Properties of Matter
Content Background Document

1. Introduction

From the moment we're born, each of us is on a quest to figure out our world. It's essential to our survival that we understand the way the world works. Even babies develop surprisingly sophisticated understandings based on such experiences as holding objects and putting them in their mouths, watching a ball drop, observing plants and animals, playing peekaboo, and interacting with hot and cold things. In trying to understand and influence the world around them, children develop ideas about how the world works and their role in it. Consequently, they begin school with their own set of ideas about the physical world. By paying attention to our students, taking their ideas seriously, and seeking to understand their thinking, we as teachers can build on what they already know. We can use these initial ideas as a foundation for developing remarkable understandings, even in the earliest grades.

In this document, we'll focus on two fundamental questions in physical science: *What is everything made of?* and *How do things in the world change?* By answering these core questions, we can develop concepts that explain and predict a wide variety of phenomena in the world around us, such as evaporating water puddles, rusting metal, and growing bodies. Making predictions and constructing explanations require a basic understanding of matter and energy, so being able to grasp the interactions between them is central to our students' science education.

STOP AND THINK

How would you answer these questions:
What is everything made of? How do things in the world change?

Did your answer to the Stop and Think questions include your ideas about how matter and energy interact? Did the states of matter—solid, liquid, and gas—come to mind? Did you think about how heating and cooling a substance can cause physical changes? Did you think of chemical changes to matter, such as burning, rusting, baking, growing, and rotting? Did atoms and molecules come to mind?

Matter is the stuff that makes up the entire universe. Scientists use the word *matter* to describe anything that takes up space and has mass. In the observable world, matter can be described as anything that is a solid, a liquid, a gas, or plasma. Plasma is a state of higher energy found in lightning or the sparks that arc from one wire to another. In science, matter includes everything that is made up of atoms and molecules.

A Framework for K–12 Science Education (NRC, 2012, p. 108) states that by the end of 2nd grade, students should understand the following:

- Different kinds of matter exist (e.g., wood, metal, water), and many of them can be either solid or liquid, depending on temperature.
- Matter can be described and classified by its observable properties (e.g., visual, aural, textural), by its uses, and by whether it occurs naturally or is manufactured.
- Different properties are suited to different purposes. A great variety of objects can be built up from a small set of pieces (e.g., blocks, construction sets).
- Objects or samples of a substance can be weighed, and their size can be described and measured.

The framework goes on to describe what students should know about changes to matter by the end of 2nd grade (p. 110):

- Heating or cooling a substance may cause changes that can be observed.
- Sometimes these changes are reversible (e.g., melting and freezing), and sometimes they are not (e.g., baking a cake, burning fuel).

To help you develop deeper understandings of these topics, this document is organized around some fundamental science questions:

- What is matter?
- What are the properties of matter?
- What is matter made of?
- How do energy and matter interact?
- How do substances change into a completely different substance?
- Can matter be created or destroyed?

The content that follows will challenge you to broaden and deepen your understandings of matter and its properties. This document has been written to support and further your own content learning about how scientists define, measure, and explain phenomena in the world related to matter and energy. The goal is for you to develop deeper conceptual understandings of these ideas so you'll be able to more effectively teach elementary students about matter and its properties. The concepts we discuss will help you answer our core questions, *What is everything made of? How do things in the world change?*

This content was written with you, the teacher, in mind. The subject matter is tied to the science lessons you'll be teaching, but the concepts are presented at a level higher to equip you with the tools and background you'll need to guide student learning. After all, teachers should know more about the science content than their students!

2. What Is Matter?

If you look up the word *matter* in a dictionary, you'll find several definitions. For example, matter can mean "the focus of concern," such as a personal matter, a family matter, or a foreignpolicy matter. It can also mean "related to" or "concerning," as in "It doesn't matter to me!" or "As a matter of fact …." It can even refer to something wrong, as in "What's the matter with you?" These are common, everyday uses of the term, but they aren't scientific definitions.
Scientists define *matter* in a very specific way:

Matter is anything that takes up space and has mass.

Most of us can picture something that takes up space—a desk, a glass of water, a person—but mass is more difficult to visualize. Although we might not know the precise meaning of the word, most of us know that mass is related to weight. When we think of matter, we may picture an object that's heavy or light, or something we can touch, taste, see, or hold in our hands. But matter also includes things we can't touch, taste, or see, such as the air.

STOP AND THINK

What different examples of matter can you think of?
Can you think of something that is *not* matter?

To better understand what matter is, let's consider the definition more carefully. What does it mean when something takes up space and has mass?

2.1 Things That Take Up Space

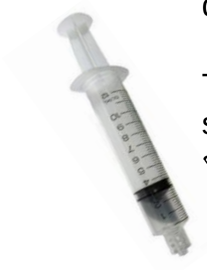
If you take up space, something else can't occupy the space you're in. Taking up space means you have volume. *Volume* is a measure of how much space you're taking up. For example, you can figure out the volume of a solid, rectangular object by measuring its height, width, and depth and multiplying those dimensions to come up with a certain number of cubic inches or cubic meters.

For a solid with a more irregular shape, you might determine the volume by dunking the object in water and measuring how much liquid was displaced (i.e., how much higher the water rose in the container). In this case, you would measure volume in units like liters.

The volume of a solid remains fairly constant even if the shape changes. If you have a lump of playdough, it will take up the same amount of space no matter what shape it's molded into. If you form it into a ball and dunk it under water, it will make the water rise a certain amount. If you shape the playdough into a long noodle and dunk it under water again, it will make the water rise exactly the same amount. If you create a playdough dinosaur and dunk it under water, once again it will take up the same amount of space because the playdough has a constant volume.

Similarly, you can measure the volume of a liquid, or the space it takes up, by placing it in a graduated cylinder, a measuring cup, a liter bottle, or a gallon jug. The volume of a liquid also stays fairly constant even though liquids change shape easily, conforming to whatever container they're in.

Measuring the volume of a gas is a little trickier. Gases expand to fill, or take the shape of, the container they're in, but they don't have a specific volume. Their volume changes depending on temperature and pressure.



Take an empty syringe (without a needle) and use the plunger to fill the syringe halfway with water. Then place your thumb over the tip of the syringe and press down on the plunger. Are you able to change the volume of the liquid? By pushing or pulling on the plunger, will the liquid take up less space, or more space?

Now fill the syringe halfway with air. Again, cover the tip of the syringe with your thumb and press down on the plunger. Are you able to change the volume of the air by pressing the gas into a smaller space? Pull up on the plunger. Will the gas fill a larger space than it did initially? Will its volume increase? What happens when you stop pressing or pulling on the plunger. Does the air return to its original volume?

This example may help to clarify the difference between the volumes of a liquid and a gas. A liquid has a constant volume, but the volume of a gas can change based on pressure. You may have experienced a similar phenomenon when traveling at different elevations. If you start at sea level with a sealed bag of potato chips and drive to the top of a mountain, the bag will puff out. With less air pressure pushing on the outside of the bag, the gas inside the bag will expand to take up more space, which increases volume.

2.2 Things That Have Mass

Mass is a measure of how much "stuff" there is. *Stuff* is a nonscientific word for matter. It's nearly impossible to measure how much matter there is of something without comparing it to something else. In the early days of scientific exploration, scientists developed an arbitrary system of determining the mass of objects by comparing them with a known quantity. A certain volume of a pure substance, such as gold or water, always has a specific mass. For example, 1 milliliter of pure water is 1 gram. This is how we determine what a single gram is as a metric unit of mass. It's constant. You can determine the mass of something else by comparing it to the mass of a certain volume of water. Mass is measured in grams.

Mass and weight are frequently confused. Mass tells you how much matter there is, and weight tells you how much gravity is pulling on that matter. You might have heard that objects weigh less on the Moon. If you went to the Moon, you would weigh a fraction of what you weigh on Earth. That's because the Moon has significantly less gravity than

Earth. You would still have the same mass or amount of “stuff” that comprises your body, but with less gravity pulling on your body, you would weigh less. Let’s say you weigh 50 kilograms (about 110 pounds) on Earth. If you were to take a spring scale to the Moon and weigh yourself, you would weigh only about 18 pounds. But if you took 50 kilograms of water to the Moon and placed it on one side of a balance and yourself on the other side, gravity would pull equally on both you and the water. The amount of “stuff” you’re made of would equal the amount of “stuff” that comprises 50 kilograms of water. Your mass would be the same whether you’re on Earth or the Moon! It all depends on how much matter is there.

In later grades, students will learn to distinguish mass (the amount of “stuff” there is) and weight (the pull of gravity on a substance), but since 2nd graders often have a difficult time differentiating these concepts, we’ve used the word *weight* in the lessons even though *mass* is scientifically accurate. Including learning goals related to mass would only distract students from the core science idea that all matter—solid, liquid, or gas—is made up of small particles that can be combined in new ways to make a variety of things.

