4. Teacher Notes

For these lessons it is assumed that students are already familiar with the saponification reaction and the type of substances which form the raw materials for making soaps. These lessons reinforce this learning and relate the reactions to the properties of actual soap in the marketplace. It illustrates that it is difficult to make a decision on which soap is best and factors such as price and advertising may well play a greater role in enabling society to choose than does the cleansing properties of the soap itself.

The lessons thus cover the cost of the soap, the solubility of the soap if left to stand in water for some time and allow students to introduce other factors that may have influence such as packaging, size of the soap bar and colour.

The actual testing of the cleansing properties reinforces the need for a control if comparisons are to be meaningful. Students are required to suggest suitable experiments, give appropriate apparatus for this (based on their experiences if prior working in the school laboratory) and, importantly, how the control experiment will be set up in each case.

Expected experiments indicated by the students are:

1. pH of the soap bar (a measurement and control is the fixed amount of soap, fixed quantity of water used and that the water must come from the same source i.e. all tap water, or all distilled (deionised – if water is truly pH = 7) water. This experiment is probably not meaningful without the use of a pH meter as the differences are likely to be small.
2. Ability to remove stains from a piece of cloth (controls are – same cloth, same size of cloth, same type of stain, same intensity of stain, same temperature, same water, same quantity of water, same type of container for undertaking the experiment, same additional aids e.g. stirring, same length of time for experiment, same post-experiment check).

Variations in these factors may affect the cleansing ability of the soap and hence experiments could vary one variable at a time using different soaps and then checks made on the effectiveness of the various soaps under each condition.

3. Ability to lather (controls here are same quantity of soap, same water, same quantity of water, same time, same additional aids such as shaking, same type of container, same instrument for measuring depth of lather.

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4.1. What is soap?

Soap is a mixture of metal salts of fatty acids (C_{12}-C_{18}) obtained by alkaline hydrolysis of fats.

4.2. Ingredients

Fats are natural complex mixtures, consisting mainly of triglycerides. Triglycerides (triacylglycerols) are esters of glycerol with fatty acids. After their origin, fats are: animals (usually solids – fat, lard) or vegetable (usually liquids - oil). Saturated fatty acids generate solid fats and unsaturated fatty acids generate liquid fats (oils).

Through the reaction of triglycerides with alkali (such as sodium hydroxide) are obtained glycerin (glycerol) and sodium salts of the fatty acids which are used in them.

The hardness, lathering qualities, and transparency of soap vary according to the combinations of fats and alkalis used as ingredients. An experienced soap crafter uses many combinations of oils

4.3. How does soap clean?

Most soaps remove grease and dirt because they (or some of their components if we consider the colouring and perfumes added) are surfactants (surface-active agents). Surfactants have a molecular structure that acts as a link between water and the dirt particles. This loosens the particles from the underlying fibres, or surfaces to be cleaned. One end of the soap molecule is hydrophilic (attracted to water), and the other is hydrophobic (attracted to substances that are not water soluble). This peculiar structure allows soap to adhere to substances that are otherwise insoluble in water. The dirt is then washed away with the soap.

4.4. A Scientific Explanation

Water molecules consist of 2 hydrogen atoms and an oxygen atom. The oxygen atom is linked to the two hydrogen atoms at a bond angle of about 104 degrees. Oxygen is far more electronegative than hydrogen and so it tends to have a higher electron density. Consequently the water molecule is polar - it has a positive charge at one end of the molecule (the hydrogen end – the positive pole) and a negative charge at the other (the oxygen end – the negative pole).

The positive pole of one water molecule will be strongly attracted to the negative pole of another water molecule. When an ionic compound, like sodium chloride, dissolves in water, the negative pole (oxygen) of the water is attracted to the cations (positive ions) while the positive pole (hydrogen) of the water is attracted to the anions (negative ions). The solubility of a substance in water is largely determined by the relative strength of the attraction of water to the substance compared to the strength of the attraction between water molecules..

In contrast to oxygen, carbon has almost the same electronegativity as hydrogen and the carbon-hydrogen bond is non-polar. For example, the octane molecule (a component of gasoline) $CH_3 - (CH_2)_6 - CH_3$ is electrically neutral, because the electron density is evenly spread along its entire length.

The simplest way to understand solubility is to remember the rule "like dissolves like," that is polar and ionic substances are soluble in polar and ionic substances while non-polar substances are soluble in non-polar substances. Thus salt dissolves in water, but not in gasoline. Oil dissolves in gasoline, but not water.

4.5. Living cells and polar/non-polar substances

Living cells need both polar and non-polar substances. The cell uses non-polar substances, fats and oils, to make up the cell membrane which separates the interior of the cell from the exterior. If the cell membrane were soluble in water, it would dissolve away and soon there would be nothing to divide the cell from the non-cell. But in order to get to the cell in the first place, all the parts of the cell must be water soluble because that's how materials are transported from place to place. What nature needs is a non-polar material that can be dissolved, moved around, and then made non-polar again. This material is known as a *lipid (fat)*, or *triglyceride*.

Although, both the fatty acid and the glycerol are water soluble (because of the polar oxygen atoms on the ends of these molecules), the lipids are non – polar substances, therefore insoluble in water, due to ester bound formed.

A fatty acid (saturated) has the formula $C_nH_{2n+1}COOH$. Because this group is polar, fatty acids tend to be soluble in water. Palmitic acid ($C_{15}H_{31}COOH$) and stearic acid ($C_{17}H_{35}COOH$) are part of most of the lipids. *Unsaturate*d fatty acids include in their molecule one or more double bounds. Two unsaturated fatty acids are: oleic acid ($C_{17}H_{33}COOH$) and linoleic acid ($C_{17}H_{31}COOH$)

Saturated fats contain saturated fatty acids residues which are solids at room temperature. Lard and butter are examples of saturated fats. Soap made from these fats tends also to be solid at room temperature. Unsaturated fats contain residues of unsaturated fatty acids and are liquids at room temperature. Generally these are called *oils* and examples include corn oil and safflower oil. These oils produce liquid soap. While unsaturated fats are generally more healthy than saturated fats, a liquid is often not very convenient. Thus margarine, which is made from unsaturated plant oils (e.g. corn oil) is hydrogenated to change it a saturated (solid) fat.

Through the alkaline hydrolyses of fats there are obtained salts of fatty acid (soap) and glycerol. In dilute aqueous solution the soap ionizes forming carboxylate anion. Carboxylate anion (RCOO-) consists of:

- *hydrophobic group* (no affinity for water) - a hydrocarbon radical (R) with a large number of carbon atoms, non – polar, insoluble in water but soluble in fats;
- *hydrophilic group* (affinity for water) - carboxylate group (COO-), soluble in water.grupare hidrofobă.

4.6. Saponification

Saponification is the term applied to the hydrolysis of fats using a strong alkali (e.g. lye). If we take a fat derived from palm oil (containing palmitic acid) and hydrolyse it using sodium hydroxide, the reaction is:

$$\begin{array}{l} CH_2 - OCO(CH_2)_{14}CH_3 \\ | \\ CH - OCO(CH_2)_{14}CH_3 \\ | \\ CH_2 - OCO(CH_2)_{14}CH_3 \end{array} + 3\ NaOH \longrightarrow \begin{array}{l} CH_2 - OH \\ | \\ CH - OH \\ | \\ CH_2 - OH \end{array} + 3\ CH_3(CH_2)_{14}COONa$$

$$\text{Fat}_{(s)} + 3\ \text{lye}_{(aq)} \rightarrow \text{glycerol}_{(aq)} + 3\ \text{sodium palmitate}_{(aq)}$$

The saponification reaction can be rewritten as follows:

$$\begin{array}{l} CH_2 - OCOR \\ | \\ CH - OCOR\ (s) \\ | \\ CH_2 - OCOR \end{array} + 3\ NaOH\ (aq) \longrightarrow \begin{array}{l} CH_2 - OH \\ | \\ CH - OH\ (aq) \\ | \\ CH_2 - OH \end{array} + 3\ RCOONa\ (aq)$$

where "R" is hydrocarbon radical.

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If you look on a list of ingredients on a soap, you will find things like "sodium stearate," or "sodium palmitate". This is simply specifying the particular fatty acids present in the soap.

When the soap molecules come into contact with dirt (made mostly from water-insoluble substances, such us fat) the hydrophobic groups of these molecules are oriented toward the insoluble substances and the hydrophilic compound to the water molecules. So the insoluble substance is divided into very small particles which, surrounded by the soap molecules form micelles. Micelles come to water and form a relative stable emulsion.

References

1. http://www.parsel.uni-kiel.de/cms/fileadmin/parsel/Material/Hatfield/pdf/Best_Soap_-_Overall.zip