Science-1A Lab: Week-14, Wednesday April 21, 2021

Interesting Molecules, Red Cabbage pH Indicator, Liquid Nitrogen and more

Interesting Molecules

Chlorophyll in plants is associated with their green color and hemoglobin in oxygenated blood is associated with its red color. The connection between these two is closer than one might expect. They are shown on page 11 on the molecular structures handout at
https://yosemitefoothills.com/Science-1A/Handouts/Week-09/AllMolecularStructureImages.pdf
The molecule **heme B** is the key molecule in hemoglobin, and **chlorophyll a** is one form of the key molecule for photosynthesis in plants. Their animations are at
https://yosemitefoothills.com/Science-1A/MolecularAnimations/Others/Heme-B.gif
and
https://yosemitefoothills.com/Science-1A/MolecularAnimations/Others/Chlorophyll-a.gif

You can see that their structures look remarkably similar with a flat section holding a metal atom in its center. For heme, that metal atom is iron Fe, and for chlorophyll it is magnesium Mg. This is likely a case of Nature re-purposing a good old idea used in plants when it needed to build a means to carry oxygen within larger collections of cells in animals. The structures holding these metals have paths of alternating double and single bonds. We saw such alternating double and single bonds in benzene and learned that the “extra” electrons making the double bonds are actually shared around the entire benzene ring. There is a similar situation here where the ring path is much larger.

The amount of light scattered off objects much smaller than the wavelength of the light is inversely proportional to the 4th power of the light wavelength. As a result, the amount of red light (wavelength of 660 nm) scattered by air molecules is much less than blue light (wavelength 425 nm) by a factor of $(425\text{ nm}/660\text{ nm})^4 = 0.17$. That is why Hawaiians get a blue sky from the sun while we are watching our reddish sunset.

So why are plant leaves green and blood red? We did not talk about paints and colored plastic films, but red paint and red blood are actually reflecting red and absorbing the other colors. Similarly the green color of **chlorophyll a** is because the molecule absorbs blue and red light and reflects green light (and also, by-the-way, infrared light). The mechanism for this is closely tied to the array of double and single bonds, but is too complicated for a simple explanation other than that the path around the alternating single and double bonds is relatively large encompassing 18 atoms. That much longer distance allows for a much stronger interaction with visible light than for the much smaller air molecules in the sky. In effect, these molecules have much better antennas for selectively absorbing and reflecting visible light wavelengths.

In the fall, the chlorophyll molecules of many trees change their bonding configuration as nutrients are pulled back toward their roots. These new configurations no longer have the same absorption and reflection characteristics; their leaves turn from green to yellow and red giving us fall colors.

Red Cabbage pH Indicator

A famous class of colored molecules is the anthrocyanins, one of which I have featured on a handout at
https://yosemitefoothills.com/Science-1A/Handouts/Week-12/RedCabbageAsApHIndicator.pdf .
There, you can see that it has an abundance of alternating single and double bonds that change depending on the pH of the surrounding solution. The test tubes shown in the picture show the colors that appear at different pH values.

To make it, take a 500 mL beaker, add about 300 mL of water, fill it with pieces of red cabbage, and boil it for two or three hours. As a result, the molecules providing its red color will move into the water. This process is called “steeping” in cooking terminology. At the end, the cabbage pieces will be blanched. Remove them from the hot liquid, let the liquid cool, and filter the solution through a coffee filter. The resulting solution is our red cabbage pH indicator. You might make it more concentrated by additional water evaporation (distillation). Unfortunately, if you try to store it for more than a few days, a mold will start to grow. That might be useful for biology experiments, but I have no idea what kind of mold it is and if it is dangerous.

Some (about 1 cc) of this indicator can be added to 3 test tubes, one containing about 5 cc of household ammonia (2.5% ammonium hydroxide NH_4OH, $pH \approx 11.3$), a second with 5 cc of pure water (H_2O, $pH \approx 7.0$), and the third with 5 cc of household vinegar (5% acetic acid, CH_3COOH, $pH \approx 2.4$). Since vinegar is used on salads, it is certainly safe in an elementary school classroom. The ammonia is a common cleaner for homes and has a pungent odor which should keep kids away. Acetic acid and ammonia are certainly dangerous in concentrated form, but these are well-diluted solution for household use.

I have taken ashes from my fireplace, soaked them overnight in water, filtered out the remains to obtain lye (NaOH and KOH), a quite nasty caustic base that should be handled with care. It has a pH of about 13 and produces a greenish-yellow color with our red cabbage pH indicator solution. Strong bases like those in lye dissolve the fats in our skin and therefore feel slimy. Eye protection should be worn and lye should be thoroughly washed off if it gets on skin.