3. What Are the Properties of Matter?

The word *properties* means “characteristics.” We can describe the *physical properties* of matter by listing the characteristics of a particular material. The properties of any substance can be observed without changing the substance itself. We can also identify unknown substances by their properties because they’re always the same. For example, if we were to describe the properties of a copper penny, we might say that it’s copper colored, round, shiny, and rigid (but can be reshaped with a hammer). We might also say it conducts electricity if connected to a battery, it melts at high temperatures, and it doesn’t dissolve in water. These are some of the *properties* of copper metal. But the properties of sugar are very different. Sugar is a solid, white crystal that has a sweet taste. It also dissolves in water, but neither plain sugar nor sugar dissolved in water conducts electricity.

Another physical property of matter is density. *Density* is a measure of mass per unit volume. Has anyone ever asked you, “Which weighs more: a pound of lead or a pound of feathers?” Though many people might say that a pound of lead is heavier, the lead and the feathers both weigh a pound. However, a pound of lead takes up a very small space, and a pound of feathers takes up much more space. If you take a gram of lead and divide it by the space it takes up (its volume in cubic centimeters), you would get a number representing its density: 11.34 grams per cubic centimeter (g/cm^3). On the other hand, if you were to take a gram of chicken feathers and make the same calculation, you would find that the feathers have a much smaller density: 0.8 g/cm^3. Therefore, a gram of lead has a greater density than a gram of chicken feathers, even though the feathers take up more space (have a greater volume).

Density is a very useful property to understand. Water has a density of 1 g/cm^3. As mentioned earlier, 1 milliliter (the same volume as 1 cm^3) of pure water is exactly 1 gram. Divide the mass of a substance by its volume, and you get its density. So the density of pure water is 1 gram ÷ 1 cm^3 = 1 g/cm^3. Anything with a density greater than 1 g/cm^3 (like lead) will sink in water. Anything with a density less than 1 g/cm^3 (like feathers) will float in water.

STOP AND THINK

Liquids, like water, have a specific density. Different liquids have different densities. Would you predict that the density of olive oil is more or less than 1? Does olive oil float on water or sink?

Gases have density too. But the density varies because the volume of a gas can change based on temperature and pressure. Particles of gas that are packed closely together have a greater density than particles of gas that are spread out in the air. Can you use density to explain why hot air rises? What do you predict might happen to the density of air if it's heated?

In addition to describing the physical properties of matter, we can also describe *chemical properties.* Substances can change into entirely new substances with different properties. For example, when a piece of paper burns, it turns into ash and carbon dioxide because the paper is flammable. Flammability is a chemical property of matter because it describes one way paper can change into other substances. Iron isn't flammable, so it wouldn't catch fire and burn. But it can rust (corrode), which is another way a substance can change chemically.

When iron reacts with oxygen, the chemical properties are very different from the chemical properties of the carbon in paper when it reacts with oxygen. Paper burns in the presence of oxygen because it's composed of carbon, but iron is a metal, so it corrodes or rusts in the presence of oxygen.

We can observe and measure the *physical* properties of matter without changing a substance into a new substance. For example, dissolving sugar in a cup of water doesn't change the sugar into a new substance. However, the *chemical* properties of matter can be observed only when molecules recombine and change into a new substance or substances with different properties, such as when paper burns or metal rusts.

4. What Is Matter Made Of?

As we discussed earlier, all matter is made up of small particles. The word *particles* doesn't sound very scientific, but if we think of matter as small bits or particles that react in predictable ways in certain situations, we can explain most of the ways matter behaves.

Scientifically, the particles that make up matter are called either *atoms* or *molecules*. Did you know there are only 118 different atoms in the world? Each of these atoms, or elements, is represented on the Periodic Table of Elements. (See the carbon example in figure 1.)

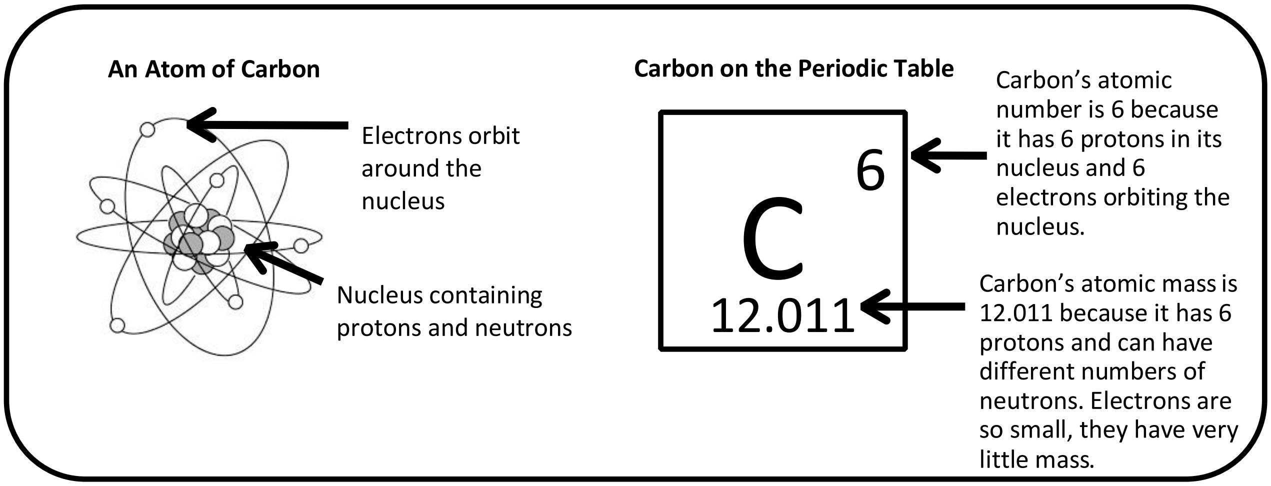


Figure 1. A model of a carbon atom, and the configuration and properties of carbon from the Periodic Table of Elements

Each element, such as carbon, hydrogen, or oxygen, has a unique *atomic number*, which represents how many protons (positively charged particles) and electrons (negatively charged particles) are in the atom. Each atom also has a unique *atomic mass*, which represents the average mass of the protons and neutrons in the nucleus of the atom.

Remember, mass determines how much "stuff" there is, and measuring mass is arbitrary. This system also applies to measuring atomic mass. Scientists created an *atomic mass unit* (amu) to measure the very small mass of a single proton in an atom. Each proton and neutron has a mass of 1 amu. The mass shown on the periodic table is the *average mass* of an atom of a particular element. It can vary in mass because each atom of an element can have a slightly different number of neutrons.

Of the 118 different kinds of atoms in the world, only about 90 of them occur naturally. It's kind of cool that most of the universe is made from only 90 types of atoms in varying combinations.

Matter can be made of individual atoms; one example is a pure substance like gold. Matter can also be made of molecules. *Molecules* are combinations of atoms bound together to form a stable substance. Even some pure substances are made of molecules. For example, oxygen doesn't exist in the atmosphere as individual atoms but as two oxygen atoms bound together as a molecule.

That's why oxygen is sometimes represented atomically as O_2.

Some molecules, like oxygen, are structurally simple. Other molecules are much more complex. Proteins or plastic, for example, have hundreds of atoms bound together as a single molecule. Each molecule (atoms bound together in a particular configuration) makes a different substance with unique properties. In fact, the particular type and configuration of atoms in a molecule are what gives each substance its unique physical and chemical properties.

STOP AND THINK

How comfortable are you with the terms *atom*, *molecule*, or *element*?
Could you define each?

As teachers, we rarely talk about atoms and molecules with 2nd graders. We're more likely to describe matter as the pieces or particles a substance is made of. But since the focus of this module is on the different ways matter can change, we introduce the terms *atoms* and *molecules* in lesson 3 so that students can differentiate what is happening when substances melt or freeze (different states of matter but the same substance; also known as *physical changes*) and when they bake, burn, rust, or fizz (atoms in molecules rearranging to form new substances; also known as *chemical changes*). To help students connect these words to the unseen particles moving and rearranging in different ways as matter changes, a Lego-brick model is used in which single Lego bricks represent atoms, different-colored Lego bricks represent different kinds of atoms, and combinations of Lego bricks represent molecules (see figure 2).

