Curriculum Units by Fellows of the Yale-New Haven Teachers Institute
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# Teaching Matter and Phase Changes

Curriculum Unit 16.04.06
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## Introduction

If everything is either matter or energy, what are thoughts and emotions? How does plasma merit being the most common state of matter in the universe? What are the similarities and differences between the processes that form dew on a lawn in the summer and frost on a car windshield in the winter?

Our world is made of matter and energy. Matter is the stuff and energy is the potential for that stuff to change. They are interconnected. This curriculum unit promotes an investigation of matter and phase changes and their relation to thermal energy. Content is described and a hands-on approach is encouraged via suggestions for discourse, demonstrations, activities, and experiments.

## Rationale

Wilbur Cross High School is located in New Haven, Connecticut. It is a comprehensive public high school located in an urban setting. It presently serves over 1,600 students. This curriculum unit can be taught in Phy/Chem, a required ninth grade physical science course with an emphasis on chemistry. It could also be taught in Chemistry, an eleventh grade requirement.

## Content

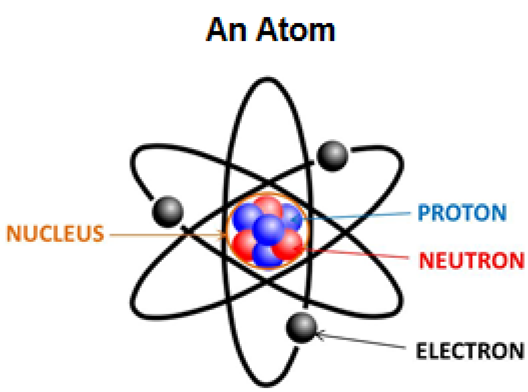
### Matter Defined

Matter is any substance that has mass and volume. If it can be proven that a substance has mass and takes up space, it is matter. Energy is the capacity to cause change and is not matter. Light energy, sound energy, heat energy, potential energy, and kinetic energy are examples.

Mass is the amount of matter. For instance, a cake has more matter that a slice of that same cake. It can be measured in milligrams, grams, or kilograms using an analytical electronic balance or a triple beam balance. This is different than using a scale to determine weight because the reading on a scale for a particular object depends on the force of gravity. Gravity is different on different celestial bodies, so weight changes according to where it is measured. Mass does not take into consideration gravity and is constant. Furthermore, mass has a positive correlation with inertia. The more massive an object is, the more inertia it has. An object with a lot of mass is more difficult to put in motion or stop if already in motion compared to an object with a small amount of mass.

Volume is the amount of space taken up. For instance, a volley ball has a larger volume than a golf ball because it takes up more space. Volume is three-dimensional and incorporates length, width, and height. It can be measured in cubic millimeters or cubic centimeters. Volume can be measured using a meter stick to measure the sides of a regularly-shaped object. To measure an irregularly-shaped object, water displacement can be determined using, for example, a graduated cylinder (assuming the object has a higher density than water). The amount of water in a graduated cylinder can be noted before an object is placed in it and after the object is placed in it. The difference of these measurements is the volume of the object.

**Basic Unit of Matter**




https://www.thinglink.com/scene/719221188345200641

An atom is the basic unit of matter. Is the smallest part of a chemical element that retains the properties of that element. An element is matter that is made up of one type of atom. There are over 110 chemical elements. Since there are over 110 elements, there are over 110 types of atoms. Everything that you see, smell, hear, taste, and touch consists of atoms.

Atoms are made up of three sub-atomic particles called protons, neutrons, and electrons. Protons are positively charged and located in the nucleus, the center of the atom. The number of protons determines which element the atom represents. Each element has a different number of protons. The number of protons is the element’s atomic number. Neutrons have no charge and are also located in the nucleus. The nucleus makes up more than 99.9% of an atom’s mass. Electrons are the smallest of these particles and travel in shells or orbitals around the nucleus, sometimes called the electron cloud. If the number of protons equals the number of electrons, the atom has no charge. If there are more protons than electrons (or vice versa) it is an ion. Electrons allow atoms to bond with each other and form molecules. A molecule is two or more atoms bonded together. When a metal element loses electrons becoming a positively charged cation and a non-metal element gains electrons becoming a negatively charged anion, an ionic bond is formed. It is valance electrons, or outermost electrons, that are transferred when ionic bonds are formed. When non-metal elements share pairs of electrons with other non-metal elements covalent bonds are formed.

