**How do you make soap?**

**People have been making soap for at least 5000 years. A soap recipe was found on a Mesopotamian clay tablet dating from 2200 BCE. It is likely that the first soaps were made by accident when a cooking oil was dropped into ashes from a cooking fire. Since wood ashes are high in potassium hydroxide (potash), the strong base reacted with the fat (a triglyceride) to make a substance that would clean by encapsulating dirt. Soap was known across the ancient world, from the ancient Greeks, to Germanic tribes, and the Arabian peninsula. The word “soap” is derived from the Celtic “saipo,” and the Roman word “sapo.” What are the chemical components of soap? How is it made? What variables cause what outcomes in the final soap? You will explore the chemistry of soap, and link its properties to those of polymers.**

**Learning Objectives**: Upon completion of this exercise, you should be able to:

1. Identify the major functional groups found in soap
2. Explain how soap works at the molecular level
3. Draw balanced chemical reactions for the soapmaking process
4. Calculate various metrics for soap and relate them to the soap’s properties
5. Compare different ways of calculating the molecular weight of soap and polymers
6. Describe the difference between major classes of polymers

**Review (material you should know or learn prior to this exercise):** organic chemistry basics, Fundamentals sections L and M

**Terms you should learn:** saponification, organic functional groups, hydrophobic, hydrophillic, molecular weight calculations, polymers

**Relevant reading**: Atkins, Jones, & Laverman: Fundamentals sections L and M, Topics 5D.2, 8C.2, 8D.2, 11A, 11B.3, 11D.2, 11D.6, 11D.7, 11E.1, 11E.2, 11E.4, Toolbox 11D.1, Figure 2B.1

**After Completing this 3-day module, textbook problems you should be able to answer**:

11A.3, 11D.1b, c, 11D.34, 11E.1, 11E.3, 11E.4, 11E.11, 11E.19a, c, 11.1, 11.16, 11.33, 11.35a, 11.36

These reading assignments, and the assigned exercises, serve as a *general introduction* to concepts that you will need in order to work on the activities in the coming periods. Your conceptual understanding of these topics will be assessed during homework, concept quizzes, and exams.

**Guided Reading part 1 due by class time Wednesday Sep 14, 2016**

Read pages F87-F90 (section L).

Be able to determine the mass or number of moles of one reagent or product given the mass or number of moles of another reagent or product (such as question L3).

How many grams of water can be formed from 140.0 g molecular hydrogen (H2) given the following reaction: CO2 (g) + 4 H2 (g) 🡪 CH4 (g) + 2 H2O (l)

Read pages F96-F101 (section M).

What is a limiting reagent?

What is the difference between theoretical yield and percentage yield?

Given the following equation, determine the limiting reagent when 12.375 g FeO reacts with 6.144 g of Al.

3 FeO (s) + 2 Al (l) 🡪 3 Fe (l) + Al2O3 (s)

What is the theoretical yield of iron metal?

**Guided Reading part 2 due by class time Friday Sep 16, 2016**

Read Topic 5D.2 and study Figure 5D.7.

Which part of a surfactant molecule is polar, and which part is nonpolar?

Draw a cartoon picture that shows how soap molecules can dissolve grease (a hydrocarbon) in water.

Even though they are all polar, and two are charged, only one of the following compounds is a surfactant. Draw each molecule, and then explain your reasoning. Me4N+ Cl- (tetramethyl ammonium chloride), CH3(CH2)10CH2SO4- Na+ (sodium lauryl sulfate), H-O-O-H (hydrogen peroxide)

Read Topics 8C.2 and 8D.2(c). Although today, lye is available commercially via electrolysis, it has been known and used since antiquity. When ash leftover from burning wood is extracted with water, the main soluble species is potassium carbonate (K2CO3). When calcium oxide (CaO, quicklime), is dissolved in water, it is converted into “slaked lime,” otherwise known as calcium hydroxide (Ca(OH)2). Slaked lime reacts with the wood ash extract to form insoluble calcium carbonate, leaving soluble potassium hydroxide (KOH).

Draw balanced chemical reactions for the conversion of wood ash extract to KOH:

a) dissolving potassium carbonate

b) dissolving quicklime

c) reaction of slaked lime with wood ash extract

Read Topic 11A.1 and 11A.2. You do not need to memorize organic nomenclature, but should be able to understand (given a table like 11A.1) a structure given a name.

What is the prefix for a carbon chain containing 8 carbon atoms?

How many isomers can you draw for the formula C5H12? For C5H10?

Read Topic 11B.3. How many moles of Br2 would you expect to react with 1 mol of any of the following alkenes? How many moles of H2 would you expect to react with 1 mol of any of the following alkenes? How are the products of the reaction with H2 and Br2 the same? Different?



Read Topic 11D.2, 11D.6 and 11D.7. Two common alcohols include the two-carbon ethanol (grain alcohol)  and the 3-carbon isopropanol , found in hand sanitizer. Glycerol, used in soapmaking, is a 3-carbon triol (triol just means tri-alcohol). Esters are formed from the combination of an alcohol and a carboxylic acid. They are named according to the name of the alcohol group and the name of the carboxylic acid. Esters are often fragrant; the major odor component of banana is isoamyl acetate. 3-Methylbut-1-yl ethanoate would be a more proper name but the 3-methylbut-1-yl group has a common name of isoamyl, and ethanoate has a common name of acetate (as in acetic acid). Ethyl acetate, , is a common solvent used in laboratories and nail polish remover. The esters found in fats are called triglycerides. They are the triply esterified version of glycerol. These naturally occurring substances are found in cell membranes and of course in fat deposits in your body. They are natures method of segregating cells and storing energy (fuel) (see structure 11 in section 11D.7).

