Water Phases

Water is the only common substance found on Earth's surface naturally as a solid (ice), liquid, and gas (water vapor or steam). The boiling or vaporization temperature of fresh water is 100 degrees Celsius or 212 degrees Fahrenheit. The melting or fusion temperature of fresh water is 0 degrees Celsius or 32 degrees Fahrenheit. Notice the perfect zero and 100 numbers. The Celsius temperature scale was developed specifically around the main properties of water. So if the boiling point of water is 212 degrees Fahrenheit, how is gaseous water naturally present on Earth's surface, when the temperature never reaches that high? To understand that we first have to describe the basic difference between solids, liquids, and gases.

As we know, all substances are made up of individual atoms. Let's imagine those atoms as marbles. To understand phases and temperature and heat, we first need to understand the concept of kinetic energy. **Kinetic Energy** is the energy of motion of the atoms in a substance. Kinetic Energy is calculated by taking the velocity or speed of motion and squaring it, then multiplying by the mass of the substance, and finally halving that product. The faster the motion of the atoms, the more Kinetic Energy it has. The velocity of a substance is how fast it's moving in a straight path or how fast it's vibrating if it's bonded to a nearby atom. **Temperature** is a measurement of the average kinetic energy of the atoms in a substance. So as velocity increases, so too does temperature. **Heat** is a measure of the total kinetic energy of all the atoms in a substance. Objects with lots of motion carry a lot of heat. We can describe the average temperature of the oceans as the average kinetic energy of all the water molecules and dissolved ions in the ocean. We can also describe the heat stored in the ocean as the total kinetic energy of all the molecules and ions combined. The lowest temperature possible is called absolute zero (it corresponds to -273 degrees Celsius – VERY cold), and it represents no motion of the atoms at all. As you speed up the atoms, their temperature rises. If you slow down the velocity of atoms, you lower their temperature. To understand phases, let's start with a a **solid** crystal at zero degrees kelvin, no kinetic energy whatsoever. The atoms are packed as closely together as they can get and are in an orderly bonded arrangement, like these marbles in a box. As heat or kinetic energy is added to the system, the marbles pick up some velocity, not enough to break the bonds, so they just sit in their orderly arrangement but vibrate back and forth. The more heat, the more velocity, or the higher the temperature. Eventually the marbles start changing partners – as the melting point approaches. One by one they leave their orderly arrangement and begin to flow smoothly around each other as a liquid. They are still confined to close proximity, but they are free to move. Again as heat is added and temperature rises, the motion gets faster, until eventually they move so fast they separate completely from each other and move in space as with no connection to any other water molecule. We call this the gas phase. Now let's do the reverse and start with a high temperature situation – which corresponds to high velocity. If we can take heat or kinetic energy away from this system, the marbles will slow down and get closer together. Their temperature will drop, and the system will contract. Eventually the marbles will get close enough together that they feel each other. Once they are close enough that they develop temporary and loose bonding, they are now like marbles in a jar, swirling around, mixing themselves up, changing partners, but stuck together within a set space. They are much more contracted (denser) and slower than they were as a gas, but they are still free to move as a **liquid**. This picture shows jelly bellies, at the factory, being rotated in drums to create an even shape. The worker here is adding the flavoring and coloring, as the jelly bellies rotate around. This process simulates what's happening at the atomic level in all liquids. The atoms or jelly beans or marbles are in a continually swirling motion, but in very close proximity. With continued heat loss, the velocity slows until atoms are trapped amongst each other, as a solid, often in an orderly arrangement. Like this image of a still jar, the marbles can vibrate in place, but it's difficult for them to change position. Notice that they are packed in an even tighter, denser arrangement.

So… back to water. How is gaseous water naturally present on Earth's surface, when the temperature never reaches that high? To make ALL the water molecules in an area into vapor, we need to get them above 100 degrees Celsius. However, if any single water molecule gets enough velocity to break the hydrogen bonds that keep it next to its buddies, then it can escape the liquid and become a gas. All open bodies of water, including a glass of water left out on your counter, will lose some of their water to the surrounding air. Anyone who's been to a desert region knows how quickly the water in their sweat will evaporate. And anyone who's been to a humid, muggy region knows how quickly water from the air will precipitate on their skin and drench them over time. We'll talk more about that later when we discuss relative humidity.

For most normal substances, as heat is removed from the molecules, they are able to get closer together and become denser. And the solid form is the most dense form. However, water behaves much differently as we know well from having our solid ice cubes float atop our liquid sodas. The solid form of water – ice –is LESS dense than the liquid form Why? The shape of the water molecule of course. As long as water molecules have enough velocity, they can slide in and around each other. However, when they slow down enough, they pack together in a hexagonal structure based on hydrogen bonding. This structure leaves a large hole in the middle of every six water molecules and thus produces a more expanded less dense form.

Dissolving salt in water not only drops the melting point of water, but also raises the boiling point. Antifreeze in your car's radiator follows a similar process. In both cases, you are adding dissolved ions which inhibit water molecules bonding to each other and traps them in hydration spheres around the dissolved ions. Antifreeze makes it harder for the radiator fluid to boil away (has to get even hotter before that happens) and harder for the fluid to freeze (has to get even cooler before that happens). The higher boiling point means that the pasta in your boiling water cooks at a higher temperature (and should be done sooner!), and the lower melting point means that adding salt to roadways means it has to get even colder before ice will form.

Pause now.

For more information and more detail, continue on to the next video in this series.

[End credits]

Seawater Physical Properties Series:
Part I: Water Molecule Shape
Part II: Water Phases
Part III: Water Density
Part IV: Heats of Water
Part V: Light, Viscosity, & Pressure
Part VI: Heat Transfer

Water Phases
Geoscience Video Tutorial
Produced by Katryn Wiese
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