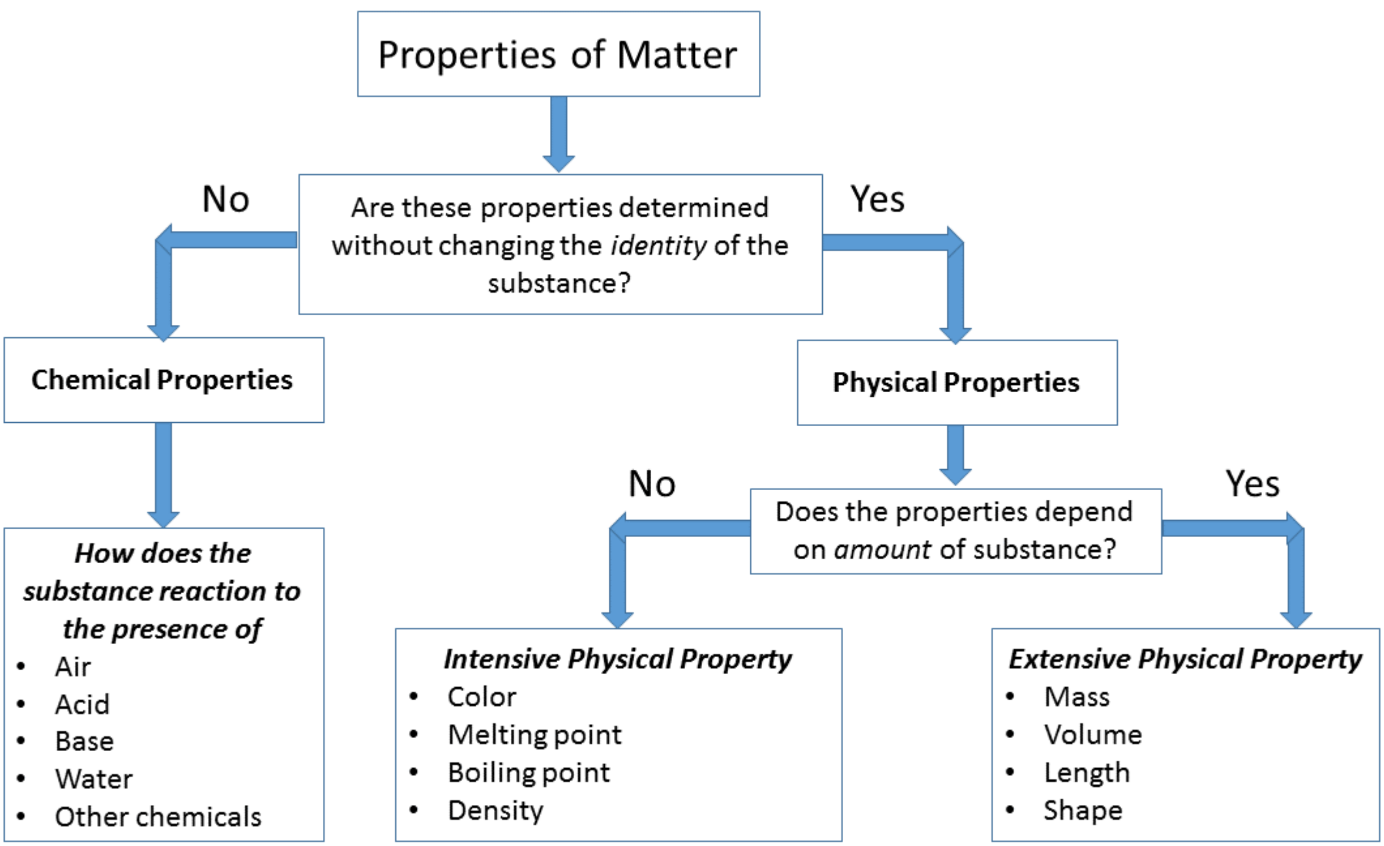
| | **Subatomic Particles** | | |
|---|---|---|---|
| | **Proton** | **Neutron** | **Electron** |
| **Symbol** | p or $p^+$ | n or $n^o$ | e or $e^-$ |
| **Charge** | +1 | 0 | -1 |
| **Mass** | 1 amu | 1 amu | .00054 amu |

