

How Soap Cleans at a Molecular Level

Soaps are chemical compounds that aid in the removal of grease and dirt from surfaces. Today, anyone who walks through a grocery store will see a profusion of cleaning products all using soap to clean hands, hair, faces, dishes, floors, and laundry. Each of these products has a different ingredient list. However, all of them are based on the use of the same cleaning process. Soap's ability to clean results from a complex molecular process in which soap molecules interact with water and human or mechanical movements to remove grease and dirt from surfaces. This paper describes in detail the **chemical makeup of soap** and the **steps involved in soaps cleaning process**, concluding with a summary of **one complete soap cleaning cycle**.

The Chemical Makeup of Soap

Soap is a surface-active chemical compound commonly known as a surfactant. It is made by mixing almost any vegetable or animal-based fat, also called a triglyceride, with sodium hydroxide. This reaction between fat and sodium hydroxide (NaOH) is called 'saponification.' In general, reactions occur when the atoms in at least two different 'reactant' materials recombine to form new 'products.' The process is driven by the desire of the electrons surrounding the atoms in the reactants to find a more stable state, a state found with the new combination of atoms in the products. In this case, the triglyceride is made up of three fatty acids with varying carbon chain lengths bonded to a single glycerol molecule. When reacted with three molecules of sodium hydroxide, the sodium, oxygen, and hydrogen within the sodium hydroxide separate and form a single glycerin molecule and three soap molecules (see Figure 1).

