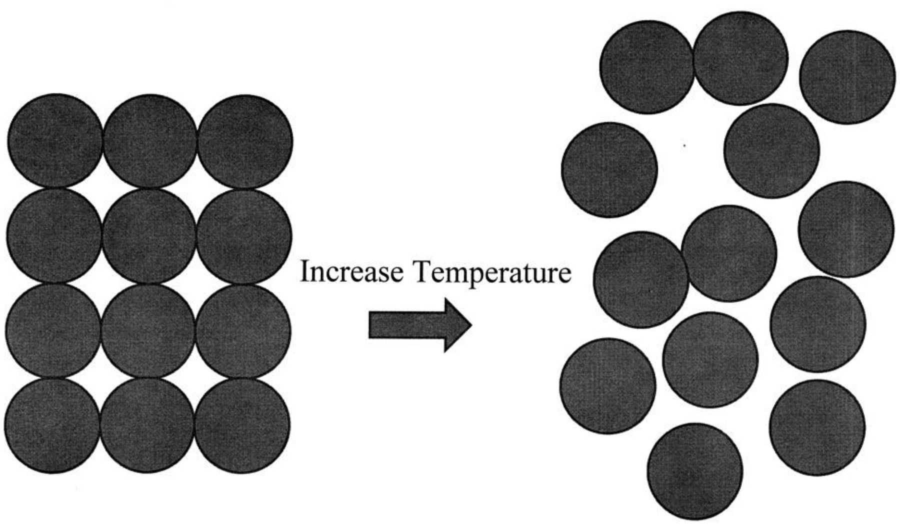
Chemistry Lecture #63: Changes of State

The physical state of a substance can be changed by increasing or decreasing its temperature.

For example, a solid substance can be converted into a liquid by heating the solid. Throw some ice into a hot frying pan and the ice will turn into water. Heat a chunk of wax and the wax will melt and turn into a clear liquid.

When a solid is heated, energy is added to its atoms or molecules. The particles begin to vibrate faster and faster. The kinetic energy of the particles increases. When the average kinetic energy or temperature is high enough, the particles begin to slip past each other and no longer have an orderly, crystallized arrangement. At this temperature, the solid begins to turn into a liquid. This temperature is called the *melting point*.

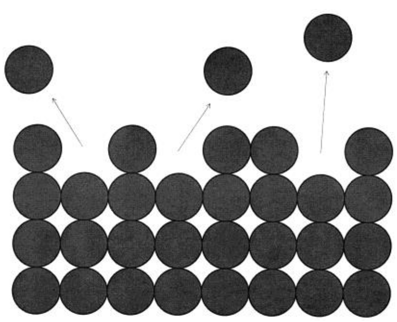


An orderly solid becomes a disorganized liquid at the melting point.

It is also possible for a liquid to be converted into a solid. If water or liquid wax is cooled, heat or energy is removed from the liquid. The molecules move more slowly. They eventually move slowly enough to allow bonds to form between the molecules. Groups of molecules bonded together grow larger and become visible crystals. The temperature at which solid crystals appear is called the *freezing point*. The freezing point is the temperature at which a liquid can turn into a solid.

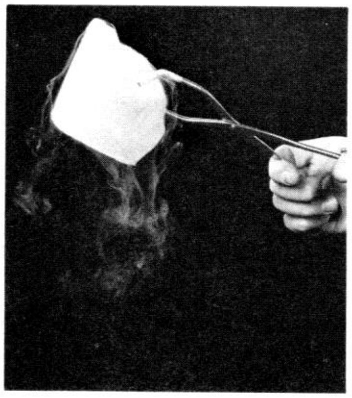
The freezing point and melting point of a substance is the same. H_2O can either melt at zero degrees Celsius or freeze. If heat is added, it will melt. If heat is removed, it will freeze. The freezing/melting point of a substance is a transition zone where both solid and liquid can exist, and the direction of transition depends on whether energy is added or removed.

A solid can also be converted into a gas. This occurs when molecules on the surface of a solid leave the surface and go directly into the surrounding atmosphere. When a solid is converted directly into a gas, the process is called *sublimation*.

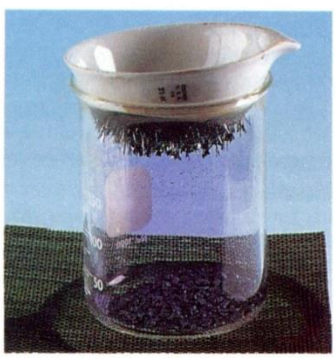


Sublimation occurs when a solid is converted directly into a gas.

Dry ice, or solid carbon dioxide, does not melt into a liquid. It sublimates into CO_2 gas. Iodine crystals also sublimate directly into iodine gas. Moth balls and air fresheners are also solid substances that turn directly into gases.



A chunk of dry ice. Notice the vapor sublimating off the block.



Iodine crystals at the bottom of the beaker vaporize into a gas, which then redeposits under the evaporating dish and becomes solid again.

Freeze dried foods are made through the sublimation process. To freeze dry a sample of food (such as ice cream), you first freeze the food so that the water in the food becomes solid ice. Next, you remove the air molecules surrounding the food. This reduces the surrounding atmospheric pressure and causes the ice in the food to evaporate. The food now has no H_2O - it's been dried out!

Freeze dried ice cream. It feels and tastes like a hard, dry cookie.

Solids can become gases through sublimation, and liquids can become gases through evaporation. In a liquid, the atoms or molecules are still attracted to each other with enough force to pull them close together. However, the particles have enough kinetic energy to move and slide past each other.

If a particle is on the surface of a liquid and has enough kinetic energy, it can overcome the intermolecular forces of attraction, leave the surface of the liquid and go into the atmosphere as a gas. This is the process of evaporation.