Lye has been used to make soap. See the handout at
https://yosemitefoothills.com/Science-1A/Handouts/Week-10/Soap.pdf .

There is a process for determining pH more accurately called **titration**. It involves using an indicator solution that clearly shows a particular reference pH, like 7.0. A known amount of acid or base is carefully added to a measured amount of the mystery solution until the indicator color shows that the reference pH has been reached. Knowing how much of the known acid or base was added along with some simple calculations reveals the pH of the unknown solution.

There are also litmus paper strips that are inexpensive ways to test if a solution is acidic or basic. See
https://en.wikipedia.org/wiki/Litmus
One source is,
https://www.amazon.com/Blue-Acid-Indicator-Strips-Combo/dp/B07FW53VJS/ref=sr_1_10?dchild=1&keywords=litmus+paper&qid=1588376760&sr=8-10

Measures of Concentration of Solutions

There are three common terms that are used to describe the amount of stuff (**solute**) in a solution (**solvent**). They are the **salinity**, **molarity**, and **solubility**. (Chemistry has a long history and with it, unfortunately for students, came lots of different and confusing measurement units.).

Salinity: The many, easily-confused different ways of measuring salinity are explained at
https://en.wikipedia.org/wiki/Salinity .
To keep things simpler here, I am just going to use the one mentioned in question 7 in the Sample Questions for Quiz 7 which reads:

> 7. (2 points) The number of grams of salt dissolved in 1000 grams of salty water is called the **__salinity__** of the water. It is expressed with the symbol ‰ (per thousand) to distinguish it from the symbol % (percent).

Molarity: This is used to quantify the concentration of a dissolved substance in water. It is number of moles of the substance dissolved in 1 liter of water, and is written in square brackets like [NaCl]. Molarity is given the unit abbreviation of simply a capital M, but I prefer to write its unit out more clearly as mol/L.

When the substance in question is hydrogen ions, this becomes $[H^+]$ mol/L. It is this concentration that must be used when calculating pH using $pH = -\log_{10}[\mathrm{H}^+]$ and it is this unit that results from $[\mathrm{H}^+] = 10^{-pH}\,\mathrm{mol/L}$.

See the handout entitled Water and Solutions at
https://yosemitefoothills.com/Science-1A/Handouts/Week-12/WaterAndSolutions.pdf
for a detailed explanation of why pH is so important and more about calculations involving pH.

Solubility: This is the maximum number of g of a salt that can be dissolved in either 100 mL or 1 L of a solvent and is expressed as g/100 mL or g/L, respectively.

When growing NaCl crystals, you need to prepare a **saturated** solution by looking up the solubility of NaCl in water, and adding a bit more salt than that to be sure. Since the solubility of NaCl in water is 360 g/L, you might add 380 g to 1 L or 38 g to 100 mL. It will take a while to dissolve to the maximum amount. Stirring and heating will help. When done and your solution has cooled down, any extra salt will form tiny crystals which should be filtered out by running your solution through a coffee filter. Your final, filtered solution will be a saturated solution that will then gradually lose water over the next few weeks causing new crystals to form. Growing a large crystal involves selectively removing the smaller crystals and regular stirring. We discussed this earlier at
https://yosemitefoothills.com/Science-1A/OnlineLectureAndLabNotes/Week-10-Lab-Wednesday-March-17-2021.pdf .

Reactions Producing CO_2 Gas

There are three common chemicals that give off carbon dioxide bubbles when household vinegar is added. They are calcium carbonate $CaCO_3$ (chalk), baking soda $NaHCO_3$, and washing soda Na_2CO_3. By adding the same amount (about 1 cm^3) of these as powders to 5 mL of vinegar in 3 test tubes, differing amounts of carbon dioxide bubbles can be observed. Baking soda is the most reactive of these and is therefore used with vinegar in elementary school "volcano" demonstrations. Chalk reacts very slightly, and washing soda is in between.

The reaction equations for these and descriptions of other simple chemical tests are at *https://yosemitefoothills.com/Science-1A/Handouts/Week-11/ChemicalAnalysis.pdf* .

Liquid Nitrogen (LN_2)

Perhaps the thing you will miss the most because of our social distancing is our use of liquid nitrogen. We normally make liquid nitrogen ice cream which uses the low temperature of liquid nitrogen to freeze a mixture of sugar, half-and-half, milk, and vanilla. This is safe because liquid nitrogen is just nitrogen gas like 79% of the air we breathe. It boils (yes *boils*, its boiling temperature is -196 ^oC = 77 K) as it cools down the ice cream mixture and disappears into the air. The liquid nitrogen is added slowly, a little bit at a time, so that the mixture remains soft enough to stir. A stainless steel bowl and a wooden stirring spoon are used because plastic items easily break when cooled by liquid nitrogen. Be sure not to swallow the liquid nitrogen or to eat the ice cream when it is far below freezing.