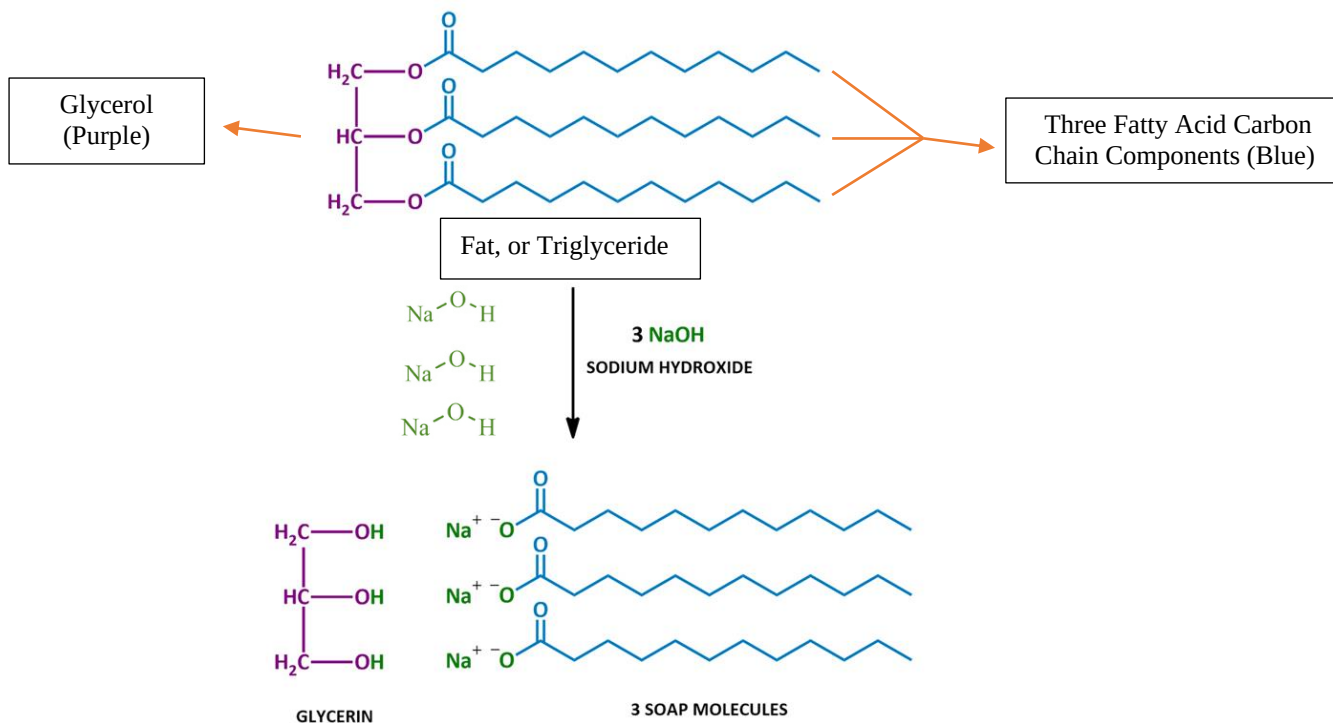


Figure 1. The Formation and Chemical Properties of Soap Molecules

Source: <https://labmuffin.com/make-your-own-soap-part-1-the-chemistry-behind-soap-making/>

In the manufacturing process, glycerin is separated from the soap and used for a variety of pharmaceutical and personal care products, ranging from laxatives to skin creams. The soap, meanwhile, is further processed into solid or liquid forms (“Saponification”).

Steps of the Soap Cleaning Process

The chemical compound of soap interacts with water in a series of molecular processes and uses motion to clean numerous surfaces. This cleaning process involves five separate steps in the following order.

- Surface Tension Reduction
- Bonding Process
- Emulsification of Grease and Dirt
- Distribution of Soap and Breakdown of Grease and Dirt
- Removal of Grease and Dirt

These steps are universal to all soap products, regardless of the surface being cleaned.

Soap Reduces Water Surface Tension

Soap uses water to enable it to move across an unclean area. To be effective for this purpose, water must spread out evenly over the area. Unfortunately, water molecules naturally stick together due to the action of hydrogen bonding in which water’s negatively charged oxygen atoms are attracted to the positively charged hydrogen atoms in the adjacent water molecules (see Figure 2). This bonding creates a tightness between water molecules which is called surface tension. Water’s surface tension causes it to bead up and form droplets.

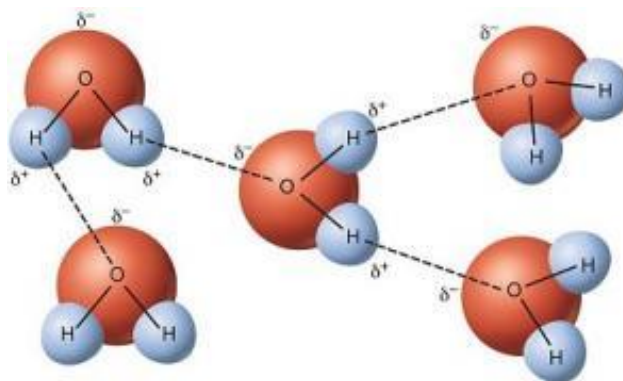


Figure 2. Hydrogen Bonding of a Water Molecule

Source: <https://manoa.hawaii.edu/exploringourfluidearth/chemical/properties-water/hydrogen-bonds-make-water-sticky>

Soap interferes with water’s hydrogen bonds and weakens them, causing water to disseminate more evenly over an area. Soap’s undermining of water’s molecular structure reduces water’s surface tension and allows it to “wet” a larger surface (see Figure 3). As a result, soap is able to act on a whole area rather than just on certain, limited spots (“Surfactants”).

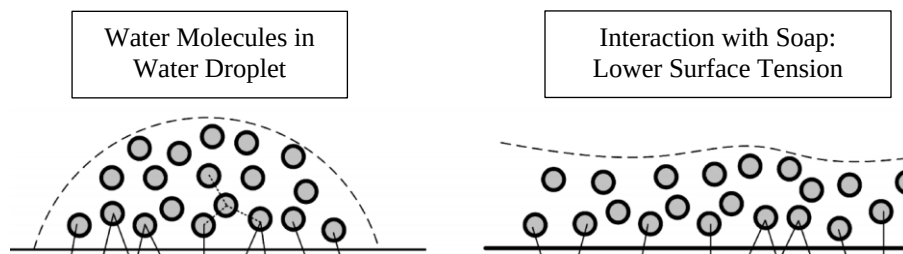


Figure 3. Soap Causes Water to Lose Surface Tension

Source: https://files.oakland.edu/users/rojo/web/p120/Readings/surface_tension.pdf