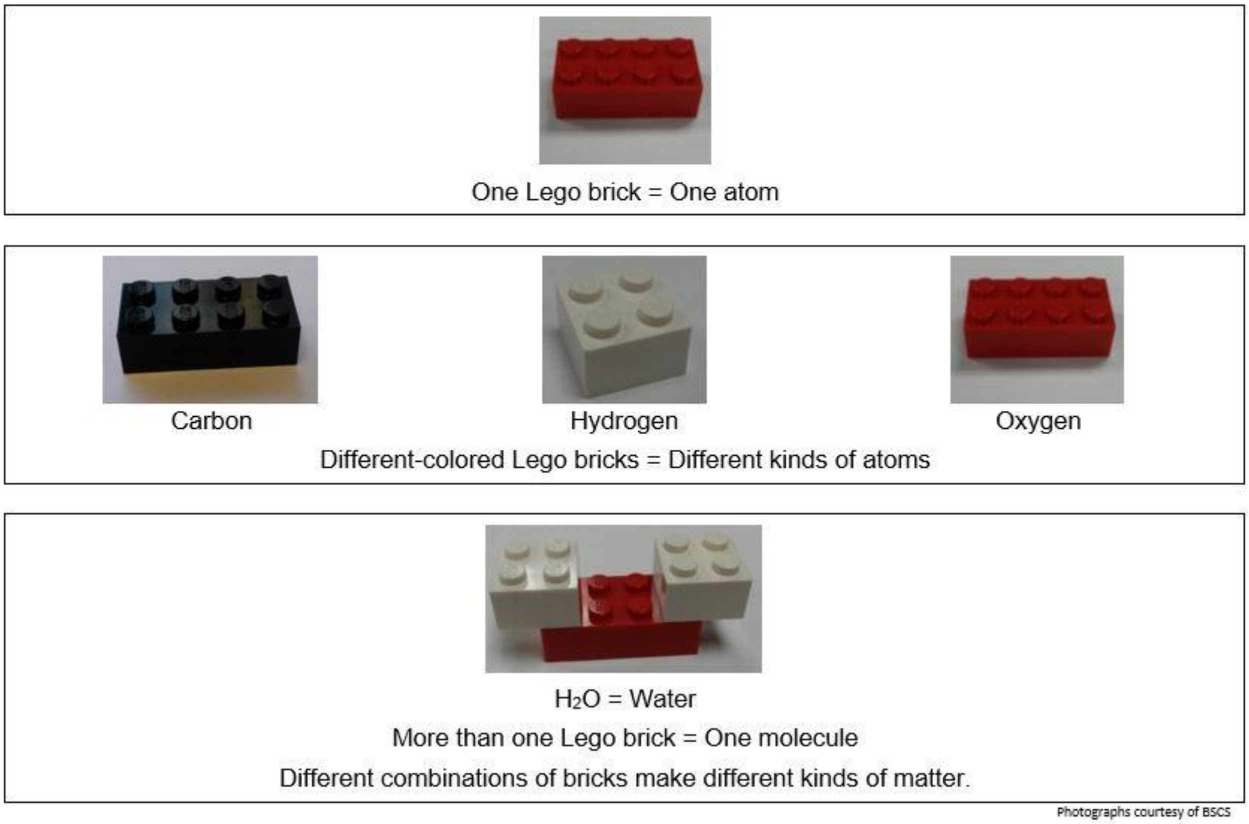


Figure 2. The Lego-brick model of atoms and molecules

One of the molecules we'll focus on in this lesson series is water in liquid and solid (ice) forms. (Water in its gaseous form (water vapor) will be introduced in later grades.) A molecule of water is made up of two hydrogen atoms and one oxygen atom, or H_2O. (The atomic symbol H on the period table with a subscript 2 is used to represent two hydrogen atoms, and O represents oxygen.)

A water molecule can be made using two white Lego bricks representing hydrogen and one red Lego brick representing oxygen. Throughout this unit, students will learn about other materials in their solid and liquid forms, including butter, chocolate, rock, and copper, but the Lego-brick model will only be used to represent water.

In later lessons on matter, students will use preassembled Lego bricks to represent the more complicated molecules in baking soda and vinegar and rearrange them to show how chemical reactions create new substances. In real life, when baking soda and vinegar molecules join together, a chemical reaction recombines them, creating a fizzing, foamy new substance composed of carbon dioxide, water, and sodium acetate.

5. Molecules in Motion

All molecules move, whether they're in the solid, liquid, or gaseous state. The slower molecules move, the easier it is for them to attract one another and arrange themselves in rigid, highly organized patterns. The faster molecules move, the harder it is for them to attract one another and arrange themselves in an ordered pattern. Instead, they repel each other and spread out.

Figure 3 shows how water molecules are organized in solid, liquid, and gaseous states. What do you notice about the molecules in each state of matter? How are they arranged? How do they move as a solid, liquid, or gas?

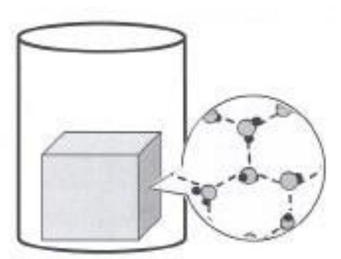
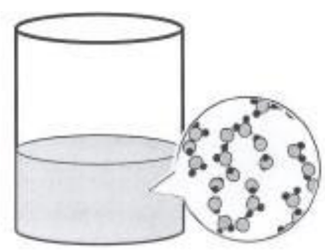
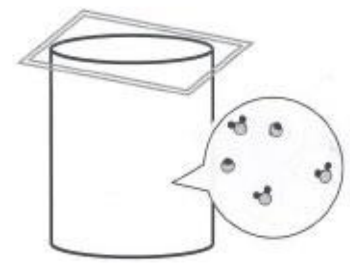
SOLID (*Ice*)	**LIQUID (*Water*)**	**GAS (*Water Vapor*)**
 As a solid, water molecules are arranged close together in a rigid, lattice-like structure and vibrate in place.	 As a liquid, water molecules are still relatively close together but aren't in a rigid structure. They attract one another, but they can also slide past each other as they move around.	 As a gas or water vapor, water molecules spread out in the air as individual molecules and are free to move in any direction.

Figure 3. The motion and arrangement of water molecules in solid, liquid, and gaseous states

As a solid, water molecules are arranged close together in a rigid, lattice-like structure with some space between molecules. In this state, the molecules vibrate in fixed positions. It's important to note that the space between the molecules allows water to *expand* when it freezes, which makes it an unusual substance. Have you ever frozen a bottle of water or a can of soda? As water freezes, the increase in volume causes the plastic bottle or aluminum can to expand and even break! Other liquids shrink when they freeze because molecules line up more closely in the solid phase than they do when they're moving around in the liquid phase.

Now look at how water molecules are arranged in the liquid state. Notice that they're closer together and can attract one another, but they aren't in a rigid structure like ice. Like a liquid swishing around in a cup, water molecules in the liquid state can actually slide past one another and change their positions in a fluid manner.

Finally, look at how gas molecules are arranged in figure 3. Water molecules as a gas are called *water vapor*. Rather than being attracted to one another, they exist as individual water molecules that move all over the place. Imagine water vapor in a sealed container. The water molecules aren't at the bottom of the container. Instead, they disperse evenly throughout the container.

STOP AND THINK

When ice (solid water) changes to liquid water,
what happens to the water molecules?

STOP AND THINK

Temperature is a measure of the average movement or speed of particles (molecules) in a substance. Can you explain why cooler molecules exist in a solid form? Why might adding heat cause a change of state to a liquid or a gas?

6. How Do Energy and Matter Interact?

At the beginning of this document, you were challenged to think of something that is *not* matter. What did you think of? Did light, heat, or sound come to mind? All of these are ways we experience energy. Energy is different from matter because it doesn't have mass or take up space. But this term is difficult to define. If you look up the word *energy* in a dictionary, you'll find many different definitions. Energy can refer to vitality, vigor, or pep. That's the meaning you may have in mind when you buy an energy drink at the grocery store. The energy in the drink can keep you wide awake or make you jittery even if the drink contains no dietary Calories. (Calories are one way scientists measure energy.)

Some days as a teacher, you may find yourself thinking, *My students have way too much energy today!* Or you may think, *I just don't have enough energy to keep up with these children today!* But these aren't scientific references to energy. Just like the word *matter*, scientists have a very specific way of defining this term:

Energy is the ability to do work.

To most of us, that definition isn't very helpful. It doesn't exactly match our experience of the energy we sense when we turn on the radio or see the flash of a lightning bolt. One of the things that makes energy so hard to understand is that it isn't a thing; it's a characteristic of an object or a system. We can't hold energy, but we can detect its presence by the way it causes something to happen (or has the potential to cause something to happen). Energy is observable in several different forms, including sound, light, heat, and motion. Each of these forms is simply revealed in different ways.

Energy is the key to understanding why things change. Things change when matter absorbs or releases energy. In this reading, we'll focus on two forms of energy—heat and motion. In science lingo, heat and motion are referred to as *thermal energy* and *kinetic energy*. Keep in mind that energy is energy is energy! Light can cause something to warm up, or sound can make something (like your eardrum) move. But both are energy. Energy simply reveals itself in the world in different ways or forms.

