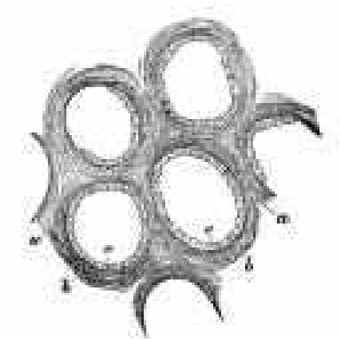
Oil & Water Plus Detergent: Exploring the Importance of Oil/Water Phase Separation

Materials as common as oil, water and detergents can be used to illustrate and illuminate a number of important phenomena. Every child knows what mayonnaise and salad dressings are, and many have also seen how old paint has separated into two layers, which on stirring form a single layer of usable paint. The principles operating in these systems are the same as operate in forming cells, folding proteins and in making advanced new materials for use in fuel cells and in turning sunlight into electricity (among many, many other applications). They also explain lots of things in the world around us; how dishwashing liquid, soap, shampoo and laundry detergent work, why soap bubbles are round, why dishwashing liquid is used to clean up oil from birds and animals caught in oil spills. The accompanying experiments were designed to start illustrating some of these important principles.

We all know that oil and water will separate. We often discuss this by saying that the attraction between water molecules is much stronger than between water molecules and oil molecules and so the water molecules stick to themselves. The oil molecules are then forced to do the same. Another way to think of this is by considering the different surface tensions of the two liquids. Surface tension is a measure of how strongly the molecules in a liquid bind to each other. Strong binding means high surface tension. High surface tension (for example, water) is what lets insects walk on water. Oil and water have very different surface tensions and so where oil and water are forced to be in contact is a region of high surface tension. Systems that have low surface tension are more stable than those with high surface tension, and so any system will change to decrease the surface tension as much as possible. This is what happens when paints and salad dressings separate. In both cases they start by having lots of small oil droplets in water. The merging of two small oil droplets into one slightly larger one decreases the total surface area, decreasing the energy of the system. Each merging reduces the surface area until in the end there is a single layer of oil in contact with a single layer of water. (in passing; shaking and stirring the system to form droplets produces the energy required to form the large surface areas of salad dressing and paint. The more energy put in by shaking the smaller the droplets and the higher the surface area.).

What does a detergent do? Detergents are special molecules, in which one part of the molecule has some of the same properties as water, and another part has similar properties to oil. So the absolute best place for a detergent molecule to be is at the interface between a layer of oil and a layer of water. It acts to bridge the two phases. This reduces the surface tension between the two phases. Chemists have their own special name for detergents which reflects the properties of these types of molecules. The name "surfactants" comes from these molecules moving to the surface of a liquid or to an interface between to liquids, and changing the properties of the surface. In most cases the surface tension falls. (one sneaky way to see this in action is watch what happens to bugs on a pond when you add detergent). Adding a detergent (say egg yolk or white) to a mixture of oil and vinegar will make it easier for the oil and water to mix, giving smaller oil droplets for the same amount of shaking. Adding detergent also makes mixtures of oil in water, such as salad dressing, last longer, since the lower surface tension means that less energy is gained by merging small droplets into large droplets. Some detergents are also electrically charged and so oil droplets surrounded by these detergent molecules cause the droplets to repel each other, so making it much more difficult for them to merge.

When washing dishes, detergent is added to dissolve the grease into little droplets which can suspend in water and so be flushed down the sink. Chemists talk about this as "like dissolves like". That is, the greasy food doesn't dissolve in water, but does dissolve in the oily part of the detergent. It can also work the other way around; adding detergents can cause very small pools of water surrounded by detergents to suspend in an oil mixture. In other cases oil, water and detergent can combine to form complex mixtures, which have very distinct and unusual properties. Materials scientists make use of all three types of systems to make materials with useful properties. Adding chemicals that dissolve in water to a mixture of water droplets in oil can make particles that are extremely small (about 1/10,000 the diameter of a human hair). Doing the same to a mixture that contains oil droplets in water makes very porous material, where a single teaspoon of material may have as much surface area as a football field.



Cells showing Cell membranes

A very special class of detergents, called phospholipids makes up the walls of our cells. Cells consist of a pool of water which is surrounded by two layers of phospholipids that separate the cell from the surrounding tissue or bloodstream. The two layers of phospholipids are arranged so that the "greasy" parts of the phospholipids form a single layer at the center of the cell membrane.

Proteins are molecules that are important components of cells. Typically proteins are made as long strands that then fold in three dimensions to give the final active form. Among the forces that direct a protein to fold in a particular manner are the tendency for the "greasy" parts of proteins to come together to get away from water. If the protein does not fold properly it will not do it's job properly, or worse still it may fold in a way that is not good for the body. Mad Cow disease is produced by a brain protein that folds the wrong way.

Another interesting example of the use of detergents to clean things up is what is called "Subsurface remediation". There have been considerable problems with the large underground gasoline storage tanks at gas stations leaking large amounts of gasoline into the ground. Cleaning this up has meant digging up the whole area, which is extremely expensive. An alternative approach being developed is to drill two holes into the contaminated area water. Detergent is pumped down one, where it mixes with the gasoline, the detergent acts to turn the gasoline into small, water soluble droplets of oil. The water containing the gasoline droplets is then pumped up the second hole.