DNAZone Classroom Kit Teacher Guide

Kit title	Kitchen Chemistry: Edible Emulsions
Appropriate grade level	High school, Advanced middle school
Abstract	This series of small experiments is designed to reinforce the concept of solubility and introduce the idea of dispersions. Students test solubility with chewing gum, sugar, chocolate, oil and water. Emulsifying agents are introduced to create an emulsion with oil and water. Then, foam is created with air and juice. The last part of the kit is to make an emulsion formed with chocolate and juice to form a Chantilly.
Activity time	Approximately one hour (three 20-minute modules): • 20-minute chocolate Chantilly demonstration • 20-minute sugar, salt, gum solubility activity • 20-minute oil/water mixture activity **An additional optional mozzarella activity takes about 1 – 1.5hr (access to a stove is required)*
PA Department of Education standards	**Science** **3.4.7.A** Describe concepts about the structure and properties of matter. • Distinguish compounds from mixtures. Describe and conduct experiments that identify chemical and physical properties. **Food Education** **11.3.9.G** Analyze the application of physical and chemical changes that occur in food during preparation and preservation.
References	Chamber, Iv, and C. S. Setser. Illustrating Chemical Concepts through Food Systems: Introductory Chemistry Experiments. *Journal of Chemical Education*. [Online] **1980,** *57*.4: 312. http://pubs.acs.org/doi/pdf/10.1021/ed057p312 (accessed June 21, 2012). Grove, Nathaniel. JCE Classroom Activities. *Journal of Chemical Education*. [Online] **2003,** *80*.10: 1139. http://pubs.acs.org/doi/pdf/10.1021/ed800135j (accessed June 21, 2012). Myers, Grace. EHow ("Science Projects on Gelatin Enzymes"). http://www.ehow.com/info_7958252_science-projects-gelatin-enzymes.html (accessed June 21, 2012). Class materials from Dr. Subha Das at Carnegie Mellon University
Kit creation date	June 21, 2012

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"Kitchen Chemistry: Edible Emulsions" Overview

Educational Objectives

- Overview of solubility
- Basic chemistry of how emulsions work

Teacher Preparation Time

Teachers should reserve a kitchen space with microwave and sink. Ingredients in kits will be ready to use right away, but teachers are asked to clean dishware before use.

Class Time

Approximately 60 minutes (or three 20-minute modules)

Materials Needed for the Core kit

- "Kitchen Chemistry: Edible Emulsions" teacher and student kits (included)
- Microwave
- Water
- Ice

Materials Needed for the Optional Mozzarella Activity

- "Kitchen Chemistry: Edible Emulsions" teacher and student kits (included)
- Microwave
- Stove
- Non-ultra-pasteurized milk
- 5 quart or larger non-reactive pot
- Measuring cups and spoons
- Knife (could be plastic) and slotted spoon

Required Student Knowledge

- Chemical Structure Notation
- Polarity of Water and various every day food chemical

Background

The solubility aspects of this experiment are meant to be exploratory and reinforce chemical concepts within a food chemistry context. The structural and microscopic image of dissolving salt in water can be overviewed by showing the spheres of hydration around the Na^+ and Cl^- ions. Dissolved salt can segue to dissolving sugar as well. The structures of oil and water can be compared to show their different polarities and explain the nature of their immiscibility, or the lack of homogeneous mixing of two substances. Oil rises to the top of water because of their respective densities (water is 1 g/cm^3 and cooking oil used here is around 0.9 g/cm^3).