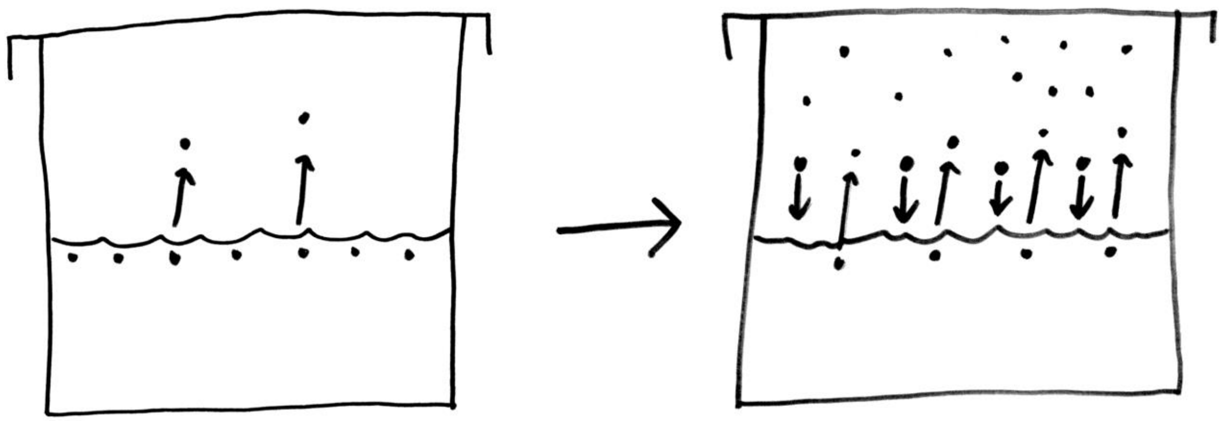
A vapor is the gaseous state of a substance that is normally a liquid or solid at room temperature. Thus, steam is a vapor because H_2O is normally a liquid at room temperature.

If a container of water is left out in the sun, the water would eventually evaporate into the atmosphere. If the top of the container were covered, the water would still evaporate, but the vapor would be trapped above the liquid.

As the water continues to evaporate, there would be a lot of vapor trapped above the liquid. Eventually there will not be enough space above the liquid to hold all the H_2O molecules. At this point, the surface above the liquid would be *saturated* with vapor. Some of the vapor molecules would go back into the liquid.

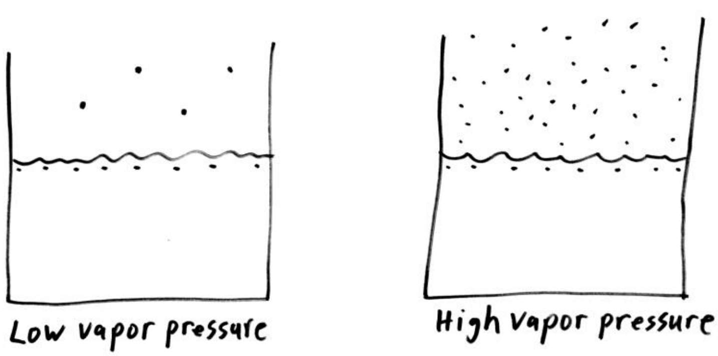
Even though vapor molecules are returning to the liquid, there are still molecules that are leaving the liquid and hovering above the surface. Eventually, the rate at which molecules leave the liquid will equal the rate at which molecules return to the liquid. There will be no net change in the amount of liquid or vapor. *Equilibrium* has been reached.

Even though the amount of liquid and vapor remain constant, molecules are still moving back and forth between the vapor and the liquid - the system is dynamic. Thus, the vapor and liquid are in *dynamic equilibrium*. There is constant movement but no net change.

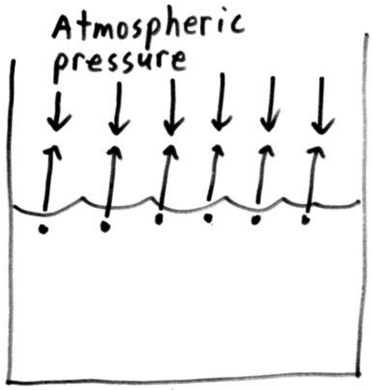


Vapor accumulates above the surface of a liquid. Eventually, the region above the liquid becomes saturated with vapor. The rate of evaporation will equal the rate of condensation.

The vapor above the liquid exerts a vapor pressure. If the liquid has a low vapor pressure, the intermolecular forces are strong. The molecules like to stick together and do not evaporate easily. If the liquid has a high vapor pressure, the intermolecular forces are weak. The molecules do not stick together and evaporate easily.



If a container of liquid is exposed to the atmosphere and is heated continuously, it begins to boil. Boiling occurs when the vapor pressure exerted by the liquid equals the atmospheric pressure above the liquid.



When atmospheric pressure on the liquid equals the vapor pressure exerted by the liquid, boiling occurs.

High atmospheric pressure interferes with the boiling process, and the liquid needs a higher temperature before boiling can occur. At lower atmospheric pressures (which occurs at the top of a mountain), boiling occurs more easily and the liquid will boil at a lower temperature.

The temperature at which a liquid boils is the *boiling point*. Most of the time we use the boiling point that occurs at normal atmospheric pressure (101.325 kPa). This particular boiling point is called the *normal boiling point*.

A liquid that boils and evaporates easily is *volatile*. Volatile liquids exert a high vapor pressure, have low boiling points, and have weak intermolecular forces. Nonvolatile substances do not evaporate easily, have high boiling points, and have strong intermolecular forces.

At its boiling point, a substance can exist as either liquid or gas. If energy is added at the boiling point, liquid will be converted into gas. If energy is removed at the boiling point, gas will condense into liquid.