# Demonstrations Explanations: A Teacher's Guide

## A Supplement to the Wonders of Physics Traveling Show

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# Introduction

The philosophy behind **The Wonders of Physics** is to take the magic out of science. During the demonstrations a concerted effort is made to explain why things happen as they do. However, it is often the case – due to time constraints or groups size – that the explanations are inadequate for many of those watching the show. The teachers are then saddled with the burden of explaining to the students exactly what happened and why. This could present an awkward situation, especially if the underlying physics principles are subtle. We present this **Teacher's Guide** to help in your efforts at demystifying science.

This packet has been especially prepared to cover those experiments that are often presented in the show. The presentation is ever-evolving; your show may not have included all of these demonstrations and may have included some demonstrations that are not explained here. The demonstrations are grouped by section (as in the show) corresponding to broad general groupings of the areas of physics. Each section contains a brief introduction describing the basic principles of its respective demonstrations. Then, each demonstration is explained individually. So as to avoid misunderstanding, the language has been simplified. The hope is to minimize translation on your part when discussing these explanations with your students.

We hope that you find this guide helpful. Questions and comments are gratefully accepted. Please feel free to write or call if you have additional questions that have not been answered here.

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# Motion

**Motion** is the area of physics that studies how things move. It was developed about 300 years ago by **Isaac Newton**. He discovered that all objects move according to three basic laws. Newton's Laws can explain almost all of physics. When we look at the other branches of classical physics, they all can be explained using these laws of motion.

The first law is the **Law of Inertia**. It says that all things will move in straight lines with the same speed or if they're not moving, they stay still. Think of a hockey puck on ice. If you don't touch it, it will sit there forever. When you push it, it will slide along the ice in a straight line – until it hits something to make it stop or turn.

The second law is the **Law of Forces**. If something is not moving in a straight line, a force must be acting on it to change its direction. A **force** is a push or a pull. In the hockey puck example, if you want the puck to start moving, you have to push it. This is a force. If you want the puck to turn, you have to hit it sideways; it won't curve by itself. Another force is friction, which slows things down by rubbing. Try pushing the puck on cement. It doesn't move very far because cement is rough. Friction between the puck and the cement slow the puck down. If something has a lot of **inertia**, it takes a large amount of force to move it. If it has not much inertia, it takes only a small force to move it.

The third law is the **Law of Rockets**: for every action, there is an equal and opposite reaction. This means if you push on something, it pushes back on you the same amount. To demonstrate this, stand with your feet together holding a heavy rock. Now throw the rock away from you as hard as you can and try not to move your feet. It's not so easy! When you push the rock away from you, at the same time the rock pushes you away from it with the same force.

These three laws help physicists to understand how most everything in the world moves. They were first used to find out how the planets move around the sun. Today they can help us to understand how to make rockets work that take us to those planets (among many other things).

**Motion**

# Pendulums

Something is called a **pendulum** in physics if it possesses two particular characteristics. First, it must move up and down or back and forth in a regular motion. This motion is called **periodic oscillation**. Second, the motion must be caused by gravity. Thus, the thing swinging back and forth in a grandfather clock is, of course, called a pendulum. A weight bouncing on the end of a spring is called a pendulum also.

**Coupled pendulums** are two or more pendulums connected together in some way. They show how **energy** can move from one place to another. In the demonstration, the two pendulums are connected together with a small spring. The spring acts as a pathway for transferring energy from one pendulum to the other. When one pendulum is started swinging, it pulls on the spring. The stretched spring, in turn, begins pulling on the second pendulum. Some of the energy of the first pendulum goes into making the second one move. Soon, both are swinging exactly the same. As time goes on, all the energy leaves the first pendulum and it stops swinging, only the second pendulum swings. But since the pendulums are still connected, the energy of this pendulum now goes back through the spring to the other pendulum. The energy will go back and forth from one pendulum to the other until friction eventually makes them both slow down and stop.

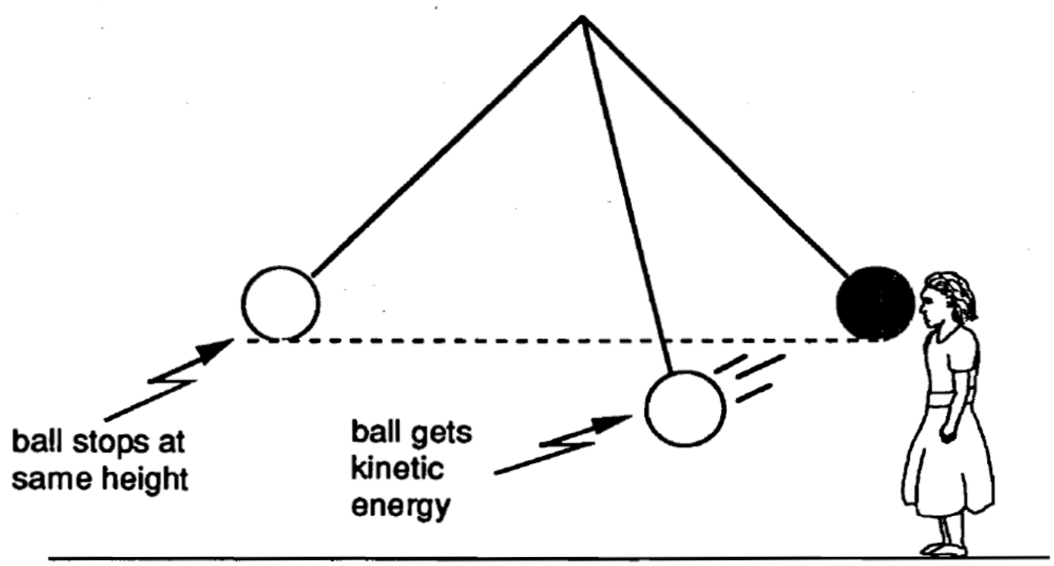
A **Wilberforce Pendulum** is two coupled pendulums in one. It is simply a weight attached to a spring and the weight has two arms, or **outriggers**, on the side. One pendulum is the weight as it bounces up and down on the spring. The other is the spinning motion of the weight as it bounces up and down on the spring. The other is the spinning motion of the weight, turning first in one direction then in the other. The outriggers can be adjusted by means of screws to make it spring faster or slower. The two motions of the pendulum are coupled to each other through the spring. When you pull on the weight, it begins to oscillate up and down. But though the spring, some of the up and down energy goes into making the weight spin back and forth. Eventually, the pendulum stops bouncing and only spins. Then the spinning slows and bouncing begins again.

**Motion**

# Bowling Ball Pendulum

A swinging bowling ball illustrates a very important principle of physics: **The Conservation of Energy**. The total amount of energy an object has stays the same, unless you do something to change it. To change the energy of something, you have to move it (for example, give it a push). The bowling ball starts with a certain amount of **potential** (stored) energy. It gets this energy because someone had to lift it up to hang it. Bowling balls are heavy and you have to do work to get it up in the air. Whenever we do work on something, we are giving it energy. When you let go of the ball, it swings downward like a pendulum. As it starts swinging, the energy changes from potential energy to **kinetic**, or moving, energy. The **total** amount of energy, moving plus stored, stays the same; it only changes form. When the ball swings back to where it started, the energy changes back to potential energy. Since the total energy has to stay constant, the kinetic energy of the ball must be zero and the ball must stop moving. It can't hit you!

**An important qualifier**: if you push the ball instead of just letting go, you give the ball some extra kinetic energy. This **extra** energy makes it swing back farther than when it started. When it comes back, you better duck!



**Motion**

# Beaker and Tablecloth

This “magic trick” very nicely demonstrates the **Law of Inertia**. **Inertia** is a measure of how hard it is to change an object’s motion. The heavier an object is, the more inertia it has – it’s harder to make a heavy object move! This means that if something it sitting still, its inertia keeps it in place.

