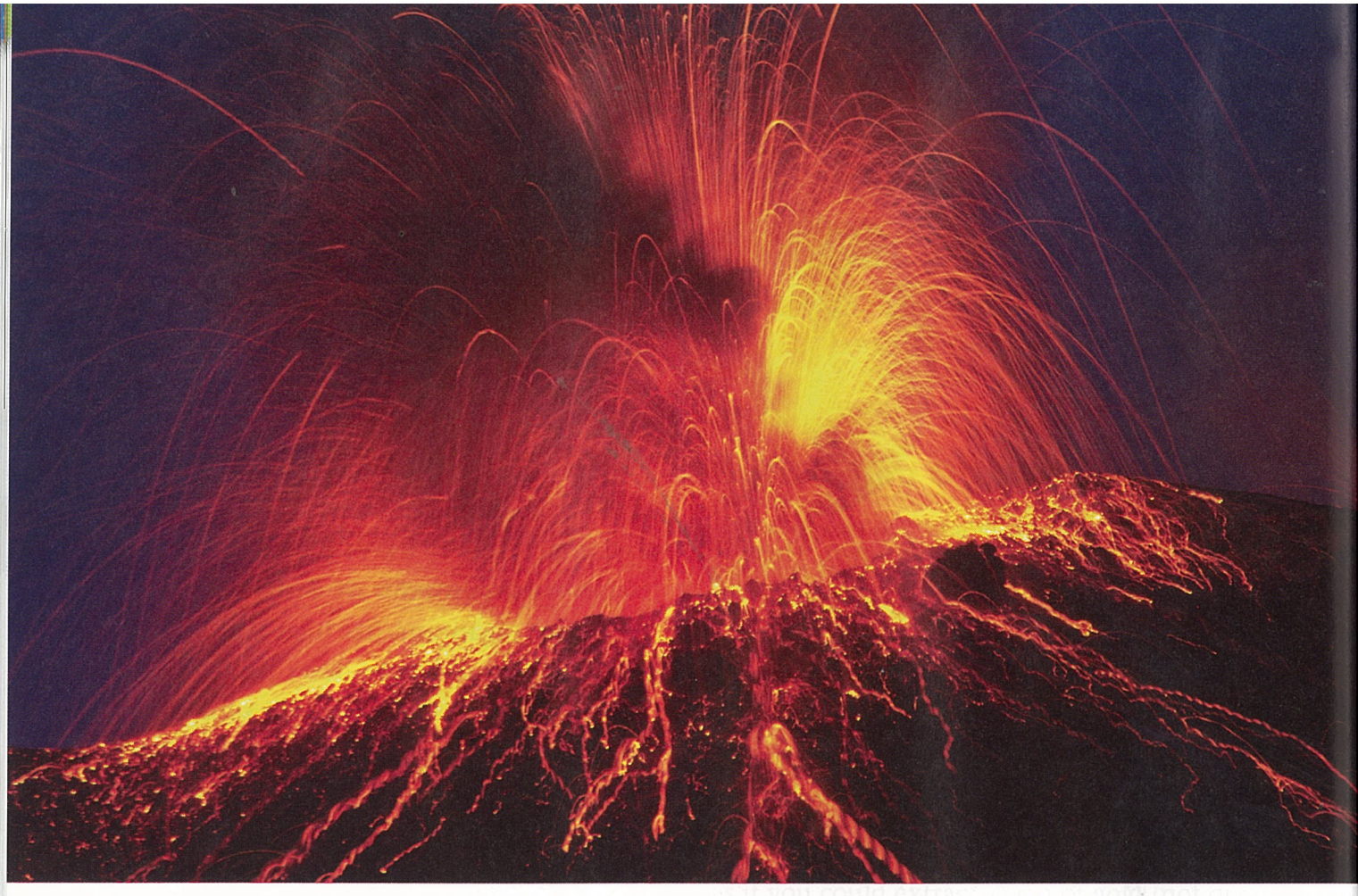


# Rock Solid

What does **lava** pouring out of a volcano have in common with a snowman? They are both going to change phase in a short time. The liquid lava will **freeze** and become solid rock. The solid snowman will melt and become liquid water.

