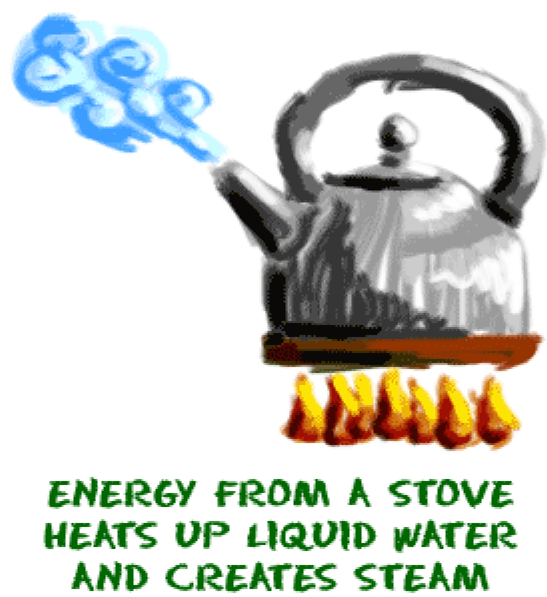
States of Matter

We look at five **states of matter** on the site. Solids, liquids, gases, plasmas, and Bose-Einstein condensates (BEC) are different states of matter that have different physical properties. Solids are often hard, liquids fill containers, and gases surround us in the air. Each of these states is also known as a **phase**.

How does matter change from one state to another? Elements and compounds can move from one state to another when specific physical conditions change. For example, when the **temperature** of a system goes up, the matter in the system becomes more excited and active. If enough energy is pushed into a system, a phase change may occur as the matter moves to a more **active state**.

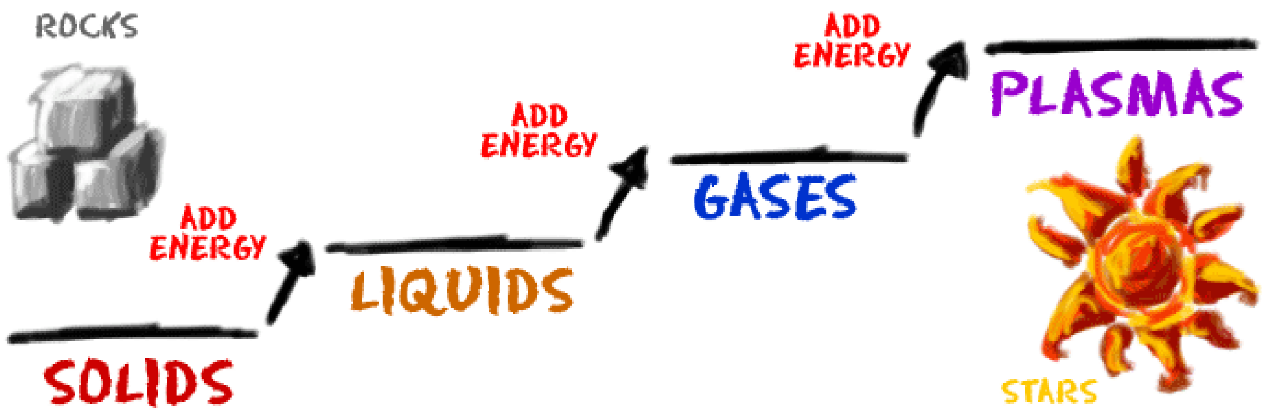


Let's say you have a glass of water (H_2O). When the temperature of the water goes up, the molecules get more excited and bounce around a lot more. If you give a liquid water molecule enough energy, it escapes the liquid phase and becomes a gas. The extra energy allows the molecules to change states.

Have you ever noticed that you can smell a turkey dinner after it starts to heat up? As the energy of the molecules inside the turkey heat up, they escape as a gas. You are able to smell the **volatile** compounds that are mixed in the air around you.

It’s About the Physical

"Phase" describes the **physical** state of matter. The key word to notice is "physical". Matter only moves from one phase to another by physical means. If energy is added (increasing the **temperature**) or if energy is taken away (freezing something), you can create a physical change.



THE STATE OF MATTER CHANGES AS YOU ADD MORE ENERGY

Changing the **pressure** of a system is another way to create a physical change. If you place a glass of liquid water on a table, it will just sit there. If you place a glass of water in a **vacuum chamber** and lower the pressure, you can begin to watch the water boil and the water molecules move to a gas phase.

When molecules move from one phase to another they are still the same substance. There is water **vapor** above a pot of boiling water. That vapor (or gas) can **condense** and become a drop of liquid water in the cooler air. If you put that liquid drop in the freezer, it would become a solid piece of ice. No matter what physical state it was in, it was always water. Even though the physical state changed, the chemical properties were the same.

On the other hand, a chemical change would build or break the chemical bonds in the water (H_2O) molecules. If you added a carbon (C) atom, you would create formaldehyde (H_2CO). If you added an oxygen (O) atom, you would create hydrogen peroxide (H_2O_2). Neither new compound is anything like the original water molecule. Generally, changes in the physical state do not lead to any chemical change in compounds.

Solid Basics

What is one **physical characteristic** of a solid? Solids can be hard like a rock, soft like fur, a big rock like an asteroid, or small rocks like grains of sand. The key is that **solids hold their shape** and they don't flow like a liquid. A rock will always look like a rock unless something happens to it. The same goes for a diamond. Solids can hold their shape because their molecules are tightly packed together.

You might ask, "Is baby power a solid? It's soft and powdery." Baby power is also a solid. It's just a ground down piece of **talc**. Even when you grind a solid into powder, you will see tiny pieces of that solid under a microscope. Liquids will flow and fill up any shape of container. Solids like to hold their shape.

In the same way that a large solid holds its shape, the atoms inside of a solid are not allowed to move around too much. Atoms and molecules in liquids and gases are bouncing and floating around, free to move where they want. The molecules in a solid are stuck in a specific structure or arrangement of atoms. The atoms still vibrate and the electrons fly around in their orbitals, but the entire atom will not change its position.

Liquid Basics

Liquids are the second state of matter we will talk about. Solids are objects you can hold and maintain their shape. Gases are floating around you or trapped in bubbles. Liquids are found between the solid and gas states. Examples of liquids at room temperature include water (H_2O), blood, and even honey. If you have different types of molecules dissolved in a liquid, it is called a **solution**. Honey is a solution of sugar, water, and other molecules.

Liquids **fill** the shape of any container they are in. If you pour water in a cup, it will fill up the bottom of the cup first and then fill the rest. If you freeze that cup of water, the ice will be in the shape of the cup.

The top of a liquid will usually have a flat surface. That flat surface is the result of **gravity** pulling on the liquid molecules. Let's go back to the cup for a moment. If you put an ice cube (solid) into the cup, it will sit there and not change shape. As the cube warms and melts, the liquid water will fill the bottom of the cup and have a flat surface on top.

Looking for a Gas

Gases are everywhere. You may have heard about the atmosphere. The atmosphere is an envelope of gases that surrounds the Earth. In solids, atoms and molecules are compact and close together. Liquids have atoms that are spread out a little more. The molecules in gases are really spread out, full of energy, and constantly moving around in random ways.

What is another **physical** characteristic of gases? Gases can fill a container of any size or shape. It doesn't matter how big the container is. The molecules spread out to fill the whole space equally. Think about a balloon. No matter what shape you make the balloon, it will be evenly filled with the gas molecules. Even if you make a balloon animal, the molecules are spread equally throughout the entire shape.

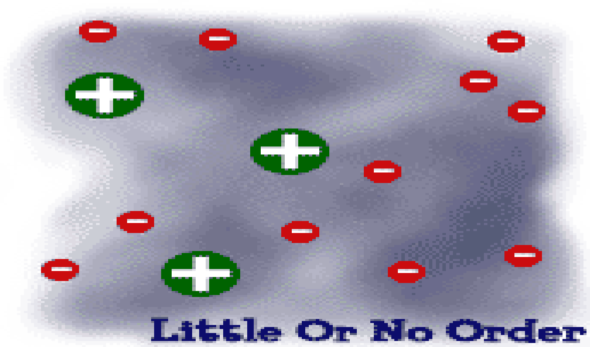
Liquids can only fill the bottom of a container, while gases can fill it entirely. The shape of liquids is very dependent on **gravity**, while less dense gases are light enough to have a more freedom to move.

Gas or Vapor?

You might hear the term "**vapor**." Vapor and gas mean the same thing. The word vapor is used to describe gases that are usually liquids at room temperature. Good examples of these types of liquids include water (H_2O) and mercury (Hg). They get the vapor title when they are in a gaseous phase. You will probably hear the term "water vapor" which means water in a gas state. Compounds such as carbon dioxide (CO_2) are usually gases at room temperature. Scientists will rarely talk about carbon dioxide vapor.

Plasma Basics

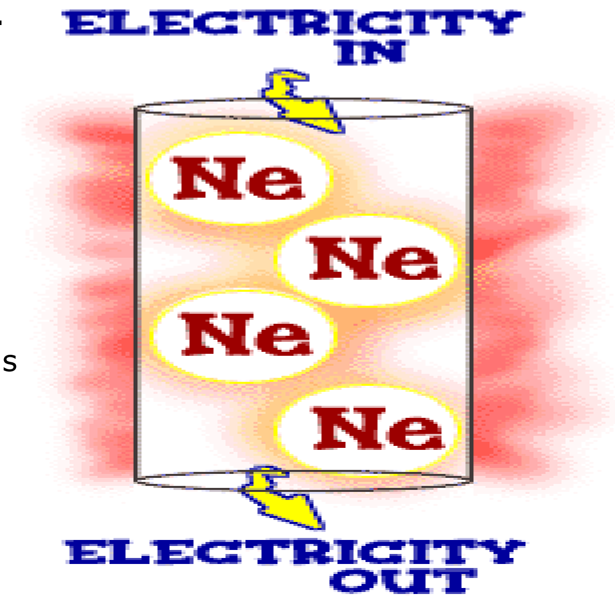
Plasmas are a lot like gases, but the atoms are different, because they are made up of free electrons and ions of an element such as neon (Ne). You don't find naturally occurring plasmas too often when you walk around. They aren't things that happen regularly on Earth.



If you have ever heard of the Northern Lights or ball lightning, you might know that those are types of plasmas. It takes a very special environment to keep plasmas going. They are different and unique from the other states of matter. Plasma is different from a gas, because it is made up of groups of **positively and negatively charged particles**. In neon gas, the electrons are all bound to the **nucleus**. In neon plasma, the electrons are free to move around the system.

Finding a Plasma

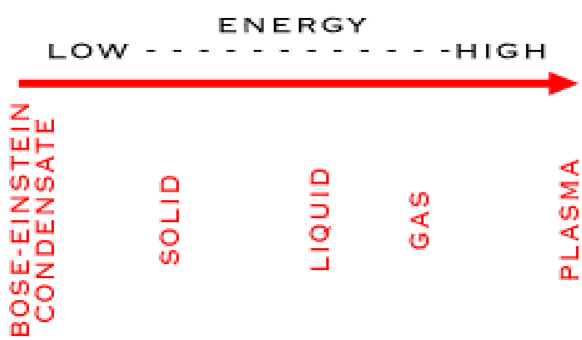
While natural plasmas aren't found around you that often, man-made plasmas are everywhere. Think about **fluorescent** light bulbs. They are not like regular light bulbs. Inside the long tube is a gas. **Electricity** flows through the tube when the light is turned on. The electricity acts as an energy source and charges up the gas. This charging and exciting of the atoms creates glowing plasma inside the bulb. The electricity helps to strip the gas molecules of their electrons.



Another example of plasma is a neon sign. Just like a fluorescent lights, neon signs are glass tubes filled with gas. When the light is turned on, the electricity flows through the tube. The electricity charges the gas and creates plasma inside of the tube. The plasma glows a special color depending on what kind of gas is inside. Inert gases are usually used in signs to create different colors. Noble gases such as helium (He), Neon (Ne), Argon (Ar), and Xenon (Xe) are all used in signs.

You also see plasma when you look at **stars**. Stars are big balls of gases at really high temperatures. The high temperatures charge up the atoms and create plasma. Stars are a good example of how the temperature of plasmas can be very different. Fluorescent lights are cold compared to really hot stars. However, they are still both forms of plasma, even with the different **physical** characteristics.

Bose-Einstein Basics



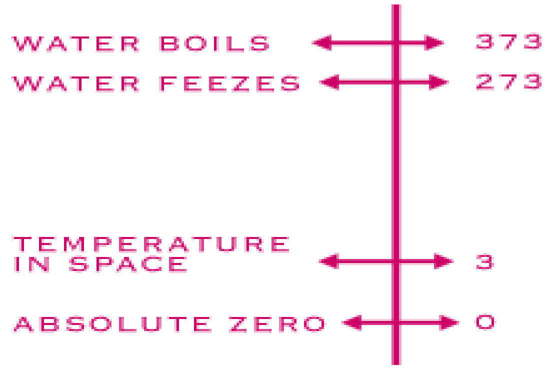
The Bose-Einstein state of matter was the only one created while your parents were alive. In 1995, two scientists, Cornell and Weiman, finally created the condensate. When you hear the word **condensate**, think about condensation and the way gas molecules come together and condense and to a liquid. The molecules get **denser** or packed closer together.

Two other scientists, Satyendra Bose and Albert Einstein, had predicted it in the 1920s, but they didn't have the equipment and facilities to make it happen at that time. Now we do. If plasmas are super hot and super excited atoms, the atoms in a Bose-Einstein condensate (BEC) are total opposites. They are super unexcited and super cold atoms.

About Condensation

Let's explain condensation first. Condensation happens when several gas molecules come together and form a liquid. It all happens because of a **loss of energy**. Gases are really excited atoms. When they lose energy, they slow down and begin to collect. They can collect into one drop. Water (H_2O) vapor in the form of steam condenses on the lid of your pot when you boil water. It cools on the metal and becomes a liquid again. You would then have a condensate.

The BEC happens at super low temperatures. We have talked about temperature scales and **Kelvin**. At zero Kelvin (**absolute zero**) all molecular motion stops. Scientists have figured out a way to get a temperature only a few billionths of a degree above absolute zero. When temperatures get that low, you can create a BEC with a few special elements. Cornell and Weiman did it with rubidium (Rb).



Let the Clumping Begin

So, it's cold. A cold ice cube is still a solid. When you get to a temperature near absolute zero, something special happens. Atoms begin to **clump**. The whole process happens at temperatures within a few billionths of a degree, so you won't see this at home. When the temperature becomes that low, the atomic parts can't move at all. They lose almost all of their energy.

Since there is no more energy to transfer (as in solids or liquids), all of the atoms have exactly the same levels, like twins. The result of this clumping is the BEC. The group of rubidium atoms sits in the same place, creating a "**super atom**." There are no longer thousands of separate atoms. They all take on the same qualities and, for our purposes, become one blob.