In the demonstration a big beaker of water is filled with water. It is put on a tablecloth made of some slippery material like rayon or polyester. If the tablecloth is pulled slowly, **friction** (rubbing) between the beaker and tablecloth will cause the tablecloth to pull the beaker with it. But, if the tablecloth is pulled quickly, the beaker won’t mover. Inertia keeps the beaker in place because friction is not as strong when you pull fast. The trick works no matter how heavy an object is since friction is weaker for lighter objects. Provided you pull quickly enough, this trick can even be done with glasses or plates.

**Motion**

# Water Pail

This demonstration illustrates Newton’s first law of motion: **Objects either remain still, or move in straight lines**. This property is called **inertia**. In order to make something move in a circle, you have to use **force** (a push or a pull). For example, take a yoyo or tie a ball on the end of a string. Now spin it around in a circle holding one end of the string in front of you. You will notice that the yoyo wants to move in a straight line and you have to supply a pulling force to make it move in a circle. If you let go, the yoyo flies off tangent to the circle, in a straight line. This particular kind of force is called a **centripetal** force.

The same is true for the pail of water. When you swing the pail back and forth, you can feel the pail and the water inside pulling on your arm because it wants to continue to move in a straight line and you want to make it go in a circle. You hold on to the bucket so it doesn’t fly away and the water pushes on the bottom of the bucket. As you swing higher and higher, the water pushes harder on the bottom of the pail. But when you swing the bucket upside down, **gravity** tries to pull the water out of the bucket. Whichever force, the gravity or the centripetal, is stronger wins. As long as you swing the bucket fast enough, the force of the water pushing on the bottom of the bucket (centripetal force) will be stronger than gravity and the water will stay in the pail. Of course, if you swing too slowly, you’ll get wet!

**Motion**

# Inertia and the Spinning Table

The **spinning table** is also used to illustrate the principle of **inertia**. When a person stands on the spinning table, they will not be able to turn themselves around. The law of inertia tells us that an object at rest stays at rest. The person wants to stay at rest, not spin around. When the person pushes off of the ground or another person that has more inertia, then they can move. Recall that if something has a lot of inertia, it is hard to move. If something has not much inertia, it is easy to move. The person on the spinning table moves a lot easier than the person on the ground, so the spinning person has less inertia.

When we give the volunteer some weights in her hands and spin her around, she can make herself go faster by bringing his arms in. This is the same move that ice skaters use to spin fast when they do fancy jumps. When the arms are in, it is easier for her to move, so this means she has less inertia. When arms are out, she moves slower and has more inertia. The effect is more pronounced with heavier weights, but you can see (and feel) it even without any weights at all.

# Bicycle Wheel Gyroscope

This illustrates an important conservation law of physics: **the conservation of angular momentum** or turning motion. Anything that is turning has angular momentum. This is similar to inertia, only in rotational motion. If a wheel is spinning in one direction, it wants to keep turning in that same direction. If it is not turning, it tries to stay still.

To show this, someone stands on a level platform that can spin around. If she gets on carefully, so that she's not turning, no matter now much she twists and dances, she won't be able to spin all the way around. Next, someone else can push her so she starts spinning. Now, no matter how hard she tries, she won't be able to stop spinning. This is conservation of angular momentum.

In the **bicycle wheel gyroscope** demonstration, there are two possible turning motions. The platform the person stands on turns like a wheel on its side. Call this **horizontal** turning motion. The other turning motion is the bicycle wheel the person is holding. Initially it is vertical, as a bicycle wheel normally stands. Call this **vertical** turning motion.

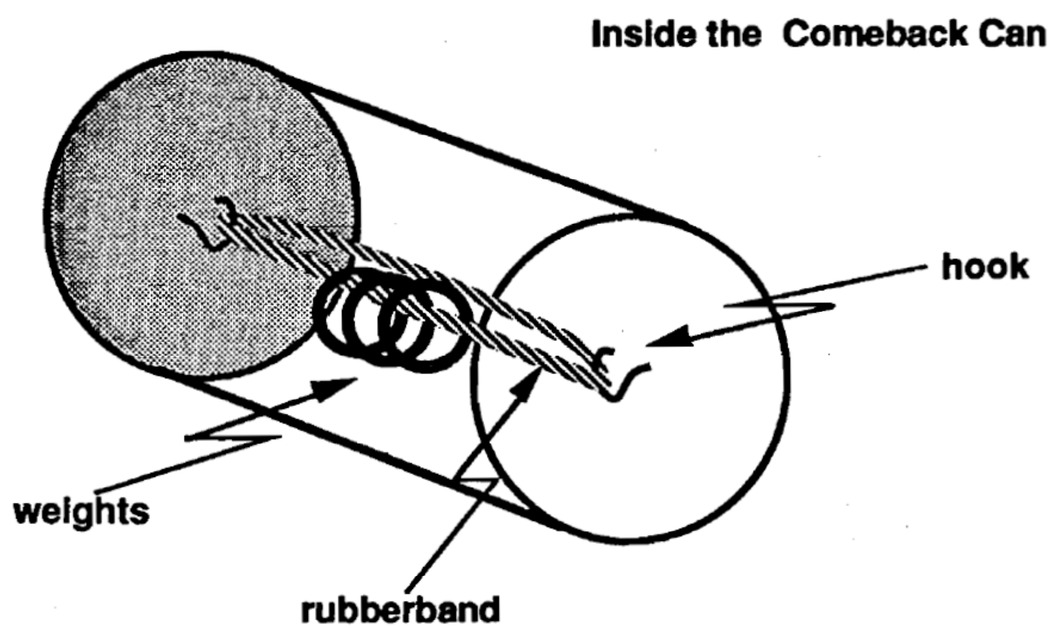
To begin with, someone spins the bicycle wheel. There is **vertical** turning motion in the bicycle wheel, but no **horizontal** turning motion of the platform. Then the person tilts the bicycle wheel to the side, so now there is horizontal turning motion where there wasn't any before. Conservation of angular momentum tries to fix this. The platform starts spinning in the direction opposite that of the bicycle wheel. If you add the backward turning of the platform and the forward turning of the bike wheel together, you get zero. So horizontal motion is the same as when we started: nothing. When the bike wheel is tilted back vertically, the platform stops spinning, as in the beginning.

Rocket ships are steered this way. They have little wheels spinning inside called a **gyroscope**. When the rocket ship turns, the spinning wheels turn the other way and bring the rocket back on course. A motorcycle turns around corners this way. When the rider leans to one side, the whole motorcycle turns around a corner.

**Motion**

# Comeback Can

This toy demonstrates a very important principle in physics: **The Conservation of Energy**. The can works by changing **kinetic** (moving) energy to **potential** (stored) energy. As shown in the drawing, there is a rubber band attached to both ends of the can. On one side of the rubber band are some weights. When you roll the can, you give it some kinetic energy. As it rolls, the weights cause the rubber band to twist up. As the rubber band winds tighter, the can slows and stops rolling. The kinetic energy of the rolling can is now stored in the potential energy of the rubber band. Then the rubber band begins to unwind, and its stored energy goes back into making the can roll back towards you. In fact, if the can keeps rolling, the rubber band will now twist up the other way. The can will roll back and forth a number of times before being stopped by friction (rubbing between the can and the ground).



# Rockets

The rocket demonstrates Newton's famous third law: **For every action there is an equal and opposite reaction**. This means that if you push on something, that something has to push back equally hard. If you push on a wall, the wall pushes back on you – otherwise the wall would fall over! Alternatively, when you pull a wagon, the wagon pulls back on you. If it didn't, the wagon would run into your heels.

