

Classroom



In this section of *Resonance*, we invite readers to pose questions likely to be raised in a classroom situation. We may suggest strategies for dealing with them, or invite responses, or both. “Classroom” is equally a forum for raising broader issues and sharing personal experiences and viewpoints on matters related to teaching and learning science.

Fall and Rise of a D_2O Ice Cube in Liquid H_2O

The demonstration described in this article is to show that while H_2O ice floats in water, D_2O ice sinks in water, proving the higher density of ‘heavy water’. This experiment can be done in a classroom or in an auditorium.

Why does ice float on water? The answer to this question is that this behavior is a consequence of hydrogen bonding. As liquid water is cooled and loses energy, water molecules have less random, thermal energy and hydrogen bonding becomes increasingly important. The molecules form an ordered, open crystal structure, called ice, which has less mass per unit volume than liquid water in which the water molecules pack more closely together. Specifically, the density¹ of liquid H_2O at $0^\circ C$ is measured to be 999.9 kg m^{-3} whereas the density of solid H_2O at $0^\circ C$ (which is its melting point at 1 atmosphere pressure) is 915.0 kg m^{-3} . Consequently, ice floats on water, which is a common experience from ice cubes in drinks to icebergs in the ocean.

But what happens when normal water, H_2O , is replaced by heavy water, D_2O ? Here D stands for deuterium, the heavy isotope of hydrogen, which contains in its nucleus one proton and one neutron, in contrast to H whose nucleus consists only of a lone proton. Consequently, D has approximately twice the weight as

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H. Let us consider what happens when an ice cube of D_2O is dropped into a beaker containing liquid H_2O . If we assume that the substitution of D for H did not change significantly the shape of the water molecule, then it is an easy matter to estimate the density of D_2O ice. It should be greater than H_2O ice by the ratio of the molecular weight of D_2O divided by the molecular weight of H_2O , that is $(20/18) \times 916.72 \text{ kg m}^{-3} = 1018.58 \text{ kg m}^{-3}$. By the same reasoning, the density of liquid D_2O is estimated to be $(20/18) \times 999.84 \text{ kg m}^{-3} = 1110.93 \text{ kg m}^{-3}$. Both of these values are only approximate. The actual density [1] of D_2O ice is 1017.5 kg m^{-3} at about 3.8°C (its melting point) and that of D_2O water at the same temperature is $1105.46 \text{ kg m}^{-3}$. Thus, it seems clear that just as normal ice will float on normal water, heavy ice will float on heavy water but sink in normal water.

It is fun as well as highly instructive to do this demonstration for a class. A video shows what happens [2]. To help tell apart the normal water ice cubes from the heavy water ice cubes, a little bit of green food coloring was added to the latter. As the video clip shows, when heavy water ice cubes are put into a beaker containing normal water at room temperature, the heavy water ice cubes sink right to the bottom of the container. There are slight changes in the density as a function of temperature but these changes are so small that they can be ignored. It might be thought that the sinking of the D_2O ice cubes is the end of this story, but with a little patience, it is seen [2] that as the heavy water ice cubes melt, they begin to rise (*Figure 1*)!

Figure 1. The D_2O ice is seen at the 'interface' of colorless H_2O and greenish D_2O layers.



What is causing the resurrection of heavy water ice cubes in normal water? The explanation becomes apparent by looking also at the food coloring dye that is being released into the solution. It does not uniformly mix but instead slowly diffuses away from the heavy water ice cubes. The same happens to the heavy water molecules from the heavy water ice cube. Because diffusion is such a slow process, this liquid heavy water collects at first at the bottom of the beaker and then the heavy water ice cube floats on its own melt. There is some mixing with the

normal water but it is so slow that the heavy water ice is still levitated. Of course, the heavy water ice cubes do not rise to the top of the beaker as the amount of heavy water coming from the melting of the heavy water ice cubes is limited by the volume of the heavy water ice cubes that were added.

A search reveals that several other video clips have been made [3–8] of what happens when a D_2O ice cube is added to liquid H_2O . Many of these videos do not show the subsequent rise of the D_2O ice cube, and those that do either provide no explanation or an incorrect explanation. Demonstrations are often most effective when some element of what is observed is not initially expected. This element of surprise stimulates deep thought about what is observed. This demonstration serves as an excellent way for a class to understand the slowness of diffusion in a liquid solution (Box 1).

Box 1.

In case this demonstration needs to be done at a different location, one of us (UM) has found that small samples of D_2O and H_2O , colored differently with commercially available food colors, can be easily carried in 5 mL disposable plastic syringes with the tip and the back portion cut. The front opening can be sealed with parafilm. These samples can be frozen by keeping them in an ice-salt bath for about 30 minutes. The colored ‘ice cylinders’ could then be pushed out with a stiff wire into *ice-cold* water taken in a 100 mL measuring cylinder (Figure A). With both D_2O and H_2O ice pieces in ice-cold water, one can easily observe that the H_2O ice melts a bit faster than the D_2O ice because of the higher melting point of the heavy water ice (Figure B).

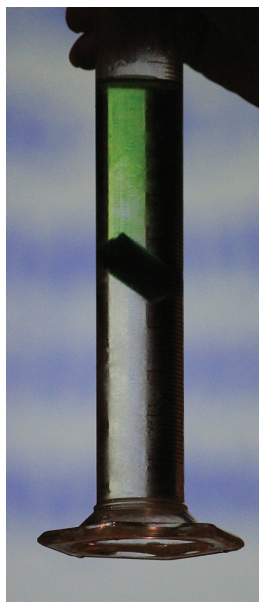


Figure A. A small piece of D_2O ice colored green is sinking in ice-cold water.

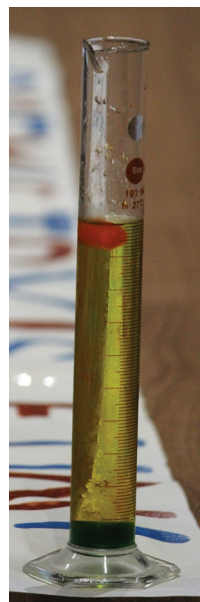


Figure B. Orange H_2O ice floating in cold water while the green D_2O ice is at the bottom.



Suggested Reading

- [1] http://www.idc-online.com/technical_references/pdfs/chemical_engineering/Water_properties.pdf
- [2] <http://www.mediafire.com/watch/8v78bc7smx2gb4p/HeavyIce.wmv>
- [3] <https://www.youtube.com/watch?v=2iIAuSEry6I>
- [4] <https://www.youtube.com/watch?v=hUVzb0fzHsk>
- [5] <http://mathscinotes.com/2014/02/heavy-water-ice-cubes-do-not-float/>
- [6] <https://www.youtube.com/watch?v=IgGlFbTN9g>
- [7] http://www.jce.divched.org/video/heavy-water-ice-cubes-deuterium-oxide?0=ip_login_no_cache%3Ded4c48369a704c4312f29e4b2382d9a5
- [8] <http://bcs.whfreeman.com/WebPub/Chemistry/ichem5e/Videos/A%20physical%20property%20of%20heavy%20water.htm>