**Classification of Matter**

Matter is either a pure substance or a mixture. A pure substance cannot be taken apart using physical means. Elements are pure substances made of one type of atom. An example is aluminum. Compounds are pure substances made of atoms from two or more elements. Water, or $H_2O$, is an example. A mixture is two or more pure substances in varying amounts that can be taken apart by physical means. Air would be an example since it is primarily a mixture of $N_2$ and $O_2$ gas. Homogeneous mixtures, also called solutions, are mixed uniformly. Sugar dissolved in water is an example. Heterogeneous mixtures, also called suspensions, are not mixed uniformly. An example is concrete. Suspensions settle out over time, like corn starch and water. Colloidal suspensions, or colloids, do not settle out over time, like milk.

**Properties of Matter**

A property is a special or distinctive attribute, quality, or characteristic. Properties can be used to identify matter. For example, different types of matter can be described by electrical conductivity, thermal conductivity, color, melting point, mass, density, or volume. Therefore, these are properties of matter.



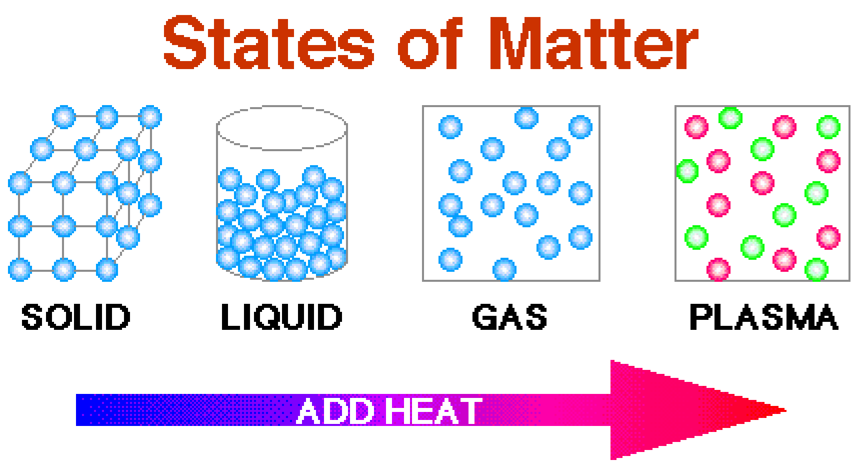
http://chemwiki.ucdavis.edu/Core/Analytical_Chemistry/Chemical_Reactions/Properties_of_Matter

Chemical properties are observed when one substance reacts with another substance and changes into a different substance. For example, when iron reacts with oxygen, it rusts and becomes reddish-brown flakey iron oxide. The ability to rust is a chemical property. Furthermore, when fire burns beige hard wood it turns into black powdery ash. This chemical property is flammability. Other chemical properties include reactivity with acids, bases, and water.

Physical properties are observed without a substance changing into a different substance. Generally, you can detect them with your senses. There are intensive and extensive physical properties. Intensive physical properties do not depend on the amount of matter present. They include color, melting point, malleability, ductility, thermal conductivity, electrical conductivity, ability to dissolve other substances,  and density. For example, the density of half a cube of lead is the same as the density of the cube of lead before it was cut in two. It is not dependent on the amount of lead present. Extensive physical properties depend on the amount of matter present. Mass, volume, and length are typical examples. The mass of half a cube of lead is half of the mass of the cube before it was cut in two, and the volume of a piece of steel depends on the amount of steel present.

**States of Matter**

A state (or phase) is the way matter organizes its atoms and molecules and is a physical property of matter. Common states of matter include solids, liquids, and gases. Plasmas are a less common state of matter.




http://questgarden.com/75/22/0/081214000133/task.htm

A solid has a definite shape and does not conform to the shape of a container. It has a definite volume, as well. The particles of a solid are arranged in an organized pattern and are tightly packed such that they move very little and are not easily compressed. They can vibrate around their equilibrium position, but their atoms are in a fixed position and do not move throughout the solid. Solids can be crystalline or amorphous. The particles of crystalline solids are arranged in an organized repeating pattern. Examples include diamond, graphite, and table salt. When broken, they have straight edges. They also have exact melting points. The particles of amorphous solids have no regular pattern. Examples include glass, plastic, and rubber. When broken, they have curved edges. They do not have exact melting points, so they become soft and gooey before turning into a liquid.