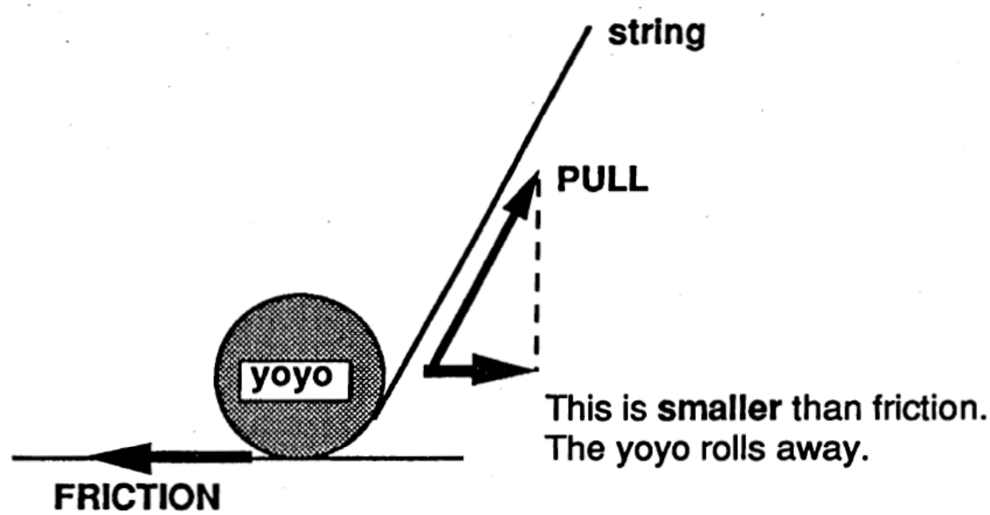
Recall our example of throwing a heavy rock from earlier (see **Motion** introduction). When you throw a heavy rock, the rock pushes back on you making you lose your balance. A rocket works using this same principle. In a **water rocket**, a little water is put inside the rocket and then air is pumped inside. When the rocket is releases, the extra air pressure squirts the water out. When the rocket pushes the water out, the water pushes the rocket forward with the same force and the rocket flies through the air. Real rockets work with water, too! They burn liquid **hydrogen** and liquid **oxygen** for fuel. Then these two burn together, they make pure water. The force of all the exhaust coming out pushes the rocket up. So the toy water rockets is not so far from reality.

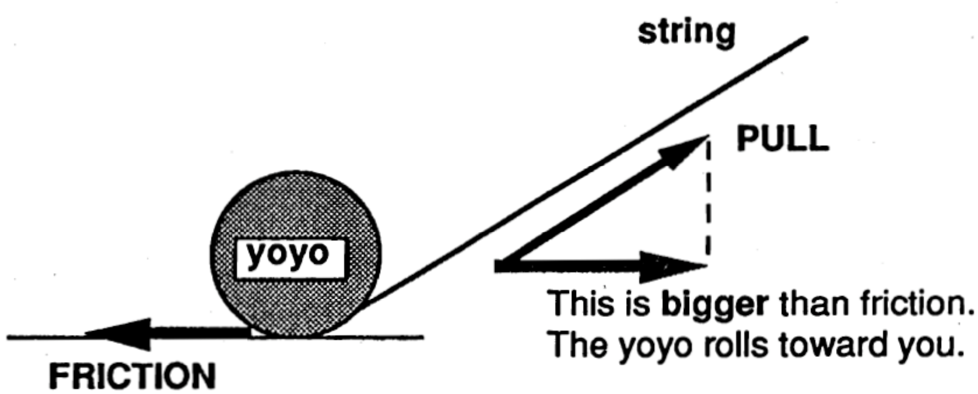
The **fire extinguisher** also acts like a rocket. It is filled with compressed **carbon dioxide** gas. When the fire extinguisher is fired on the spinning table, the compressed gas shoots out and pushes the person around in the opposite direction.

**Motion**

# Undecided Yoyo

The motion of the **yoyo** shows the effect of different **forces**. Depending on how you pull the string, the yoyo will either come towards you or roll away from you. A force in physics is a push or a pull. As shown in the diagram, there are two forces on the yoyo. One obvious force is the pull on the string. The other force is **friction**. Friction is a rubbing force; the yoyo rubs on the ground. The friction force always opposes your motion. When you pull on something, friction pulls the other way and you can feel the object dragging. Changing how high or low you pull on the string changes how strong the pulling force is opposite to friction. If you pull the string near the ground, the pulling force is stronger than the friction and the yoyo rolls toward you. If you pull with the string high above the ground, the friction force is stronger and the yoyo moves away from you. At some angle the friction and the pulling force just balance and the yoyo won't roll at all.



# Heat

Physicists study **heat** to understand how things act at different temperatures. Heat is a form of **energy** and temperature measures how much energy an object has. The study of heat is really the study of the **atoms and molecules** that make up an object. The faster the atoms are moving, the hotter the temperature because they have more energy. (The picture shows kids behaving like hot atoms.)

Heat can be made in many ways. One way is **burning**. Here, the chemicals of the burning object change into other chemicals and release energy in the process. Heat can also be made by friction (rubbing). Try rubbing your hands together and notice how they get hot. In both of these cases, the atoms and molecules are moving around more when they heat up.

In the US, we measure temperature in degrees Fahrenheit ($^{o}$F). Water freezes at 32$^{o}$ F and boils at 212$^{o}$ F (at sea level). In most other countries they measure temperature in degrees Celsius ($^{o}$C). In Celsius, water freezes at 0$^{o}$ C and boils at 100$^{o}$ C. Scientists use Kelvin (K) to measure temperatures.

When we take heat energy away from something we make it cold. The coldest anything can get is -460$^{o}$ F (-273$^{o}$ C or 0 Kelvin). This is called absolute zero. At this temperature almost everything is frozen solid, even the air we breathe. On the other hand, things can theoretically get as hot as they like. The hottest things we know of are stars. They have temperatures of many millions of degrees.

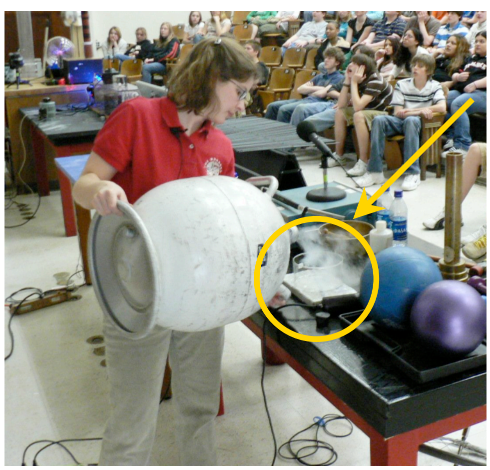
**Heat**

# Liquid Nitrogen

**Nitrogen** is a gas in the air. In fact, air is about 78% nitrogen. Air is also made up of **oxygen, carbon dioxide, hydrogen, water vapor**, and many other gases in small amounts. When a gas is made very cold, it turns into a liquid similar to water. **Liquid nitrogen** is just very cold nitrogen. It is $320^{o}$F below zero ($-196^{o}$C). It's so cold that it freezes anything it touches almost instantly. Also, anything at normal room temperature is so much hotter than liquid nitrogen that the liquid nitrogen **boils** when it touches something. This is what causes the cloud when liquid nitrogen is poured into a beaker (see picture).

When a balloon is but into the liquid nitrogen the air inside gets cold. Normally, when things get cold then **contract**, or get smaller. (Water is a notable exception – ice floats!) As the air inside the balloon contracts, the balloon shrinks. If you look closely, you can see that the air inside the balloon has turned into a liquid. When the balloon is removed from the liquid nitrogen then air inside the balloon begins to get warm again and it **expands**. The liquid air inside vaporizes and the balloon grows back to its original size. The tires on your car do the same thing, though not as drastically. In the winter, the air inside contracts because its cold outside. You have to put more air in to pump them up. In the summer, the air expands and air must be let out.