First, let's consider how matter can gain or lose energy even though the combinations of atoms remain the same. For example, gaining or losing energy can cause matter to change state from a liquid to a solid or a solid to a liquid. These processes are called *freezing* and *melting*. Melting and freezing occur when a substance gains or loses thermal energy. Gaining thermal energy is more commonly referred to as *warming*, and losing thermal energy is often called *cooling*.

Why do scientists talk about something "gaining thermal energy" instead of simply saying that something is "heating up"? For scientists, *heating* (used as a verb) refers to a process in which thermal energy (heat energy) is transferred from an object with a higher temperature to an object with a lower temperature. When a substance gains thermal energy, the molecules move faster, and as long as the substance isn't changing state, its temperature rises. If a substance gains enough heat (such as heating a solid to its melting point), the thermal energy causes the molecules speed up, break away from their rigid structure, and move around more freely.

What we want students to understand is that the higher the temperature of a substance is, the faster the molecules in that substance will move. If we heat an ice cube, the solid water will melt and change state to liquid water because the molecules are moving fast enough to break away from their rigid structure. If we take away thermal energy (cooling), the molecules will slow down, return to their rigid shape, and simply vibrate in place.

Most substances have a unique temperature at which they change from a solid to a liquid. This temperature is called a *melting point*. The melting points of substances vary widely. For example, the melting point of water is 0 degrees Celsius (C), or 32 degrees Fahrenheit (F). The melting point of most metals is relatively high, but the metal gallium melts at 30 °C (about 86 °F). This means that gallium is a solid at room temperature, but if you were to make jewelry out of it and wear it next to your skin at 37 °C (about 98 °F), it would melt! Common table salt has a melting point of 801 °C (about 1490 °F).

Freezing is the reverse process of melting, so the *freezing point* of a substance is the same as its melting point.

Melting and freezing are called *physical changes*, as are evaporation and condensation. We learned earlier that *physical properties* are characteristics of a substance that can be observed without changing the substance itself. Similarly, physical changes occur without changing the molecular structure of a substance. A molecule of solid water

(H_2O) is exactly the same as a molecule of liquid water (H_2O); the molecules are just rearranged and move differently.

7. How Do Substances Change into a Completely Different Substance?

When substances change into a completely different substance (or substances), this is called a *chemical change*. Chemical changes occur when the atoms of one or more molecules recombine in new ways to produce one or more different substances. Another way to say this is that a *chemical reaction* has occurred.

As we discussed earlier, in the lessons on matter, students will experience the chemical reaction that happens when baking soda and vinegar are combined. Baking soda is a stable molecule, and so is vinegar. But when the molecules are joined together, the atoms recombine in a chemical reaction to create a fizzing, foamy new substance composed of carbon dioxide, water, and sodium acetate.

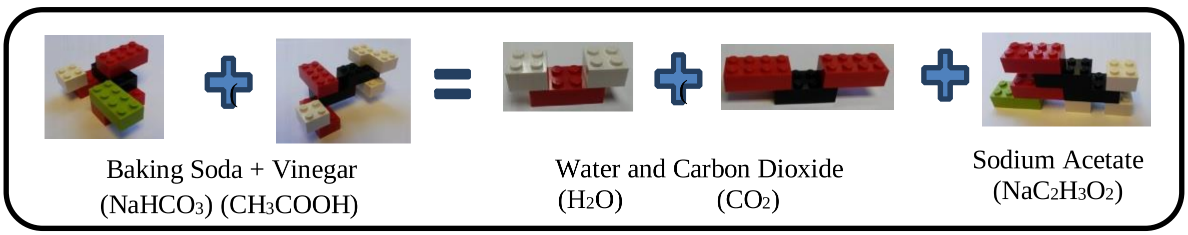


Figure 4. Lego-brick model of the chemical reaction between baking soda and vinegar

Every day we encounter many kinds of chemical reactions. For example, when you bake cookies, the heat energy of the oven causes the molecules in the dough to gain kinetic energy, resulting in collisions that cause the atoms to rearrange and recombine to form an entirely new substance or substances. The same thing happens when you fry an egg. The runny, raw egg is transformed into a solid, fried egg as its molecules recombine to form new substances. When you burn a log in the fireplace or when gas combusts in your car engine, the solid and liquid molecules that make up the initial fuel recombine to form gas molecules, and in the process, energy is released that results in work. When you pour bleach into your washing machine, it reacts with the stains and colored dyes in your laundry, causing the original colors to lighten.

8. Can Matter Be Created or Destroyed?

The ancient Greek philosophers believed that nothing comes from nothing. Another way of saying this is that what exists now has always existed. No new matter can come into existence where there was none before. In the 1700s, a French chemist, Antoine Lavoisier, carefully measured and compared the mass of the substances involved in chemical reactions—much like your students will compare the mass of baking soda and vinegar before and after they chemically react. Lavoisier determined that the total mass of these substances never changed. As a result of Lavoisier's work, the law of conservation of mass was discovered. This law states that in ordinary chemical and physical changes, matter is neither created nor destroyed; it is conserved. The number of atoms doesn't change, and their mass doesn't change. Atoms are simply rearranged.

That's why you learned in chemistry class how to balance chemical equations so that the number of atoms on one side of the arrow equals the number of atoms on the other side. Do you recall the chemical reaction that occurs in photosynthesis? In photosynthesis, plants use carbon dioxide and water to produce glucose and oxygen:

Carbon Dioxide + Water → Glucose +

Oxygen The equation would look like this:

$$CO_2 + H_2O \longrightarrow C_6H_{12}O_6 + O_2$$

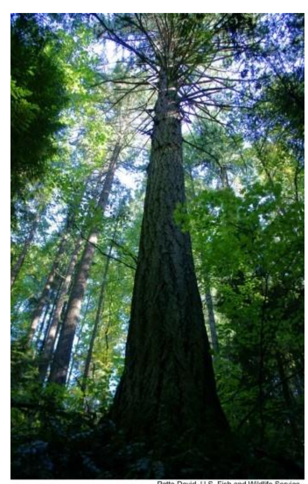
If you add the molecules on each side of the arrow, you'll find they aren't equal. There is only one carbon atom on the left side, but there are six carbon atoms on the right side of the equation.

The law of conservation of mass says that can't happen. So chemists balance the equation to show the same number of atoms of each type on both sides of the equation. No matter is created; no matter is destroyed.

6 CO2 + 6 H2O → C6H12O6 + 6 O2

6 Carbon-Dioxide Molecules + 6 Water Molecules → 1 Glucose Molecule + 6 Oxygen Molecules

This important concept helps us understand many different phenomena in the real world.


Patte David, U.S. Fish and Wildlife Service

Look carefully at the photosynthesis equation above. If a tree grows because of photosynthesis, then based on this equation, we know that most of the matter that forms the tree comes from thin air—carbon dioxide and water. Atoms in the molecules of carbon dioxide recombine with atoms in the water molecules using energy from the Sun, which is absorbed by the leaves. The eventual product (cellulose) that makes the wood of a tree is composed of long strings of glucose. This might lead us to conclude that the mass of the tree— the matter that the tree is made of—came from the dirt it's growing in. But if that were the case, wouldn't there have to be a hole in the ground as big as the tree itself? *Nothing comes from nothing*. The matter that made up the tree must have come from somewhere else, and this equation tells us that much of it comes from the air and water.

Consider another example. If you burn a candle, the candle wax seems to disappear. But it doesn't really disappear. The burning process chemically changes the wax by recombining the molecules into carbon-dioxide gas (CO_2) and water (H_2O), plus a small amount of ash you might see as smoke rising into the air.

Photograph by Patte David / Wikimedia Commons

Likewise, when water evaporates, it might seem to disappear. But the molecules are still there; they're just moving around in the air as water vapor, individual molecules we can no longer see that still have mass.

Your students will experience conservation of matter in one of the lessons when they place solid material and melted material on either side of a balance and observe that their mass hasn't changed. (Remember that mass is called *weight* in the lessons.) Students will also place the uncombined baking soda and vinegar (before the chemical reaction) on one side of the balance and the combined substances (after the chemical reaction) on the other side and observe that their mass hasn't changed.

Understanding conservation of matter is an important step in understanding our world. Childdevelopment researchers have found that up until about the age of 7, children have a hard time recognizing that physical properties of substances don't change, even when they look different. These lessons will help students experience conservation of matter in ways that will support scientific reasoning throughout their lives.

