SUPERCHARGED SCIENCE

Unit Zero: Overview

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Appropriate for Grades: K-12

Duration: 6-10 hours, depending on how many activities you do!

Have you ever picked up a textbook, completed a worksheet, or done a science experiment and wondered: *"What is my child really learning with this?"*

Parents wonder exactly what bases they should cover for their kids to understand science before they hit the high school or college scene.

This is a difficult question to answer, because it depends not only your child's interest and ability levels, but also on your ultimate educational goals are. If you want your child to just her feet wet and see what science is really all about, then grab a couple of science experiments and just play and focus on getting curious about the world.

On the other hand, if your kids read every science book and are still thirsty for more, there are a few basics you can cover to ensure they are both well-rounded and happy about learning.

Are you ready to get started?

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Materials for Experiments

Ball (any size)

Garden hose attached to a faucet

4 sheets of paper

Ping pong ball

Small funnel (you can even make one out of a cone of paper)

A couple of large latex balloons, un-inflated

Two thin magnets (you're going to break one)

Strong, thick magnet (Radio Shack #64-1877)

Large nail (at least 2 inches long)

Spool of magnet wire (Radio Shack #278-1345)

Sandpaper

D-cell battery

Paper clips

Compass (any cheap one will work)

Glass of water

Glow-in-the-dark toy

Cup of hot coffee

Can of soda

Optional: 12V DC motor (Radio Shack #273-256)

Optional: Bi-Polar 2-color LED (Radio Shack #276-012)

Optional: Camera flash (you can use sunlight instead if needed)

Key Vocabulary

Acceleration is the rate of change in velocity. In other words, how fast is a change in speed and/or a change in direction happening?

An **atom** is smallest bit of stable matter. The proton and neutron make up the core (nucleus) surrounded by electrons in shells.

Changing from a liquid to a gas is called **boiling**, evaporating, or vaporizing. Boiling point is the temperature at which a material changes from liquid to gas. Objects absorb heat as they evaporate.

The proton has a positive **charge**, the neutron has no charge (neutron, neutral get it?) and the electron has a negative charge. These charges repel and attract one another kind of like magnets repel or attract. Like charges repel (push away) one another and unlike charges attract one another. Generally things are neutrally charged. They aren't very positive or negative; rather have a balance of both.

Conservation of Energy means that in a closed system energy can neither be created nor destroyed.

The **electromagnetic force** keeps the electrons from flying away from the nucleus. When a plus (the nucleus) and minus (the electron) charge get close together, tiny particles called photons pull the two together.

Zipping around the nucleus is the **electron**, which carries a negative electrical charge and very little mass. Electrons cannot be split apart.

Energy is the ability to do work. Energy can be transferred, in other words it can be changed from one form to another and from one object to another.

The amount of **energy** a photon (packet of light) has determines whether it's a particle or a wave. Photons with the lowest amounts of energy and longest wavelengths (some are the size of football fields) are **radio waves**. The next step up are **microwaves,** which have more energy than radio waves. **IR** has slightly more energy, and **visible light** (the rainbow you can see with your eyes) has more energy and shorter wavelengths. Ultraviolet (UV) light has more energy than visible, and x-rays have even more energy than **UV**, and finally the deadly **gamma rays** have the most amount of energy.

Force is a push or a pull, like pulling a wagon or pushing a car.

A **force field** is an invisible area around an object within which that object can cause other objects to move. A force field can be attractive (pull an object towards it) or repulsive (push an object away).

The four **force fields** are gravity, magnetic, electric, and electromagnetic.

Changing from a liquid to a solid is called **freezing**. Freezing point is the temperature at which a material changes from liquid to solid. Objects release heat as they freeze.

The **fundamental strong** force holds the quarks together inside the proton and neutron.

Gases have no bonds between the molecules.

Gravity is a force that attracts things to one another. Gravity accelerates all things equally. This means all things speed up the same amount as they fall.

All bodies (objects) have a **gravitational field**. The larger a body is, the greater the strength of the gravitational field.

Heat is the movement of thermal energy from one object to another. Heat can only flow from an object of a higher temperature to an object of a lower temperature. Heat can be transferred from one object to another through conduction, convection and radiation.

Light travels like a wave and interacts like a particle. Light exists in tiny packets called photons, which can be defined by four things: intensity (how bright), frequency (or wavelength), polarization (the direction of the electric field), and phase (time shift).

Objects can either be a **light source** (like the sun) or **reflect light** (like the moon).

Light can change speeds, but the maximum **light speed** is through a vacuum (186,000 miles per second). Light changes speeds when it passes through a different material (like water, glass, or fog).

Liquids have loose, stringy bonds between molecules that hold molecules together but allow them some flexibility.

Changing from a solid to a liquid is called **melting**. Melting point is the temperature at which a material changes from solid to liquid. Objects absorb heat as they melt.

If an atom has more electrons spinning in one direction than in 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.

Mass is a measure of how much matter (how many atoms) make up an object.

Matter is anything that has mass. Another way to think about it is that matter is anything affected by gravity.

Neutrons are made from two down and one up quark. Neutrons carry no charge.

Plasma is similar to gas but the molecules are very highly energized. The molecule is in the gas phase but are vibrating and moving around so vigorously that they knock electrons off each other, which ionizes the gas and gives the gas different properties (like being able to conduct electricity).