When an object with lots of water in it – like a banana or an apple – is put in liquid nitrogen the water freezes. This is because the liquid nitrogen is much colder than $32^{o}$F, the temperature at which water freezes. The banana turns solid like an ice cube. It's so hard that it can be used to hammer a nail into a piece of wood!



**Heat**

# Nitrogen Cannon

The **Nitrogen Cannon** demonstrates how most things **expand** when they get hotter. Remember that **liquid nitrogen** is just very cold air that has turned into something like water. It has a temperature of 320$^{o}$F below zero. Everything in the room is much hotter than it is. The cannon is a metal pipe, which is closed at one end. First a small container of liquid nitrogen is put inside. Then a cork is put in the open end of the cannon to make the tube airtight. Now the cannon is loaded and ready to fire!

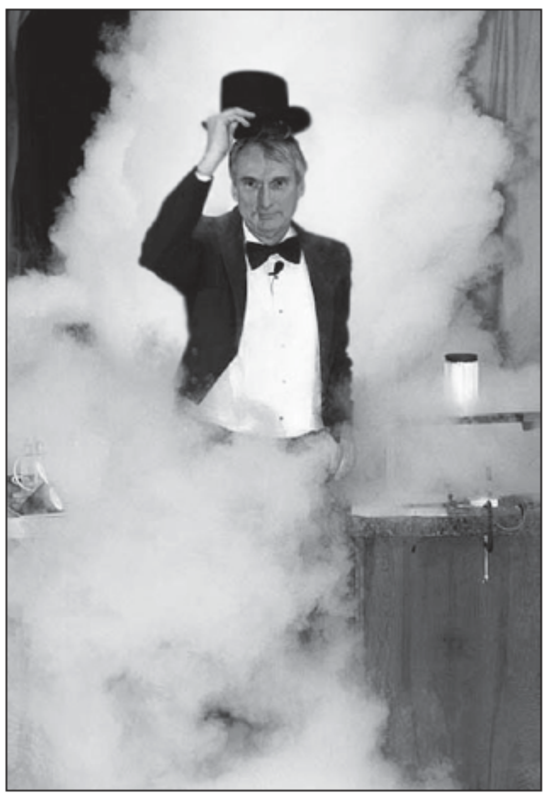
When you shake the cannon (or just hold it sideways), the liquid nitrogen spills out of its container and touches the metal pipe. The cannon is warm (relative to the nitrogen) and the liquid nitrogen turns into nitrogen **gas** very quickly. The liquid nitrogen boils, just like water on a hot stove. When things get hot, they expand. For example, if you put a lid on a boiling pot it jumps around because the hot steam takes up more space than the hot water. The nitrogen gas expands very quickly and the pressure inside the cannon gets so high that the cork blows off. **BOOM**!

# Nitrogen Cloud

The **nitrogen cloud** is not a cloud of nitrogen, but is just like the clouds we see in the sky. The physics behind making the nitrogen clouds is the same as that for making normal clouds.

A cloud is made up of millions of very tiny droplets of water. **Water vapor** is always in the air and on hot, humid summer days you can feel that water vapor as **humidity**. The air high up in our atmosphere is very cold – near the freezing point of water. Because it is so cold, the water vapor in the air **condenses** into tiny liquid water droplets. These droplets reflect light giving clouds their white color. When the droplets get too big, **gravity** causes them to begin to fall. As they fall, the droplets collect more and more water to make raindrops.

To make a nitrogen cloud all that is needed is lots of **liquid nitrogen**. The liquid nitrogen is heated until it boils, which is at $-320^{o}F$ so it is still very cold. The cold nitrogen cools the air around it. Just like in the sky, the water vapor in the cold air condenses forming tiny water droplets. This makes the cloud. If you stand close enough you can feel how cold the air really is.



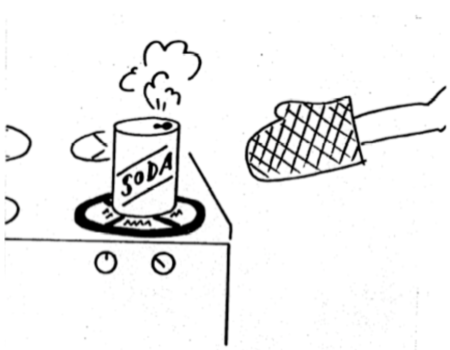
# Collapsing Can

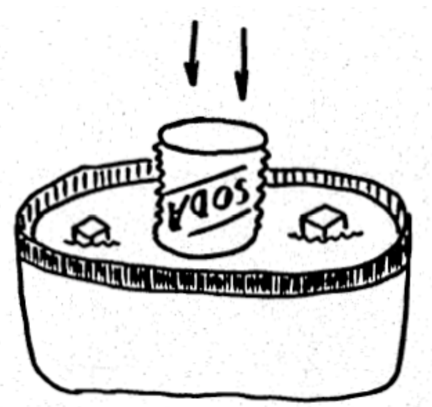
The **collapsing can** demonstrates that things **contract**, or get smaller, when they get cold. It also shows that the **atmosphere** exerts **pressure**. That is, the air around us pushes on things because air has weight. At sea level, the pressure of air is about 15 pounds per square inch (psi). That is about 150 pounds of pressure pushing on your hand alone! You don't feel it since the pressure is the same everywhere.

An aluminum can is filled with a bit of ordinary water. The can is then heats over a flame or hot plate. As you know, when water is heats it boils and turns into **steam**. Steam, like air, is a gas, whereas water is a liquid. Gases take up more space than liquids, so we say they are less **dense**. When the water boils, the can fills with steam and the air is pushed out.

Once the can is full of steam, it is turned upside down into a pan of cold water. This is down for two reasons. First, water seals the opening of the can making it airtight. No more air can get out. Second, the water is cold so it cools the steam in the can very quickly. The cooled steam **condenses** back to water. But water takes up less space than steam. Since no air can get in to take up the extra space, something else has to give: the can gets smaller.

Really what happens is that the water takes less space than the steam when the it condenses. This makes the pressure inside the can drop. Now the air pressure outside the can is much higher than the pressure inside the can. In fact, if all the air inside the can is gone, that's about 700 pounds pushing on the sides of the can! No wonder the can gets crushed.



# Car Engine (Ethanol Vapor Explosion)

The **ethanol vapor explosion** demonstrates that things expand when they get hot. However, instead of just being heated, the ethanol actually burns. **Ethanol** is a kind of alcohol made from plants. When something burns, it changes from one chemical to another. When ethanol burns, it mixes with **oxygen** in the air to make water vapor and **carbon dioxide**.

A little bit of ethanol is put inside a bottle and then the top is sealed with a cork. Two screws are in the sides of the bottle so that there points almost touch. The bottle must first be shaken so the ethanol **evaporates** and mixes thoroughly with the oxygen inside. This makes it burn faster. To ignite the engine, we need some energy, which we get from a high voltage sparker. (See the section on **Tesla Coils** for how the sparker works.) Eventually, a spark jumps between the points of the screws inside the bottle. The spark ignites the ethanol, which burns very quickly. As it burns, it changes to the hot gases carbon dioxide and water vapor. The heat of the burning makes them expand, causing an explosion. This blows the cork off the bottle.

You may know that cars run on ethanol instead of gasoline. A car engine works the same way as the exploding bottle. Gasoline or ethanol comes into the engine and mixes with oxygen. A spark from the **spark plug** lights the mixture causing an explosion. This forces the **piston** out, like the cork in the bottle. The pistons are attached to the wheels, which turn to make the car go. The explosion in the bottle is like a one cylinder car engine.