A liquid has particles that flow past each other, so it has an indefinite shape and takes the shape of the container in which it is poured. The particles of a liquid, which have greater kinetic energy than a solid, are still relatively close to each other so it has a definite volume. A liquid is very difficult to compress and has a top surface. A liquid has surface tension because like particles have cohesion and are attracted to each other more than to other particles with which they may be in contact. Surface tension allows an insect like a water strider and a reptile like a basilisk lizard to "walk on water." Cohesion is stronger below the surface of a liquid where like particles are surrounded by each other. This causes a liquid to form a sphere. When gravity acts on a drop of rain, small raindrops stay spherical, medium-sized ones flatten a bit, and large ones become teardrop-shaped. The particles of a liquid are also attracted to different particles, like those of a container, because of adhesion. Acting together, cohesion and adhesion create a meniscus or concave shape at the surface. If a liquid is in a graduated cylinder, the mark at the base of the meniscus should be used to measure the volume. Adhesion is also the reason for capillary action, the movement of a liquid up a narrow tube. Water drawn up the xylem of a bonsai tree or a giant sequoia tree are examples of this. The term viscosity refers to how freely a liquid flows. For example, maple syrup is more viscous, or thicker, than water.

A gas has enough kinetic energy (thermal energy) to overcome intermolecular forces and spread apart, so it has an indefinite shape and volume. Without the confines of a container, a gas will spread without limit. If in a container, a gas will take on the shape and volume of the container. Since gas molecules are far apart from each other, a gas can easily be compressed. The volume, temperature, and pressure of a gas are interrelated. Boyle's law states that gas particles will collide more often in a container with less volume, thus creating more pressure if temperature is held constant. Charles' law states that gas particles will increase their movement and occupy more volume when temperature is raised if pressure is held constant. To maintain that pressure, the volume of a container must increase when a gas is heated.  Avogadro's law states that gases contain an equal number of molecules when the temperature, pressure, and volume are the same. The ideal gas law is a combination of these laws and is written $PV = nRT$, where P, V, and T are pressure, volume, and temperature, respectively, n is the number of moles (or essentially, the amount of substance), and R is a constant. Kinetic Molecular Theory explains the behavior of gases. It is based on the following assumptions:

- Gases are composed of particles in constant motion.
- The particles move in straight lines unless they collide with each other or the wall of their container.
- The particles are much smaller than the space between them, so a gas is mostly empty space.
- Collisions are elastic and no energy is lost.
- The average kinetic energy of the particles depends on the temperature of the gas.

A plasma is a charged gas of particles with extremely high kinetic energy. Therefore, a plasma has an indefinite shape and volume. Particles are very far apart. Some plasma atoms lose electrons making them into positively charged ions. Stars, with extremely high temperatures, are plentiful and made of plasma which means that plasma is the most abundant state of matter in the universe. However, on earth, they are less common than other states of matter, but examples exist such as neon lights and the aurora borealis.

| | **States of Matter** | | |
|---|---|---|---|
| | **Solid** | **Liquid** | **Gas** |
| **Shape** | Definite | Takes shape of container | Takes shape of container |

| | | | |
|---|---|---|---|
| **Volume** | Definite | Definite | Takes volume of container |
| **Particle Position** | Tightly packed | Less closely packed | Very far apart |
| **Particle Motion** | Very little motion, Vibrate within limited area | Moderate motion, Flow around each other | Constant random motion, Fly in all directions at great speeds |
| **Compressibility** | Not easy to compress | Not easy to compress | Easy to compress |

All matter has thermal energy, or heat. Heat is the total energy obtained from the movement of particles. A greater amount of particle movement means more heat. For instance, the human body shivers when it is cold to generate more heat for itself. Heat flows from a warmer object to an object that is cooler. Temperature is a measure of the average kinetic energy of particles. If a pail has just been dipped into the ocean, the water inside the pail is the same temperature as the ocean. The ocean, though, has much more heat content as it is vast in comparison to the pail of water.

Heat can be transferred in three ways. Convection is the transfer of heat through a fluid, namely a liquid or a gas. As the fluid heats, its particles move farther apart and rise. Cooler particles move in below, thereby creating circular convection currents. Water being heated in a pot on the stove moving in a circular pattern is an example. Conduction is the transfer of heat through a solid. Heat from a source on one end of a solid making particles move more will travel along the solid and make adjacent particles move more. Heat traveling up the handle of a metal spoon partially submerged in boiling water is an example. Radiation is the movement of electromagnetic waves and can occur without a medium. Sunlight that travels to Earth through space is an example.