Most matter on Earth exists in one of three forms: solid, liquid, or gas. The forms are called states or phases of matter.

The clothes you wear, the forks and spoons you eat with, and your books and pencils are a few examples of matter in its solid phase.

The olive oil you put on your salad, the shampoo you use to wash your hair, and a refreshing glass of cold milk are examples of matter in its liquid phase.

The helium in a party balloon, the air you pump into a soccer ball, and the carbon dioxide in your exhaled breath are examples of matter in its gas phase.

Snow is solid water.

## Properties of the Phases of Matter

Many substances can exist in more than one phase. The snowman, for instance, is made of solid water. We have many common names for solid water, including ice, frost, and snow.

Water can also exist as liquid. Liquid water falls from clouds as rain and flows to your home in pipes. Earth is mostly covered by an ocean filled with liquid water.

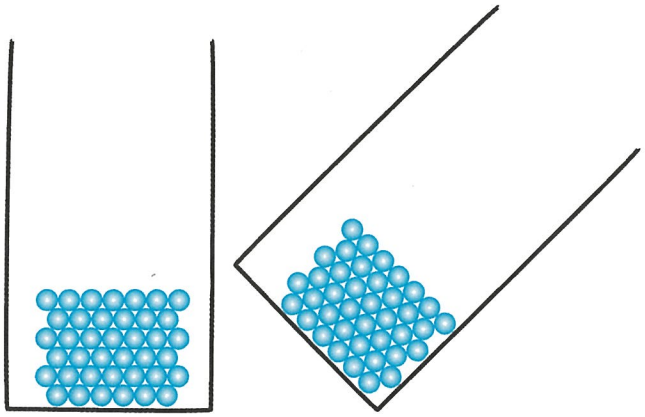
Water also exists as gas. Water in its gas phase is called water vapor. We are usually not aware of water vapor because it is invisible. Most of the water vapor on Earth is in the atmosphere as part of the air.

Ice, liquid water, and water vapor all look different. But they are all forms of water. What is the same and what is different about ice, water, and water vapor?

All three phases of water are made of exactly the same kind of particle. The chemical formula for the water particle is $H_2O$. Ice, water, and water vapor are all made of water particles.

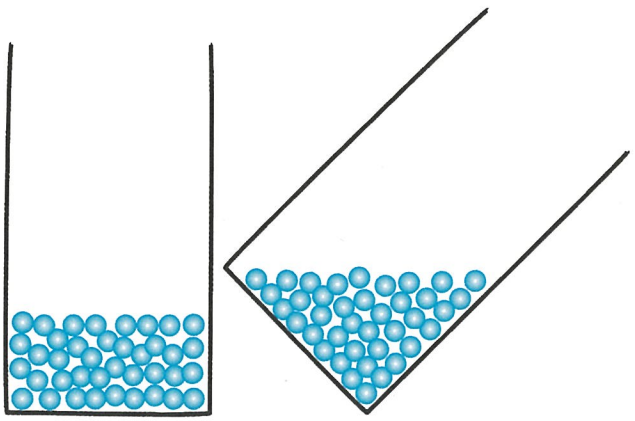
The thing that is different about ice, water, and water vapor is the relationship between the water particles.

In the article "Three Phases of Matter," we considered how solids, liquids, and gases differ. In solids, the particles are attached to one another. The attachments are called bonds. The bonds in solids are so strong that the particles cannot change positions. That's why solids have definite shape and volume.