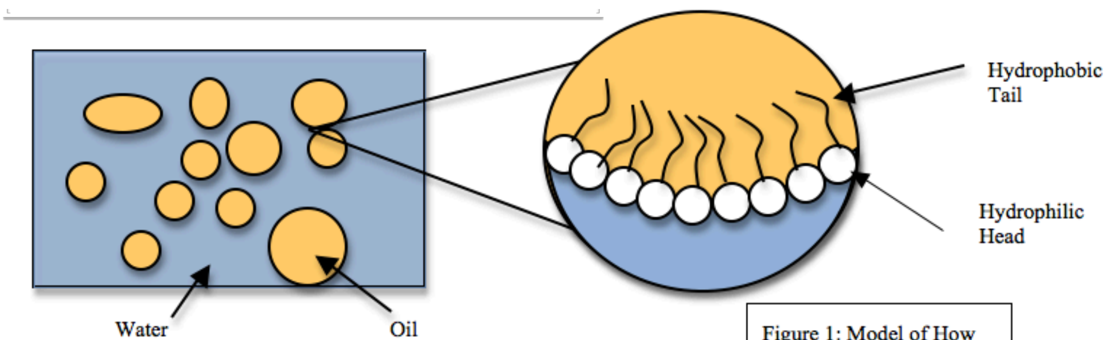


Figure 1: Model of How and Emulsion Forms

Adding food coloring to the oil/water mixture shows the miscibility, or ability to mix homogeneously, of the food coloring with the water and not with the oil. The surface tension of water can also be observed as the food coloring is poured slowly into the separated oil/water mixture. It will build up below the oil but above the water. Once enough food coloring is there to break the surface tension, it will mix with the water.

Adding detergent to the oil/water mixture will form an emulsion of the oil and water as the foam settles down. The mixture is stabilized by the emulsifying properties of the detergent because of the hydrophobic and hydrophilic qualities of the detergents molecules (Figure 1). The hydrophobic end associates more with the oil and the hydrophilic end associates more with the water. When shaken up the detergent molecules will surround droplets of oil or water depending on which has a larger volume in the mixture.

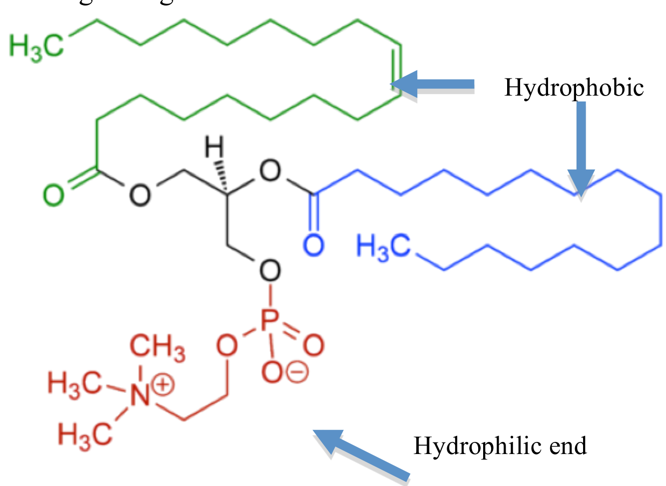


Figure 2: Phophatidylcholine

Adding soy lecithin to the oil/water mixture then does a very similar thing because of the phospholipid molecules that makes up lecithin. It can be found in egg yolks, the emulsifying agent in mayonnaise, and also can be extracted from soy beans. Phosphatidylcholine is the phospholipid of lecithin (Figure 2). It consists of a charged amine and phosphate group at one end (hydrophilic due to charged atoms) and a long carbon chain at the other end (hydrophobic because lack of charge or polar bonds).

For the foam creation, the phospholipids again stabilize the droplets of air within the liquid, which is mostly water based. The hydrophobic ends will surround air forced into the liquid with the frother and the polar water will surround the hydrophilic end. Air mostly consists of non-polar diatomic molecules of nitrogen and oxygen that favor hydrophobic environments more than polar ones.

The emulsion of the chocolate Chantilly forms because of the presence of lecithin already within the chocolate. The chocolate and water are heated to melt the fats in the chocolate. Once melted and seemingly homogeneous, the mixture is whipped vigorously and the water or juice starts forming into droplets within the fatty chocolate. The lecithin surrounds the droplets of water with the polar phosphate end and the fatty chocolate is then interacting with the non-polar carbon chains of the fatty acids of the lecithin molecule.

For students interested in learning more, emulsions are part of a larger class of mixture called dispersions or colloids. Dispersion is simply one substance in a state of matter, suspended in another substance in that same state or another one. Many other food examples and everyday items are dispersions as Table 1 highlights.

Table 1: Adapted from materials at FoodEducation.com

		Dispersed phase (droplets, bubbles, particles)		
		Gas	Liquid	Solid
Continuous phase	Gas	**Gas/gas mixture** (air)	**Liquid aerosol** (deodorant spray, vegetable oil spray, fog/clouds, sneeze)	**Solid aerosol** (powder fire extinguisher, smoke, asthma inhaler)
	Liquid	**Foam** (meringue, whipped cream, soap foam)	**Emulsion** (mayonnaise, butter, vinaigrette)	**Suspension** (fruit juice, drinking chocolate, milk, paint, tooth paste)
	Solid	**Solid foam** (bread, foam rubber, pumice)	**Gel** (jelly, cheese, boiled egg, meat, vegetable- and fruit flesh)	**Solid suspension** (coloured plastic, granite)

The concept of water solubility of various sweetening agents is also explored in this activity. The structures of the three sweetening agents used here, sucrose, sucralose and aspartame, are illustrated below. Sucrose is the most common sweetening agent and is extracted from cane; it is a disaccharide, meaning it is composed of two sugar monomers (one fructose, one glucose). It contains multiple polar functional groups, such as alcohol (-OH) and ether linkages (C-O-C), which participate heavily in hydrogen bonding with water. Therefore, sucrose is readily soluble in water.

