Earth will feel no tug from the Earth's gravitational pull. If it gets closer it will feel a slight tug. Closer still, a stronger tug will be felt. The closer something gets to the source of a field (gravitational, magnetic, or electric) the stronger the pull of the field force is. If you're standing on top of the Sears Tower in Chicago, you are actually going to weigh less than if you're standing in the street.

Weight depends on the pull of gravity. The farther you are from the Earth, the less gravity pulls on you and the less you will weigh!

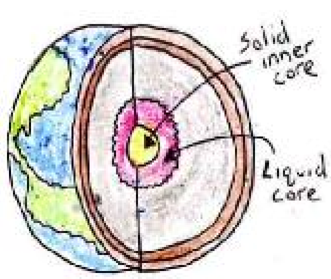
There's an instant diet plan for you!

A BIG Magnet



Right under your feet, there's a magnet. Go ahead take a look. Lift up your feet and see what's under there. Do you see it? It's huge! In fact, it's the largest magnet on the Earth. As a matter of fact, it is the Earth! That's right, the Earth is one huge, gigantic, monolithic magnet!

The Earth's a Magnet?



"But, we've learned that magnets need electrons flowing and the right metals and stuff like that. Is the Earth one big hunk of iron?"

No, but that's a good question. Where does the magnetic field come from? At this point, folks are still trying to figure that out. The most widely accepted theory is that the magnetic field comes from the Earth's core. The core of the Earth is solid but around that core is a liquid. The liquid is basically molten iron, nickel, and a few other elements. It is the flowing of the electrons in this liquid metal that probably causes the Earth's magnetic field.

So, yes the Earth is a magnet, but not a very strong one. You probably couldn't even stick it to a sun-size refrigerator. The Earth has a magnetic pull 100 times weaker than the magnets on your fridge. The Earth, by the way, is not the only giant magnet in the Solar System. The Sun, Jupiter, Saturn, Uranus, Mercury, and Neptune are also magnets.

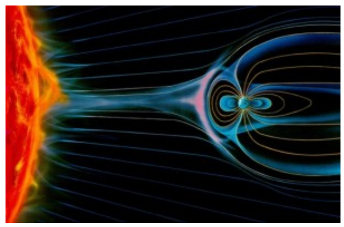
The Poles

"Oh, yeah. Now I remember. That's the deal with the north and south poles right?"

Well, yes and no. To confuse things a bit, there are two sets of north and south poles. There are the geographic North and South Poles and the magnetic north and south poles. To be completely honest, there are EIGHT magnetic poles on the Earth, but we'll just focus on the two strongest ones for now to cut down on the confusion.

The geographic poles are located at the axis of the Earth. The axis is where the Earth turns day after day, like the top and bottom of a toy top. The magnetic poles are close to the geographic poles but they are off by quite a bit. And actually, the South Pole isn't even in Antarctica—it's in the ocean. In fact, the north and south magnetic poles of the Earth move from year to year and have completely flipped a couple of times!

Magnetic Field

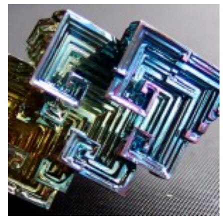


The Earth may be a weak magnet, but it has a gigantic magnetic field. The Earth's magnetic field gets warped by the Sun's solar winds. So on the side towards the Sun, the field can reach over 43,500 miles, or 70,000 km, into space.

On the side away from the Sun, the field can stretch out much farther. This field forms a bit of a barrier against the cosmic rays from the Sun and is called the magnetosphere.

Sun flares often hit this magnetosphere and create auroras. Auroras are beautiful light shows in the sky that normally take place in the very northern or southern hemispheres.

Diamagnetic



Diamagnetic materials (like bismuth, water, and graphite) have very weak magnetic fields. When the electrons have about the same number spinning left and spinning right, they cancel each other out and the atom has no magnetic poles. However, if you bring a magnet near, the magnetic field causes the individual electrons in the atom to move, and since moving electrons create a magnetic field, the electrons create a magnetic field opposite to the original magnetic field and the atom moves away from the magnet. The effect is very weak, but with enough care you can see this effect in water (which is what a grape is mostly made up of).

Paramagnetic

Paramagnetic materials (like aluminum, helium, and platinum) need to be chilled in order for their magnetic fields to be noticeable. Here's why: what if the atom has more electrons spinning left than right? When this happens, the atom now has magnetic poles (north and south), and you can think of each atom like a little magnet.

However, these magnets are not all lined up in the same direction, so their overall magnetic effect cancels out. If you bring in a magnet (or place the atoms in a magnetic field), they start to line up in the same direction and the material starts to become magnetized. But not quickly, or easily, because the atoms still have so much energy that they keep bouncing around, even when in a solid state.

