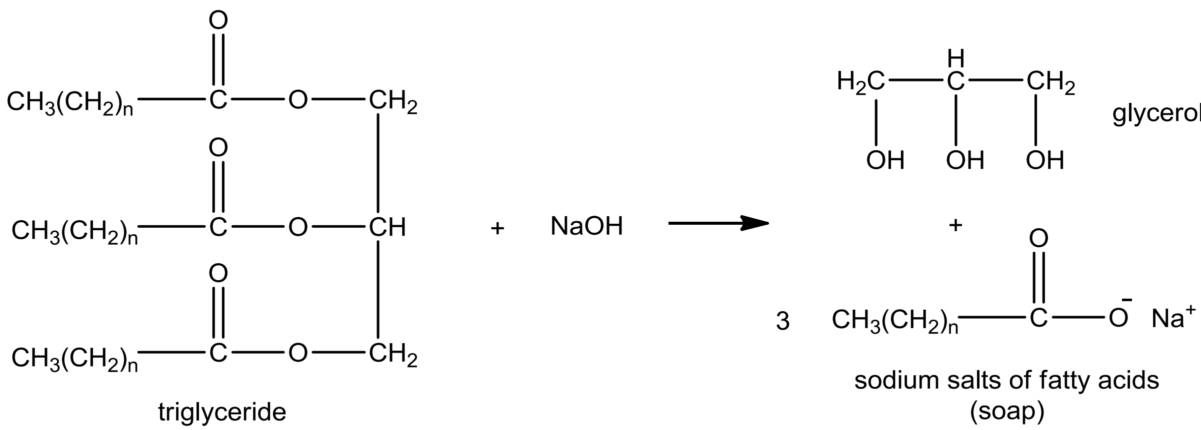
Soap

Introduction

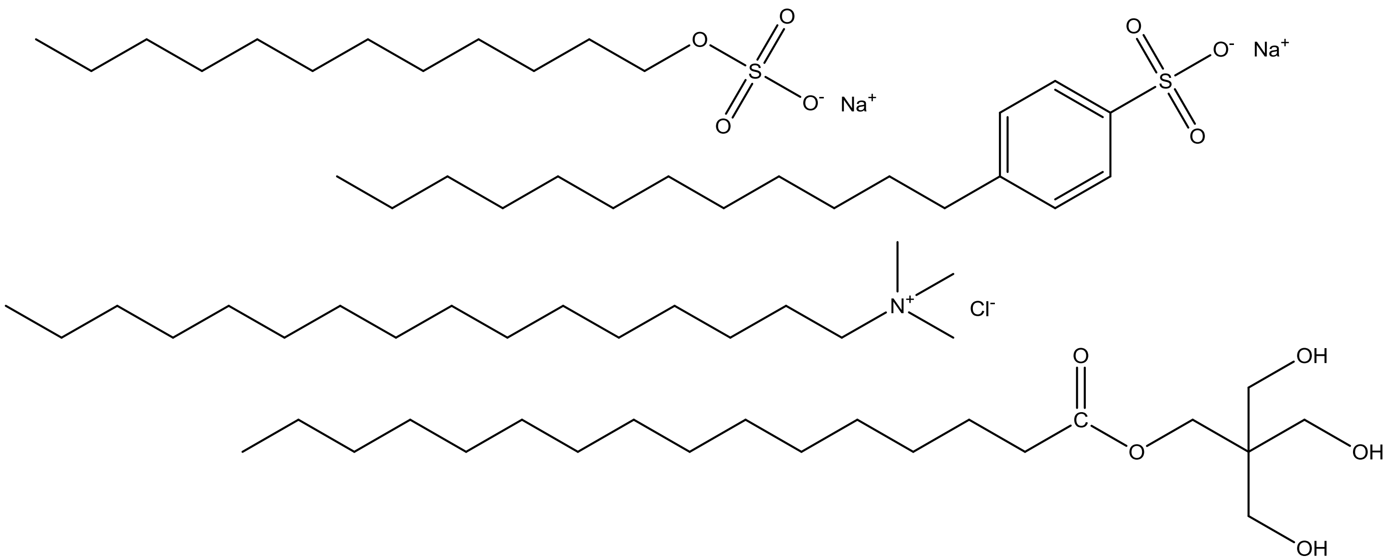
A fat (or oil) is a triple ester made from three fatty acids and a 3-carbon alcohol called glycerol (one -OH group per C atom). For this reason, fats are often called triglycerides. If you treat a fat with base, it will cause the fat to hydrolyze. Historically, this was done with wood ash, but nowadays we just use NaOH. First, the fatty acids are separated off from the glycerol molecule. Then, the fatty acids react with the base to from sodium salts, which are the components of common soap.



Soap is effective as a cleaning agent because it is amphiphilic; it is partly polar and partly nonpolar. Soap molecules contain an intensely polar "head" (the ionic part) and a non-polar "tail" (the long hydrocarbon chain, usually 10-18 carbons, depending on which fatty acid is used). The polar part is often referred to as being hydrophilic (water-loving) whereas the tail is called hydrophobic (water-hating) because of its non-polar character. With both features, soap molecules are able to emulsify oils and dirt in water, which means they will cause two normally insoluble layers (the oil and water) to combine into a single layer. This action is often achieved via the formation of spherical structures consisting of many soap molecules that are called micelles, in which the nonpolar tails are attracted to nonpolar oil molecules held in the interior while the polar heads interact with water on the outside of the micelle.

Soap is usually very good at what it does, but it is vulnerable. "Hard water" contains ions such as calcium, magnesium, and iron. These ions are generally healthy for you (areas with hard water typically have lower instances of heart disease), but they render soap ineffective. The sodium ion of the soap is replaced by one of these new ions, and the resulting salt is no longer soluble. It then drops out of solution and can no longer clean anything. "Soft water" contains sodium, potassium, or no ions at all. These ions do not change the solubility of the soap molecules, so the molecules will stay dissolved in water and the cleaning ability is retained.

Detergents are synthetic amphiphilic molecules that have structural features similar to soaps. There are three major types of detergents, classified by the charge of the molecules: anionic, cationic, or nonionic detergents. Anionic detergents are usually alkyl sulfates or alkyl benzene sulfonates, while cationic detergents are typically quaternary ammonium salts. Unlike anionic and cationic detergents, nonionic detergents have uncharged polar groups.



Safety

Although soap is generally harmless, the sodium hydroxide used to create it is a strong base. If you get any of it on yourself (or think you may have done so), wash immediately with lots of water.

Procedure

Saponification

1. Place 5 g of shortening into a 150-mL beaker.
2. Place this beaker on a hot plate and turn the temperature up to about 100°C.
3. Dissolve 2.5 g of sodium hydroxide in 20 mL of a 50:50% ethanol-water mixture (the mixture has already been prepared) in a separate beaker. Add this solution to the beaker containing the shortening.
4. Continuing heating at around 100°C for 20 minutes, stirring constantly. If the solution starts to foam too much during this time, try adding about another 1 mL of the alcohol-water mixture. While you are waiting, put about 20 mL of distilled water into a flask and cool in an ice bath for use in step 7.
5. Remove the beaker from the hot plate after 20 minutes and allow it to cool.
6. Add 75 mL of a saturated NaCl solution. This should cause the soap to precipitate. Stir the solution vigorously so that the new precipitate does not form large clumps.
7. Collect the soap via vacuum filtration. You can wash the soap by slowly sprinkling 20 mL of ice-cold distilled water on the soap while it is on the filter paper.
8. You now have (hopefully) pure soap. Take about 1 g of your product and dissolve in 100 mL of distilled water to create a soap solution you can test.

Tests

In addition to the solution of your soap, you will also need a detergent solution to test. To prepare this detergent solution, add a few drops of commercial detergent to 100 mL of distilled water to create a detergent solution for comparison purposes. Stir briefly.

1. Test the pH of your soap solution and the detergent solution by placing drops of the solutions on pH paper using a glass stirring rod. Record the pH of the solutions.
2. Assemble two test tubes in a rack. Place 10 mL of the soap solution in one test tube and 10 mL of the detergent solution in the other test tube. Add 1 drop of phenolphthalein to each test tube. A pink color indicates a pH greater than 7. Add hydrochloric acid solution (about 5 mL of 3 M HCl) until the solutions turn clear. Record your observations.
3. Add about 1 mL of dilute calcium chloride, magnesium chloride, and/or iron(III) chloride solution to the 10 mL of the soap solution in a test tube. Shake. Record your observations. Repeat with the detergent solution.
4. Assemble three test tubes in a rack. In the first test tube put 10 mL of distilled water, in the second put 10 mL of your soap solution, and in the third put 10 mL of the detergent solution. Add a few drops of mineral oil to each test tube and shake. Record your observations.

Waste

The filtrate, which is the liquid that passed through the filter paper, contains leftover sodium hydroxide; therefore, it should be disposed of in the aqueous waste container. The soap/detergent solutions used for the tests can also be placed in the aqueous waste container. The solid soap can be thrown away in the trash.

Data

	Soap Solution	Detergent Solution	Control (water)
pH			
Reaction with HCl			
Reaction with metal ions			
Emulsification			

Pre-lab Questions

Use your lecture notes or textbook to answer the following questions.

1. What is a lipid?
2. Write the general formula of…
   (a) a fatty acid
   (b) glycerol
   (c) a fat
3. Draw the structure of a soap molecule formed by the reaction of NaOH with an 18 carbon carboxylic acid. Label the hydrophilic and hydrophobic regions.
4. What is emulsification?
5. In the 1970s, water-softeners (machines that changed water from hard water to soft water) were popular throughout households in America. They work by replacing hard water ions with soft water ions. Write down which ions are replaced and also which ions replace them.

Post-lab Questions

1. Overall, was your soap an improvement over the detergent? Why or why not? Summarize your results.
2. The pH of the soap should be neutral (close to pH 7), but this is often not the case. What would cause the pH of the prepared soap to be greater than 7? What could you do to try to achieve a neutral pH? Which step(s) of the procedure would most influence the pH of the final soap?
3. Acidic solutions yield hydronium ions, H_3O^+ ions, which can interact with soap molecules. How might this alter the cleaning ability of soap? Explain.
4. Soaps and detergents are supposed to be emulsifiers.
   a. Explain how the chemical structure of a soap molecule leads to the emulsification properties of soap via the formation of micelles.
   b. Was your soap an effective emulsifying agent?
5. Calcium chloride contains calcium ions and is therefore a reasonable approximation of what hard water would be like.
   a. Describe what hard water does to soap. Include a chemical equation as part of your answer using the sodium salt of $CH_3(CH_2)_{10}COOH$ (lauric acid) as the initial soap that reacts with calcium chloride.
   b. Was the detergent affected by calcium chloride? Why do you think this was the case?
6. We used a fat to create the soap in this lab. If we had used an oil instead, what would be the difference in the chemical structure of your soap? Include examples of an oil and the resulting soap molecules (draw structures).