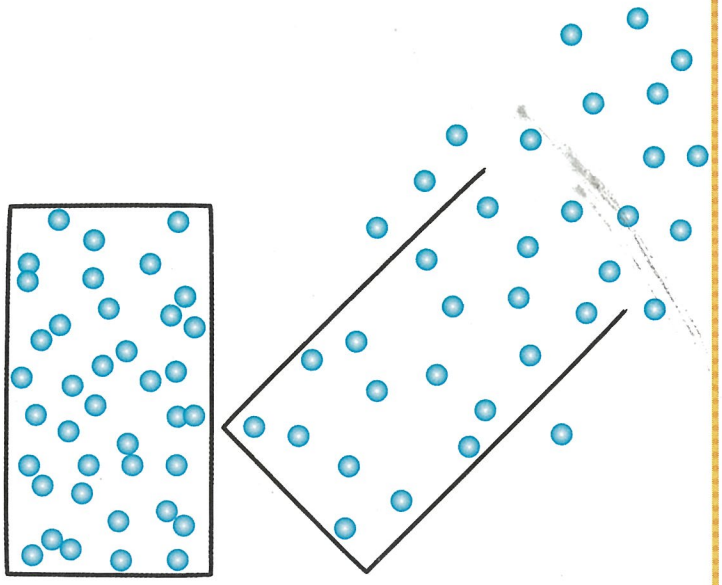
Ice in a vial will move from side to side, but will not change volume or shape.

In liquids, the bonds are weaker. The particles are still held close together, but they can move around and past one another. As a result, liquids flow. That's why liquids have definite volume, but their shape changes.



Liquid water has definite volume, but its shape changes to fit the container it is in.

In gases, bonds do not hold the particles together. Individual particles of gas fly around in space. That's why gases do not have definite volume or shape.



**Water vapor (gas) does not have definite volume or shape. If the container is open, the gas will expand, and the particles will leave the container.**

## Phase Change

The snowman wasn't always solid. And it won't stay solid. The solid snowman will melt and turn into liquid water. The liquid lava wasn't always liquid. And it won't stay liquid. The liquid lava will freeze and turn to solid rock.

Change from solid to liquid and change from liquid to solid are examples of phase change. What causes substances to change phase?

Heat causes phase change. Or, more accurately, energy transfer causes phase change. Here's how it works.

**When ice cubes are heated they change to liquid water.**

When a piece of ice is placed in a warm room, energy transfers from the air particles to the water particles in the ice. The kinetic energy of the water particles increases until the ice reaches 0 degrees Celsius (°C).

As more and more energy transfers to the 0°C ice, the bonds holding the water particles together start to break. When most of the bonds are broken, the water particles are no longer held in place. They start to move over and around one another.

When particles flow over and around one another, we say the substance changed from solid to liquid. The process is called melting. Substances melt when enough energy transfers to the particles of a solid and breaks the bonds holding particles in place.

That's why the snowman melts. Energy from the Sun transfers to the water particles in the snow crystals. The bonds that hold particles together as a solid are broken, and the solid water changes to liquid water. The snowman changes into a hat and scarf on top of a puddle of water.

What about the lava? How does it change phase? When lava pours out on Earth's surface, it is extremely hot (up to 1,100°C). The kinetic energy of the rock particles is so great that most of the bonds holding them together have been broken. The rock particles move over and around one another. The rock is liquid, so it flows down the side of the volcano.

Air is cooler than lava . . . a lot cooler than lava. Energy from the liquid rock particles transfers to the air particles. The rock particles lose kinetic energy, and the mass of lava cools. As the lava cools, stronger bonds form between the rock particles. When enough energy has transferred from the rock particles, the particles are locked in place by the bonds.

When particles stop flowing over and around one another, we say the substance changed from liquid to solid. The process is called freezing. Substances freeze when enough energy transfers away from the particles of a liquid.

That's why the liquid lava freezes and becomes solid rock. Energy transfers away from the rock particles, bonds hold the particles together in a fixed position, and the rock changes from liquid to solid.

## Evaporation

Let's get back to the snowman. After a day or two, all that remains is the hat and scarf. Even the puddle of liquid water has disappeared. Where did the water go?

**Hot, liquid lava will freeze and change to solid rock.**

As sunshine falls on the puddle of liquid water, energy transfers to the water particles. The kinetic energy of the particles increases. When enough energy transfers to a particle, the particle breaks all the bonds holding it to the mass of liquid. The particle breaks free and flies into space. The water changes phase again, but this time from liquid to gas.

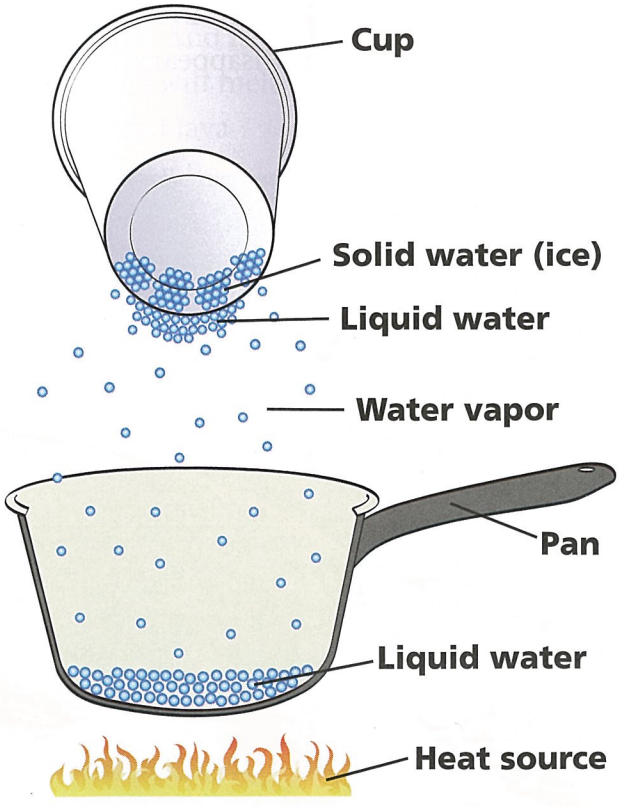
The phase change from liquid to gas is called **evaporation** (or vaporization). Water in the gas phase is called water vapor. The individual water particles are too small to see, so water vapor is invisible. Water vapor enters the air and becomes part of Earth's atmosphere.

Water can change from gas to liquid, too. The process involves energy transfer. Can you predict what energy transfer takes place?

When energy transfers away from the water vapor particles, they lose kinetic energy. When enough energy has transferred from the particles, bonds form between them. The water changes phase from gas to liquid. The process is called **condensation**. Substances condense when energy transfers away from the particles of a gas.

Condensation on a window

Look at the illustration of an experiment. A pan of liquid water is heated. Water evaporates. The water vapor condenses on a cup filled with ice. Study how the water particles change phase from liquid to gas, and then back to liquid. You should be able to see where evaporation and condensation are taking place.




Liquid water evaporates when it is heated. Water vapor condenses on the outside of a cup containing ice.

## Melt and Freeze

There are three important things to understand about melting and freezing.

**Substances don't have to be cold to freeze.** *Freeze* just means changing phase from liquid to solid, and this happens at different temperatures for different substances. Granite freezes at about 1,650°C. On the other hand, oxygen freezes at –218°C. Every substance has its own freezing temperature. Any solid substance is technically frozen, even a hot metal pan on the stove.

**Phase is a relationship between particles.** The phase of a substance is determined by what is happening between the particles in the substance. Particles in solids have strong bonds, particles in liquids have weak bonds, and particles in gases have no bonds.

