PhyzGuide: The Trouble with Ice

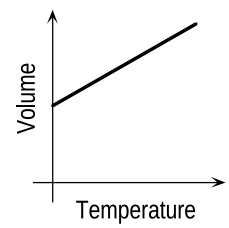
and really cold water, for that matter

LIFE AS WE KNOW IT

Water does something strange when it solidifies. It gets bigger. Among the more important results of this expansion is that life as we know it evolved as it did. Actually, water has many unusual properties key in the development of life on this planet, but those are stories for other science classes.

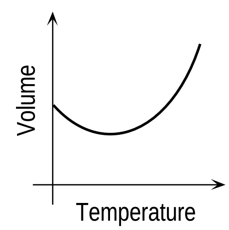
THE WAY IT OUGHTTA BE

At standard pressure, water exists as a liquid in the temperature range of 0°C to 100°C. If liquid water behaved as most substances do, it would expand in a nearly linear direct proportion with temperature. That is, the volume of a given mass of water would increase if it were heated from 0°C to 100°C as depicted on the graph to the right. (Reasons for this expansion are described in painful detail in the "Thermal Expansion" PhyzGuide.)



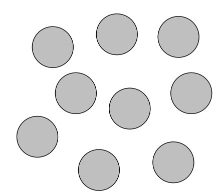
THE WAY IT IS

For the most part—from about 10°C to 100°C—water does what it's supposed to do. But from 0°C to 10°C, it does something that few substances do. Starting from 0°C and warming it up, a mass of water undergoes a contraction! At about 4°C, the volume bottoms out. From 4°C through 10°C, the volume increases in a non-linear fashion. From 10°C on, water is pretty normal.



HOW COME?

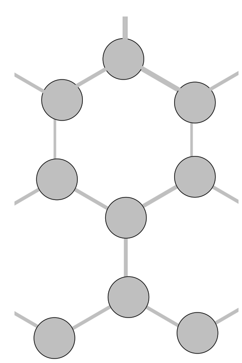
You may already be aware that ice is bigger than water. In other words, when you fill the ice cube tray with water and come back later for the frozen trapezoidal solids, you notice the "cubes" take up more space than the water you made them with: they've risen!



Cold water molecules swimming close to each other.

This happens because when water freezes, the molecules formerly swimming freely in the liquid state lock onto each other in a regular arrangement. This crystal structure is very open and "wastes" a great deal of space. The molecules don't cram in; they leave large open spaces that can't be occupied by anything.

This is unusual. In most substances that can exist as liquids and solids, the solid structure is tighter and thus denser. In water, this pattern is oddly reversed. The solid structure is more open and thus less dense. That's one of the reasons ice cubes float on water. (Another reason ice cubes float is they usually have air bubbles trapped inside.)



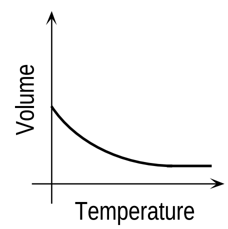
Solid water with molecules in a crystal configuration.

BUT WEREN'T WE TALKING ABOUT *LIQUID* WATER?

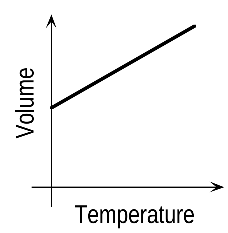
Remember that temperature is a measure of the average kinetic energy associated with random translational motion of the molecules in a sample. Focus on the term average. A sample of water at 10°C has some molecules whose individual kinetic energies correspond to temperatures above 10°C. More important to us are the molecules whose individual kinetic energies correspond to temperatures below 10°C.

As we cool the entire sample from 10°C to 0°C, the low-energy molecules in the sample reach 0°C before the entire sample does. These low-energy molecules start to freeze. That is, they stick to each other and start to form crystal patterns.

As the temperature approaches 0°C, the number of these small-scale crystal structures grows. Water at 0°C has a fair volume of "microscopic slush." This slush isn't apparent upon casual observation and it doesn't give the water the consistency of a Slurpee™, but it *is* there and it *does* have its effect. As the number of microscopic ice rings increases, so too does the volume of "wasted space" associated with the rings.

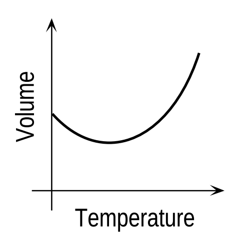


So let us return to the sample of water at 0°C that we heat. As we heat it, the microscopic crystal rings break and the volume of the water decreases. If this were the only thing going on, our volume vs. temperature graph would look like the one shown above and to the right.



Of course, traditional thermal expansion is occurring at the same time. If this were the only thing going on, our volume vs. temperature graph would look like the one shown to the right.

Both effects occur simultaneously. So the actual volume vs. temperature graph is a combination of the previous two graphs.



SO

When bodies of water freeze, they freeze from the top down instead of the bottom up. This allows plant and animal life in large bodies of water to continue beneath the ice.

Water at the bottom of large lakes is 4°C all the time. Water is most dense at this temperature, so 4°C water sinks in water that is colder or warmer. Water warmer or colder than 4°C that finds itself at the bottom of a lake will experience a buoyant force (like the kind that lifts hot-air balloons) and be lifted above the bottom of the lake.