**Heat**

# Exploding Balloons

The **exploding balloons** demonstrate that nothing can be taken for granted in science. If you buy a balloon from a vendor, it's probably filled with **helium**. Helium is a gas like air; in fact, air has some helium in it. But helium is lighter than air. If you take the same volume of air and helium and weight them on a scale, the helium will weight less. This is because helium is less **dense**. Because helium is lighter than air, a helium balloon rises. **Hydrogen** is another gas lighter than air; it is even lighter than helium. Hydrogen is not used in balloons and this demonstration shows why.

Helium is a special gas called a **Nobel Gas**, which means it doesn't burn. When a match is held near a helium-filled balloon, the balloon pops. That's it. But when a match is held near a hydrogen-filled balloon: **BOOM**! a real explosion. This is because hydrogen burns very easily. It combines with oxygen to make water vapor. Even though both balloons look the same from the outside, there may be something very different on the inside.

# Sound

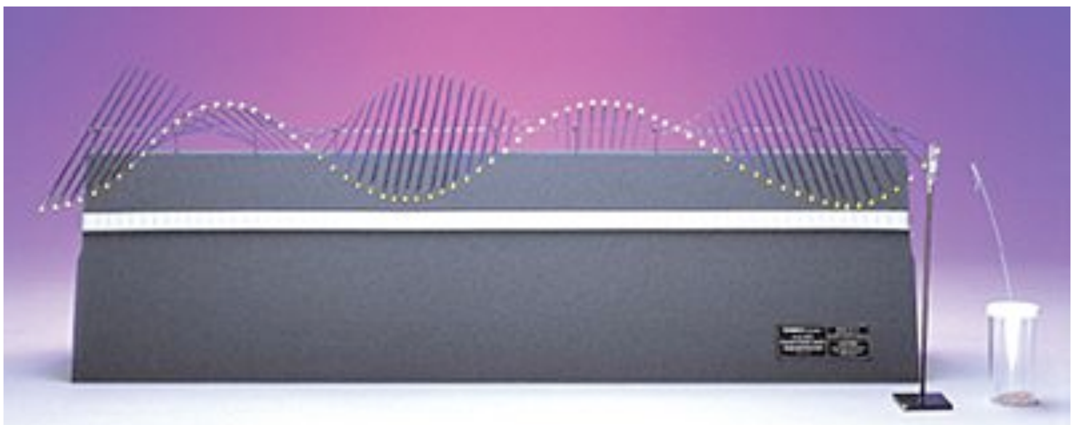
**Sounds** are just **vibrations** that we can hear. These vibrations happen when some object moves up and down or back and forth rhythmically. Usually, we hear sounds in air, but we can also hear sound in solid objects. Put your ear to the wall sometime. The air vibrates **sound waves** similar to the kind of waves you see on the ocean. The difference is that sound waves go back and forth whereas water waves go up and down. We hear different sounds depending on how far apart these waves are. The different sounds are called **frequencies**. The ear can hear sounds as low as 20 waves per second up to about 20,000 waves per second. For a musician, the note A on the piano is 440 waves per second. Most sound is a mixture of many frequencies. Some mixtures sound good, like a violin, and some not so good, like a jackhammer.

**Sound**

# Wave Machine

The **wave machine** is a very simple device used to show what **waves** look like. It has many long steel rods connected by a thin wire. When you move the rod on the end, it transmits **energy** to the other rods through the wire. The wave shown here is analogous to a sound wave and we can use it to see what different **frequencies** look like.

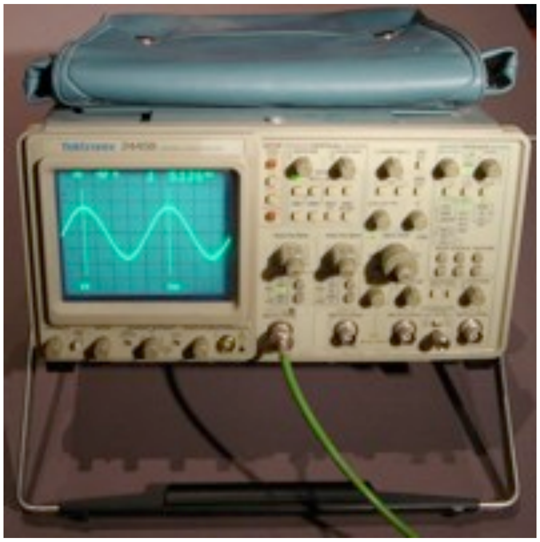
This wave is also similar to the wave you do at sporting events. Instead of people moving up and down, we have metal rods moving up and down. In both cases, energy is transmitted in the form of a wave. A **sound wave** is similar to this, but in a sound wave the movement is back and forth instead of up and down.



**Sound**

# See Your Voice (Oscilloscope)

You can see sound waves when a **microphone** is connected to an **oscilloscope**. A microphone changes the **sound waves** into an **electrical** signal. The oscilloscope then shows what these electrical waves look like. For a pure sound of only one **frequency** – like a tuning fork or whistling – the wave looks smooth and regular (as in the picture below). These are called **sine waves**. High notes have a high frequency and the waves are very close together. Low notes have a low frequency and the waves are spread out. Other pretty sounds, like singing or a violin, are also regular. They make waves that repeat themselves, but they are not as smooth. This is because many frequencies mix together to make the sound. Ugly sounds, like noise or talking, make jagged lines. There seems to be no pattern at all. Too many frequencies are mixed up together.



**Sound**

# Changing Voice

As you know, sound we normally hear travels through air. Sound in air has an important property; it travels with a certain **speed**, about 750 miles per hour or 1200 kilometers per hour. You can demonstrate this by having a friend shout at you while she is a long way away. You can see her mouth move before you can hear her voice. Or go to a baseball game. You can see the batter hit the ball before you hear the crack of the bat. The speed that sound travels depends on how heavy the gases in the air are. Since the composition of the air is usually a constant mixture of the same gases, you've probably never noticed the speed change much. But what if you use a different gas besides air?

When people speak, their **vocal chords** vibrate, making the air vibrate which makes **sound waves**. The voice you usually hear sounds that way because people normally breathe air. What if you breathe in a different gas, say **helium**? The speed of sound in helium is faster than in air because the helium is lighter than air. (This is why helium balloons float.) This makes your voice sound very high, like Donald Duck. On the other hand, suppose you breathe in a gas that is heavier than air? **Sulfur hexafluoride** makes your voice sound very low because sound travels slower in heavy gases.

**DON'T** try this yourself. Breathing strange gases in dangerous. People need oxygen to stay alive and some gases are **poisonous**.

# Electricity

Most people know what **electricity** is. It comes out of the wall sockets in our homes and makes the lights go on. It can hurt you if you touch it. Why is that? Why do you get a shock when you touch a doorknob? Lightning looks like electricity. Why is that?

Everything in the world is made up of tiny particles called **atoms**. They are so small that they cannot be seen even with a microscope. Atoms are made of two kinds of **electric charge**. In the middle of the atoms are the **positive charges** and flying around the outside are the **negative charges**. Most of the time, there are just as many positive charges as negative charges. Each positive charge has a negative partner. Sometimes, however, there are too many of one kind of charge. These extra charges go looking for a companion. These negative charges are called electrons and are not held very tightly in the atom so it is easy for them to move around. The moving electrons make up what we call electricity. There are two kinds of electricity: **static** and **current**.

You are probably familiar with **static electricity**; it is what makes your hair stand up when you rub a balloon against it or gives you a shock from your doorknob. In static electricity, electrons are moved around **mechanically** (i.e. by someone rubbing two things together). When you drag your feet across the carpet, extra charge is scraped off the rug and collects on your body. When you touch a doorknob, all the charge wants to leave you and go to the doorknob. You see a spark and get a shock as the electrons leave you.