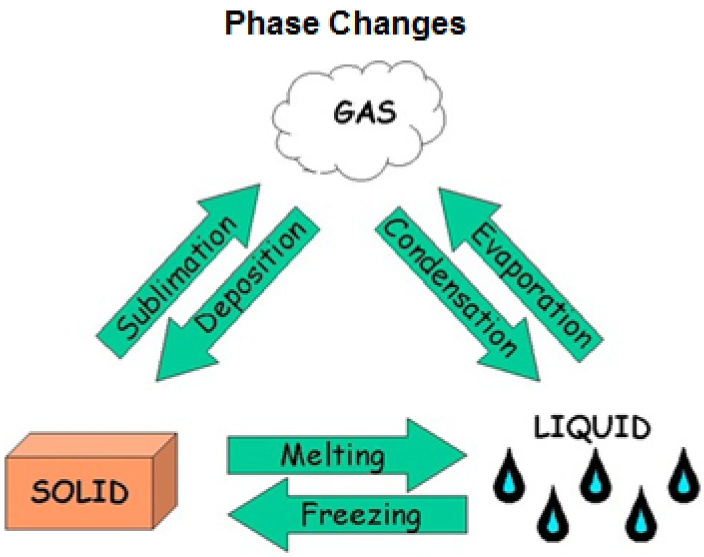
Density is mass per unit volume, another physical property of matter.  Density varies with pressure and temperature, affecting gases more than solids or liquids.  An increase in pressure decreases volume and therefore increases density. An increase in temperature generally increases volume and therefore decreases density. Different elements have different densities. Sometimes an element can even be identified by its density. Density is related to buoyancy and purity.

**Phase Changes**

Phase changes occur when a substance transforms from a solid, liquid, or gas into a different phase or state. All substances change phases depending upon temperature and pressure. Each substance has unique intermolecular forces and these influence the temperature and pressure at which substances will change their state. When a substance does change, two phases exist at the same time as the transition occurs. There are six categories of phase change, each being reversible:

- Melting or fusion is when a solid turns into a liquid.
- Freezing or solidifying is when a liquid turns into a solid.
- Evaporation or vaporization is when a liquid turns into a gas.
- Condensation is when a gas turns into a liquid.
- Sublimation is when a solid turns directly into a gas.

- Deposition is when a gas turns directly into a solid.