So to magnetize something quickly, you need to bring down the temperature to reduce the motion of the atoms. Then they start to really line up. Paramagnetic materials are attracted to both ends of a magnet.

Ferromagnetic

There are four elements (iron, nickel, cobalt, and gadolinium) that most permanent magnets are made up of. These atoms stay lined up together, even when they are at temperatures that would cause other atoms to bounce out of alignment. The magnetic effects are mostly caused by the innermost electrons in the inner orbits, which all align the same way and contribute the magnetic field.

Antiferromagnetic

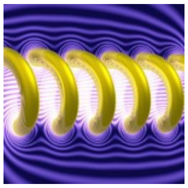
Some paramagnetic materials (like chromium and manganese) have atoms pair up and cancel each other out. The north pole of one atom will line up with the south pole of another.

Electromagnets

Now we've covered the fact that magnetic fields are caused by electrons moving in the same direction. Up to this point, we've been focusing on magnetism being caused by an unequal number of electrons spinning in the same direction in an atom.

If an atom has more electrons spinning in one direction than in the other direction, that atom will have a magnetic field. When bunches of these atoms get together, we have a permanent magnet. Now we're going to talk about what happens if we force electrons to move.

Moving magnets create electricity?



This is one of the most important scientific discoveries of all time. One story about this discovery goes like this:

A science teacher doing a demonstration for his students (can you see why I like this story) noticed that as he moved a magnet, he caused one of his instruments to register the flow of electricity. He experimented a bit further with this and noticed that a moving magnetic field can actually create electrical current, thus tying the magnetism and electricity together.

Before that, they were seen as two completely different phenomena! Now we know that you can't have an electric field without a magnetic field. You also cannot have a moving magnetic field without causing electricity in objects that electrons can move in (like wires). Moving electrons create a magnetic field and moving magnetic fields can create electric currents.

"So, if I just made electricity, can I power a light bulb by moving a magnet around?"

Yes, if you were to move that magnet back and forth fast enough, you could power a light bulb. However, by "fast enough", I mean that you would have to move that magnet like 1000 times a second or more! If you had a stronger magnet, or many more coils in your wire, then you could make a greater amount of electricity each time you moved the magnet through the wire.

Believe it or not, most of the electricity you use comes from moving magnets around coils of wire! Electrical power plants either spin HUGE coils of wire around very powerful magnets or they spin very powerful magnets around HUGE coils of wire. The electricity to power your computer, your lights, your air conditioning, your radio, or whatever comes from spinning magnets or wires!

"But, what about all those nuclear and coal power plants I hear about all the time?"

Good question. Do you know what that nuclear and coal stuff does? It gets really hot. When it gets really hot, it boils water. When it boils water, it makes steam and do you know what the steam does? It causes giant wheels to turn. Guess what's on those giant wheels. That's right, a huge coil of wire or very powerful magnets!

Coal and nuclear energy basically do little more than boil water. With the exception of solar energy, almost all electrical production comes from something huge spinning really fast!

In this unit, we're going to make several really fun gadgets that rely on this "electricity makes magnetism" and "magnetism makes electricity" thing. You'll be able to baffle most grown-ups with these creations!

How magnets make sound

We've come a long way with this magnetism thing and hopefully you're feeling pretty good about how magnetism works and what it does. Now we're going to use what we've learned to make simple versions of two gadgets that you use every day.

Let's start with the slightly simpler gadget. Now to understand what's happening here, we need to recap: Remember that electricity is moving electrons, and what do moving electrons create? A magnetic field.

Also, remember that a magnetic field, when moved near a metal that can conduct electricity, will create an electric current in that metal.

Magnetism can create electricity and electricity can create magnetism. Now, let's go way back in time and try to remember the work we did with sound in Unit 6. Sound is vibrations. If something vibrates between a frequency of 20–20,000 Hz, our ears can detect it as sound.

To make a speaker, we need to somehow make something vibrate. "Hmmm, I wonder if this magnetism/electricity could somehow be useful here."

So what's going on with a speaker? What makes it work? Okay, here's the deal. The radio provides the electricity that gets pumped through the wires. The radio very quickly pumps electricity in one direction and then switches to pump it in the other direction. This movement of electrons back and forth creates a magnetic field in the coil of wire.

Since the electricity keeps reversing, the magnetic field keeps reversing. Basically, the poles on the electromagnet formed by the coil go from north to south and back again. Since the poles keep reversing, the permanent magnet you have taped to the cup keeps getting attracted, then repelled, attracted, then repelled. This causes vibrations.

The speaker cone (or cup, as in the speaker we're going to make) that's strapped to the coil and magnet acts as a sound cone. The magnet causes the sound cone to vibrate and, since it's relatively large, it causes air to vibrate. This is the sound that you hear.

Almost all speakers work just like the one you are going to create in this unit. They just use fancier materials so that the sound is louder and clearer.