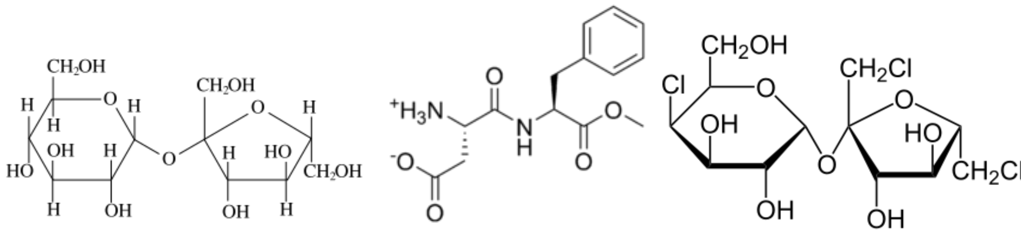
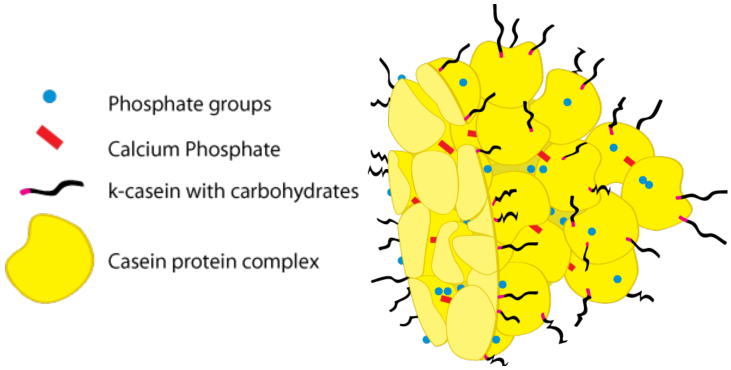


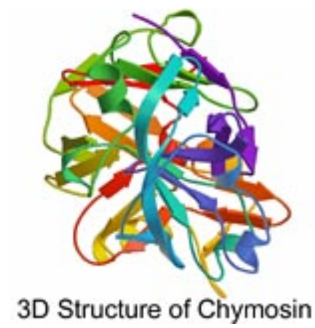
Figure 3. (From left to right) sucrose, aspartame, sucralose.

Advancement in the food industry regarding sweetening agents is propelled by three factors: 1) increasing the sweetness, 2) decreasing the amount consumed for more efficient metabolism and/or excretion and 3) more efficient synthesis on an industrial scale. Aspartame (NutraSweet) was approved by FDA in 1981, and is found to be 160-200 times sweeter than sucrose by weight. The exact mechanism of the detection of increased sweetness is still an on-going research; however, it is believed taste receptor cells (TRC) are responsible for all five basic modalities (bitter, sour, sweet, umami, salty) and are located everywhere on the tongue. Difference in structure of these sweetening agents could have different binding affinity with the TRCs and hence accelerated detection or transmission. Moreover, aspartame differs from sucrose greatly in structure; the former is essentially a terminally methylated dipeptide, or two monomers of amino acids (which are building blocks of proteins). The industrial synthesis pathway of aspartame is significantly easier than any saccharide-based or other sweeteners. Aspartame contains multiple functional groups: while some are capable of having hydrogen bond interactions with water and aspartame is ionic in a neutral pH environment, it also contains a very hydrophobic group in the phenyl substituent; therefore, aspartame is only slightly soluble in water.

Sucralose (Tate & Lyle) is a close derivative of sucrose in terms of structure and was approved by FDA in 1998; it is determined to be 600 times sweeter than sucrose by weight! In sucralose, alcohol groups are replaced with chlorides at the 4' position of glucose in a different geometric conformation (i.e. the Cl group is pointing up instead of down), and 1' and 6' positions of fructose. While the C-Cl bonds are not as polar as C-O/O-H bonds, they still have significant dipole moments and sucralose is soluble in water. In addition, the human body lacks an enzyme to metabolite, or digest, sucralose due to the aforementioned modifications; as a result, the body can process sucralose through the digestive system and excrete it out of the system without gaining any calories.