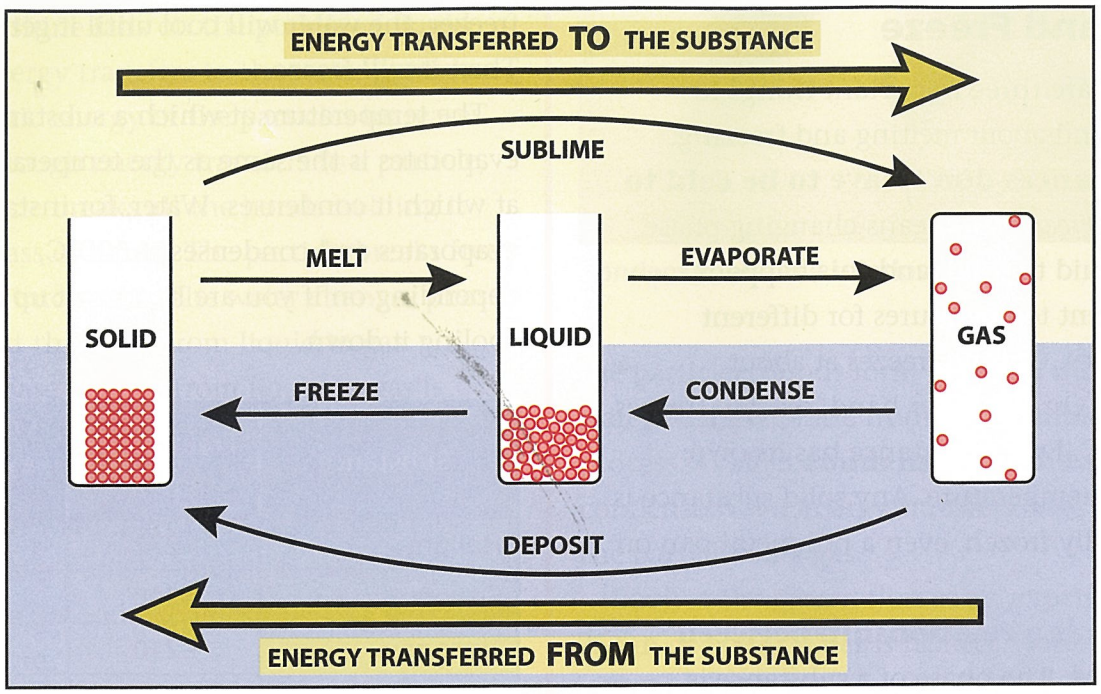
**Freezing temperature = melting temperature.** A substance freezes and melts at the same temperature. Water, for instance, freezes and melts at 0°C. If you move a piece of ice from a freezer to a warm room, the ice will warm up until it reaches 0°C. Then it will melt. If you put a cup of warm water in a freezer, the water will cool until it gets to 0°C. Then it will freeze.

The temperature at which a substance evaporates is the same as the temperature at which it condenses. Water, for instance, evaporates and condenses at 100°C, depending on if you are heating it up or cooling it down.

Melting gold at a foundry

| Substance | Freeze/melt (°C) | Condense/ evaporate (°C) |
|---|---|---|
| Helium | –272 | –269 |
| Oxygen | –218 | –183 |
| Nitrogen | –210 | –198 |
| Carbon dioxide | — | –78 |
| Chlorine | –101 | –34 |
| Mercury | –39 | 357 |
| Water | 0 | 100 |
| Sodium | 98 | 883 |
| Lead | 327 | 1,749 |
| Aluminum | 660 | 2,519 |
| Calcium chloride | 775 | 1,936 |
| Sodium chloride | 801 | 1,465 |
| Silver | 962 | 2,162 |
| Gold | 1,064 | 2,856 |
| Copper | 1,085 | 2,562 |
| Iron | 1,538 | 2,861 |
| Tungsten | 3,422 | 5,555 |

**The freeze/melt temperatures and condense/ evaporate temperatures for some common substances are shown here. Carbon dioxide is a special substance. Do you see that it has no freezing and melting point? Keep reading to find out why.**




Phase-change vocabulary

This illustration summarizes how energy transfer affects phase change. The top half shows how substances go from solid to liquid to gas as energy transfers *to* the particles of the substance. The bottom half shows how substances go from gas to liquid to solid as energy transfers *from* the particles of the substance.

Notice that a substance can go straight from solid to gas. This process is called **sublimation**. Carbon dioxide is a substance that sublimes. And when energy transfers the other way, carbon dioxide **deposits**. It changes from a gas to a solid without going through a liquid phase. That's why solid carbon dioxide is called **dry ice**.

As dry ice sublimes, it changes from solid to gas without passing through a liquid phase.

## Think Questions

1. What causes a substance to change from one phase to another?
2. What are the three important things to know about freezing and melting?
3. What happens to water particles as a cup of ice melts and then evaporates?