Hydrophilic and Hydrophobic Ends Bond with Water and Grease

Soap chemical compounds are long, linear molecules with two sections (see Figure 4). One section is hydrophilic, meaning that it loves water. This end bonds with and easily attaches to nearby water molecules. Consequently, soap is able to both mix easily with water and stay attached to water molecules.

The second section of soap molecules is hydrophobic, meaning that it hates water. Just as oil and water do not mix, this part of the soap molecule does not mix with water. Instead, it is attracted to the fat and oil in grease and dirt (Hickok).

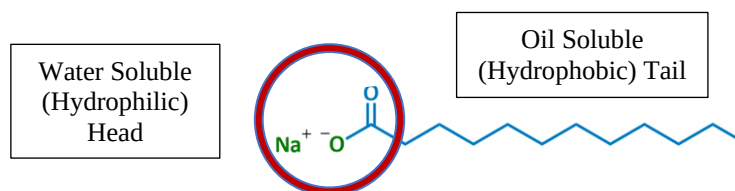


Figure 4. Soap Molecule's Hydrophilic Head is Attracted to Water Molecules, and Hydrophobic Tail Attaches to Oil Molecules

Source: <https://labmuffin.com/make-your-own-soap-part-1-the-chemistry-behind-soap-making/>

Soap Emulsifies Grease and Dirt

The hydrophobic end of the soap molecule surrounds particles of grease and dirt, creating a micelle which is a conglomeration of molecules (see Figure 5). Formation of the micelle enables soap to pick up and move grease and dirt because one end of each soap molecule is attached to grease and dirt while the other one is attached to water. This process of micelle formation is called emulsification, and can be seen in Figure 5. Soap's emulsification capacity combined with its abilities to reduce water surface tension make it especially effective at surface cleaning (Hickok).

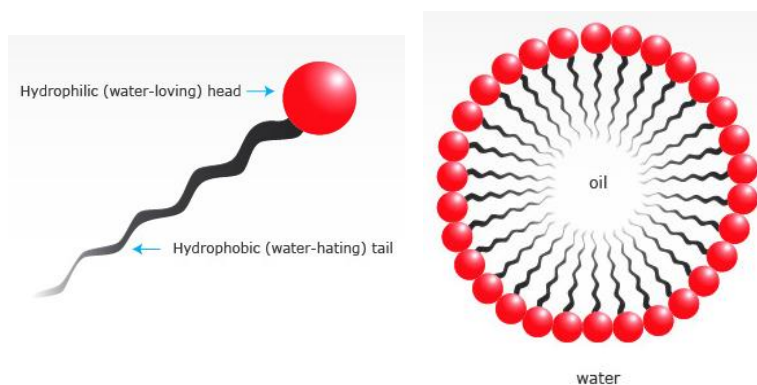


Figure 5. Emulsified Oil Droplet in Micelle Formation

Source: <https://www.sciencelearn.org.nz/images/1291-surfactants>

Motion Distributes the Soap Molecules and Breaks Down the Grease and Dirt

Motion can take the form of hands moving underwater, a sponge rubbing across a surface, or an agitator in a washing machine stirring the soap and water solution. These movements have two consequences. First, they distribute the soap molecules throughout the water, ensuring that they touch all surfaces. This process allows the soap molecules to encircle all grease and dirt in the area. Second, the movements break down the grease and dirt into smaller particles. This fragmentation of the grease and dirt allows for more effective action by the soap molecules. As grease and dirt are broken up, they are lifted from surfaces (see Figure 6) and more easily surrounded by the hydrophobic portion of the soap molecules. (“How Cleaning Works”) (Kadolf et al.).

