Which Soap is Best ?

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 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.

   1. 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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What is soap ?

Soap is a cleansing agent made from fats and oils with alkali.

Ingredients

Oils and fats for soap are esters of fatty acids which react with alkalis such as sodium hydroxide to form glycerol and the sodium salt of the fatty acid. The fatty acids required for soap making can come from animal fats, grease, fish oils, and vegetable oils. 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.

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.

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) and a negative charge at the other (the oxygen end).

The positive end of one water molecule will be strongly attracted to the negative end of another water molecule. When an ionic compound, like sodium chloride, dissolves in water, the oxygen (negative) end of the water is attracted to the cations (positive ions) while the hydrogen (positive) end 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) consists of 8 carbon atoms in a chain, with 2 hydrogen atoms attached to the interior carbons and 3 hydrogen atoms on the end carbons. Since the electron density is evenly spread, the molecule is electrically neutral 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.

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*.

A lipid is an ester and basically consists of two parts - a fatty acid and a trihydric (3 OH groups) alcohol called glycerol. Both the fatty acid by itself and the glycerol by itself are water soluble, because of the polar oxygen atoms on the ends of these molecules. In a lipid, three fatty acids are bonded to the three oxygen atoms (3OH groups) on the glycerol. Although the oxygen atoms are still there, they are now buried inside the molecule and the lipid is essentially non-polar. The lipid is therefore insoluble in water. A fatty acid (saturated) has the formula $C_nH_{2n+1}COOH$. The chemistry is dominated by the properties of the COOH group. Because this group is polar, fatty acids tend to be soluble in water. Octanoic acid, $C_8H_{17}COOH$, is just one of a very large number of fatty acids. In fact, most fatty acids are longer than octanoic acid. Two very common components of lipids are palmitic acid ($C_{15}H_{31}COOH$) and stearic acid ($C_{17}H_{35}COOH$). Solid lipids are generally called *fats*. Another class of fatty acids are the *unsaturated* fatty acids, with less than 2n+1 hydrogens for every n carbons. Oleic acid, for example, has formula $C_{17}H_{33}COOH$ and linoleic acid has formula $C_{17}H_{31}COOH$.

Saturated fats contain saturated fatty acids and 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 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 from an unsaturated oil to produce a saturated (solid) fat.

To make soap, the trihydric ester (fat) is hydrolysed (broken down) into its fatty acid and glycerol constituents. The fatty acid has a long hydrocarbon tail which is soluble in fats, and a polar oxygen end which is soluble in water. Thus a fatty acid in solution acts as a soap by dissolving fats in one end of the molecule and water in the other. When a strong base, such as lye, is used to hydrolyse (saponify) the fat, the fatty acid is then present as a large cation, which is polar at one end and non-polar at the other. Just as sodium chloride and sodium carbonate which are soluble in water, sodium octanoate, the sodium salt of octanoic acid is also soluble in water.

Saponification

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

$[C_{15}H_{31}CO]_3[C_3H_5O_3](s)$ + 3 NaOH(aq) -----> 3 $C_{15}H_{31}COONa(aq)$ + $C_3H_5(OH)_3(aq)$
fat(s) + 3 lye(aq) -----> 3 sodium palmitate(aq) + glycerol(aq)

While this reaction may appear intimidating because of the long formulas, it is, in fact, quite simple. It could be written generally as

$[RCO]_3[C_3H_5O_3](s)$ + 3 NaOH(aq) -----> 3 RCOONa(aq) + $CH_2OH.CHOH.CH_2OH(aq)$
where "R" is some long carbon hydrogen chain.
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 fat is introduced to a soap solution, the non-polar tail of the fatty acids dissolves in the non-polar fat, leaving the water-soluble oxygen end at the surface of the fat globule. With enough soap, these fat globules become covered with a water-soluble coating and disperse throughout the solution, as in the last figure. They are not truly dissolved since individual fat molecules are not dispersed in the solution. Rather, the fat is *emulsified*.

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