**Lightning** is the result of static electricity. In a thunderstorm, negatively charged particles can build up in a cloud. Electrons **repel** each other; they really don't like each other and want to get as far away from each other as possible. The farthest they can get away from each other is if they go into the ground because it's the biggest thing around. As the electrons jump to the group, we see lightning. It's just like a big spark. Benjamin Franklin found out that lightning can be very dangerous. Lightning has more than 20 million Volts!

In **current electricity**, electricity has to flow in a closed loop called a **circuit**. If the loop is broken anywhere, the electricity can't get through. This is like blood in the body. Blood gets pumped through your arteries by the heart and eventually comes back to the heart through your veins. In a circuit, electric charges are the blood and the wires are the arteries and veins. Electric charges have a certain amount of energy. The measure of this energy is called **voltage** (**Volts**). A flashlight battery has about 1 ½ Volts and your wall socket has about 120 Volts. The electrons moving through a circuit are called a **current**. You can get an electric shock when a big current – lots of electrons – flows through your body.

The electrons in a circuit have to be pushed by something, like a **battery**. If you look at one end of a battery, there is a + sign, this where the extra positive charges are. At the other end, where there's a – sign, there are extra negative charges (electrons). When we turn on a flashlight the electrons race out of the battery through the wires to get to where the positive charges are. On their way, they run through the wire inside the light bulb. The thin wire inside the bulb gets very hot and makes light.

**Electricity**

# Van de Graaff Generator

A **Van de Graaff generator** is a device for making lots of **static electricity**. Static electricity is made from extra charges stored some place so that they can't move. Normally charges don't like to collect in one place. The like to find opposite charges as partners and run away from particles with the same charge. The Van de Graaff generator used in the demonstration can store up to about 300,000 **Volts** of the same kind of charge. Compared to the normal house voltage (about 120 Volts) that's a lot!

The generator makes static electricity the same way you do when you rub your feet on the carpet and then touch a doorknob. Inside the generator is a giant rubber band that rubs across a piece of felt, stealing its **electrons**. The rubber band then spins around and the electrons travel up to the big metal ball on top. If you have a hand on the metal ball, the electrons will go into you.

Generally, the stored charges on the Van de Graaff generator want to try to get into the ground. The earth is very big and the negatively charged particles (electrons) can get very far away from each other. If a metal ball, which is connected to the ground if brought near the generator, the charges will jump through the air from the generator to the ball.

If you touch the generator, all that electricity will go through your body giving you a big shock. It can actually be dangerous. You can be protected from the ground by standing on a piece of rubber or plastic. We say plastic and rubber are **insulators** since charges can't travel through them very easily. When you touch the generator now, the charges can't get to the ground. You are now filled up with electrons. The electrons don't like each other and are trying to get as far away from each other as possibly. Usually this makes your hair stand up because it is filled with electrons that are **repelling** each other.

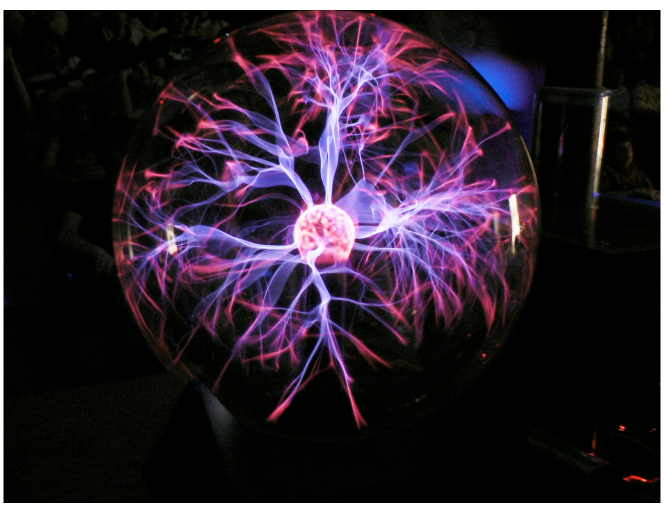
**Electricity**

# Tesla Coil and Plasma Ball

A **Tesla coil** is a device for making very high voltages. **Voltage** is a way to measure how much energy an electric charge has. Tesla coil can make voltages of more than a million **volts**. The small one used in the demonstration makes about 60,000 volts. Normally, such high voltages are very dangerous, but the Tesla coil makes very high **frequency** electricity. This means the coil turns on and off very quickly so they electricity flows on the outside of your skin instead of through your body.

The Tesla coil is very different from the **Van de Graaff generator**. A Van de Graaff generator makes **static electricity**; the charges don't move on their own. A Tesla coil makes **current electricity**; the charges are flowing. One end of the Tesla coil is connected to the ground. Because the coil makes very high voltages, the electricity can leave the Tesla coil and go through the air to get back to the ground. If a fluorescent light bulb is held near the coil, the electricity will then go through the light bulb to get to the ground, which makes it light up. If you get the light bulb close enough to the Tesla coil, you can see the electricity jumping into the light bulb.

The **plasma ball** is a smaller Tesla coil. Inside the glass globe is **a partial vacuum**. This just means that some of the air has been sucked out. Because there is not as much air in there, it is easier to make electric sparks that can be seen. The electrons then travel out into the air from the glass ball. We know this because the plasma ball lights up the light bulb, just like the big Tesla coil. If you touch the plasma ball, all of the electrons will go through you to the ground. You see only one big spark inside the ball where you put your hand. If you touch it long enough, you get filled with electrons and can light up a light bulb!



# Jacob's Ladder

The **Jacob's Ladder** is a relatively simple device. The big box on the bottom is called a **transformer**. A transformer is something that changes the voltage going to a device. You probably have several transformers in you home; for example, the charger on your cell phone is a transformer. Your cell phone converts the 120 Volts that come out of the wall into 9 or 12 Volts. The Jacob's Ladder converts the same 120 Volts to more than 500 Volts!

When the Jacob's Ladder is turned on, **electrons** are fed into one of the wires. These electrons want to get away from each other, so they jump across to the other wire, which is connected to the ground. When they jump, we see a bright spark in the air. The spark then climbs up the ladder as it heats the air around it. Remember that hot air rises, and in this case takes the spark with it. This spark is very hot, so hot that it can be classified as a **plasma** (see Plasma Tube). Eventually the spark dissipates and releases all of those electrons into the air.