Photon is a packet of light. Just like M&Ms are packets of chocolate, photons are packets of light in a predetermined amount.

The number of **protons** inside the atom determines what type of element it is. Protons are made from two up and one down quark. Protons carry a positive charge.

The **residual strong force** is the glue that sticks the nucleus of an atom together, and is one of the strongest force we've found (on its own scale).

Solids have strong, stiff bonds between molecules that hold the molecules in place.

There are four **states of matter**: Solid, liquid, gas and plasma. (The fifth state, BEC, is found only in a lab, so we'll disregard it for now.)

Temperature is basically a speedometer for molecules. The faster they are wiggling and jiggling, the higher the temperature and the higher the thermal energy that object has. Your skin, mouth and tongue are antennas which can sense thermal energy. When an object absorbs heat it does not necessarily change temperature.

Velocity has both a speed (like 55 mph) and a direction (northeast).

Weight is a measure of how much gravity is pulling on an object.

Work is moving something against a force over a distance. Mathematically, work = force x distance. Work can be measured in Joules or calories.

Introduction

There are 18 scientific principles, most of which kids need to know before they hit college. With the content in this unit, you'll be able to quickly figure out what they know and where the gaps are, so you can focus on the areas you need to most.

Once kids have wrapped their heads around these ideas, they can pretty much explain the universe around them, including why airplanes fly, how electricity works, and why socks disappear in the dryer.

Don't worry if these ideas are new to you – it may have been that no one has ever explained them to you or how important they are. The content in this unit is just a quick overview of what we'll be learning in the main e-Science Online Learning program. The content in this program can be stretched over several years, so don't try to cover it all in one night.

You'll be able to tell when your child has mastered these principles in the way they describe how things work when they teach these ideas to others.

One of the most important things you can do as parents is to focus on the long-term outcome (how to think like a scientist), not how quickly you can get your child to memorize these top principles.

Scientists do real science by being patient observers, getting curious about the world around them, and asking questions.

There seems to be a predominant myth about scientists: that real scientists put on a white lab coat, walk into their lab, and have an *ah-HA!* moment about how to cure the common flu or invent warp drive and then fame and fortune follows (along with a wild hairdo).

That's not the way real scientists do science. In fact, nothing could be further from reality.

Real scientists are everyday folks that have a curiosity mindset (*How does that work? Why did that happen? What's really going on here?*) and are really good at watching the world around them. They see things in ways most people overlook. Why are things overlooked? Either because they are too busy or just weren't trained to think like a scientist.

Thinking like a scientist is a way you train your mind to focus on how you can make things better for people or the planet. It's a way of contributing while at the same time challenging yourself to understand something that you didn't just a moment ago. It's fun to figure things out if they are not too far out of reach. Just as you wouldn't teach a toddler to sky-dive, we wouldn't start you on your science adventure with stuff that too complicated to understand. We'll make sure to go at your pace and throw enough solid content your way so you grow in order to keep up.

One of the quickest ways to kill your child's passion for science is to not teach him how to deal with frustration when it pops up. If you're anxious about doing science because you don't want him to ever feel frustrated while doing science, let me tell you the good news up front:

SCIENCE CAN BE FRUSTRATING! This is especially true if you're doing an experiment right in front of other people.

While every scientist gets to feeling frustrated or disappointed at times, they also don't stay there long. When an experiment goes awry, or something doesn't work, it's important to work through these emotions (and events) with your child so they get into the habit of picking themselves up, brushing themselves off, and getting back in the saddle. What this usually means is taking a closer look at your experiment setup, your original ideas and guesses and see what happened.

Everyone gets frustrated. It's part of life, part of reality. What's *not* realistic is letting frustration stop you, or even reliving the same frustration over and over in your mind. That's not how the real world operates. Everyone experiences setbacks, and the sooner your child figures out how to deal with these, the more resilient they are going to be and the faster they're going to learn what works and what doesn't.

In fact, one of the greatest experiments of all time gave a null result, which baffled top scientists for decades until Einstein came to the rescue with his special theory of relativity. It was the 1887 Michelson-Morley experiment

that failed to detect the Earth’s motion through the ‘ether’. It’s good thing, too, because now we know the truth Einstein’s relativity principles that tell us the speed of light being constant for all observers (we’ll cover more of that in later units).

We’re going to focus on the top scientific principles that will make you a brainiac extraordinaire. You might be surprised at the materials or experiment setup. But real science doesn’t need to be fancy – you can demonstrate all of these spades of science for dirt cheap. Ready?

Top Scientific Principles

Scientists study motion. They study how things move through space and time in order to understand and predict the world.

Newtonian Physics

The Principles of Galilean (Newtonian) Relativity are where Einstein's original principles of relativity came from. The ideas that "I am at rest" don't mean anything unless you talk about your motion relative to something else.

There is a **natural state of motion to move at constant speed in a straight line.** When you toss a ball, it wants to go in a straight line. But air resistance (drag) and gravity are working to bring it to a stop. Launch a Voyager spacecraft into space and it goes in a straight line until it hits something or is gravitationally affected by another object.

Newton's three laws of motion (which are based on Galileo's work) make all motion predictable once we know all the forces acting on the object:

<u>*First Law:*</u> ***Objects at rest stay at rest.*** Objects move uniformly unless acted on by outside forces. The soccer ball rolls down the field because you pushed it (or kicked it), and it rolls to a stop because of air resistance (the ball hits air particles) and friction (between the ground and the ball).

