Density Bottles

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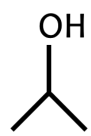
Overview

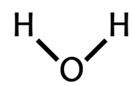
Did you ever wonder about seeing different layers of liquids (like a layered drink) separate from each other in a glass? It looks amazing, right? Do you know why this happens? Here, we will explore the phenomenon of density separation.

Theory

If you buy isopropyl alcohol at the store, the option you're most likely to encounter is labeled "70% isopropyl alcohol". This means that, by volume, the solution in the container is 70% isopropyl alcohol and 30% water. Isopropyl alcohol and water mix easily in this solution, because they are both *polar* — there are parts of each molecule that "pull" on electrons more strongly than other parts, leading to partial positive and negative charges within the molecules. Let's take a molecular view:



A representation of the isopropyl alcohol molecule. A central carbon is bonded to two methyl groups and an OH group.



A representation of the water molecule. An oxygen atom is bonded to two hydrogen atoms.

In both of these molecules, the oxygen atom "wants" electrons more than the atoms around it. The electrons tend to spend more time hanging around the oxygen than those neighboring atoms, so the oxygen gets a partial negative charge, and the neighboring atoms get partial positive charges. The positively-charged atoms within isopropyl alcohol molecules are attracted to the negatively-charged atoms within water molecules, and vice-versa, so the two types of molecules can bond together and mix into solution.

Of course, polarity isn't the only important characteristic of a molecule (though it is pretty darn important). Isopropyl alcohol and water have different *densities*. Density is a measure of the amount of matter — the amount of "stuff" — in a given volume of a substance. You probably know that a cup made of glass will be a lot heavier than a cup made of Styrofoam, even if the cups are the same size. This is because the density of glass is much greater than the density of Styrofoam. You also probably already know another thing about density: It can be used to separate different elements of a mixture. Ice floats on top of liquid water because ice is less dense than liquid water. Oil floats on top of vinegar in a bottle of salad dressing that's gone a while since its last good shake because oil is less dense than vinegar. We should be able to separate out isopropyl alcohol and water, if we can just solve this pesky polarity problem.

To get our density separation, we will actually leverage polarity. Check out the molecular structures above again. The "bottom" end of the isopropyl alcohol molecule is a whole bunch of carbons (and hydrogens). There's not much difference at all in how much any of those atoms "wants" electrons, so that part of the isopropyl alcohol molecule is *nonpolar*. The water molecule is polar, because the oxygen "wants" electrons. This means that if we add an *ionic compound* — one in which a positively- and negatively- charged atoms are held together by electrostatic forces — it will “like” water more than they “like” isopropyl alcohol. It’s more favorable for the charged atoms in the compound to bind with a more-polar molecule than a less-polar one. Before adding salt, you will see that the water and alcohol mix very well with each other. Fortunately, most of us have an ionic compound on hand at all times: salt. Common table salt is (mostly) NaCl — an ionic compound of sodium and chloride.

If you add salt to 70% isopropyl alcohol, the salt will preferentially bind with the water molecules rather than the alcohol molecules. Add enough salt (like, a LOT of salt), and you’ll “force out” all the isopropyl alcohol molecules from the salty water. The salty water is more dense than the isopropyl alcohol, so you’ll end up with two layers, separated by density: nearly-pure isopropyl alcohol on top, salty water on bottom (and some loose salt at the very bottom, because you added a LOT of salt). Once the layers are separated, the differing polarities of each layer can again be leveraged to enhance the visual drama of the separation — some pigments are more polar and will “stick” in the water layer; others are less polar and will “stick” in the alcohol layer. The density separation point can also be further emphasized by adding bits of different types of plastics (check the resin code — the little number inside the “recycle”-looking symbol — to identify the type), which often differ in density and thus in stable position within the layers. This is an easy, inexpensive, and highly engaging and edifying classroom activity for students who can safely handle common household chemicals.

Doing the activity

SAFETY NOTE: Isopropyl alcohol is readily flammable. Always keep alcohol well away from open flames and other intense sources of heat.

Before-class prep: *Wearing disposable nitrile gloves, cut and/or break open the highlighters (this can take some effort!), and extract the dye-filled cores. Store the cores in tightly-sealed plastic bags until ready for use. You can also cut up the bits of plastic, but you may choose to have your students do this, so they can see where the pieces came from.*

Necessary materials:

- clear plastic or glass bottles with lids
- 70% isopropyl alcohol
- water
- table salt (non-iodized)
- variety of highlighters
- food coloring
- bits of plastic (cut-up pieces from

1. Elicit your students’ prior knowledge around density. Have they noticed that ice always floats on liquid water? That oil separates out from vinegar in salad dressing? Other interesting examples? Get a sense for their level of understanding of the physical reason for these phenomena. Tell them that they’ll be doing an experiment to explore their ideas.
2. Have students add some bits of plastic to their bottles. Encourage them to pick out a mix of different types of plastic, so they can compare the behavior of each.
3. Fill the bottles a bit less than halfway with isopropyl alcohol. Wearing disposable nitrile gloves, add few drops of highlighter color to the alcohol (it’s generally best if you, the instructor, do this step, to avoid much staining of clothing), then mix very well. Encourage your students to observe carefully: Do the isopropyl alcohol and highlighter fluid make a solution? What’s happening to the different plastic pieces? What might explain these observations?
4. Add a volume of water to each bottle that is approximately equal to the volume of isopropyl alcohol. Add few drops of food coloring, and mix well. Again, encourage your students to observe. What’s happening to all the different components of the bottle? Why might this be?
5. Add a LOT of salt to the bottles. You will think you have added enough salt. You need more salt. You will need a volume of salt approximately equal to half the volume of water

in the bottle. It is a LOT of salt. Close the cap of the bottle and shake the bottle vigorously. After shaking it well, give the mixture some time to settle out. As before, ask your students to observe the settling process closely. Do they notice any trends or patterns emerging?

6. When the solution settles out, you should observe two distinct layers of liquid: the top layer contains isopropyl alcohol and highlighter fluid; the bottom layer contains salty water and food coloring. (If you do not observe two layers, try — you guessed it — more salt.) Hopefully, you also have different types of plastics floating at different depths in the bottle.

An image of a just-shaken (fully mixed) density bottle (well, this one's a jar, but you get the idea). The mixture in the bottle appears to be uniformly purple.

An image of the same density bottle as it's in the process of settling out. A pink layer is forming at the top of the bottle and a blue layer is forming at the bottom, but there's still a murky purple band in the middle.

An image of the same density bottle, now fully separated. The pink layer on top contains isopropyl alcohol and highlighter fluid. The blue layer below contains salty water and food coloring. A 6-sided die is floating at the sharp interface between the layers.

7. Using students' prior knowledge, original hypotheses, and observations throughout the activity, work together as a class to develop a theory that explains students' observations of the jars. This is a pretty convincing and striking way for students to come to the concept of density!

As an extension, you can try making more bottles with different liquids. Vegetable oil and corn syrup may be interesting additions!

Summing up

Once students have a solid grounding in the concept of density, explorations of many fascinating applications are open to you. Applications of density are relevant in fields as different as recycling (density separation of plastics is common) and astronomy (density has a key role in determining the layered structures of planets and stars).

For more information

Little Shop of Physics: https://www.lsop.colostate.edu

Colorado State University College of Natural Sciences: https://www.natsci.colostate.edu