The making of mozzarella cheese is one of the classic examples of kitchen chemistry due to its simplicity and the several important concepts it demonstrates. Milk is mainly composed of water, protein, lactose and fat; the water soluble proteins are called whey, and the water insoluble proteins are called casein. Casein is a family of phosphoproteins: they have a micelle structure, with negatively charged phosphate groups on the outside. Rennet contains chymosin, a protease enzyme which breaks apart proteins (in this case, caseins) at specific locations.





When citric acid is added to milk, the phosphate groups on caseins are protonated. Then when rennet is introduced, the chymosin removes the outer hydrophilic layer of caseins and leaves behind the hydrophobic core. The hydrophobic remains of caseins form complexes with each other due to hydrophobic interaction, and in turn surround the milk fat molecules. By stretching the curds, multiple casein-milk fat complexes aggregate, forming cheese.

The concept of molecules having hydrophobic and hydrophilic ends and forming shapes like the micelle structures of the droplets in emulsions and foams can be related to many biological phenomena. The phospholipid bi-layer of cell membranes is formed based on hydrophobic interactions. Many proteins fold and form their tertiary structures (overall three dimensional orientation of protein) based on hydrophobic and –philic interactions. Also the structure of DNA arises from charged phosphate groups on the outside of the helical structure and nucleotide bases within the strand. The nucleotide bases form favorable interactions with one another (hydrogen bonds) and the charged phosphate groups on the outside are favorable with polar environments of water.

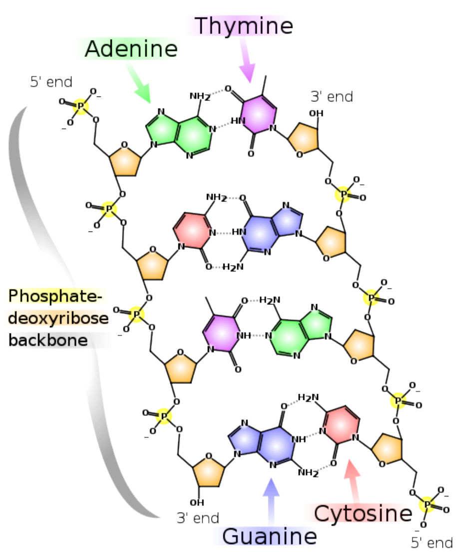


Figure 4: DNA close up of base pairs. Charged phosphate groups on outside. Hydrogen Bonded base pairs within the structure.

Although all of the emulsions take place on a slightly larger scale, similar concepts of molecular interactions can be connected to these important biological explanations.

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Wikipedia. http://en.wikipedia.org/wiki/File:DNA_chemical_structure.svg (accessed June 21, 2012).

Procedures

Part I: Sugar, Salt and Gum Solubility

Activity Time: Approximately 20 minutes

IMPORTANT: Wash hands before preparing food and perform in a non-laboratory environment.

Materials:

- Gum with hard shell
- Chocolate
- Oil (baby oil or olive oil)
- Water
- Cane sugar (sucrose)
- Splenda (sucralose)
- Nutrasweet (aspartame)
- Ionized salt
- 8 tubes
- Gloves if desired

Procedure:

1. Place 5 mL water in four 15 mL centrifuge tubes and 5 mL oil in four other tubes.
2. Add cane sugar in one tube containing water and another to a tube containing oil, shake, let settle, and see if it dissolves.
3. Keep adding cane sugar to the water until it does not dissolve. Calculate the solubility of cane sugar in water, which is the maximum mass of cane sugar that dissolved in water over the volume of water used.
4. Repeat step 3 using Nutrasweet, Splenda and table salt and determine the solubility of these compounds in water.
5. Chew a piece of gum until the hard shell dissolves. Then chew the gum together with a piece of chocolate and observe what happens as you chew.

Part II: Oil/Water Mixtures

Activity Time: Approximately 20 minutes

IMPORTANT: Wash hands before preparing food and perform in a non-laboratory environment.