A recipe for making liquid nitrogen ice cream is at the following link:
https://www.stevespanglerscience.com/lab/experiments/liquid-nitrogen-ice-cream/ .
Welding supply stores are likely to sell liquid nitrogen. A few liters is needed which can be quite costly (about $50). The liquid nitrogen stays at 77 K until it has completely boiled away just as water stays at 100 ^oC until it has completely boiled away. All heat that enters is used to change liquid to gas, not to warm up the liquid.

I worked with liquid nitrogen and liquid helium for 30 years, and my kids were dipping flowers, etc., into it from when they were 2 years old. If you put your hand in it for **½ second**, it is unable to damage your hand because a layer of bubbles is generated between your hand and the liquid. That bubble layer greatly reduces the heat loss from your hand. Leaving your hand in for much longer can give you a bad case of frost bite and you might lose your fingers. When pouring it, you don't want it to spill down your shirt sleeves or onto your lap. Be careful. Living cells cooled to 77 K freeze and expand like ice. That will usually kill them by shattering their surrounding cell membranes. Sometimes, however, when low-temperature physicists warm up their experiments, they find spiders that survived cooling to 4 K.

After making the ice cream, we can play with the liquid nitrogen. First, a length of soft plastic (Tygon) tubing can be dipped into the liquid nitrogen for about a minute until the frantic boiling ceases as the tubing finishes cooling. Then, when it is pulled out and the frozen end hit with a hammer on the floor, it shatters like glass. If you watch glass-blowing videos, you can see that hot glass is soft and flexible, but as it cools to room temperatures it becomes brittle. It is the same with rubbery things (including fingers) at room temperature. When they are cooled by liquid nitrogen, they become brittle.

Remember, nitrogen gas is not poisonous, but it does not support life. When workers entered a deep tank that had held nitrogen gas, the first one collapsed at the bottom. The next person went down to help, but he also collapsed. Both died for lack of oxygen. You do not want to be in a space that has been purged of air by evaporating liquid nitrogen. Your body does not notice a lack of oxygen in your lungs, only an excess of carbon dioxide. People can simply pass out and die without any warning if they are exhaling carbon dioxide while breathing air that lacks oxygen.

Paper dipped in liquid nitrogen looks wet when pulled back out, but the liquid nitrogen "wetness" soon disappears and the paper is back to normal although perhaps still a little cool.

Another fun demonstration is to pour the liquid nitrogen on the floor. It forms evaporating droplets that skeeter along the floor and collect dust. Quit a sight. You may have observed what a little bit of water does when it falls on a hot skillet. It forms small droplets that dance around the skillet on cushions of their rapidly-evaporating gas.

A coil of copper wire that measures hundreds of ohms resistance lowers its resistance to tens of ohms when cooled to 77 K. This is not superconductivity, but just that the copper atoms jiggle less at the lower temperatures and therefore obstruct the flow of electrons less.

Superconductivity, by the way, happens in lead, aluminum, tin, and many other metals, but not in copper, silver, or gold. It is an abrupt cessation of all electrical resistance below a certain “critical” temperature because of very magical quantum mechanical effects that required 50 years for physicists to explain. The powerful magnets of MRI machines used in hospitals are made possible by the use of superconducting magnets cooled to the temperature of liquid helium (-269 ºC = 4 K).

Finally, another amazing quantum phenomenon happens when liquid helium is cooled below 2.172 K. It becomes a “superfluid” able to flow through extremely tiny pores and also able to carry heat with an efficiency much better than pure copper. When pumping on liquid helium at 4 K, it bubbles furiously and slowly cools down as the hotter atoms are pumped away. When it reaches 2.172 K, all bubbling abruptly ceases; no bubbles can form because all extra heat is immediately carried to the atoms at the liquid surface.

To earn credit for this lab, report that you have done the following:

1. Read this handout.

2. Looked at the animations of heme and chlorophyll at
   https://yosemitefoothills.com/Science-1A/MolecularAnimations/Others/Heme-B.gif
   and
   https://yosemitefoothills.com/Science-1A/MolecularAnimations/Others/Chlorophyll-a.gif

3. Read the handout about red cabbage indicator and imagined making and using some for a K-6 classroom.
   https://yosemitefoothills.com/Science-1A/Handouts/Week-12/RedCabbageAsApHIndicator.pdf .

4. Read the handout entitled "Water and Solutions" at
   https://yosemitefoothills.com/Science-1A/Handouts/Week-12/WaterAndSolutions.pdf

5. Wished that COVID-19 had not prevented us from making LN_2 ice cream and playing with LN_2.