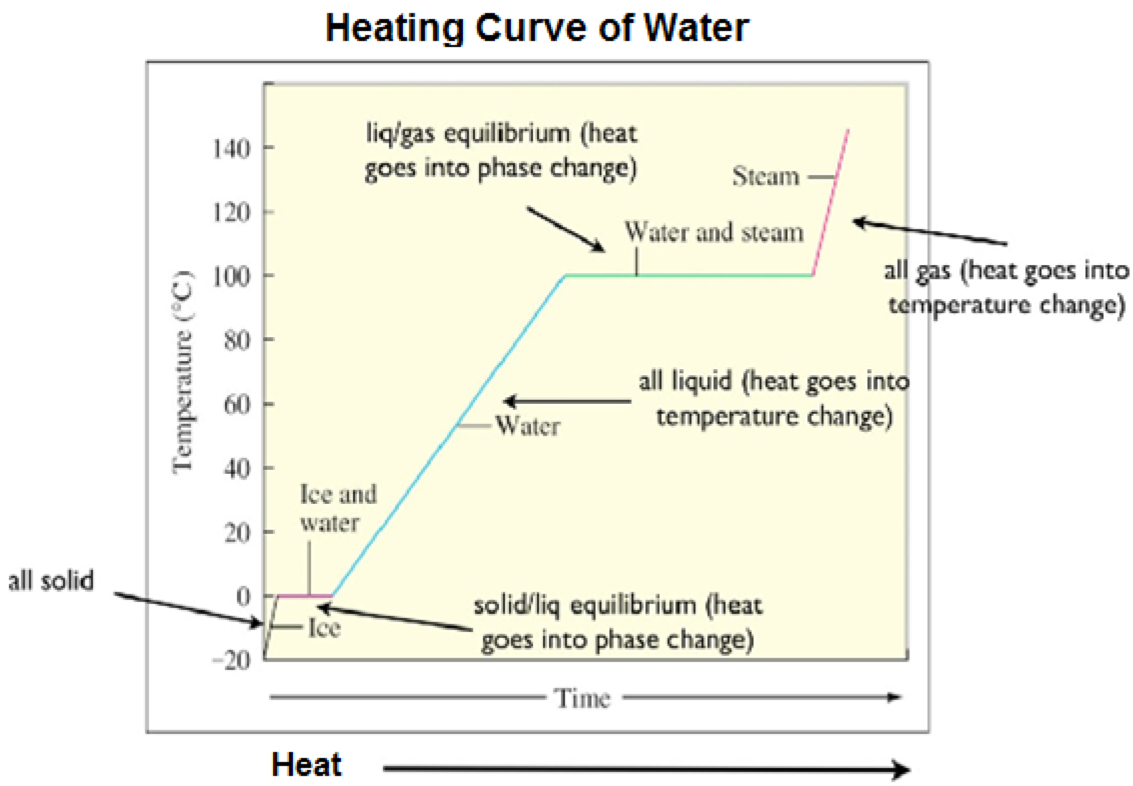

"Quizlet." Chemistry. Accessed June 28, 2016. https://quizlet.com/80471746/chemistry-phases-flash-cards/.

Melting, evaporation, and sublimation are endothermic processes. The substances absorb energy from the surroundings which enables the change to occur. A way to remember this is to think of "endo" as entering. Energy goes into, or enters, the substance. Therefore, the surroundings are cooled.

Freezing, condensation, and deposition are considered exothermic. The substances release energy into the surroundings enabling the change to occur. A way to remember this is to think of "exo" as exiting. Energy goes out of, or exits, the substance. Therefore, the surroundings are heated.

**Phase Changes**

| | **Phase to Phase Change** | **Endothermic or Exothermic?** | **Example** |
|---|---|---|---|
| **Melting** | Solid to Liquid | Endothermic | Ice Cube to Water |
| **Freezing** | Liquid to Solid | Exothermic | Sweetened Cream to Ice Cream |
| **Evaporation** | Liquid to Gas | Endothermic | Puddle to Water Vapor |
| **Condensation** | Gas to Liquid | Exothermic | Water Vapor to Dew Drops |
| **Sublimation** | Solid to Gas | Endothermic | Dry Ice to Carbon Dioxide Gas |
| **Deposition** | Gas to Solid | Exothermic | Water Vapor to Frost |




http://ch301.cm.utexas.edu/section2.php?target=thermo%2Fenthalpy%2Fheat- curves.html

Temperature can enable a phase change to occur. Heating an ice cube, a solid, over a hot plate changes it into water, a liquid. The substance changes when its melting point is reached. Melting point is the temperature at which a solid turns into a liquid. With continued heating, the water, a liquid, will change into water vapor or steam, a gas. The substance changes when its boiling point is reached. Boiling point is the temperature at which a liquid turns into a gas.

Pressure can also enable a phase change to occur. An increase in pressure, at a constant temperature, can cause a gas to turn into a liquid and a liquid to turn into a solid. The reverse can happen with a decrease in pressure.

When a substance is heated two things can happen. The temperature of the substance can increase or a phase change can occur. If heat is added to a solid it will get hotter until its melting point is reached. At that point, the added heat will enable a phase change from a solid to a liquid, but the temperature will not rise. Then, once all of the solid melts, the liquid will get hotter as heat continues to be added. When the boiling point is reached, a phase change will occur and the liquid will turn into a gas. The plotting of temperature versus time is called a heating curve. It is level during phase changes because the added heat is used to facilitate the change and break intermolecular forces rather than increase the temperature.

## Classroom Activities

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**Gum Lab**

This lab provides students with practice using a triple beam balance to determine mass. They predict whether the mass of a piece of chewing gum will increase, decrease, or stay the same after it has been chewed for several minutes. Also noted are any changes in color, shape, texture, smell, or taste of the gum. After the data is gathered, students need to explain why their gum lost mass.