Draw a picture explaining why alcohols have significantly higher boiling points than the corresponding alkane.

Read the following paragraph on biological oil components.

Common cooking oils, such as corn, canola, coconut, and olive oil, are not pure compounds. They are extracted from their respective plants using a solvent, and removal of the solvent leaves behind the oil. Scientists use a similar extraction of plant oils from oranges using liquid carbon dioxide; you did or will do this experiment in Chem 24! The following figure lists some of the structural variety of the carboxylic acid groups found in natural fats. Most of the carboxylic acids are alkanes, though there are a few alkenes. Note that all naturally occurring double bonds in fats are “*cis”* double bonds, which means that the alkyl groups on either side of the double bond are both coming off of the same side. Some synthetic fats are hydrogenated (such as those found in margarine) and imperfect hydrogenation can lead to incorporation of “*trans*” double bonds which can not be processed by the body and therefore can lead to health problems.



Octanoic acid: C8H16O2

Lauric acid: C12H24O2

Myrstic acid: C14H28O2

Palmitic acid: C16H32O2

Linoleic acid: C18H32O2

Oleic acid: C18H34O2

Ricinoleic acid: C18H34O3

Stearic acid: C18H36O2

Natural oil components:

***Canola Oil (wt %)***

*Oleic 61%*

*Linoleic 32%*

*Palmitic 4%*

*Stearic 3%*

***Coconut Oil (wt %)***

*Lauric 50%*

*Myristic 16%*

*Palmitic 9.5%*

*Octanoic 15%*

*Oleic 9.5%*

***Olive Oil (wt %)***

*Oleic 75%*

*Palmitic 13%*

*Linoleic 10%*

*Stearic 2%*

**In class activity Day 2**

Draw a balanced chemical reaction for the reaction of glycerol tributanoate with excess sodium hydroxide in aqueous solution.

Compare your picture explaining why alcohols have significantly higher boiling points than the corresponding alkane to those of your partners. Discuss similarities and differences.

Do you expect carboxylic acids to have similarly high boiling points? Why or why not?

Do you expect esters to have similarly high boiling points? Why or why not?

Compare the picture or cartoon you drew that explained how soap works at the molecular level with your partners. Include several sentences of description.

How many grams of molecular iodine (I2) would you need to react with 100 g of the carboxylic acid shown here?



Calculate the iodine number for canola oil. The iodine number is the mass of iodine (in grams) that would react with 100. g of the oil. Do you expect the iodine number for coconut oil to be higher or lower? Why?

Why is canola oil a liquid at room temperature while coconut oil is a solid?

**Guided Reading part 3 due by class time Monday Sep 19, 2016**

Read Topics 11E.1, 11E.2,

What is the major difference between an addition and a condensation polymerization? Which reaction type is generally greener? Why/how?

Read Topic 11E.4, 11E.5, and 11E.6.

Find 5 different objects made out of plastic and find the recycling code on that object. What are your objects and what are the codes?

Read about molcular weight and polymer molecular weight on these websites (Also available on Sakai “Molecular Weight.pdf,” and “polymer molecular weight.pdf”)

<http://pslc.ws/macrog/average.htm>

<http://pslc.ws/macrog/weight.htm>

Why does a synthetic polymer not have a well-defined molecular weight?

Write the definition for the number average molecular weight *Mn* in your own words.

Write the definition for the Weight Average Molecular Weight, *Mw* in your own words.

Read this paragraph on the polydispersity index (PDI).

Distribution of molecular weights in a polymer sample (polyethylene, polypropylene, polystyrene) are expressed as the polydispersity index (PDI). Lower PDIs means a more uniform polymer. PDIs are always greater than 1; the Mw is always greater than the Mn.

In real life, molecular weights are often determined by osmometry, light scattering, sedimentation, viscosimetry, gel permeation (size exclusion) chromatography. Some of these techniques give Mw values directly, while others give Mn values directly. Neither is a *perfect* measure of the molecular weight, but each give a different characterization of the molecular weight distribution.

**In class activity Day 3**

What is the “average population” of the following four cities? What is the weighted average population? To determine the weighted average, consider the fraction of people who live in each particular city as the ‘weight fraction’, and the population as the ‘molecular weight.’

city population

A 750,000

B 65,000

C 25,000

D 10,000

Explain the difference in molecular weights in a few sentences. Extend that analysis to the molecular level: what is the difference between an average molecular weight and a weighted molecular weight for a polymer sample?

Which of these two chemical reactions would result in the formation of a polymer? Draw the products of the following reactions (page 193). Include the paranthetical bracket notation for any polymer that is formed.



An amide is similar to an ester, in that it is a reaction of a carboxylic acid with another group that replaces the –OH group. In amides, the replacing group is an amine (H2NR for example), and the amide is R(C=O)NHR. Draw the reaction of adipic acid (1,6-hexanedicarboxylic acid) with 1,6-hexanediamine. Can this reaction form a polymer? This equation represents the synthesis of nylon. Does it proceed by an addition or condensation mechanism?

Proteins are biopolymers. A short polymer chain is shown. Is this a polyester or a polyamide? Do you expect the PDI for a protein to be > 1 or = 1? Why?

