

The Story Behind Soap

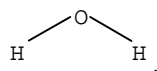
Not the over-acted daytime dramas, the stuff that makes everything nice and clean. Soap, we all use it on a daily basis, but how many of us know how it actually works? Mankind has been making soap for over two millennia. Everything from the original lye soap to the modern synthetic detergents. They all have something in common. The operation of soaps and detergents is a ballet involving chemistry and physics at the molecular level.

Let's first look at the history of soap, one of our species oldest chemical industries. The Phoenicians originally made soap around 600 BC from goat fat mixed with extracts of wood ash, sodium carbonate is the active ingredient for making soap. The reaction of these two compounds resulted in a flaky substance commonly known as hard soap. Inland areas used wood ash since it was easy to come by. Coastal areas used the ash from sea plants which provided potassium carbonate instead of sodium carbonate. This slightly different compound produced soft soap instead of the hard soap produced from wood ash. The Romans knew about soap but it is not known from where they acquired their knowledge. They may have gotten soap from the ancient Mediterranean people or from the Celts. In fact, the modern word "soap" is derived from the Celtic word "saipo." Wood ash was used as a source of alkali until the 1800s when soda ash, another name for sodium carbonate, was first made from common salt and more readily available.

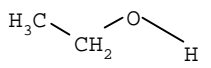
Oils released by the body make up most of the dirt on skin or clothing. And as anyone who has made vinegar and oil salad dressing or seen the media images of oil spills knows, oil and water don't mix. If people or clothes were washed with plain water, they would not get very clean.

To explain the action of soap requires some basic chemistry. We need to look at what causes molecules of different compounds to mix or not to mix. As pointed out earlier, oil and water don't mix. Why not? After all, they are both liquids. The reason lies in the microscopic structure

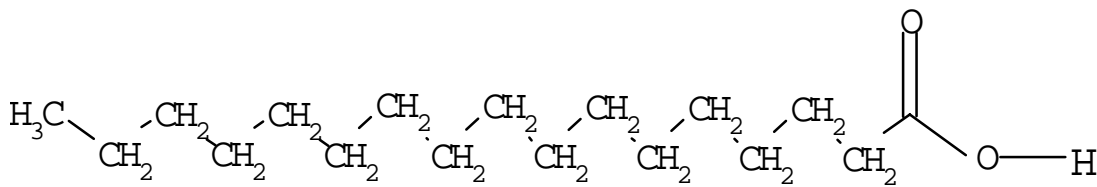
of the molecules. In order for two liquids to dissolve in one another, they need to have some structural similarities. For example, alcohol dissolves in water because they are structurally similar. Water has a structure like this:



Ethanol, which is the alcohol used in alcoholic drinks, looks like this:



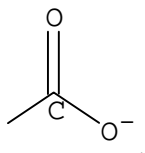
These two molecules are structurally similar. Whereas water has a hydrogen atom attached to a O-H particle, ethanol has a group of carbon and hydrogen atoms. These two molecules are so structurally similar that they mix together extremely well in all proportions. Now, back to oil and water. We have already seen the structure of water. Cooking oil is made of a class of molecules called fatty acids and has a structure something like this:



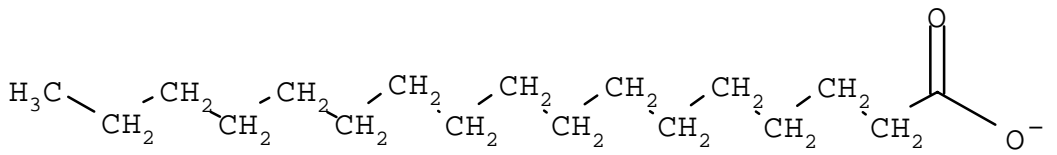
These two molecules, water and the oil, do have a part which is similar. However, the molecules are dissimilar enough overall that they do not mix very well. The oxygen-hydrogen end of this molecule will dissolve in any water with which it comes into contact. The rest of the molecule is very different from water and tends to avoid any nearby water and stick with similar molecules. Soap molecules however are similar to fatty acids.

The carboxylate ion is the part of the soap molecule that allows it to work the way it does.