Materials:

- Oil (baby oil or olive oil)
- Water
- 3 capped tubes
- Liquid detergent
- Soy lecithin
- Food coloring

Procedure:

1. Add first 5 ml of oil and then 5 ml of water to a tube. Close the cap and shake vigorously. Watch what happens.
2. Now add 5 mL of water first and a drop of food coloring. Then add 5 mL of oil slowly, without letting it break the surface of the water. Observe what happens. Shake vigorously and let stand. Note how much time it takes for the layers to separate.
3. In another tube, add 5 mL each of oil and water and then 1 ml of dish washing soap and mix. Let the mixture stand and observe what happens. Note how much time it takes for the layers to separate.
4. Add the same volume of oil and water in the 3rd tube, and add a small amount of soy lecithin to the mixture. Shake vigorously and let stand. Note how much time it takes for the layers to separate.
5. Compare the structure of the detergent and phosphatidylcholine molecules. Try to relate them to the observations made in the experiments.

Edible Foams

IMPORTANT: Wash hands before preparing food and perform in a non-laboratory environment.

Materials:
- Plastic cup
- Assorted juices
- Soy lecithin
- Mini electric frother
- Wooden or plastic spoons
- Saran wrap

Procedure:
1. Add ~50 ml of juice in plastic cup. Cover with plastic saran wrap, leaving a corner open to place frother into the container. Try creating bubbles and foam with the electric mixer
2. Add a small amount, less than 0.5 g, of soy lecithin.
3. Use electric mixer/frother to create foam. Keep frother on the side of the container, near the surface of the liquid and have bubbles gather.
4. Use a spoon to transfer the foam that begins to build up to a cup. Then continue to froth to create more foam.
5. What substances are combined to form the foam? What stabilizes the foam formation?
6. Try again with oil and lecithin instead of water and see if you can make foam. Does it work as well? Why or why not?

Part III: Chocolate Chantilly

Activity/Demonstration Time: Approximately 20 minutes

IMPORTANT: Wash hands before preparing food and perform in a non-laboratory environment.

** The teacher can choose to do this as a demonstration, or he/she can opt to make this a classroom activity and have the students attempt to make their own chocolate Chantilly!*

Materials:
- Small glass bowl
- Large bowl filled with ice
- Electric mixer
- 225 g of chocolate
- 200 mL juice
- Microwave

Procedure:
1. Chop the chocolate in as fine pieces as possible.
2. Combine the juice and chocolate in small bowl and heat in a microwave until chocolate melts, about 4 minutes.
3. Set the bowl of melted chocolate in the bowl of ice.
4. Mix vigorously with the electric mixer until the mixture begins to thicken
5. Remove from ice once it is fully thickened
6. If mixture doesn't thicken in 15 minutes, reheat, melt, add more chocolate, and repeat the mixing.
7. If the emulsion is too thick, reheat, melt, add more juice, and repeat the mixing.
8. Make sure to do the lab in a non-laboratory environment so the chocolate can be tasted. Also go around and try the other flavors from other groups with different juices and see the differences.

Part IV (Additional Optional Activity): Mozzarella Cheese

Activity Time: approximately 90 minutes

IMPORTANT: Wash hands before preparing food and perform in a non-laboratory environment.

Materials:

Ingredients –
1 $^{1}/_{4}$ cup water
1 $^{1}/_{2}$ teaspoon citric acid
$^{1}/_{4}$ liquid rennet
1 gallon of milk (whole or 2%, not ultra-pasteurized)
1 teaspoon of kosher salt

Equipment –
5 quart or larger non-reactive pot
Measuring cups and spoons
Thermometer
Knife (can be steel or plastic, as long as it can reach the bottom of the pot)
Slotted spoon
Microwave bowl
Rubber gloves

Procedure:
1. Measure out 1 cup of water into one bowl, and stir in citric acid until it is dissolved.
2. Measure out $^{1}/_{4}$ cup of water into another bowl, and stir in rennet until it is dissolved.
3. Pour milk into pot. Stir in citric acid solution, and warm the milk to 90^{o}F, stirring gently. Do not go over 90 degrees.
4. Remove milk from heat, gently stir in rennet solution. Keep stirring and count to 30. Stop stirring, cover pot, and let sit for 5 minutes.
5. The milk should have set and should be spongy. There should clear separation between pale yellowish liquid and white solids. If still liquidly, re-cover the pot and let sit for another 5 minutes.
6. Make several vertical and horizontal cuts to the curds (the white solids); knife must reach the bottom of the pot.
7. Heat the milk to 105^{o}F. Stir slowly. Do not overheat the curds, or break apart the curds too much.
8. Remove curds from the heat and stir for 5 minutes.
9. Ladle the curds into a microwave-safe bowl
10. Microwave the curds for one minute, and drain off the whey.
11. Put on gloves and fold the curds over on themselves for several times.
12. Microwave the curds for 30 seconds until they reach an internal temperature of 135^{o}F.
13. Sprinkle kosher salt over the cheese. Stretch and fold curds to make mozzarella cheese!

Concepts Questions & Calculations

1. How would you define the terms hydrophobic and hydrophilic?

2. What is an emulsion?

3. How does an emulsion differ from a solution?

4. What was the solubility for salt and sugar in water for the first experiment?

Application questions

1. Using the concepts learned in the chocolate Chantilly activity, explain how gum is dissolved by chocolate in the first activity.

2. Assuming the amounts are the same (i.e. by number of molecules, not weight), predict which of the following would be the most water soluble: sucrose, aspartame and sucralose. Provide an explanation.

3. Provide 2 other day-to-day examples that utilize the concept of hydrophilicity/hydrophobicity.

4. Until very recently, [1] boiling an egg has been known to be an irreversible process: that is, a hardboiled egg cannot return to its original form as egg yolk and egg white. What is the main component of eggs, and which of its characteristics dictate this irreversible reaction?

[1] Weiss, G.A. et al. "Shear-Stress-Mediated Refolding of Proteins From Aggregates and Inclusion Bodies." *Chem. Biochem*. **2015**, 16, 3, 393-396.

Answers

Concepts Questions & Calculations

1. Hydrophobic means water loving, which refers to the polar nature of a molecule that is attracted to polar water. Hydrophilic means water hating, which refers to the non-polar nature of a molecule that is more attracted to non-polar molecules like long carbon chains.

2. An emulsion is the suspension of droplets of one liquid within the liquid of another sort. The droplets are in many cases stabilized by molecules with hydrophobic and hydrophilic ends, one example being emulsifying agents.

3. A solution is when a solid or ions are dissolved within a liquid, and an emulsion is the suspension of a liquid within another liquid.

4. Approx. 35 g NaCl / 100g of water and 200 g of sucrose / 100 g of water

Application questions

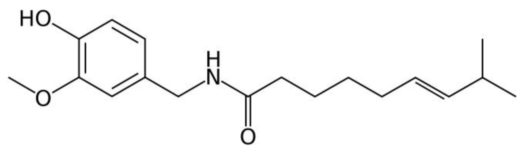
1. Chocolate contains emulsifying agent such as cocoa butter and lecithin. When mixed with gum, these emulsifiers surround and assist in breaking up the gum. So it appears chocolate can "melt" gum.

2. Sucrose would be the most soluble in water (2114g/L @ 25^{o}C),[2] followed by sucralose (283g/L),[3] then aspartame. Sucrose contains 8 –OH groups, which are polar and can have significant hydrogen bonding interactions with water, and therefore is very water soluble. Sucralose contains only 5 –OH groups and 3 C-Cl groups: C-Cl bonds are not as polar as O-H bonds, so sucralose is less water soluble than sucrose. Aspartame is the least water soluble since it contains a very hydrophobic group in the phenyl substituent.

[2] Lowe, Belle. "Experimental Cookery From the Chemical And Physical Standpoint." San Francisco: John Wiley & Sons, 1937. Print.
[3] Jenner, M. R.; Smithson, A. "Physicochemical Properties of the Sweetener Sucralose." *J. Food Sci*. **1989**, 54, 1646.

3. Be creative! Here are two examples:

    a. Chili does not mix with water because capsaicinoid, the main compound responsible for the spiciness, is nonpolar due to the long and hydrophobic hydrocarbon chain.



    b. Oxygen gas (O_2) is a nonpolar diatomic molecule. As described above, the phospholipid bi-layer of membranes of cell tissues is hydrophobic. Because O_2 is small and nonpolar, it can freely diffuse across cell membranes without any assistance. Otherwise, oxygen would not be delivered to different parts of one's body, which would be a major issue!

4. Protein is the main component in eggs. Protein in its natural conformation is folded due to hydrophobic and hydrophilic interactions between amino acids; once unfolded (such as by heating, i.e. cooking the eggs), proteins cannot refold since it is unfavorable for the amino acid chain to stretch and curl around to take up the initial conformation again. It is like opening the Pandora box!