<u>*Second Law:*</u> ***F=ma*****.** This tells us how much force makes a change in motion. Acceleration (a) is the change of velocity. Velocity has two parts: speed and direction (55 mph heading east is velocity.)

When you hit the gas pedal (accelerator) in the car, the car changes speed (accelerates). When you make a turn while traveling at constant speed, you are also changing the velocity (changing the direction), so traveling in a circle is also acceleration.

This law also states that momentum is always conserved. That is, mass multiplied by velocity into a system equals the mass multiplied by the velocity coming out. For example…

When you aim a billiard ball toward another, the momentum is transferred from one ball to another. The first ball will slow if not stop altogether after impact while the second one zooms away.

<u>*Third Law*</u>: ***For every action there is an equal and opposite reaction.*** Another way of saying this is that forces come in pairs. If you push against the wall, the wall pushes back against you with the same about of push (force). A rocket fires a flame out the back which pushes it forward.

<u>*Law of Gravitation:*</u> ***Every object attracts another with a force that depends on both their masses and the distance between them.***

Newton realized that the circular motion of the planets and the apple falling from the tree are really the same thing. (Whether he was hit on the head with the apple first is still up for debate.)

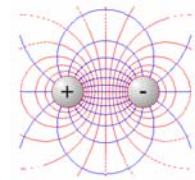
Further, he guessed that all objects have an attraction to each other.

He was on his way to prove this idea when he ran into a road block – the math he needed to prove his idea about gravitation did not yet exist. So he invented a branch of Mathematics (called Calculus) in order to figure out his law of gravitation. More on this in Unit 1.

Maxwell's Equations

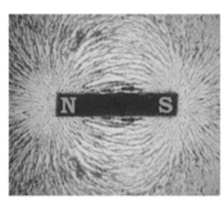
James Maxwell and a host of others worked to form new ideas that formed a new branch of physics called *Electricity & Magnetism*.

<u>*Maxwell's First Equation*</u>: ***Electrical charge is a fundamental property of matter.*** Like charges repel, and opposite charges attract. A balloon rubbed on your hair collects a negative static charge as electrons are collected on the balloon. These negative charges attract the positive charges in your hair and your hair stands up when the balloon is brought close.



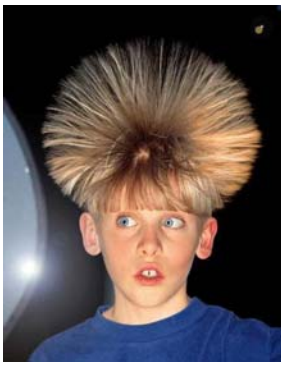
<u>*Maxwell's Second Equation:*</u> ***All magnets have two poles.*** Like poles repel, opposite poles attract. North attracts the South pole of a bar magnet.

<u>*Maxwell's Third Equation:*</u> ***Invisible fields exert forces on charges and magnets.*** You can have an electric field or a magnetic field (or both).



Drop a magnet into a pile of iron filings, and you'll find the filing arrange themselves to show you the magnetic field lines around the magnet.

You detect an electric field when you have a bad hair day! But here's another way:



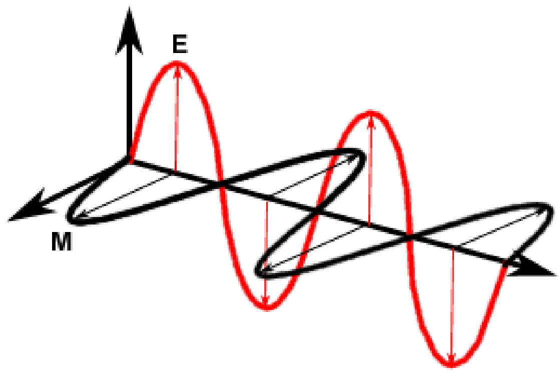
Place an object that is sensitive to electrical charges (like a fluorescent light) in an electrical field (you can do this by vigorously rubbing the outside of a long fluorescent light with a plastic bag), and you'll find the fluorescent tube lights up without having it being plugged in!

<u>Maxwell's Fourth Equation:</u> ***A moving electric charge produces magnetism.***

When you wrap a wire around a

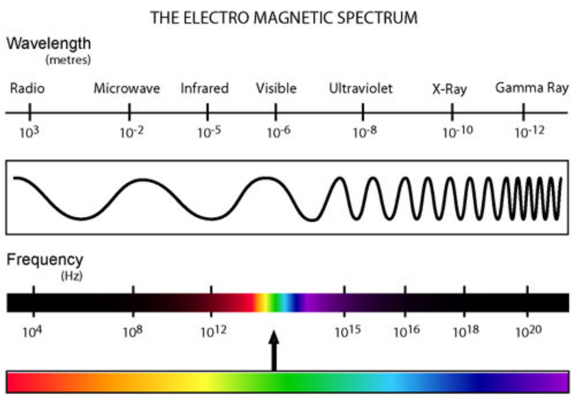
nail and run electric current through the wire, the nail-coil turns into a magnet (you can even pick up paper clips!). It's called an electromagnet, as you can turn the magnet on and off by switching the electricity on and off.

<u>Changing magnetic fields produce electric fields.</u> Wave a permanent magnet back and forth along a coil of wire (or your electromagnet nail used previously), and you'll measure a pulse of electricity.



Electromagnetic Waves were first predicted by James Maxwell. He suggested when the magnetic fields produce electrical fields, those emerging electrical fields generated magnetic fields, which then created electrical fields… and continue to create each other, leap-frogging their way through space. He calculated the speed those waves would travel at and was surprised to find it was the speed of light! Maxwell concluded that ***light must be an electromagnetic wave traveling at speed c*** (c = 186,000 miles per second), which created a new field of study called *optical science*, now a branch of electromagnetism.

We'll cover more on magnetism in Unit 11, and how to make circuits in Units 10 and 14.



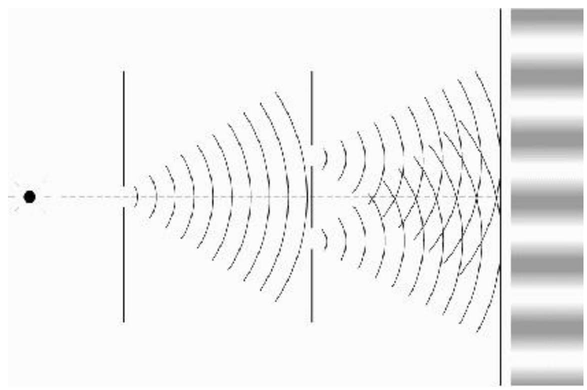
The Electromagnetic Spectrum

If a wave moves across the surface of a pond, wave itself moves, not the water. The energy travels through water as a wave, just like light. Light waves are traveling energy, but they don't need substances to travel through – they can travel through the vacuum of space.

If you could count the number of waves that pass by you in one second, the number would determine what color of light you see. Red light has 430 trillion waves that pass by in one second, while violet light has 750 trillion. The more energy a light wave has, the higher the frequency. Violet light is higher energy than red light.

Light travels at different speeds, depends on what it travels through. When light passes through different substances, the speed of the wave and the angle change, which is exactly what eyeglasses to: they allow you to focus the light.

In the early 1800s, Thomas Young's double-slit experiment showed the world that light was a wave.

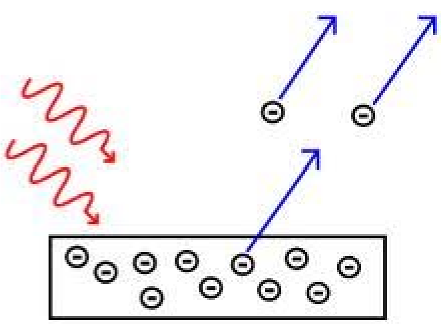


He aimed sunlight through two very narrow slits and found a wave-like interference pattern on the wall behind the slits, something you'd only get with waves.

If you had a pool of water and you were creating waves, you'd see this same effect. Add a breakwater partition with a small opening in the middle (as shown in above), and you'll find that the waves spread out after emerging from the opening. For two openings, they would interfere with each other as shown. So it was easy to see how light acts like a wave.

James Maxwell predicted light would be an electromagnetic wave (more on this in Unit 10) in the 1860s after doing several experiments with electricity and magnetism. He further predicted that this wave would travel at speed *c* (where *c* = 186,000 miles per second).

In the 1800s, scientists had observed the photoelectric effect, in which a light particle hits a free electron and knocks it out of a metal plate. A particle (like a marble) can do this, but waves don't act this way at all.



In 1905, Einstein explained the photoelectric effect by suggesting that light comes in bundles and behaves like it was a particle.

Glow-in-the-dark toys work on a similar principle: the light particles hit the electrons and transfer some of their energy to the electron. The result is that the electron emits another light particle of a different wavelength, which is why glow-in-the-dark toys don't reflect back the same color light they were charged with. If light were a wave, the atom would emit back the same color light, but it doesn't. So clearly light acts like a particle in this case.

So we have two seemingly opposing points of view – light sometimes acts like a wave, and sometimes acts like a particle. So which is it?

It turns out to be both**. Light is both a particle and wave**, and furthermore, these two ideas actually complement each other. You need both in order to describe all the different ways that light behaves. We'll cover this in a lot more detail in Unit 9.

Ideal Gas Law

We live in a sea of air called the atmosphere. Everything around us has atoms pushing on it equally in all directions, a lot like a room full of continuously-bouncing ping pong balls.

Think of each ping pong ball as a molecule. If we raise the temperature of the molecules, they start whizzing around faster and faster. **Temperature is basically a speedometer for molecules.** The faster they are wiggling and jiggling, the higher the temperature and the higher the thermal energy that object has.

If we lower the temperature, the ping pong balls move more slowly. The push the wall feels from each ball add up to equal the total pressure on the wall by the balls. The faster the balls move around, the more pushes the wall feels. This means the **higher the temperature, the higher the pressure.**

If we keep the temperature constant but instead shrink the size of the room in half, the balls also move more quickly. **When the volume of a gas decreases, the temperature and pressure increase.** More on this in Unit 13.

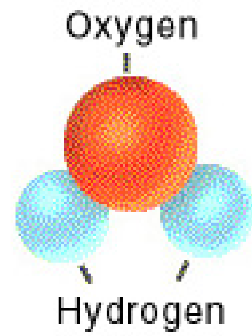
The Atom

All matter is made of atoms. An atom is the smallest part of stable matter.

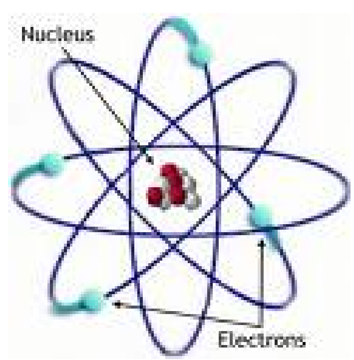
If you magnify an apple to be the size of the earth, the atoms inside would be the size of an apple.

If you magnified the atom to be the size of the earth, then nucleus would be the size of a basketball at the center of the earth and the first electron shell would be on the surface of the earth. An atom is mostly empty space!

Atoms rarely hang out alone. They join together in groups from two to millions of atoms. H_2O for example is made up of two hydrogen atoms and one oxygen atom.



Atoms are made of three basic particles: neutrons, protons, and electrons. Neutrons and protons are made up of smaller particles called quarks (more on this in Unit 7).



Neutrons and protons are together in the middle of the atom and make up the nucleus of the atom. Electrons move around the nucleus. They don't "orbit" the nucleus. Next lesson we will talk more about how they move. It's one of the wacky things about electrons.

Atoms differ from one another by how many protons, neutrons, and electrons they have in them.

Elements are specific kinds of atoms. Every atom is a type of element.

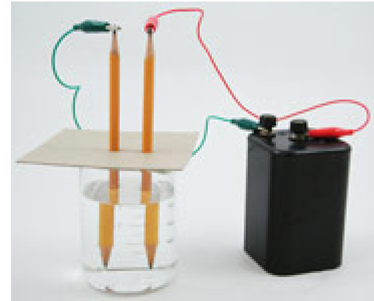
There are over 112 elements. Ninety of which are found naturally. Twelve different elements are the major ingredients of over 90% of all matter.

Five different elements are the major ingredients of all living things. Carbon, Hydrogen, Oxygen, Nitrogen, and Calcium are the five main elements that make up all living matter.

Most atoms come from stars and have been around since the beginning of time.

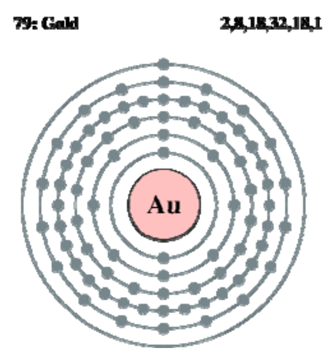
Atoms get used, and reused again and again as things change over time. **Atoms, which is to say matter, cannot be created or destroyed, only changed into another form.**

You can split apart the water molecule into separate tubes of hydrogen and oxygen using a battery. You can then recombine the hydrogen and oxygen back into water and use the energy generated by this combination to power a motor. It takes energy to split apart the molecules, and the chemical reaction of recombining the atoms into a new molecule generated energy. **Matter and energy are two sides of the same coin** (more on this soon when we get to $E=mc^2$).



Electrons are as small as you can get (we call particles we can't split apart any further 'elementary particles'). Electrons don't orbit nuclei. They pop in and pop out of existence. Electrons 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.



An atom can have as many as seven shells. The number of electrons an atom has determines how many shells it has. A shell can only hold so many electrons. Atoms are "satisfied" if they have a full outer shell or if they have a multiple of eight electrons in their outer shell. If an atom is not "satisfied" it will gladly share electrons with other atoms forming molecules. We'll cover more on this in Units 3 and 8.

States of Matter

There are five states of matter: Solid, liquid, gas, plasma, and BEC. Since BEC is only found at very unusual places in special laboratories, we'll outline the four more common states of matter.

Solids have strong, stiff bonds between molecules that hold the molecules in place.

Liquids have loose, stringy bonds between molecules that hold molecules together but allow them some flexibility.

Gasses have no bonds between the molecules.

Plasma is similar to gas but the molecules are very highly energized. The molecules in this state are moving around so fast that they are knocking electrons off each other, which ionizes the gas (gives the molecules in the gas an electrical charge).

Materials change from one state to another depending on the temperature and these bonds.

Changing from a solid to a liquid is called melting. When enough energy is added to a solid, the atoms start vibrating so hard that they jiggle loose from the solid structure into a liquid form.

Changing from a liquid to a gas is called boiling, evaporating, or vaporizing. When more energy is added to the liquid, the top layer vibrates even faster and breaks free of the liquid state atoms to float off in a gaseous state.

Changing from a gas to a liquid is called condensation. When you pull enough energy from a substance, you slow down the molecules enough that they start to link up with each other.

Changing from a liquid to a solid is called freezing. When enough energy is pulled from the system, the atoms (or molecules) lock into place with strong bonds.

We'll discover more about matter and the bonds that hold it together (including how to break them!) in Units 3, 8, and 15.

Energy

There are many different kinds of energy: kinetic, potential, elastic, chemical, nuclear, electrical, mechanical, thermal…

Energy can be transferred, in other words it can be changed from one form to another and from one object to another.

First Law of Thermodynamics:
Energy cannot be created or destroyed in a closed system. A system is the place the energy is happening in.

The terms hot, cold, warm etc. describe what physicists call **thermal energy**. Thermal energy is how much the molecules are moving inside an object. **The faster molecules move, the more thermal energy that object has.**

Heat is the movement of thermal energy from one object to another.

Second law of thermodynamics:
Heat can only flow from an object of a higher temperature to an object of a lower temperature. Heat can be transferred from one object to another through conduction, convection and radiation.

Imagine your cup of hot coffee on a cold morning… which way does the heat flow? Does your coffee get warmer or cooler over time?

Gravitational potential energy is the amount of energy something has due to its height above the ground. The higher it is and more mass it has the more gravitational potential energy it has.

Kinetic energy is energy of motion. The faster something is moving and/or the more massive it is the more kinetic energy it has.

Imagine a ball dropping and hitting the floor. If the system is closed, that means no energy can get in or escape from the system. The energy the ball started with is the same energy it hit the floor with and transferred to the floor at impact. No energy was created or destroyed, just transferred within the system.

Now here's a question you may be asking yourself, "If energy is neither created nor destroyed in a closed system then why doesn't a kid swinging on the playground swing go forever?

Energy is neither created nor destroyed, but it can be transferred into non-useful energy. In the case of the swinging kid (picture a pendulum), every swing loses a little bit of energy, which is why each swing goes slightly less high than the swing before it.

Where does that energy go? To heat. The second law of thermodynamics states basically that eventually all energy ends up as heat. If you could measure it, you'd find that the string, and the weight have a slightly higher temperature then they did when they started due to friction.

Elastic Potential Energy is the energy stored by stretching or compressing something. If you take a rubber band and stretch it out, you're storing more energy in that rubber band. We'll cover more on this in Units 4 and 5.

Airplanes are Heavier than Air… How Do They Fly?

There's air surrounding us everywhere, all at the same pressure of 14.7 pounds per square inch (psi). (Remember the ping pong ball experiment earlier?)

An interesting thing happens when you change a pocket of air pressure – things start to move. **Higher pressure always pushes** stuff around. While lower pressure does not "pull," we think of higher pressure as a "push". The higher pressure inside a balloon pushes outward and keeps the balloon in a round shape.

When air moves quickly, it doesn't have time to push on a nearby surface, such as an airplane wing. The air just zooms by, barely having time to touch the surface, so not much air weight gets put on the surface. Less weight means less force on the area, which really means less pressure.

<u>*Bermoulli's Principle:*</u> ***Fast moving air creates low pressure regions.*** There's a reason airplane wings are rounded on top and flat on the bottom. The rounded top wing surface makes the air rush by faster than if it were flat.

When you put your thumb over the end of a gardening hose, the water comes out faster when you decrease the size of the opening.

The same thing happens to the air above the wing: the wind rushing by the wing has less space now that the wing is curved, so it zips over the wing faster, and creates a lower pressure area than the air at the bottom of the wing. The faster air travels over a surface, the less time it has to push down on that surface and create pressure.

The reason airplanes fly? There's more lift (generated from the wings) than weight and more thrust (from the engine) than drag. We'll talk a lot more about this in our unit on aerodynamics in Unit 20.

Mass and Energy

$E=mc^2$ is the conversion between mass and all energy. This includes nuclear, chemical, electromagnetic, elastic, potential, kinetic, electrical, mechanical, thermal, etc. (*not* just the energy inside the nucleus).
If you stretch a rubber band, you could measure the mass and find it's slightly greater than its unstretched length (if you had a scale sensitive enough).

The extra mass didn't come from extra atoms, but rather from the energy you put into the rubber band by stretching it. The energy is stored in the electromagnetic forces holding the atoms together, and anything that stores energy will have mass associated with it. We've got an entire lesson on this in Unit 7.

Experiments & Activities

1. **First Law of Motion: Objects in motion tend to stay in motion unless acted upon by an external force.** What happens when you kick a soccer ball? The 'kick' is your external force. The ball will continue in a straight line as long as it can, until air drag, rolling resistance, and gravity cause it to stop.

2. **Second Law of Motion: Momentum is conserved.** Place your thumb partway over the end of a garden hose. The water shoots out faster because the same amount of "stuff" has to pass through the exit. When the exit area decreases, less mass can pass through at one time, so the velocity increases. Momentum is velocity multiplied by mass.

3. **Higher pressure always pushes**: Blow hard under a sheet of paper. It should be no surprise that it flies up. Now blow *hard* over the top of a sheet of paper… and watch it fly up! Why does it fly up like that? Lower pressure is on the top surface, and since higher pressure always pushes, the sheet flies up!

4. **Bernoulli's Principle: an increased speed of moving fluid (or air) results in a lower air pressure.** Place a ping pong ball inside a funnel. Sick the funnel between your lips, point your nose to the ceiling, and try as hard as you can to blow the ball out of the funnel. What's going on? The air travels further to get around the ball, so the air speed increases. The curved surface of the ball increases the airflow past the ball, which drops the pressure. As higher pressure always pushes, the ball will remain in the funnel the harder you blow.

5. **Third Law of Motion: For every action, there is an equal and opposite reaction** Hold a balloon between your fingers and let go. Which way does the air inside the balloon travel relative to the balloon itself? The balloon travels to the right and the air inside the balloon (at least initially) travels to the left.

6. **Maxwell's First Equation: Like charges repel; opposites attract:** Rub your head with a balloon and hold the charged balloon near your head so that your hair sticks to the balloon. Is there glue on the balloon?

Why does your hair stick to the balloon? The positively charged hair sticks to the negatively charged balloon.

7. **Maxwell's Second Equation: All magnets have two poles.** What happens if you cut (or break) a magnet in half? The new magnets will each sport their own North-South poles!

8. **Maxwell's Third Equation: Invisible magnetic fields exert forces on magnets:** play with a couple of magnets or place a magnet in a test tube and then in a bed of iron filings. Do you see the magnetic field?

9. **Maxwell's Third Equation: Invisible electrical fields exert forces on objects:** Notice how your hair sticks up when you build up a static electrical charge. You can build up a charge on dry days by scuffing along the carpet in socks, rubbing your hair with a balloon, sliding down a plastic slide, or by rubbing a fluorescent bulb with a wool sweater or plastic bag. Bring these charged items next to a pile of paper shreds or packing peanuts (or even a ping pong ball on a smooth, flat surface) and you'll find the objects follow the charged object when placed near an electrical field.

10. **Maxwell's Fourth Equation: Moving electrical charges (fields) generate magnetic fields:** Wrap wire around a nail and connect to power to create a simple electromagnet that can pick up paper clips. Or you can make a galvanometer: wrap your wire around a toilet paper tube and remove the tube after you've got 30+ turns of wire around it. Hook up the ends of the wire to a battery and place a compass through the middle of the coil. The needle should move when you energize the coil! How does this work? Since many electrons are moving in one direction, you get a magnetic field! The nail helps to focus the field and strengthen it. In fact, if you could see the atoms inside the nail, you would be able to see them turn to align themselves with the magnetic field created by the electrons moving through the wire.

11. **Maxwell's Fourth Equation: Changing magnetic fields generate electrical fields (electricity):** Connect a standard LED to the terminals of a 12DC motor and give the shaft a spin. The LED will light up! Why is that? There is a permanent magnet and an electromagnet (coil of wire) inside the motor. When you spin the shaft, you are essentially waving a permanent magnet past the coil of wire. The two ends of the coil wire are

connected to the motor terminals, which are connected to the LED. You have just made an electric generator.

As a second experiment: You can make a second galvanometer and connect it to your first one, and then wave a magnet through the inside of one of the coils and watch the compass move inside the other! What's going on here? The same as previously, only this time the magnet is being passed through (back and forth) one coil, which generates electricity in the wire and powers the second coil and turns the second coil into a magnet (as indicated my movement with the compass near the second coil).

12. **Light acts like a wave .** To show how light acts like a wave, you can pass light through a glass of water and watch the rainbow reflections on the wall. Why does this happen? When the light passes through the glass and the water, it changes wavelength and angle to give different frequencies of light (different colors).

Dip your fingers in a bathtub of water. Can you see the ripples traveling along the top surface? Light travels just like the waves on the surface of the water.

Light acts like a particle. Use a camera flash to quickly charge a glow-in-the-dark toy in a dark closet. The light particles (photons) hit the electrons in the toy and transfer energy to the electron. The result is that the electron emits another light particle of a different wavelength, which is why glow-in-the-dark toys don't reflect back the same color light they were charged with.

13. **Mass is conserved: Mass cannot be created or destroyed only change form.** When you eat a banana, the matter is converted into energy. Ignite a sheet of paper and the paper molecules combine with oxygen through a chemical change and turn into smoke and ash.

14. **First Law of Thermodynamics: Energy is conserved: Energy cannot be created or destroyed, but can be transformed.** Roll a ball down a hill. The amount of energy the ball had while at rest at the top of the hill (potential energy) turns into kinetic energy while it zips to the bottom.

You can also swing on a swing and see this effect happen over and over again: when you're at the highest point of your swing, you have the highest potential energy but zero kinetic energy (your speed momentarily goes to zero as you change direction). At the lowest point of your swing (when you're moving the fastest), all your potential energy has turned into kinetic energy. Why do you eventually stop? The reason you eventually slow down and stop instead of swinging back and forth forever is that you have air resistance and friction where the chain is suspended from the bar.

15. **Second Law of Thermodynamics: Heat flows from hot to cold.** Leave a cup of hot coffee out on a cold morning. Does the coffee get warmer or cooler over time? Your coffee gets cooler, as heat travels from the coffee to the cool morning.

16. **There are three primary states of matter: solid, liquid, and gas.** Grab a can of soda. Can you identify the states? The tin can is the solid, the drink is the liquid, and the bubbles are the gas.

    There are two more states of matter: You'll find plasma in the sun, neon signs, fluorescent lights, and small bits in a flame. The fifth state of matter has only been shown to exist in a lab, and happens only in a *very* short temperature range.

17. **Ideal Gas Law**: When temperature increases, pressure and volume increase. Blow up a balloon and stick it in the freezer. What happened? The balloon shrinks – there is less pressure holding the shape of the balloon.

    Hold a balloon in your hands and try to stuff it into a cup. Why is this so hard? You're decreasing the volume and therefore increasing the pressure inside the balloon. Since a balloon is so stretchy, this is near impossible to do without laughing.

18. **There are four fundamental forces of nature: strong force, gravitational force, electromagnetic force, and the weak force**. What are examples of the first three? The protons and neutrons on an atom are glued together via the strong force (which is broken when you dump salt into water and measure the temperature increase). Gravitational forces happen every time you throw a ball. Make the electromagnet mentioned above experiment to demonstrate electromagnetic forces.

Exercises for the Top Scientific Principles

1. **What would happen if you belched in Antarctica?** (By the way, the freezing temperature of CO_2 is -109^{o}F and Antarctica can get below -140^{o}F) (a) the carbon dioxide in the burp would freeze into a solid (b) the carbon dioxide in the burp would sublimate (c) nothing special (d) the oxygen and carbon dioxide will form will liquefy into carbon trioxide (e) are you serious?

2. **When you cap a lit candle in a glass jar, what happens?** (a) the flame eventually goes out because fire eats air and the flame runs out of oxygen which is required for combustion (b) nothing special (c) the flame gets brighter and lasts longer (d) an explosion takes place that shatters the jar

3. **What is the difference between a light bulb and a laser beam?** (a) the laser is a focused beam, while the bulb is a scattered beam (b) the laser is a scattered beam and the bulb is a focused beam (c) lasers emit photons and bulbs emit only electrons (d) this is why I dropped out of science (e) they're both breakable and not allowed anywhere near my kids

4. **Which one generates light by electrifying a gas?** (a) incandescent bulb (b) neon sign (c) fluorescent bulb (d) car headlight

5. **What happens when you scuff across the carpet in socks on a dry day?** (a) you can zap your kids (b) you store up an electric charge in your body (c) you store up extra neutrons in your body (d) the same thing that happens to blankets in the dryer

6. **What is an atom made up of?** (a) photons, electrons, and positrons (b) neutrinos, positrons, and bosons (c) protons, neutrons, and electrons (d) gluons, muons, and gravitons (e) what on earth is a 'boson'?

7. **Which are the three primary colors of light?** (a) red (b) blue (c) green (d) yellow (e) pink

8. **If you inflate a balloon (don't tie the end), which direction does the air in the balloon and the balloon itself travel?** (a) both the same way (b) in opposite directions (c) nothing happens (d) inside-out

9. **What happens if a tank of oxygen leaks and fills an entire room, and you walk in and strike a match?** (a) nothing (b) BOOM!!! (c) the match will burn brighter (d) I don't even want to know

10. **When you combine baking soda and vinegar together, what happens?** (a) bubbles foam up (b) it belches (c) carbon dioxide gas is released (d) it produces a chemical reaction that can propel a rocket skyward

11. **If you blow up a balloon and stick it in the freezer, what happens?** (a) it gets bigger (b) it gets smaller (c) nothing (d) it glows

12. **Where is the higher pressure in a balloon**? (a) on the inside (b) on the outside (c) both are the same (d) none of the above

13. **When you wire up a circuit and it does not work, you should** (a) check for good metal-to-metal connections between wires (b) see if the batteries are in the right way (c) replace the entire thing (d) reverse the wires powering your electrical component

14. **What does it mean when batteries get hot to the touch?** (a) they are working well (b) they are about to explode (c) you are running the electricity back into the battery and this heats up the battery (d) they are about to leak acid everywhere

15. **Higher pressure does which?** (a) pushes (b) pulls (c) decreases temperature (d) causes winds, storms, and airplanes to fly (e) meows

16. **What happens when you put a large chocolate bar in the microwave without a turntable?** (a) it melts only in certain spots (b) it freezes (c) you can measure the speed of light (d) the chocolate bar emits radiation

17. **Which of the following are examples of light?** (a) radio (b) TV remote controls (c) ultrasounds (d) microwaves (e) sunburns

18. **The electricity from an electrical outlet is the same kind as** (a) lightning (b) the shock you get from scuffing along the carpet (c) the electrons that flows in a circuit (d) the electricity from a battery (e) the light show from wool socks fresh from the dryer

19. **What happens when you combine a red beam of light with a green beam of light?** (a) you see polka-dots (b) you get yellow light (c) you get cyan light (d) you get that muddy-looking color just like when you mix all the paints together (e) nothing – they stay the same

20. **If an apple is the size of the earth, then the atoms inside the apple are the size of:** (a) Manhattan (b) a grain of sand (c) the size of the original apple (d) Alaska (e) zooplankton

21. **What are the five states of matter?** (a) solid, liquid, gas, plasma, and BEC (b) earth, wind, fire, water, and wood (c) oxygen, fuel, spark, ice and heat (d) ice, water, bubbles, steam, and vapor

22. **Which of the following are seriously dangerous chemicals?** (a) dihydrogen monoxide (b) sodium chloride (c) sodium tetraborate (d) sodium bicarbonate (e) all of these (f) none of these

Answers to Exercises

1. **What would happen if you belched in Antarctica?** (By the way, the freezing temperature of CO_2 is -109^{o}F and Antarctica can get below -140^{o}F) (a) the carbon dioxide in the burp would freeze into a solid (b) the carbon dioxide in the burp would sublimate (c) nothing special (d) the oxygen and carbon dioxide will form will liquefy into carbon trioxide (e) are you serious?

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22. **Which of the following are seriously dangerous chemicals?** (a) dihydrogen monoxide (b) sodium chloride (c) sodium tetraborate (d) sodium bicarbonate (e) all of these (f) none of these (By the way: a is water, b is salt, c is laundry soap, d is baking powder)