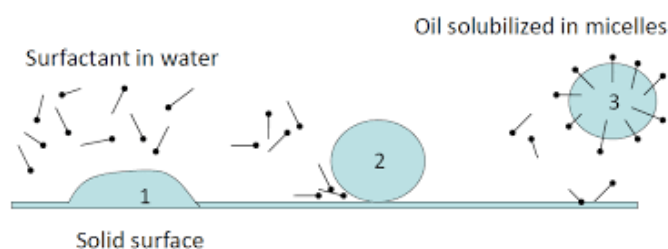


Figure 6. Motion Aids Soap in Lifting Grease and Dirt

Source: <https://www.onepetro.org/download/conference-paper/SPE-153265-MS?id=conference-paper%2FSPE-153265-MS>

Soap Removes Grease and Dirt Once Water is Withdrawn

Now that soap molecules are both completely surrounding all grease and dirt particles and are bonded to water molecules, the surface area can be cleaned. The water used in the soap cleaning process is contaminated with soap molecules surrounding dirt and grease. This water is separated from the surfaces being cleaned by draining or shaking the water away from the surfaces or by using a clean water rinse. As the contaminated water is

withdrawn from the surfaces, the soap molecules carry the grease and dirt with them, away from the now clean areas. The soap molecules remain attached to both the water and the grease and dirt and pull them with the water down the drain. The remaining surface is clean, free from grease and dirt as well as water and soap.

Conclusion: One Complete Soap Cleaning Cycle

The soap cleaning process removes grease and dirt from surfaces through a five-step cycle. First, soap reduces water surface tension by weakening water's hydrogen bonds causing water to spread out and cover an entire area rather than limiting its impact to droplets. Second, soap molecules attach to water using their hydrophilic (or water-loving) ends to bond with water molecules. Soap molecules also surround grease and dirt using their hydrophobic (or water-hating) ends to bond with the oil in grease and dirt. Third, soap molecules emulsify grease and dirt by encircling the grease and dirt particles and forming micelles, or conglomerations of molecules. Fourth, motion, through the movement of hands or mechanical agitators, distributes the soap molecules across the surface and breaks down the size of grease and dirt particles. This step allows the soap molecules to lift and surround the grease and dirt more easily. Fifth, the soap molecules remove the grease and dirt attached to them with the contaminated water when the water is withdrawn from the surfaces. This five-step cycle is used to clean different surfaces and can be amplified by adding chemicals designed to kill germs, making soap an antibacterial cleaning product.

References:

Hickok , Kimberly. “Why Do We Use Soap?” *Live Science*, Future US Inc. , 5 Mar. 2020, www.livescience.com/57044-science-of-soap.html.

I used this source to summarize the meaning of hydrophilic and hydrophobic ends of a soap molecule. I also used this source to paraphrase the emulsification process and micelle formation.

“How Cleaning Works.” *The American Cleaning Institute (ACI)*, www.cleaninginstitute.org/understanding-products/science-soap/how-cleaning-works.

I used this source, along with Kadolph et al. to summarize and paraphrase how a mix of motion and soap can break down and lift grease and dirt from a surface.

Kadolph, Sara J., et al. “Laundering Factors in Soil Removal (PDF).” *Fashion & Textile Research Journal*, Korea Science: The Society of Fashion and Textile Industry, www.koreascience.or.kr/article/JAKO200123659443362.do.

I used this source, along with “How Cleaning Works” to summarize and paraphrase how a mix of motion and soap can break down and lift grease and dirt from a surface.

Saponification: The Preparation of Soap . web.fscj.edu/Milczanowski/eleven/Soap.pdf.

I used this source to summarize the concept of saponification, including how soap is formed chemically from fats, glycerol, and NaOH.

“Surfactants.” *About Cleaning Products*, www.aboutcleaningproducts.com/ingredients/surfactants/.

I used this source to summarize how soap causes a decrease in water tension.