This ion is a group of three atoms, a carbon atom and two oxygen atoms, which has a negative charge. The three atoms bond together in the following fashion:



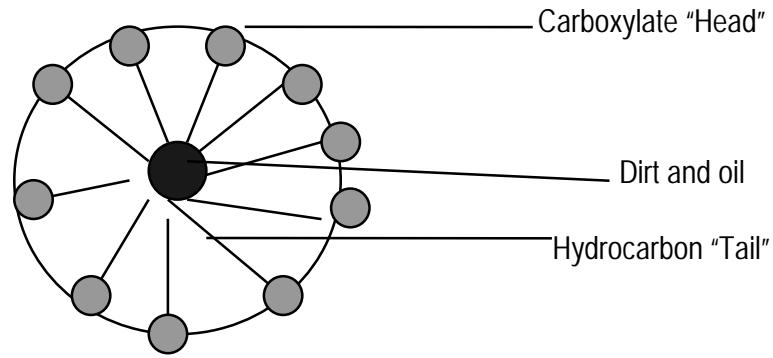
This end of the soap molecule looks very much like the right end of the fatty acid molecule above, except it is missing the hydrogen atom bonded to the lower oxygen. The charge on this group of atoms makes it very soluble in water. However, if the whole molecule had a charge, people everywhere would get a shock from it every time they picked up their soap to take a bath. Since all molecules must have no net charge, the carboxylate ion requires a positively charged ion to balance its negative charge. The positive ion this combines with is usually a sodium or potassium ion, both of which have a +1 charge. The carboxylate ion part of the molecule chemically bonds with a long chain of carbon and hydrogen atoms (a hydrocarbon chain), very much like the fatty acid molecule.



This combination of two kinds of molecule is responsible for the cleaning action of soaps.

The different types of molecules combined above have different responses. The long hydrocarbon chain will be attracted to the oil and dirt on skin or clothing. The carboxylate ion end

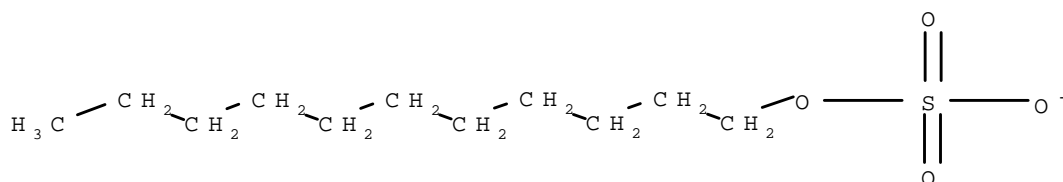
will be attracted to the surrounding water. This slightly schizophrenic behavior results in a cluster of molecules called a micelle. Micelles have the following form:



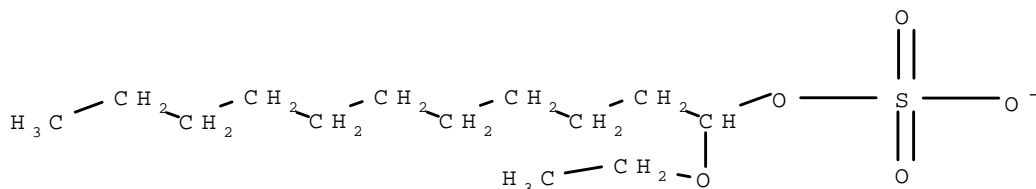
This is a view of a slice through the micelle. These objects are produced whenever soaps or detergents are used to clean something. The outer "skin" of the micelle is comprised of the carboxylate ions while the inside is made of the hydrocarbon chains, dirt and oil. Due to this particular self-assembling arrangement of molecules, carboxylate ions on the outside and the hydrocarbons inside, the entire micelle is soluble in water. The dirt or oil, which will not easily come out in water alone, now dissolves in an environment it likes.

Detergents have a similar chemistry behind them. Again for a detergent to work properly, we need a molecule which can act in two different ways. The detergent molecules are similar to the soap molecules in that they contain a part which is soluble in water and a part which is not. In soap molecules the water soluble part of the molecule is always the carboxylate ion. This is not the case for detergents. Detergents can contain an ion which contains oxygen and is fairly large. The two main ions used for this are the sulfate ion and the phosphate ion. The sulfate ion contains one sulfur atom and 4 oxygen atoms and has a negative 2 charge. The phosphate ion contains a phosphorus atom and 4 oxygen atoms also, but it has a negative 3 charge. When a cleaner is stamped with the words "No Phosphates," it is indicating that the detergents inside do not use the

phosphate ion as the water soluble part of the compound. Both of these ions are larger than the carboxylate ion and this makes detergents more effective at making soluble micelles. A common detergent used in shampoos is sodium lauryl sulfate. This molecule contains the negatively charged sulfate ion and a positively charged sodium ion. The "lauryl" part of the compound is the long hydrocarbon chain similar to the compound above:



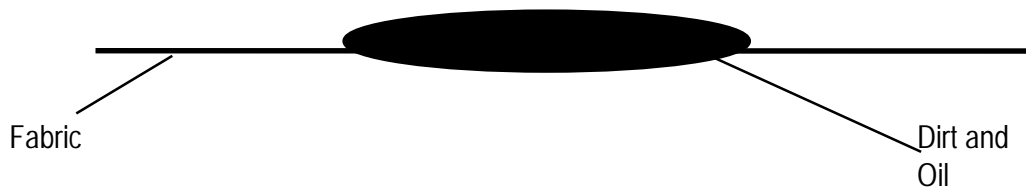
Occasionally, a close cousin of this molecule is used instead, sodium laureth sulfate. This indicates that a different type of functional group is involved, the ethoxide group, $\text{CH}_3\text{CH}_2\text{O}-$. This group attaches to the compound at the carbon next to the sulfate ion:



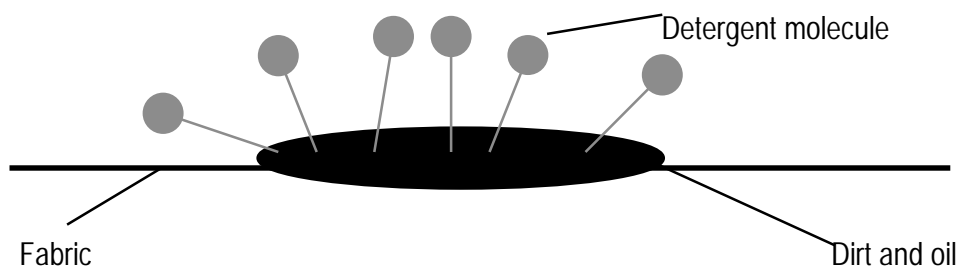
This combination makes the ion end of the molecule more polar and as a result more soluble in water, a desirable thing.

Up to this point, all that has been discussed is the chemical make-up of the compound used in detergents, soap being a type of detergent. Let's look more closely at what happens on a microscopic level. We'll go on a fantastic voyage and imagine that we have been shrunk to a small enough size that we can see what is happening at the molecular level as the detergent does its work.

This is what we would see if we were in the washing machine with a load of dirty clothes and were anchored down so that we were not tossed around in relation to the particular dirt bit which we are observing:

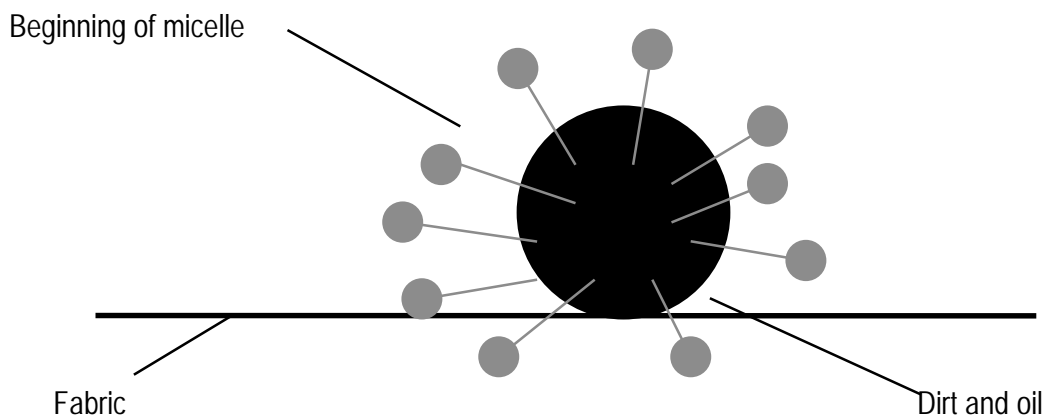


If water alone was used, the water would have no way of getting between the dirt, or oil, and the fibers of the clothing, since the oil and dirt get "wrapped around" the fibers in the fabric, the familiar "ground in dirt." We need a way to pull the dirt and oil away from the fabric. That is the purpose of detergents. The detergent starts to dissolve the dirt and oil in the hydrocarbon end of the detergent molecule. This allows the water to start to dissolve the entire collection of detergent, dirt and oil. At this point in our microscopic adventure we would be seeing something like this:

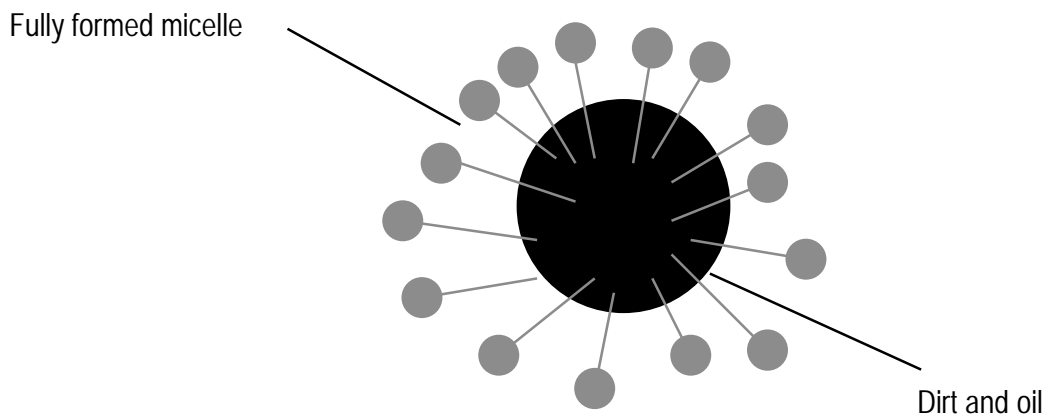


Now that the detergent has a chemical grip on the dirt and oil, the water can start to work on getting it out of the fabric. The interaction of the various forces between molecules forces the detergent, dirt and oil to form micelles. The agitator in the washing machine helps in the micelle formation. Without the agitator the micelles would still form, but it would take much longer than the

15 to 20 minutes of the agitation cycle of the washing machine. The water molecules pull on the detergent molecules which then pull on the dirt and oil. As long as the interactions between the detergent and dirt are stronger than those between the dirt and the fabric, the dirt will be pulled out. At this point in our molecular play we would see this:



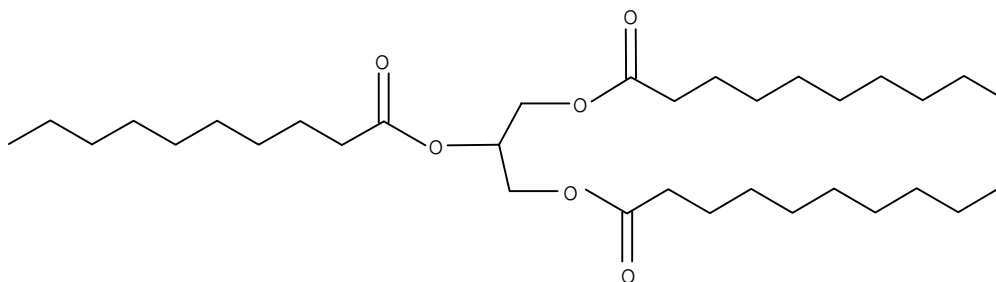
Now the water can start to get between the dirt and oil, which is now being formed into a micelle, and the fabric. The agitation of the machine not only helps with the micelle formation but also with the removal of the micelles from the fabric. Once the micelle is free of the fabric, it can be washed away in the rinse cycle of the machine. We would see out of our microscopic craft the following picture:



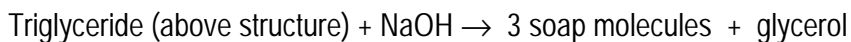


The clothes are now clean and our microscopic adventure has come to an end. Let us now look at the production of soap and detergents.

Soap was originally made from animal fat. Animal fat is a type of molecule called a triglyceride. Triglycerides look like the fatty acids above but there are three of them connected to a short hydrocarbon chain:



Mixing the triglyceride with sodium hydroxide, also known as lye, breaks apart the triglyceride into three soap molecules in a process known as saponification. The written reaction looks like this:



Since the soap is produced from lye it is often known as lye soap. Soap produced from sodium hydroxide is hard soap. If potassium hydroxide is used instead, it is soft soap. The glycerol that is also produced in this process is often removed and has its own uses.

Soap, which started out as a household handicraft, is now a multi-million dollar industry. The process hasn't changed much since the ancient Phoenicians started making soap 2600 years

ago. However, for most cleaning uses, synthetic detergents have usurped the role once held by soap. This shift is due mainly to the World Wars. Industry moved away from the fats and alkalis for making soap and shifted to synthetics. Shampoos, dish washing detergents and clothes washing detergents are all synthetically produced. The industry has changed a some even in the last few decades. The synthetic detergents were posing a problem that soap did not. Bacteria were not able to break down the hydrocarbon portion of the molecules from detergents like they could from soap. This lead to a simplification of the structure of the detergents. Another problem then arose. The phosphates used in some detergents were causing a different kind of water pollution. This lead to the abandonment of the phosphate ion as the water soluble part of the detergent molecule. Most of the soaps and detergents we use today are ecologically sound and much more effective that those used even in the early part of this century.