**Electricity**

# Human Generator

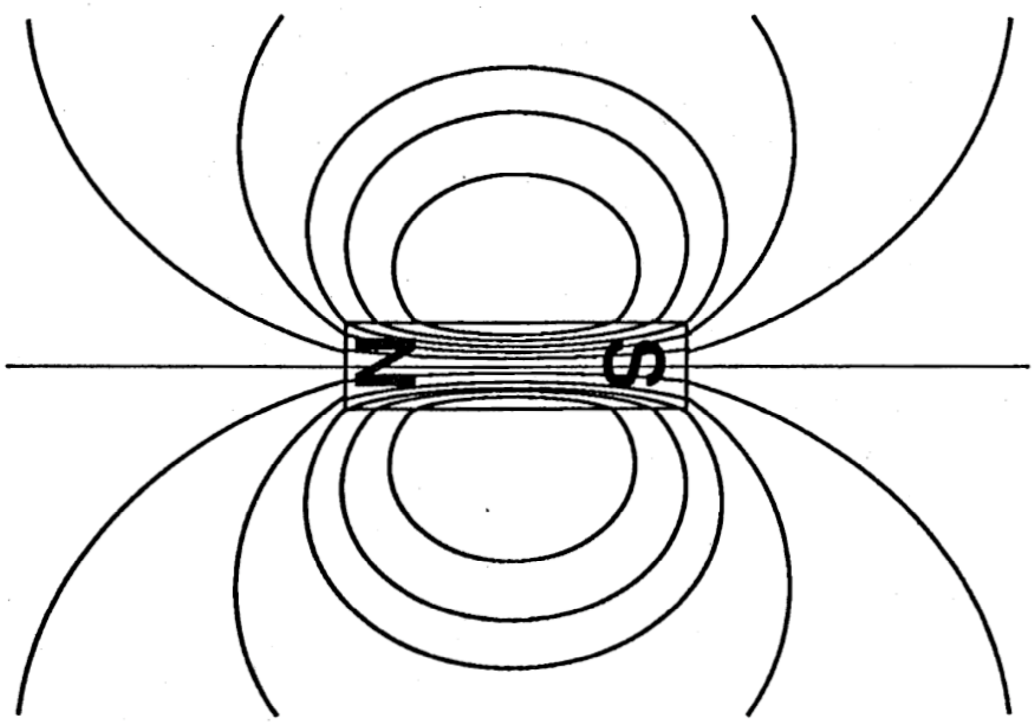
The **human generator** is very similar to an emergency generator you may have at your home or school. In order to make **electrons** move through a **circuit**, they must receive a push. This usually comes from a **battery** or electrical socket. But when the lights go out, we need another way to generate **electricity**.  When you turn the crank, you are turning a magnet and causing a magnetic field to spin around. The changing magnetic field pushes the electrons around and creates a current in the wires. The human generator is kind of like the opposite of an **electromagnet**, which uses electricity to make a magnet; the generator uses a magnet to create electricity. As you turn the crank, you are turning a magnet that pushes on the electrons. An emergency generator also has an electromagnet that spins to create electricity. Electricity can also be generated from other forms of **motion** such as windmills and hydroelectric plants.

# Magnetism

**Magnets** are objects, which can **attract,** or pull, on some metals, like iron and steel. If you rub a piece of steel with a strong magnet, the piece of steel will because a magnet too. It has become **magnetized**. Other metals, like copper or gold, are not attracted to magnets. Magnets can also attract each other, but only if they face in opposite directions. A magnet has two ends called **poles**; one end is the north pole and the other is the south pole. A north pole will attract a south pole; the magnets pull on each other. But the two north poles will push each other away. We say the magnets **repel** each other. Magnets seem to act something like positive and negative **electric charges**. Electricity and magnetism are very closely related.

If the words north and south remind you of anything, the **earth** is in fact a giant magnet. A **compass** is a tiny magnet balanced on a point so it can turn freely. The magnet is attracted by the earth's magnetic north pole and always points in that direction.

A good way to see how the magnet attracts is to do the following experiment. Take a strong bar magnet and putt a piece of pare over it. Then sprinkle some **iron filings** on the paper. The iron fillings will make a pattern. This pattern shows the **magnetic field**. The drawing below shows what the magnetic field looks like for a **bar magnet** (although the lines don't really exist). Now try it with two magnets. Point their north poles at each other. The iron filings show how the magnetic field looks when the magnets repel. Now turn one magnet in the other direction to see how the magnets attract.



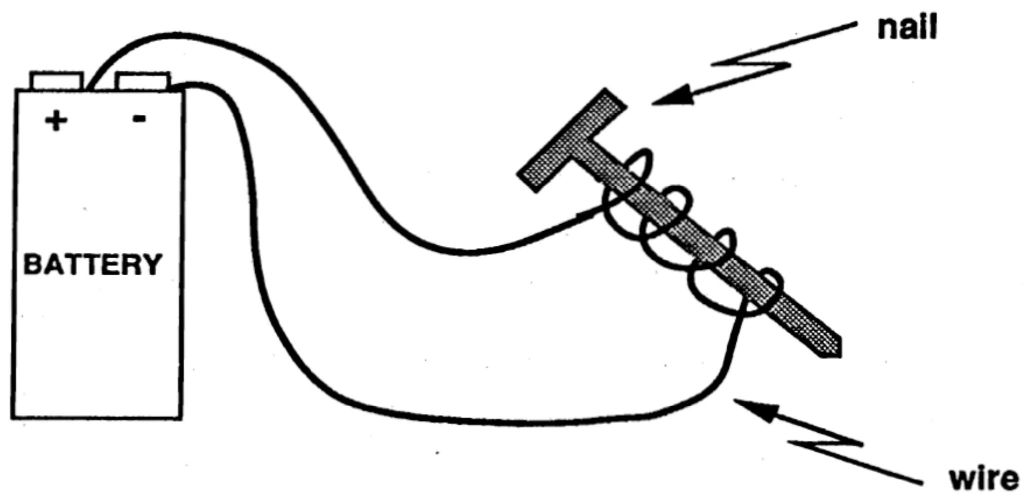
**Magnetism**

# Electromagnets

Electricity and magnetism are very closely related. This is dramatically demonstrated by the **electromagnet**. An electromagnet is a magnet made with electricity. Normal magnets are called **permanent magnets**. An electromagnet has the same properties as an ordinary magnet. It has a north and south pole and it attracts steel and iron. It is different from a permanent magnet because it can be turned on and off.

When electricity flows in a circle of wire, it makes a magnet. One side of the wire is a north pole, the other side is a south pole. If there are many loops of wire, the magnet is stronger.

The way to make a simple electromagnet is shown in the drawing. All that is needed is a long piece of steel, like a big nail, some insulated wire and a strong battery. A 1 ½ volt D cell is good. (A car battery is too strong.) The magnet is made by winding the wire around the nail very tightly. The more windings, the stronger the magnet, but be sure to leave the ends free. Make only one layer of wire on the nail. Hook up the ends to a battery. Make sure that you get a good connection between the wires and the battery. Now you can pick up paper clips, staples, and even other nails. Try using a permanent magnet to find the north and south poles of the electromagnet. When you disconnect the battery, the electromagnet is turned off. The nail may still be a bit magnetized, but it will soon wear off. Don't leave the electromagnet on for too long; it will quickly get hot and drain the battery.



# Jumping Ring

The **jumping ring** makes a metal ring jump up into the air using an **electromagnet** like the one described earlier. It is actually two electromagnets in one. Wire is wrapped around a base made of **iron**. The wire is connected to the **electricity** and when current flows in the wire, the iron becomes a very strong magnet. The second magnet is a metal ring. It sits on top of the iron base. The magnetic field from the iron in the base causes electricity to flow around through the ring. The electricity in the ring is called an **eddy current**. The eddy current causes the metal ring to become a magnet. The two electromagnets are arranged so that their **north poles** point at each other. Two north poles **repel** each other, so the base and the ring push each other away. Since the ring is very light, it gets pushed up into the air.

When you add an additional iron bar into the electromagnet, it increases its strength. (This is why we used a nail in the previous electromagnet experiment.) A stronger magnet makes the ring jump much higher! If you add a second ring, you might expect it not to go as high because there is twice as much mass. But, there is also twice as much ring to turn into a magnet that will be repelled and it launches just as high.

We can make the ring jump much higher by using **liquid nitrogen** to make it very cold. When things are very cold, electricity can flow more easily. Since the electricity can flow through the ring better, the ring becomes a stronger magnet and jumps a lot higher.

If the ring gets cut, it won’t jump. We said some of the electricity in the wire gets into the ring to make it into a magnet. But, electricity has to flow in a complete circle to make a magnet. Since there is a cut, the electricity can’t get all the way around. The cut keeps the ring from turning into a magnet.

**Magnetism**

# Can Crusher

The **can crusher** is a giant **electromagnet**. A wire comes from the **capacitor**, which is like a big battery. Then the wire wraps around in a **coil** to make an electromagnet. The coil becomes a very strong magnet when the can crusher is turned on. It is thousands of times stronger than the earth's magnetic field and its strength can be used to crush a metal can.

When we put a can in the coil and turn the can crusher on, **electricity** flows through the coil. Also, some of the electricity flows around the outside of the can. Like the jumping ring, the can crusher has two electromagnets: the coil and the can. We know that magnets **repel** each other if they point the same way. The can is repelled by the coil from all directions. Since the can is inside the coil, the sides of the can get pushed away from the coil. This crushes the soft metal can. We can also put the can on top of the coil instead of inside it. Now the bottom of the can is repelled by the top of the coil. Instead of crushing the can, it goes shooting off into the air like a rocket.

**Magnetism**

# Floating Globe

The **floating globe** is a popular desk toy. The small globe has a **magnet** in it and the top of the device is an **electromagnet**. The electromagnet is pulling up on the magnet in the globe just enough to balance the earth's **gravity** pulling down on it. The two forces are equal and opposite so the globe floats in mid-air! (Until the table gets bumped.)

**Magnetism**

# Plasma Tube

The **plasma tube** is used to show you the unique behavior of **plasmas**. Plasmas are extremely hot gases, at least 10,000 degrees! When gases get this hot, the **atoms** are moving very fast and bumping into each other all over the place. They bump into each other so hard that the **electrons** are knocked off of the atoms leaving a mix of negatively charged particles (electrons) and positively charged particles (ions). Whenever you see a spark or a stream of electrons, you are seeing a plasma. Other plasmas can be seen with the **Tesla Coil** and the **Jacob's Ladder**.

The plasma tube is a glass tube filled with **air**. Because it takes so much energy to make a plasma, we have to first pump out some of that air using a vacuum. When there is only a little bit of air left in the tube, we apply energy in the form of a **high voltage** to excite the atoms of air. The resulting plasma looks like a **neon sign** that you may see in a store window. There is a good reason for this, as neon signs are also plasmas.

The plasma in the tube can be moved around using a strong **magnet**. Because plasmas are so hot, the only way to control them is using magnets. Electricity and magnetism are very closely related (see **electromagnets**). This means that moving charges, such as the electrons in a plasma, can behave as a magnet and be affected by a magnetic field. Scientists use strong magnets to confine plasmas that are millions of degrees!

# Light

In order to see, there must be **light.** Light shines on an object, then bounces off, or **reflects**, back to our eyes. Our eyes are sensitive to a certain kind of light called **visible** light. Visible light is all the colors (red, yellow, blue, etc.) that we can see. But there are many other kinds of light that we cannot see. **Radio** waves are really the same as light. A radio is sensitive to this kind of light and turns it into music that you can hear. **X-rays** are also a kind of light. Doctors use a special kind of film to see x-rays when they shine through your body. Some animals, like bees can see **ultraviolet** light. This is the kind of light that comes from a black light and also the light that causes sunburn when you stay outside too long.

Light is a kind of wave, somewhat like ocean waves or sound waves. Waves carry energy from one place to another. But light waves don't need water or air or anything to travel. They can move even in empty space (unlike sound waves). Light waves are made of a mixture of electricity and magnetism so they are called **electromagnetic** waves. These waves travel very quickly, about 186,000 miles (300,000 kilometers) per second. This means a beam of light could go 7 ½ times around the world in one second.

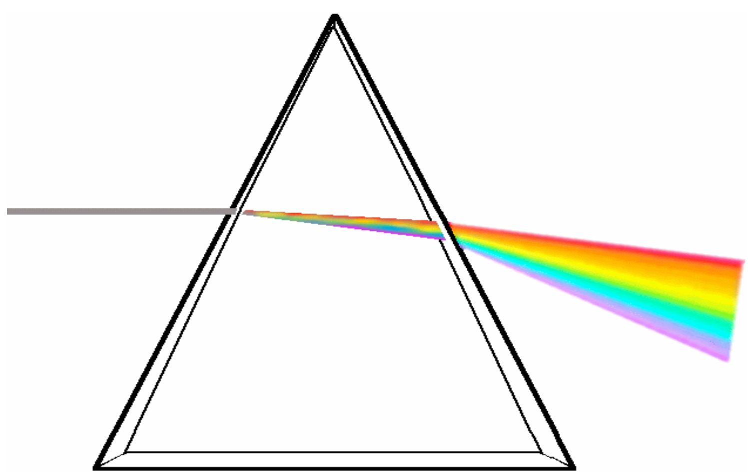
# Solar Panels

**Solar panels** can be used to convert **solar energy** into other kinds of energy such as **motion**, as in our solar robot, or **electricity** in homes. A huge amount of energy hits the earth each day in the form of solar radiation, or heat from the sun. We can harness this energy using solar panels and use for anything that currently uses electricity. One common use of solar panels is to fuel calculators. They can also be used to heat water in homes or power roadside emergency telephones. Every year, the cost to produce solar panels decreases so they may soon be used more widely to generate electricity.

# Prism

Our eyes can see many colors of **visible** light. Sunlight is a mixture of many colors together. Light from the sun looks **white** to our eyes. All of the colors are in white light, they are just all mixed up. To see all the colors separately, you can use a **prism**. A prism is a piece of glass or plastic in the shape of a triangle. The colors of the rainbow in order are: **red, orange, yellow, green, blue, indigo,** and **violet**. Many people remember this by the first letters that spell **Roy G. Biv**.

A prism works because the different colors of light travel at different speeds inside the glass. Because the colors of light travel at different speeds, they get bent by different amounts and come out all spread out instead of mixed up. Violet travels the slowest so it is on the bottom (least bent) and red travels the fastest so is on the top (most bent). The other colors are somewhere in between. When the air is full of water, like after a rainstorm, the water droplets act like a prism and can make a **rainbow**. Rainbows are circular in shape because the prisms (raindrops) that created them are spherical.



# Lasers

**Lasers** make very pure, intense light. Remember that light is made of **waves**. Normal light has many waves all bouncing around at different times. It looks like a choppy lake on a stormy day. Lasers are different. In a laser, all the waves bounce at the same time. The light is called **coherent**. Laser light is usually one single color, but sometimes a few colors can be mixed together. Normal light is a mixture of many colors (see Prisms).

A laser works just like a fluorescent light. Inside a laser there is a tube filled with gas. When electricity flows through the gas it lights up. By using mirrors inside the tube, the light is made to bounce back and forth many times making it stronger and coherent.

Light can only be seen if it **reflects** off of something so you can't normally see laser light. If there is some dust in the air, then a very fine **laser beam** can be seen. Another way to see a laser beam is to shine it into a **light pipe** (or light guide). A light pipe is clear plastic or glass. When light shines into it, the sides of the light pipe act like many tiny mirrors. The laser beam reflects off the sides and can travel from one end of the tube to the other before it gets out. It can even travel in a curve, something light can't normally do.

**Light**

# Optics

**Optics** is the study of **light** and how it bends, or **refracts**. Because light can be bent using glass or plastic, we can make all kinds of useful devices such as cameras, eye glasses, and video projectors. Light slows down when it moves through materials other than air, which is why we see it bend as it goes through a lens. The lasers show how light bends with different lenses.

A **converging lens** focuses all the light to one point. This is the kind of lens that is in your **eye**. If you have trouble seeing, it is probably because the light isn't being focused on the right spot at the back of your eye. You can change where the light focuses by adding another lens. When you are young and nearsighted, you need a **diverging lens** to help spread out the light (see picture). When you are older and farsighted, you need a converging lens to make the light focus closer to the eye's lens.

In a **camera**, converging and diverging lens work together to bring your image into focus. In an old camera, you can manually move the lenses around to adjust where the focus in your picture will be. Digital cameras use this same technology; they just save it onto a computer chip instead of film. Movie projectors, telescopes, and binoculars use this same technology.