Why Does Ice Float in Water and not in Alcohol?

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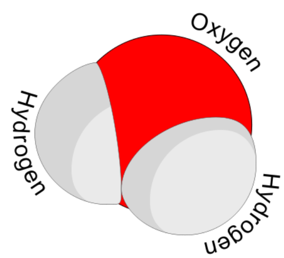
Why does a cube of ice float in a cup of water? In order to answer this question we need first to understand the principle by which something may float when placed into a liquid, and then examine in detail why ice from water floats on liquid water, instead of sinking to the bottom.

In general, a substance floats on the surface of a fluid if the substance is less dense than the fluid. That is, the substance must have less mass per unit volume, than other components in the fluid. For example, a rock placed on the surface of a bucket of water will sink at the bottom of the bucket because the rock is denser compared to the water. The water in the bucket, which is less dense than the rock, will instead float to the top.

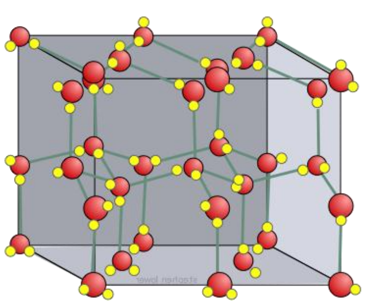
When you place a cube of wood into the bucket, the cube will also push the water out of the way, or displace it, until it reaches equilibrium at which point it will float. You can notice that the level of the water in the bucket went up. If you measure the weight of the volume of water that the cube of wood displaced, you would find that it is equal to the weight of the cube. The cube, because of its mass, is pushing the water down, but it also feels an upward force called *buoyancy*. The buoyancy force is exactly equal to the weight of liquid displaced by the cube. Therefore, the cube of wood floats because it displaces a weight of fluid equal to its own weight. Finally, the volume of the water displaced by the cube is less than the volume of the cube of wood itself; therefore the density of the cube is less than the density of the water. This is true also for fluids floating on the surface of other fluids. For instance oil will float on water because oil is less dense than water.

Now, let's get back to the ice cube in water.

In general, most substances have a lower density when they are in a liquid phase then when they are in a solid phase (frozen). Water is a nice exception. Water reaches its maximum density at 4°C (40°F). As it cools down further and freezes into ice, it actually becomes less dense. The reason for this is found in the molecular structure of water and because of its hydrogen bonding.



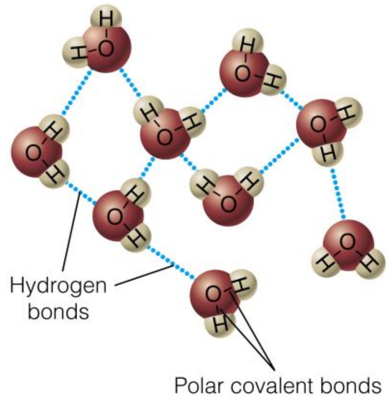
A water molecule is made of one oxygen atom and two hydrogen atoms, strongly joined to each other with covalent bonds. The sharing of the (negatively charged) electrons among the three atoms creates a feature by which overall the charge of hydrogen atoms become slightly more positive compared to the charge of oxygen atom that, instead, become more negative. For this reason, water molecules are also attracted to each other by (weaker) hydrogen bonds between the positively charged hydrogen atoms and the negatively charged oxygen atoms of neighboring water molecules. As water is cooled below 4°C, the hydrogen bonds adjust to hold the negatively charged oxygen atoms apart with space in between. This produces a crystal lattice, which is commonly known as 'ice'.



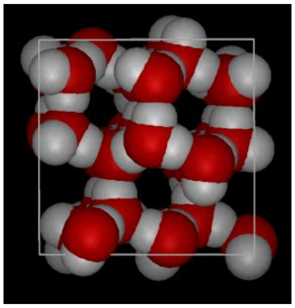
In this configuration, ice water is about 9% less dense than liquid water. In other words, ice takes up about 9% more space than water, so a liter of ice weighs less than a liter of water. Thus, ice water is less dense than liquid water.

One fortunate consequence of this physical phenomenon is that lakes and rivers freeze from top to bottom, allowing fish to survive even when the surface of a lake has frozen over. If ice sank, the water would be displaced to the top and exposed to the colder temperature, forcing rivers and lakes to fill with ice and freeze solid.

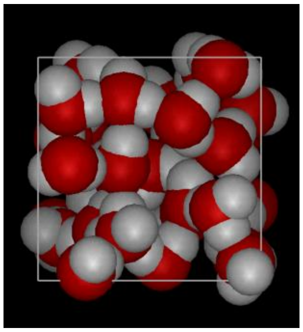
The most energetically favorable configuration of water molecules is one in which each molecule is hydrogen-bonded to four neighboring molecules. Because of the thermal motion of the molecules above the freezing point, this ideal configuration is never achieved in the liquid phase. But when water freezes to ice and thermal energy is removed, the water molecules settle into exactly this kind of an arrangement in the ice crystal.



To make the comparison more explicit, observe here two 3-dimensional views of a typical structure of ice (top) and liquid water (bottom).



Notice the greater openness of the ice structure in the ice, which is necessary to ensure the strongest degree of hydrogen bonding in a uniform, extended crystal lattice when the amount of thermal energy available to the molecules is less.



Instead, in liquid water a more crowded and jumbled arrangement of water molecules is possible because of the greater amount of thermal energy available above the freezing point.

The two arrangements above show that when hydrogen bonding is at its maximum in ice, solid water (ice) has a more open structure, and thus a lower density than liquid water.

What about a cube of ice into a glass of alcohol?

The molecular structure of liquid alcohol is very different than that of liquid water and more complex. In particular, the spacing between molecules in liquid alcohol is larger per unit volume than that of ice. In other words, the density of alcohol is less than the density of water (either ice or liquid). For this reason, the ice cube will sink at the bottom of a glass of alcohol.