A similar lab could provide students with practice determining volumes. Students could measure the dimensions of a block of wood to determine its volume. They could estimate whether a beaker or test tube has a greater volume and figure out how to prove their prediction. Proper use of a graduated cylinder would need to be taught with an emphasis on taking the measurement at the bottom of the meniscus and reading it at eye-level. Students could also use the water displacement method to determine the volume of an irregular-shaped object, such as a rock. Furthermore, they could even blow into a hose submerged in a water-filled graduated cylinder to discover lung capacity.

**Is Air Matter? Lab**

This lab provides students with a hands-on experience that reinforces the definition of matter. They state whether they think air is matter and explain why they came to that conclusion. The volume of a balloon is estimated when it is bunched and empty as well as filled. They try to fill the balloon partially placed in a 2-liter bottle without and then with a straw beside the balloon. Then they mass the balloon when it empty and filled. After the data is gathered, students need to explain why air is indeed matter.

Previous to this lab, a discussion of what is matter and what is energy should take place. During that discussion, students should also be challenged to decide how to categorize thoughts and emotions. What is love? The talk can also include discourse about the energy in our bodies and what happens to it when a person passes away. Energy cannot be created or destroyed. The dialogue will be meaningful

A demonstration of crushing a can using atmospheric pressure can accompany this lab. A small amount of water can be boiled in a soda can. When steam appears, the can should be turned over into a shallow container of cool water, sealing the top of the can. The steam condensates on the inside of the can creating a vacuum, which causes the can to crush instantly.

An additional lab would have to do with flammability. Caution needs to be a priority when working with a flame. Furthermore, care should be taken to not set off a fire alarm or sprinkler system. The preferred venue for working with a flame would be outdoors. If that is not possible, at a minimum the lab should be practiced by the instructor outdoors before performing it indoors. Then the instructor would be familiar with what to expect. Partially opened windows can provide ventilation and a means for smoke to leave the classroom, as well. A prediction can be made as to whether the masses of paper and fine steel wool will increase, decrease, or stay the same after being burned. Matches can be used to light each sample in a small aluminum container. A 9-volt battery could also be used to light the steel by making contact with the terminals. An explanation of why the mass of the steel wool increases should include the topics of oxidation and rust.

A couple of flammability demonstrations incorporate corn starch. It is preferable to perform each outdoors with students a safe distance away. If that is not possible, the instructor should first practice them outdoors to become familiar with what to expect. For one, 1.5 meters of tubing is inserted into the lowest point on the side of a gallon paint can. The tubing is inserted about a centimeter. Some corn starch is piled inside the can, in front of the tubing. Opposite the pile is placed a couple of short candles seated on a piece of wood to elevate them. The candles are lit and the lid, which has been punctured and tied to the can, is placed on top of the can closing it. When air is blown through the tubing and into the can it disperses the corn starch throughout the can, and it rapidly burns. A large flame will pop the lid off the can.

For another demonstration, a meter of plastic tubing can be affixed to the length of a gas grill lighter along its top. The end of the grill lighter should extend about a centimeter beyond the end of the tubing. The tubing can be filled with corn starch by squeezing it in with a plastic condiment bottle. The lighter is clicked on and the flame should point up and be in front of the tubing hole. When the corn starch is then quickly blown through the tubing, it will ignite as it passes over the flame and shoot forward as a much larger flame. In connection with these two demonstrations of a chemical property, flammability, discourse about the dangers involved with the storage of grains and other powdered materials will be meaningful.

**Corn Starch Lab**

This lab challenges students to classify whether a substance is a solid or a liquid. Corn starch is mixed with water in a 1:1 ratio and a 1:1.5 ratio. The mixtures are poked, prodded, squeezed, and held to analyze and compare them. Interestingly, students will find that the 1:1 ratio acts like a solid and a liquid at the same time. After the data is gathered, student are asked to predict whether 1:0.5 and 1:2 mixtures will be liquids or solids.

Another lab that touches on states of matter can be done with dry ice. The masses, over a ten minute span of time, of beakers filled with a combination of water and ice as well as water and dry ice are compared. After the data is collected, students need to explain why the breaker of water and dry ice lost mass. A discussion of sublimation and condensation need to be included. Carbon dioxide is colorless and the condensation of water vapor is what is seen. Students need to explain why frozen carbon dioxide is called “dry” ice. It skips the wet liquid stage when it goes from a solid to a gas. Activities with dry ice can be included, as well. Sliding dry ice, placing it in warm water, placing it in soapy water, placing it in a closed film canister, pouring it over a lit candle, and pushing a coin into dry ice are only a few of many things you can do to create interest and discourse.