9. Back to the Beginning

In the introduction of this document, we considered two fundamental questions in physical science: *What is everything made of?* and *How do things in the world change?*

How has your understanding of matter changed based on this discussion? Have you developed new ideas and connections that can help you make sense of everyday phenomena in the world? Do you have a better understanding of what happens when you see a puddle of water evaporating, metal rusting, or your students' bodies growing? Can you categorize these everyday occurrences into physical and chemical changes? Can you picture the atoms and molecules that make up the solid, liquid, and gaseous substances in your world moving and recombining, such as when baking soda and vinegar combine to form carbon dioxide, water, and sodium acetate? Can you apply ideas about matter and energy to the substances and processes you see in your everyday life?

What new questions do you have about matter in the world around you? Keep track of these questions and discuss them with your colleagues and PD leaders to broaden, deepen, and enrich your knowledge of matter throughout this year in the RESPeCT program.

10. Summarizing the Big Ideas

As we wrap up this discussion of matter and its properties, let's summarize the big ideas we explored:

1. All matter is made up of small particles called *atoms* or *molecules*.
2. There are 118 different atoms in the world, each represented on the Periodic Table of Elements.
3. Molecules are stable combinations of two or more atoms.
4. Matter exists as a solid, a liquid, a gas, or plasma.
5. Particles (molecules) in a solid are in a rigid, lattice-like arrangement and vibrate in place.
6. Particles (molecules) in a liquid are attracted to one another but are able to move around more freely in relation to one another.
7. Particles (molecules) in a gas move in all directions as individual molecules.
8. Adding heat energy increases the motion of particles (molecules). Conversely, removing heat energy decreases the motion of particles.
9. *Temperature* is a measure of the average movement or speed of particles (molecules) in a substance.
10. Substances have a unique or characteristic temperature at which they melt or freeze, evaporate or condense.
11. Physical changes, such as melting, freezing, evaporation, and condensation, occur without changing the molecular structure of a substance. Only the arrangement and motion of the molecules change.
12. Chemical changes occur when the atoms of one or more molecules rearrange and recombine to create new substances with different properties than the original substances.
13. During physical or chemical changes, matter is neither created nor destroyed. Atoms and mass are conserved.

References

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3. Atomic Structure and the Periodic Table

3.1 Internal Structure of an Atom

Dalton's Atomic Theory: To account for the chemical reactivity **John Dalton** in his atomic theory postulated that:

1) Matter is composed of small indivisible particles.
2) An element is composed of identical tiny particles called atoms.
3) Compounds are formed when atoms of different elements combine.
4) Chemical Reactions involve rearrangement of atoms to form new compounds.

First and second this postulate is the most important concept in his theory to show clearly for the first time the existence of atoms. This was necessary to explain the fixed properties of an element. Third postulate was necessary to explain the existence of compounds and the breaking of compounds into elements. Fourth postulate was necessary to define and describe the chemical reaction or chemical changes.

Discovery of subatomic particles and nucleus Radioactivity and instability of elements

Henry Becquerel had already noted that uranium emanations of ionizing radiation and then **Pierre and Marie Curie** measured the ability of emanations from various. Curies tested an ore of uranium, pitchblende's ability to emanate ionization radiation found it 300 times stronger than that produced by pure uranium. The Curies reasoned that a very active unknown element (a new unstable later named polonium) must have been produced must exist within the pitchblende in addition to the uranium (U). They introduced the new term: "radioactive." **Radioactivity** to explain the instability of atomic nuclei of certain lighter and all heavier elements after lead (Pb). These unstable radioactive elements disintegrate into **stable nucleus** while giving out three types of ionizing radiation: 1) α-(He nuclei), 2) β(fast moving electrons), and 3) γ-(high energy electro magnetic radiation) radiation.

Discovery of radioactivity was a prelude to the discovery of the subatomic particles.

Discovery of Electrons:

Thomson's cathode ray tube experiments

Electrons: Electrons are sub-atomic particles with a mass of 9.11 x 10^{-28}g (1/1833 times mass of a proton) and a negative charge of 1.60 x 10^{-19} c (c=coulombs) or -1.60 x 10^{-19} c.

Electron was first discovered by J.J. Thompson using cathode-ray tubes or Crook's tubes.

Measuring Electronic Charge: Millikan's oil drop experiments

American physicist **Robert Andrews Millikan** (1868-1953) designed an experiment to measure the electronic charge. He found that electron has a negative charge of 1.60 x 10^{-19} c (c=coulombs) or -1.60 x 10^{-19} c.

Discover of Nuclear atom: Rutherford's a-particle experiment

A New Zealander, **Ernest Rutherford** passed Alpha(α-)particles through an extremely thin gold foil. He expected them to go straight through with perhaps a minor deflection. Most did go straight through, but to his surprise some particles bounced directly off the gold sheet! This means there something in the atom that deflected the alpha particles. Rutherford hypothesized that the positive alpha particles had hit a concentrated mass of positive particles, which he termed the **nucleus**.

Nucleus: The mass and the positive (+) charge of an atom are concentrated in the center. This center is called nucleus, and it has radius of about 10^{-13} cm.

Proton: Henry Moseley is credited for the work leading the atomic number and the proton. Proton is a sub-atomic and sub-nuclear particle. A proton has a mass of 1.67 x 1024 g (which is 1833 times heavier than electrons) and carries a positive charge of 1.60 x 10

19

c.

Neutron: **Henry Moseley** is credited for the discovery of neutron which is a sub-atomic and sub-nuclear particle with a mass of 1.675 x 10^{-24} g (which is 1833 times heavier than electrons) and carrying no charge.

An atom is the smallest particle of an element that determines the physical and chemical properties of that element. An atom has a **nucleus** a sphere with a very dense center containing the **protons** and **neutrons** around which negatively charged **electrons** move like the planets around the sun. The atom can be thought of as a sphere of empty space where electrons move and 90% of atom's mass located in the nucleus at the center. **protons**, **neutrons** and **electrons** called **subatomic particles**.

Subatomic particle	**Mass**		**Charge**
Electron (**e^-**)	9.109 x 10^{-28} g	0.0055 amu	**-**1.60 x 10^{-19} C
Proton (**p^+**)	1.672 x 10^{-24} g	1.0087 amu	**+**1.60 x 10^{-19} C
Neutron (**n^0**)	1.675 x 10^{-24} g	1.0073 amu	0

* amu atomic mass units

Nucleus has a radius of about 10^{-13} cm. An atom has a radius of about 10^{-8} cm or 1 Å (angstroms). If an atom were the size of a football stadium, with the electrons out around the upper deck, the nucleus down at midfield would be smaller than the coin flipped at the start of the game.

3.2 Atomic Number and Mass Number

Atomic number (Z): Number of protons in a nucleus of an atom is called atomic number (Z). Z is characteristic of an element. An atom of oxygen always has eight protons and atomic number equal to eight.

Mass Numbers (A): Number of neutrons and protons together in a nucleus of an atom is called mass number (A).

3.3 Isotopes and Atomic Masses

Atoms of an element having different number of neutrons in the nucleus are called isotopes. These atoms of the same element (same **Z**) have different atoms different **Mass Number (A)** values.

Isotopic symbol: Element symbol (**X**) found on the periodic table with number of protons or atomic number (**Z**) written as left subscript, and mass number (**A**), total of number of protons and neutrons written as left superscript.

$$^{A}_{Z}X \qquad \text{E.g } \textbf{carbon-12}: \quad ^{12}_{6}C$$

or simply written as ^{12}C because once atomic symbol is known atomic number could be found easily from the periodic table.

Carbon-12 with natural abundance of 99.90%

Carbon-13 with natural abundance of 1.10%

The average atomic weight of carbon is listed as 12.0107

$$^{1}_{1}H \qquad ^{2}_{1}H \qquad ^{3}_{1}H$$

hydrogen-1 **hydrogen-2** **hydrogen-3**

hydrogen-1 isotope has 1 proton and 1 electron **hydrogen-2** isotope (deuterium) has 1 proton, 1 neutron, 1 electron.

Hydrogen-3 isotope (tritium) has 1 proton, 2 neutrons, and 1 electron.

Average Atomic Mass (A.A.M)

Average atomic mass **(A.A.M)** for an element which is reported on the periodic table is calculated based on the masses of isotopes and their relative composition.

Most of the elements have two or more isotopes. Atomic weights based on the masses of isotopes and their relative composition. For example, Gallium in nature consists of two isotopes:

Isotope	Isotope Mass	Fractional Abundance	% Abundance
gallium-69 (^{69}Ga)	68.926 amu (M_a)	0.601 (a)	60.1 (%a)
gallium-71 (^{71}Ga)	70.925 amu (M_b)	0.399 (b)	39.9 (%b)

Using factional Abundances	**Using % Abundances**
A.A.M = M_a x a + M_b x b = 68.926x(0.601)+70.925 x(0.339) = 69.723	A.A.M = $\frac{M_a \times \%a + M_b \times \%b}{100}$

A.A.M. (Ga) = = 69.723 **amu** or **g/mol**	68.926x(60.1)+70.925 x(0.39.9) AAM = ------------------------------------ 100 A.A.M. (Ga) = = 69.723 **amu** or **g/mol**

Silicon exists as a mixture of three isotopes. Determine its average atomic mass based on the following data to correct significant figure.
Isotope Mass (amu or g/mol) Abundance

Isotope	**Isotope Mass**	**Fractional Abundance**	**% Abundance**
Silicon-28 (^{28}Si)	27.976 9265	0.9223	92.23 %
Silicon-29 (^{29}Si)	28.976 4947	0.467	4.67 %
Silicon-30 (^{30}Si)	29.973 7702	0.310	3.10 %

Using factional Abundances	**Using % Abundances**
A.A.M = M_a x a + M_b x b + M_c x c = ___x(___)+ ___x(___)+ ___x(___)=___ A.A.M. (Si) = = ___ **amu** or **g/mol**	M_a x %a+ M_bx%b + M_c x %c A.A.M = ______________________________ 100 ___x___+ ___x___+ ___x___ AAM = ------------------------------------ 100 A.A.M. (Ga) = ___ **amu** or **g/mol** Ans:__________

The atomic masses of ^{35}Cl (75.53%) and ^{37}Cl (24.47%) are 34.968 amu and 36.956 amu, respectively. Calculate the average atomic mass of chlorine. The percentages in parentheses denote the % relative abundances. Ans:__________

Chemistry at a Glance: Atomic Structure

3.4 The Periodic Law and the Periodic Table

In the early 1800's many elements had been discovered and found to have different properties. **Newlands** – "law of octaves", a pattern of reactivity follows after 8 elements.

However, no one had found a clear "order" in their properties until **Mendeleev**, Dmitri (1834-1907) arranged 63 then known elements in the order of **increasing atomic mass** in a periodic table and showed some **chemical properties** would reappear periodically. In certain cases, he placed a lighter slightly heavier element before a lighter element so that the chemical properties of the vertical columns would be preserved.

In Mendeleev's table, there was a gap. He purposely left blank position in his table so that the consistent vertical columns with the same chemical properties would be preserved. These missing elements were later discovered.

The periodic law is an organized "map" of the elements that relates their structure to their chemical and physical properties. The periodic table is the result of the periodic law, and provides the basis for prediction of such properties as relative atomic and ionic size, ionization energy, and electron affinity, as well as metallic or non-metallic character and reactivity.

The modern periodic table exists in several forms. The most important variation is in group numbering. The tables in the text use the two most commonly accepted numbering systems.

Periods and Groups

Periods are the **horizontal rows** of elements in the periodic table; the **columns** represent **groups** or **families**.

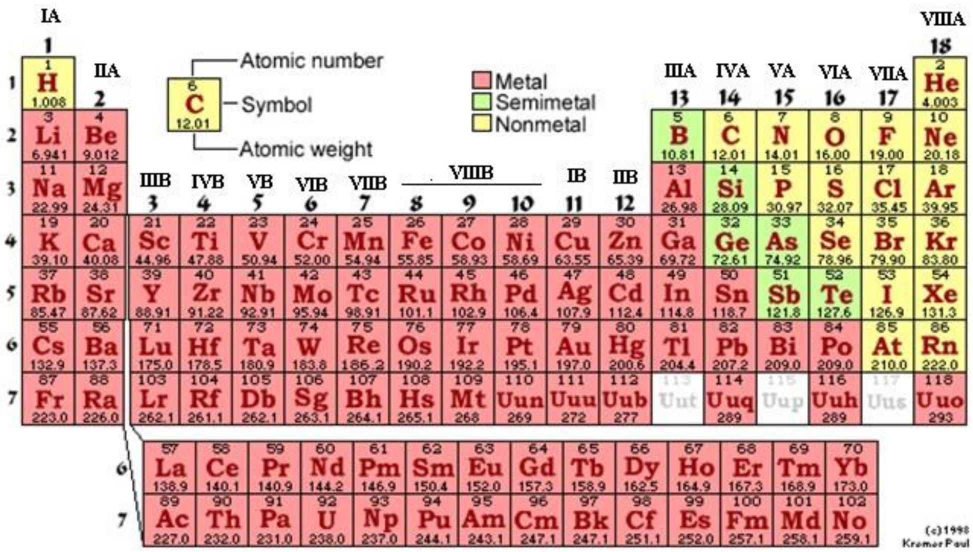
Elements in a **vertical group** have similar chemical properties. The vertical groups are currently named by numbers ranging from **1** to **18**. An older way to identify the vertical groups is to use a Roman number and the capital letters **A** or **B**. Vertical groups of main group elements (or representative elements) were given a Roman numeral plus the letter A. Vertical groups of transition elements were given a Roman numeral plus the letter B.

Representative elements are elements that always lose or gain the same number of electrons in chemical reactions.

Transition elements are elements that can lose or gain variable numbers of electrons in chemical reactions.

Lanthanide series and the **actinide series** are parts of periods **6** and **7**, respectively, and groups that have been named include the **alkali metals**, the **alkaline earth metals**, the **halogens**, and the **noble gases**. **Group A** elements are called representative elements; **Group B** elements are transition elements. **Metals**, **metalloids**, and **nonmetals** can be identified by their location on the periodic table.

These groups are number from **1 - 18**, left to right and groups have their Roman numbers and **A** or **B** classification.



3.5 Metals and Nonmetals

Most of the elements in the periodic table are **metals**. Note the stair step line in the periodic table. Elements to the left of the line are metals. Elements to the right of the line are **nonmetals**. In between metal and non-metals there are **semi-metals** or **metalloids**.

Metals lose electrons and nonmetals gain electrons.

Problem: Pick the a) representative elements, b) transition elements, c) inert gas elements, d) elements that from anions, e) semi- metals, and f) elements that from cations from the following list: Ca, Si, K, Ar, Cu, Fe Zn, Ge, Kr, Cl, O, F.

Answers:

a) Representative elements: Ca, Cl, O, F

b) Transition elements: Cu, Fe

c) Inert gas elements: Ar, Kr

d) Elements that from anions: O, F

e) Semi- metals: Si, Ge

f) Elements that from cations: Ca, K, Cu, Fe Zn

Problem: Use your periodic table to find the symbol, atomic number and atomic mass rounded to two decimal place of each of the following elements: a) Magnesium b) Neon c) Selenium d) Gold **Answer**:

Mg, atomic number = 12, mass = 24.31 amu

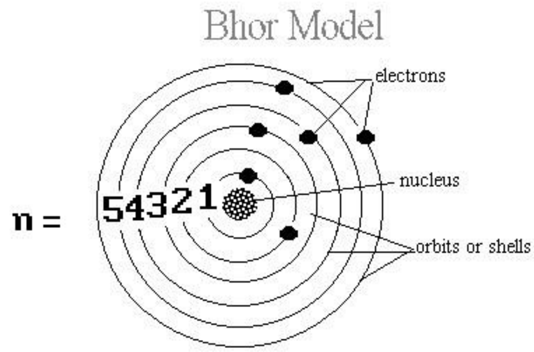
Ne, atomic number = 10, mass = 20.18 amu

Se, atomic number = 34, mass 78.96 amu

Au, atomic number 79, mass 197.0 amu

3.6 Electron Arrangements within Atoms
Basic postulates of Bohr's theory

Niels Bohr in 1913, developed a theory describing the possible arrangement of electrons around the uncles of the hydrogen atom to explain emission and absorption **electro magnetic radiation (EMR)**. It has four postulates:



1. An electron in hydrogen atom moves in a **circular orbit** or **shell** about the nucleus under the influence of the charged attraction between the electron and the nucleus
2. It is **only allowed** for the electron to move in a circular shell with increasing distance from the nucleus in the following order: **Shell 1**-K (**n=1**), **Shell 2**-L (**n=2**), **Shell 3**-M(**n=3**), **Shell 4**-N (**n=4**), **Shell 5**-O (**n=5**), **Shell 6**-P (**n=6**), **Shell 7**-Q (**n=7**). **n** is called **principle quantum number** of the electron.
3. The electron moving in an allowed shell has fixed energy and the energy of the shells increase in the following order: **Shell (n=1**)< **Shell** (**n=2**)< **Shell <**(**n=3**), **Shell <** (**n=4**), **Shell <** (**n=5**), **Shell <** (**n=6**), **Shell <** (**n=7**).
4. Electromagnetic radiation (EMR) is **emitted** when the electron, initially moving in a shell of higher energy moves to a lower energy shell or **absorbed** when moving from lower to higher.

What is electromagnetic (EM) radiation (EM)?

Electromagnetic radiation is a form of self-propagating waves which does not require a medium to travel. It has its own **electric and magnetic field component** which oscillate in phase perpendicular to each other and to the direction of energy propagation. Examples of EM radiation include radio waves, microwaves, infrared radiation (IR), **visible light**, ultraviolet radiation (UV), X-rays and gamma(γ) rays. Of these, radio waves have the longest wavelengths and Gamma rays have the shortest. Higher wavelength shorter the frequency and lower the energy. the A small window of frequencies, called visible spectrum or light, is sensed by the eye of various organisms.

Which of the following electromagnetic radiation have shortest wavelength?
Infrared radiation or radio waves.

Which of the following electromagnetic radiation have higher frequency? **ultraviolet radiation (UV)** or visible light.]

Which of the following electromagnetic radiation have higher energy?
Infrared radiation (IR) or **gamma(γ) rays**.

Using Bohr model:

Which of the following Shell has the shortest distance to the nucleus?
Shell 1-K (**n=1**), **Shell 2**-L (**n=2**), **Shell 3**-M(**n=3**), **Shell 4**-N (**n=4**), **Shell 5**-O (**n=5**), **Shell 6**-P (**n=6**), **Shell 7**-Q (**n=7**). Ans: **Shell 1**-K (**n=1**)

Which of the following Shell has the highest energy?
Shell 1-K (**n=1**), **Shell 2**-L (**n=2**), **Shell 3**-M(**n=3**), **Shell 4**-N (**n=4**), **Shell 5**-O (**n=5**), **Shell 6**-P (**n=6**), **Shell 7**-Q (**n=7**). Ans: **Shell 7**-Q (**n=7**).

Assign the energy change as emission or absorption for the following electron transitions beween shells with certain n= the principle quantum number

a) **Shell 1**-K (**n=1**) to **Shell 4**-N (**n=4**): Ans: **Absorption**.
b) From **Shell 5**-O (**n=5**) to **Shell 2**-L (**n=2**): **Emission**.

Modifications to Bohr's theory using Wave-mechanical" approach

Bohr in his model of the atom assumed electron as particle carrying an negative charge. A new approach treating electron as an wave called **Wave-mechanical Model** seem to explain much more experimental observations and the arrangement elements in the periodic table.

According to new **Wave-mechanical model** an electron a hydrogen atom has addition features:

1) Each shell could have sub-shells called s, p, d and f. Listed below is sub-shell description of each shell with certain principle quantum number:
2) Each sub-shell s, p, d, f, ~~g~~ , ~~h~~ and ~~i~~ in each shell can have 1,3, 5, 7, 9, 11 and 13 atomic orbital's. Even though 6ds, 6fs, 7ds 7fs, g and h sub-shells are possible they are never used for electrons in any of the atoms discovered so far and we ignore them. Sub-shells energy order: s< p < d < f < ~~g~~ < ~~h~~ < ~~i.~~
3) Each atomic orbital can have maximum of 2 electrons with spins ↑ (up) and ↓ (down).

The maximum number of electrons is a given shell is calculated using the formula, $2n^2$.

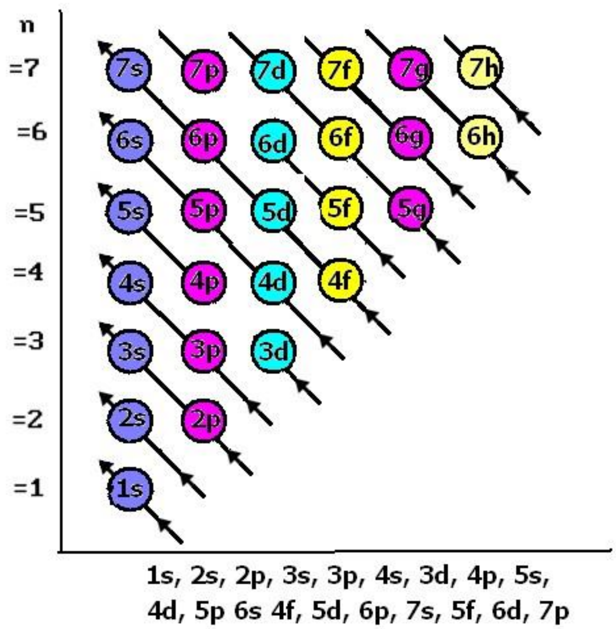
4) The orbital filling order for multi-electron atom: 1s, 2s, 2p, 3s, 3p, 4s, 3d, 4p, 5s, 4d, 5p 6s 4f, 5d, 6p, 7s, 5f, 6d, 7p

Summary of Wave-mechanical Model

n	**Shell**	**Sub-shells**	**Atomic Orbitals** One s, three p, five d, seven f, nine g, eleven h 1, 3, 5, 7, 9, 11, 13 odd series	**Total elens. ($2n^2$)**

1	1	s	**1s**	2
2	2	s, p	**2s**, **$2p_1$, $2p_1$, $2p_3$**	8
3	3	s, p, d	**3s**, **$3p_1$, $3p_2$, $3p_3$**, **$3d_1$, $3d_2$, $3d_3$, $3d_4$, $3d_5$**	18
4	4	s, p, d, f	**4s**, **$4p_1$, $4p_2$, $4p_3$**, **$4d_1$, $4d_2$, $4d_3$, $4d_4$, $4d_5$** **4f1, 4f2, 4f3, 4f5, 4f6, 4f7**	32
5	5	s, p, d, f, ~~g~~	**5s**, **$5p_1$, $5p_2$, $5p_3$**, **$5d_1$, $5d_2$, $5d_3$, $5d_4$, $5d_5$** **5f1, 5f2, 5f3, 5f5, 5f6, 5f7**, ~~**gs**~~	50
6	6	s, p, d, ~~f~~, ~~g~~, ~~h~~	**6s**, **$6p_1$, $6p_2$, $6p_3$**, ~~**$6d_1$, $6d_2$, $6d_3$, $6d_4$, $6d_5$**~~ ~~**6f1, 6f2, 6f3, 6f5, 6f6, 6f7, gs and hs**~~	72
7	7	s, p, d, ~~f~~, ~~g~~, ~~h, i~~	**7s**, **$7p_1$, $7p_2$, $7p_3$**, ~~**$7d_1$, $7d_2$, $7d_3$, $7d_4$, $7d_5$**~~ ~~**7f1, 7f2, 7f3, 7f5, 7f6, 7f7 gs, hs and is**~~	98

Multi-electron atom orbital filling diagram: Building up principle of electron configuration: 1s, 2s, 2p, 3s, 3p, 4s, 3d, 4p, 5s, 4d, 5p 6s 4f, 5d, 6p, 7s, 5f, 6d, 7p



Chemistry at a Glance: Shell, Sub-shell and Orbital Interrelationships.

The total number of electrons that can be accommodated in the sub-levels within: a) n = 1 b) n = 2 c) n = 3 d) n =4 e) n = 5 Ans:
a) n = 1 ($2n^1$= 1) b) n = 2 ($2n^2$= 8) c) n = 3 ($2n^2$= 18)d) n =4 ($2n^2$= 32) e) n = 5 ($2n^2$= 50)

How many orbitals are in the following sub-shells:
a) s b) p c) d d) f e) g

Ans:

a) s (1) b) p (3) c) d (5) d) f (7) e) g (9)

How many electrons that can be accommodated in the following sub-shells:
a) s b) p c) d d) f e) g

Ans:

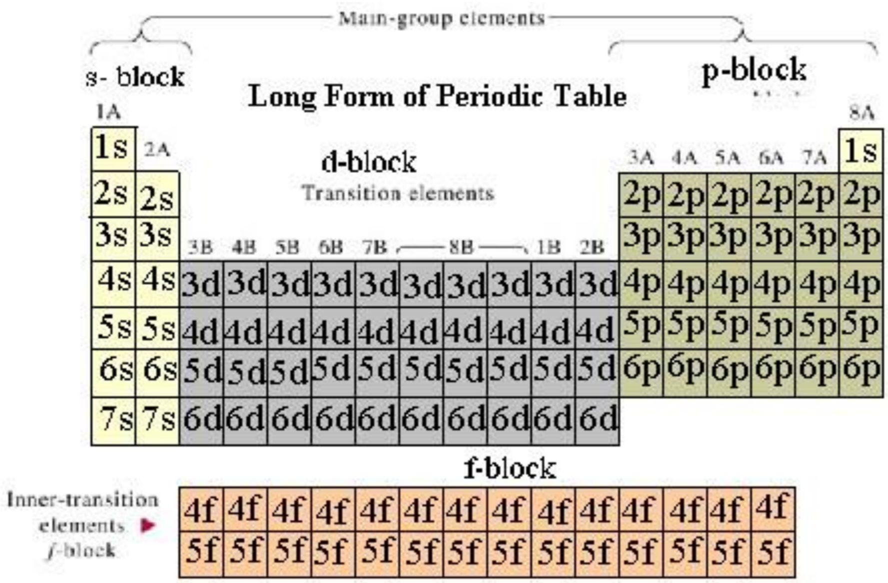
a) s (1 x 2= 2) b) p (3x 2= 6)) c) d (5 x 2 =10) d) f (7 x 2 =14) e) g (9 x 2 = 18)

3.7 Electron Configurations and Orbital Diagrams
Electronic configuration element and the periodic table

Electronic configuration of an element: Arrangement of electrons in atomic orbitals in the order of increasing energy. E.g.

H :$1s^1$, **He** :$1s^2$, **C**: $1s^2 2s^2 2p^2$, **O**: $1s^2 2s^2 2p^4$

Periodic Table and the Atomic Orbitals: Periodic table is useful in getting an electron configuration of an atom since modern periodic table is a direct reflection of filling order of electron into a multi electron atom.



Orbital filling order: 1s, 2s, 2p, 3s, 3p, 4s, 3d, 4p, 5s, 4d, 5p 6s 4f, 5d, 6p, 7s

Assign atomic orbital block where last electron is added in following elements:

a) **alkali metals** b) **alkaline-earth metals** c) **halogens** d) **noble gases**

a) **alkali metals(s-block)**

b) **alkaline-earth metals (s-block)**

c) **halogens (p-block)**
d) **halogens (p-block)**

Electronic configuration for an atom is obtained using following procedure:

1) Number of electron in an atom is equal to its Atomic number:
2) Following atomic orbitals s, p, d , and f can have maximum of 2, 6 , 10 , and 14 electrons respectively.
3) Use the filling order which is obvious in the periodic table: Period number gives principle quantum number, orbital block shows when you add an electron which types of orbital it would be added to.

E.g. Oxygen (O)
Fill the atomic orbitals starting from lowest 1s and assuming that a **s orbital** can only take up 2 electrons p orbital six d orbital ten, f orbital 14 etc.
Atomic number is 8 therefore it has 8 electrons
Orbital filling order: **1s, 2s, 2p**, **~~3s, 3p, 4s, 3d, 4p, 5s, 4d, 5p 6s 4f, 5d, 6p, 7s~~** Only fist three lowest energy atomic orbitals are used for 8 electrons.
O: **$1s^2$** ….two in 1s orbital …. **$2s^2$** two in 2s orbital and ….remaining 4 electrons in 2p orbitals **$2p^4$**
Electronic configuration of O: $1s^2 2s^2 2p^4$

What is the electron configuration of atoms of flowing elements: In, Co and Ca?
In
Atomic number is 49 therefore it has 49 electrons
Orbital filling order: **1s, 2s, 2p**, **3s, 3p, 4s, 3d, 4p, 5s, 4d, 5p** **~~6s 4f, 5d, 6p, 7s~~** Only fist eleven lowest energy atomic orbitals are used for 49 electrons.
In: **$1s^2$** ….two in 1s orbital …. **$2s^2$** two in 2s orbital and ….remaining 6 electrons in 2p orbitals **$2p^6$..etc.**

Electronic configuration of In: $1s^2,2s^2,2p^6,3s^2,3p^6,4s^2,3d^{10},4p^6,5s^2, 4d^{10},5p^1$

Electronic configuration of Co: $1s^2,2s^2,2p^6,3s^2,3p^6,4s^2,3d^7$

Electronic configuration of Ca: $1s^2, 2s^2, 2p^6$

Valence shell electronic configurations

Complete electronic configurations shows how electrons are added to the subshell of lowest energy until it reaches its capacity. The most important shell of electrons in the atom fro the chemical reactivity is the outermost shell: **The valence shell**. Valence

Shell electronic configuration is written by summarizing the **inner shell** or **core electron** configuration using form what we call **inert-gas core format.**

Complete electronic configurations	**Electronic configuration in inertgas core format.**
C: **1s2**2s2 2p2	**C**: **[He]** $2s^2\ 2p^2$
O: $\mathbf{1s^2}2s^2\ 2p^4$	**O**: **[He]**$2s^2\ 2p^4$
In: $\mathbf{1s^2,2s^2,2p^6,3s^2,3p^6,4s^2,3d^{10},4p^6}$,$5s^2$, $4d^{10}$,$5p^1$	**In:** **[Kr]** $5s^2$, $4d^{10}$,$5p^1$
Co: $\mathbf{1s^2,2s^2,2p^6,3s^2,3p^6,4s^2,3d^7}$	**Co:** **[Ar]**$\mathbf{4s^2,3d^7}$
Ca: $\mathbf{1s^2, 2s^2,2p^6,3s^2,3p^6,4s^2}$	**Ca:** **[Ar]**$\mathbf{4s^2}$

Complete electronic configurations:

C: 1s22s2 2p2

O: 1s22s2 2p4

Electronic configuration in core format:

O: [He]$2s^2\ 2p^4$

Give the valence electron configuration in core format of following atoms: a) Na b) Cl c) P d) O

Valence-shell Electron Configuration: Electron configuration of the outer most shell (maximum n)

Ans: a) Na: [Ne] $3s^1$ b) Cl: [Ne] $3s^2,3p^5$ c) P : [Ne] $3s^2,3p^3$ d) O : [He] $2s^2,2p^4$

Valence shell orbital diagrams

Shows how electrons the details of the **Complete electronic configurations** and the **valence shell**. Here we mainly focus on **Valence shell orbital diagrams.**

3.8 The Electronic Basis for the Periodic Law and the Periodic Table

Representative elements: **s-block** and **p-block** elements that always lose or gain the same number of electrons in chemical reactions.

Transition elements: d-block elements that can lose or gain variable numbers of

Electronic configuration in inert-gas core format.	**Valence shell orbital diagrams**
C: **[He]** $2s^2\ 2p^2$	$2s^2$ [↓↑] ; $2p^4$ [↓] [↓] [ ]
O: **[He]**$2s^2\ 2p^4$	$2s^2$ [↓↑] ; $2p^4$ [↓↑] [↓] [↓]
In: [Kr] $5s^2$, $4d^{10}$,$5p^1$	$2s^2$ [↓↑] ; $4d^{10}$ [↓↑] [↓↑] [↓↑] [↓↑] [↓↑] ; $5p^1$ [↓] [ ] [ ]
Co: [Ar]$4s^2$,$3d^7$	$4s^2$ [↓↑] ; $3d^7$ [↓↑] [↓↑] [↓] [↓] [↓]
Ca: [Ar]$4s^2$	$42s^2$ [↓↑] ; $4p^0$ [↓] [↓] [ ]

electrons in chemical reactions.

Lanthanide series and the **actinide series: f-block** elements are parts of periods **6** and **7**, respectively.

3.9 Classification of the Elements in the periodic table

a**) Alkali metal: Li, Na, K, Rb, Cs, and Fr** **Valence** Li, Na, K, Rb, Cs, Fr **ele.^{n} con^n** $2s^1$ $3s^1$ $4s^1$ $5s^1$ $6s^1$ $7s^1$	Loose one electron and get noble gas electron configuration and forms mono positive cations
b) **Alkaline Earth Metals Be, Mg, Ca, Sr, Ba, and Ra** **Valence** Be, Mg, Ca, Sr, Ba, Ra ele.^{n}con^n $2s^2$, $3s^2$ $4s^2$ $5s^2$ $6s^2$ $7s^2$	Loose two electron and get noble gas electron configuration and forms di-positive cations.
c) **Halogens: F, Cl, Br, and I** **Valence F, Cl, Br, I ele.^{n} con^n** $2s^22p^5$,$3s^22p^5$,$4s^24p$, $5s^25p^5$	Gains one electron and achieve noble gas configuration and forms mono positive anions
d) **Noble gases: He, Ne, Ar, Kr, Xe and Ra** **Valence** He, Ne, Ar, **ele.^{n}con^n** He :$1s^2$, Ne:$2s^{2\ e}2p^6$, Ar: $3s^23p^6$, Kr, Xe Ra Kr:$4s^24p^6$, Xe:$5s^25p^6$, Ra:$6s^26p^6$	Have closed shell electron configurations. Do not loose or gain electrons.

Alkali metals: ns^1-group **alkaline earth metals: :** ns^2 -group, the **halogens**, and the **noble gases**. **Group A** elements are called representative elements; **Group B** elements are transition elements. **Metals**, **metalloids**, and **nonmetals** can be identified by their location on the periodic
table.

Chemistry at a Glance: Describe Element Classification Schemes and the Periodic Table **Chemical Connections**: Describe heat Protium, Deuterium, and Tritium: The Three
Isotopes of Hydrogen; Importance of Metallic and Nonmetallic Trace Elements for Human Health; Electrons in Excited States