Along with these labs, states of matter can be analyzed using virtual interactive simulations found on the PhET website provided by the University of Colorado. Registering as a teacher is easy and free.

Some demonstrations can be performed related to heat transfer. A flask of freezing blue water can be placed in the tank. Even if on its side, that water would not spread far. A similar tiny flask containing boiling red water could be placed in a tank or room-temperature water. It should be noted that the hot water rises to the surface where the water is the coolest because heat travels from hot to cold objects. Pepper could be placed in a beaker and then heated. Convection would circulated the flakes. An empty Bigelow tea bag could be placed vertically on one palm and then lit. As the flame lowers it will be lifted by a convection current before the hand is burned. A plastic and metal spoon could be placed in boiling water. If the handles are touched, the metal one will be hot due to conduction.

**Density Lab**

This lab gives student experience solving problems. Previous to this lab, students have been taught that density equals mass divided by volume. They find the density of a liquid by determining its volume and mass. They also find the density of a solid object, such as a block of wood. After that, students are challenged to identify the composition of a cube by first finding its density. A set of density cubes, including brass, acrylic, and steel, that can be purchased through a school science materials vender are needed. After measuring a cube's volume and mass to determine its density, that value is compared to density values on a chart that lists a variety of materials. The same can be done with irregularly-shaped samples and the chart if they are denser than water and the displacement method can be used to determine their volume. If they are less dense than water, the students could devise a way to submerge them.

Another lab related to density has to do with forming a column of liquids with different densities. Vegetable oil, water, dish soap, corn syrup, and honey can form a gradient of colorful liquids laying atop each other. Solids, like a cherry or an ice cube, can also be added to the column. After the data is gathered, students are asked why the density of all other substances are compared to the density of water. Lastly, students are asked to explain why oil and water do not mix. They separate primarily because oil and water are immiscible and secondarily because oil is less dense than water. If you shake an oil and water mixture, you first get a dispersion of very tiny oil droplets in the water (or the other way around, depending on which one has a greater quantity), and then the density difference will cause the water to settle at the bottom.

A further lab related to density could be based on a problem that is posed. Students could be asked to determine the thickness of aluminum foil. A chart of density values for common elements would be provided. After being given the density chart and asked to solve the problem, they would need to figure out how to solve it on their own. The students could cut their sample of foil in exact metric length and width dimensions as well as mass the cut sample of foil. After that, they would simply need to solve for thickness using the formula for density. They might also fold or stack multiple layers of foil, measure the thickness, and divide by the number of layers. A comparison of which approach to the problem was most successful would lead to interesting discourse.

Along with this lab student should be given an opportunity to solve problems related to density. Recreating a triangle of mass at the top with density and volume at the base provides students with a mechanism for retrieving three formulas that solve for any of the components.

**Phase Changes of Water Lab**

This culminating lab provides an opportunity for students to demonstrate their understanding of solids, liquids, gases, and phase changes. Students take measurements of the temperature inside a beaker of ice each minute as it is heated on a hot plate. After collecting their data, students create a heating curve by plotting time versus temperature on a graph. They are then asked which phase changes they observed. During the experiment, students were asked to note when melting started and stopped. So, they are asked where the constantly added heat goes during melting since the graph is flat during that period of time. They should respond that the heat is used to overcome intermolecular forces and enable the phase change to occur. Students are asked where the added heat goes after melting stops and before boiling begins. Likely, they will respond that the liquid is being heated and its temperature is rising. The graph is proof that the temperature of the liquid water is rising because the heating curve is angled upward at that time. Students are also asked whether water and water vapor can exist at the same time and if so at what temperature. They need to explain what is happening during this period of time.

# Resources

## Student Resources

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"Matter Is the Stuff Around You." Chem4Kids.com: Matter. Accessed June 28, 2016. http://www.chem4kids.com/files/matter_intro.html.

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## Next Generation Science Standards for Grades 9 - 12

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**HS-PS1-3 Matter and its Interactions**

Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.

**HS-PS1-4 Matter and its Interactions**

Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy.

**HS-PS1-7 Matter and its Interactions**

Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction.

**HS-PS3-2 Energy**

Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects).