Oakland Schools Chemistry Resource Unit

Organic Chemistry

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<u>Organic Molecules</u>

Content Statements:

C4.2x: Nomenclature

All molecular and ionic compounds have unique names that are determined systematically.

C5.8: Carbon Chemistry

The chemistry of carbon is important. Carbon atoms can bond to one another in chains, rings, and branching networks to form a variety of structures, including synthetic polymers, oils, and the large molecules essential to life.

Content Expectations:

C4.2e: Given the formula for a simple hydrocarbon, draw and name the isomers.

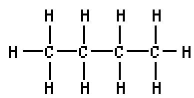
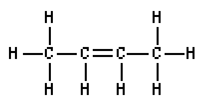
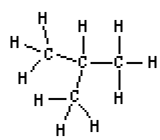
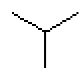
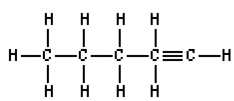
C5.8A: Draw structural formulas for up to ten carbon chains of simple hydrocarbons.

C5.8B: Draw isomers for simple hydrocarbons.

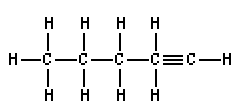
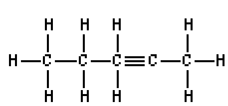
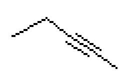
C5.8C: Recognize that proteins, starches, and other large biological molecules are polymers.

Instructional Background Information:

Hydrocarbons: Hydrocarbons are molecules composed exclusively of carbon and hydrogen which can be arranged in simple or complex chains, rings, and with single (alkane), double (alkene), or triple (alkyne) bonds.

Lewis Structure	Organic Shorthand	Name
		Butane
		But-2-ene
		2-methyl propane
		Pent-1-yne

Isomer: Molecules with the same chemical formula but different structural connectivity are called isomers. Each isomer has a unique Lewis structure which allows for easy naming. Naming is based on the presence of double or triple bonds, the length of the longest carbon chain, and the lengths, numbers, and locations of any side chains.

Lewis Structure	Organic Shorthand	Name
		Pent-1-yne
		Pent-2-yne

Polymer: Large molecule composed of repeating smaller units. Examples include: proteins, starches, nucleic acids and cellulose.

The Nature of Organic Chemistry

There are over six million organic compounds characterized, including the foods we eat, (made of carbohydrates, lipids, proteins, and vitamins), furs and feathers, hides and skins, and the organisms they came from. Not to mention plastics, synthetic and natural fibers, dyes and drugs, insecticides and herbicides, ingredients in perfumes and flavoring agents, and petroleum products.

The name *organic* chemistry came from the word organism. Prior to 1828, all organic compounds had been obtained from organisms or their remains. The belief then was that the synthesis of organic compounds from inorganic compounds in the laboratory was impossible. All efforts had failed, and scientists became convinced that some "vital force" that living organisms had was necessary to make an organic compound. The synthesis of urea from inorganic substances in 1828 led to the disappearance of this *vital force theory*.

The Uniqueness of Carbon

The great number of carbon compounds is possible because of the ability of carbon to form strong covalent bonds to each other *while also holding the atoms of other nonmetals strongly*. Chains of carbon atoms can be thousands of atoms long, as in polyethylene.

Polyethylene chain:

```
  H H H H H H H H H H H
   | | | | | | | | | | |
H-C-C-C-C-C-C-C-C-C-C-C-etc.
   | | | | | | | | | | |
  H H H H H H H H H H H
```

Isomers

Isomerism is another reason why there are so many organic compounds. *Isomers* are compounds with identical molecular composition but their structures are arranged differently. Depending on how they are arranged, they may have similar or different properties.

Because the number of carbons per molecule increases as the compound gets more complex, the number of possible isomers for any given formula becomes very, very large.

Formula	Number of Isomers
C_8H_{18}	18
$C_{10}H_{22}$	75
$C_{20}H_{42}$	366,319
$C_{40}H_{82}$	6.25×10^{13} (approx.)

Examples of Isomers:

```
                        H
                        |
   H H H H          H H-C-H H
   |  | |  |           |   |   |
H-C-C-C-C-H       H-C---C---C-H
   |  |  |  |          |   |   |
  H H H H            H   H   H
```

butane   2-methyl propane

Butane and 2-methyl propane both have the molecular formula C_4H_{10}.

```
  H H           H   H
   | |           |   |
H-C-C-O-H    H-C-O-C-H
   | |            |   |
  H H            H   H
```

ethanol dimethyl ether

Ethanol and dimethyl ether both have the molecular formula C_2H_6O.

Hydrocarbons

Hydrocarbons are organic compounds that consist of only C and H atoms. They include the alkanes, alkenes, alkynes, and aromatic hydrocarbons. Because of their relatively nonpolarity, all hydrocarbons are insoluble in water (see previous section). When hydrocarbons burn in sufficient oxygen, carbon dioxide and water are the sole products. The main structural difference among hydrocarbon families is the presence of double or triple bonds between carbon atoms. The alkanes are *saturated organic compounds*, or those with only single bonds. *Unsaturated organic compounds* are those which have double or triple bonds.

Sources of Hydrocarbons

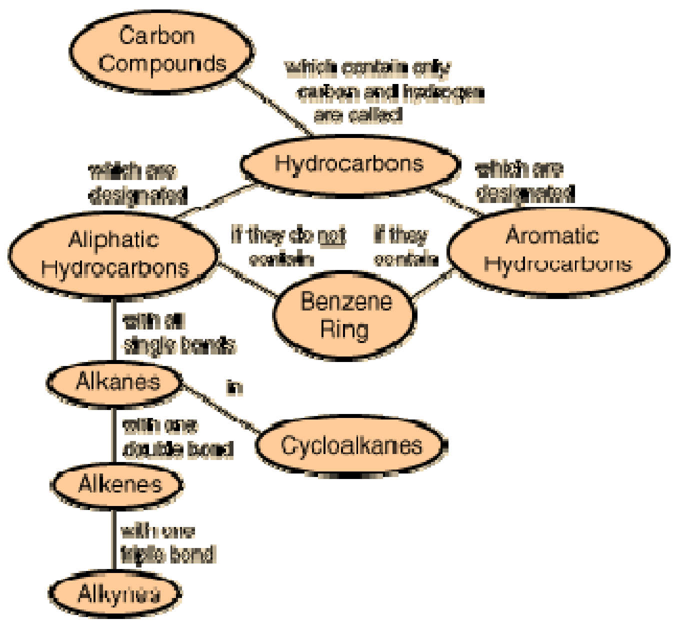
Almost all useable supplies of hydrocarbons are obtained from fossil fuels--coal, petroleum, and natural gas. Through distillation, crude oil is boiled and condensed over several *fractions* to give the desired mixture of compounds. Gasoline, for example, is a fraction boiling roughly between 40 and 200°C. The vapors that are condensed in this fraction are mostly alkanes and have between 5 to 10 carbon atoms.

Biochemicals

Biochemistry is the study of the chemicals of living systems and their interactions. Alone, these chemicals are not living, but together, their interactions work together to create and sustain a living organism. The reactions between them obey all of the known laws of chemistry.
To sustain a living system, materials, energy, and information is needed. The substances that supply these three necessities are the basic materials which, together with water and a few kinds of ions, make up cells and tissues.
Proteins are the main source of the materials. Lipids and carbohydrates are the major sources of the chemical energy needed to maintain function. And information is carried in a *genetic code* by molecules of nucleic acid.
This section will not be very in depth because many aspects extend into the field of biology.

Hydrocarbons

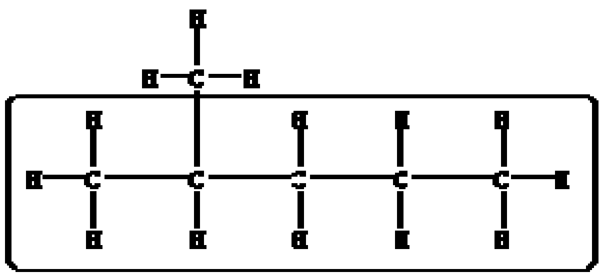
Hydrocarbons are the simplest organic compounds . Containing only carbon and hydrogen, they can be straight-chain, branched chain, or cyclic molecules. Carbon tends to form four bonds in a tetrahedral geometry. Hydrocarbon derivatives are formed when there is a substitution of a functional group at one or more of these positions.



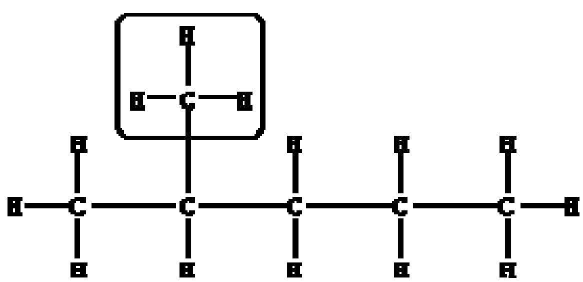
The Nomenclature of Alkanes

Common names such as pentane, isopentane, and neopentane are sufficient to differentiate between the three isomers with the formula C_5H_{12}. They become less useful, however, as the size of the hydrocarbon chain increases.
The International Union of Pure and Applied Chemistry (IUPAC) has developed a systematic approach to naming alkanes and cycloalkanes based on the following steps.

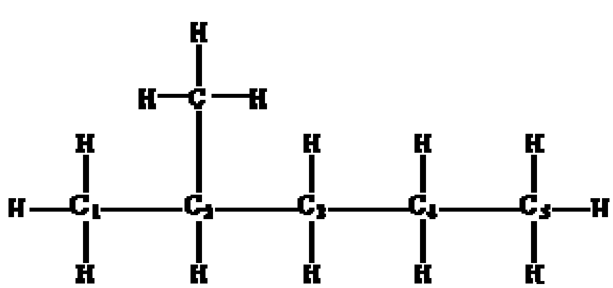
- Find the longest continuous chain of carbon atoms in the skeleton structure. Name the compound as a derivative of the alkane with this number of carbon atoms. The following compound, for example, is a derivative of pentane because the longest chain contains five carbon atoms.



- Name the substituent on the chain. Substituents derived from alkanes are named by replacing the -**ane** ending with -**yl**. This compound contains a methyl (CH_3-) substituent.



- Number the chain starting at the end nearest the first substituent and specify the carbon atoms on which the substituents are located. Use the lowest possible numbers. This compound, for example, is 2-methylpentane, not 4-methylpentane.



- Use the prefixes **di-**, **tri-**, and **tetra-** to describe substituents that are found two, three, or four times on the same chain of carbon atoms.
- Arrange the names of the substituents in alphabetical order.

http://library.thinkquest.org/3659/orgchem/organicchemistry.html

Table 12 Structure & Physical properties of isomers

		mp°C	bp°C	Density g / ml 20
Pentane	$CH_3-CH_2CH_2CH_2-CH_3$	-130	36	0.626
Isopentane	$(CH_3)_2CHCH_2-CH_3$	-160	28	0.620
Neopentane	$C(CH_3)_4$	17	10	0.614
Cyclopentane	ring of CH_2, H_2C, H_2C, CH_2, CH_2	-94	49	0.746

http://www.pinkmonkey.com/studyguides/subjects/chem/chap13/table13_22.gif

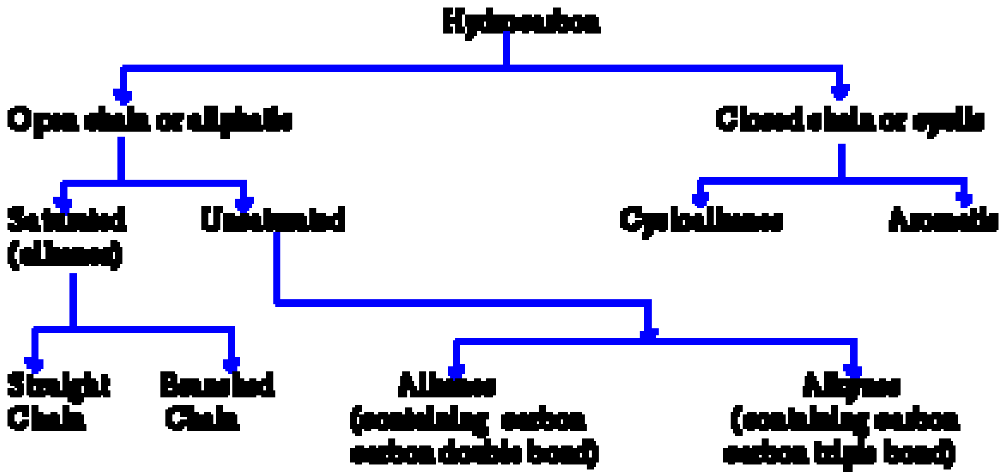


Figure 35

http://www.pinkmonkey.com/studyguides/subjects/chem/chap13/fig35_13.gif

Terms and Concepts

Alcohol	Double bond	Petroleum
Alkane	Ester	Single bond
Alkene	Functional Group	Triple bond
Alkyne	Hydrocarbon	
Boiling Point	Intermolecular forces	
Distillation	Lewis Structure	

Instructional Resources

Teacher driven information and worksheets/lessons:
http://www.sciencenetlinks.com/lessons.cfm?BenchmarkID=4&DocID=469

Fractional distillation of crude oil background information:
http://www.elmhurst.edu/~chm/onlcourse/chm110/outlines/distill.html

Fractional distillation of petroleum background information:
http://library.thinkquest.org/C006295/course/loader.php?subject=course&location=petroleum_fractional_distillation.htm

List of petroleum topics for teachers:
http://64.233.167.104/search?q=cache:Zgr-Gip93z4J:www.rvh.richland2.org/~gmaynes/ChemCom%2520Unit%25203.doc+fractional+distillation+petroleum+lab&hl=en&ct=clnk&cd=11&gl=us

Study guides:

http://www.pinkmonkey.com/studyguides/subjects/chem/chap13/c1313101.asp

Organic Molecules

Activity #1 – Hydrocarbon Boiling Points Activity

Questions to be investigated

Can the properties of hydrocarbons be predicted by their formulas?

Objectives

Students will understand the relationship between size of molecule and London Dispersion Forces (LDF)

Teacher Notes

These activities can be used with Excel or other graphing software and incorporated into a graphing assignment.

Materials

Activity Worksheet

Real-World Connections

The variance in boiling point can be exploited for the separation of crude oil via fractional distillation (see activity #3).

Sources

Graphing Calculators & Calculator Based Laboratory:

http://dwb.unl.edu/calculators/activities/BP.html

Procedure / Description of Lesson

Activity One

Chemists often gather data regarding physical and chemical properties of substances. Although these data can be organized in many ways, the most useful ways uncover trends or patterns among the values. These patterns often trigger attempts to explain regularities.

The development of the periodic table is a good example of this approach. Recall that you predicted a property of one element from values of that property for neighboring elements on the periodic table.

In a similar vein, we seek patterns among boiling point data for some hydrocarbons. During evaporation and boiling, individual molecules in the liquid state gain enough energy to overcome intermolecular forces and enter the gaseous state.

table 1 Hydrocarbon boiling points

Hydrocarbon	boiling point (°C)
Butane	-0.5
Decane	174.0
Ethane	-88.6
Heptane	98.4
Hexane	68.7
Methane	-161.7
Nonane	150.8
Octane	125.7
Pentane	36.1
Propane	-42.1

Questions:

1. Answer the following questions about boiling point data given in table 1 above.

- a. In what pattern or order are Table 1 data organized?

- b. Is this a useful way to present the information? Why?

2. Assume we want to search for a trend or pattern among these boiling points.

- a. Propose a more useful way to arrange these data.

- b. Reorganize the data table based on your idea.

3. Use your new data table to answer these questions:

- a. Which substance(s) are gases (have already boiled) at room temperature (22 C)?

- b. Which substance(s) boil between 22 C (room temperature) and 37 C (body temperature)?

4. What can you infer about intermolecular attractions in decane compare to those in butane?

5. Intermolecular forces also help explain other liquid properties such as viscosity and freezing points.

- a. Based on their intermolecular attractions, try to rank pentane, octane, and decane in order of increasing viscosity. Assign "1" to the least viscous ("thinnest") of the three.

- b. Check with your teacher to see whether you are correct.

Activity Two

Alkane Boiling points: Trends

Boiling is a physical change whereby a liquid is converted in to a gas. Boiling occurs when the vapor pressure of a liquid is equal to the atmospheric pressure pushing on the liquid. But what other factors affect the boiling point of a liquid?

To explain relative boiling points we must take into account a number of properties for each substance. The properties include molar mass, structure, polarity and hydrogen bonding ability. All of these properties can affect the boiling point of a liquid. In this exploration we will investigate the boiling points for the first ten straight chain alkane hydrocarbons. We are most interested in the effect of molecular size (mass) upon a substance's relative boiling point.

1. Listed in table 1 below is boiling point data for the first ten straight chain alkanes. Enter the data into your calculator for analysis by assigning:

- L1 = carbon number
- L2 = boiling point

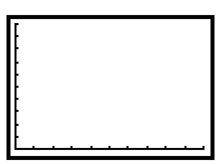
DIRECTIONS FOR TI-82/83

[Y=] Clear all equations
[STAT] EDIT

Table 1 *Hydrocarbon Boiling Points*

Hydrocarbon	**Formula**	**Boiling Point (°C)**
Butane	C_4H_{10}	-0.5
Decane	$C_{10}H_{22}$	174.0
Ethane	C_2H_6	-88.6
Heptane	C_7H_{16}	98.4
Hexane	C_6H_{14}	68.7
Methane	CH_4	-161.7
Nonane	C_9H_{20}	150.8
Octane	C_8H_{18}	125.7
Pentane	C_5H_{12}	36.1
Propane	C_3H_8	-42.1

2. Construct a scatterplot of carbon number vs. boiling point and sketch the graph in your lab report.



DIRECTIONS FOR TI-82/83

[2nd] [Y=]
Plots Off
[ENTER]
[2nd] [Y=]
Plot1
ON
Xlist=L1 Ylist=L2 Mark: ▪
[ZOOM]
ZoomStat

3. Use your graph to determine the average change in boiling point (in degrees Celsius) when a carbon atom and two hydrogen atoms are added to a given alkane chain.

4. Describe the relationship between the number of carbons and the boiling point by using one of the following terms (# of carbon atoms and boiling point ""):

- vary directly
- vary inversely
- directly proportional
- inversely proportional

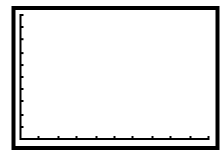
5. The pattern of boiling points among the first ten alkanes allows you to predict the boiling points of other alkanes. Let’s assume the relationship is linear and proportional. Use the calculator to Calculate the regression equation for the data. Enter the equation into Y1 and plot the line of "best fits". Record the regression equation and sketch the calculator screen in your lab report.

Directions for the TI-82/83

STAT
CALC
LinReg(ax+b)
ENTER
L1,L2
ENTER
Y=
Y1
VARS
Statistics
EQ
RegEQ
GRAPH

Regression Equation

Y= ____________________



6. From your graph, extrapolate the boiling points of undecane (C11H24), dodecane (C12H26) and tridecane (C13H28).

WINDOW
Xmin = 0
Xmax = 15
Xscl = 1.5
Ymin = -200
Ymax = 500
Yscl = 70
GRAPH
2nd.
CALC
Value
ENTER
Y=
Eval X=11
ENTER

7. Compare your predicted boiling points to actual values provided by your teacher. Calculate the percentage error for each value. Suggest reasons, both mathematical and chemical for any differences in your predictions.

8. We have already noted that a substance's boiling point depends on its intermolecular forces-that is, on attractions among its molecules. In a summary paragraph discuss how intermolecular attractions are related to the number of carbon atoms in each molecule for alkanes you have studied.

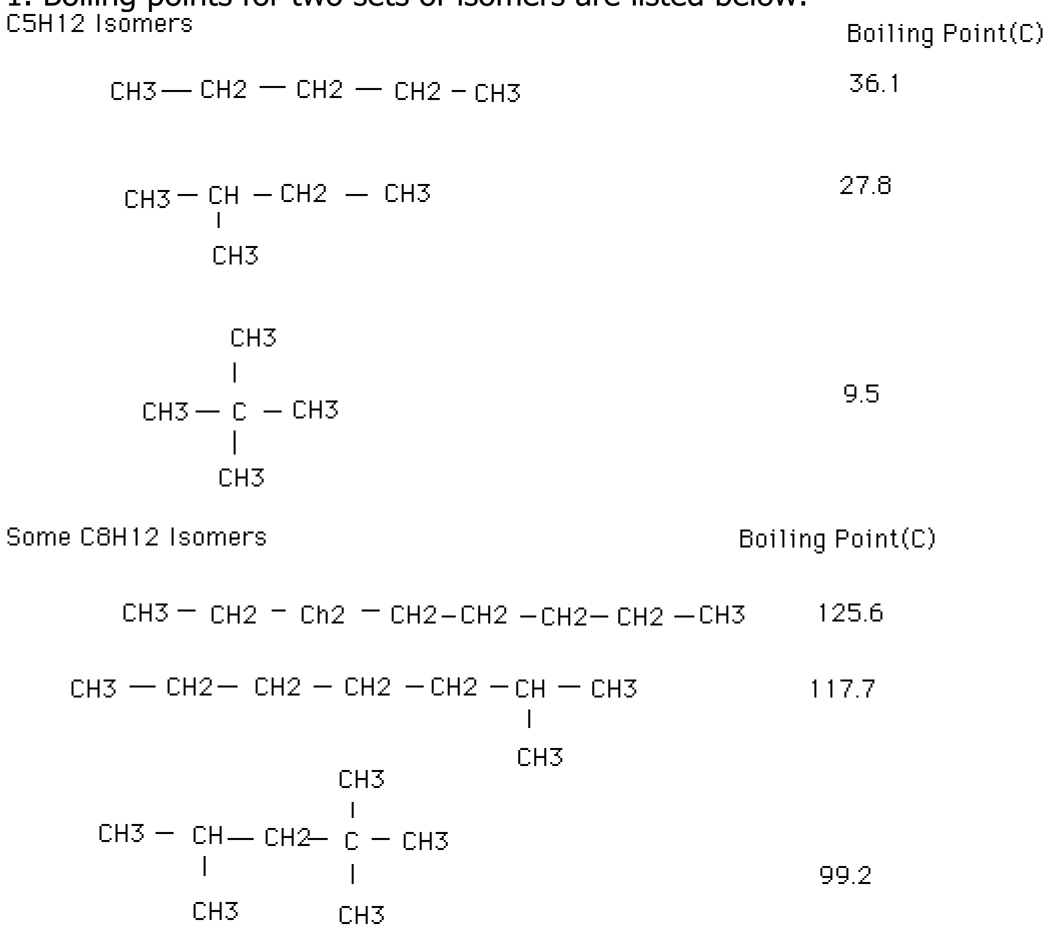
Activity Three

Alkane Boiling Points: Isomers

You have already observed the boiling points of straight chain alkanes are related to the number of carbon atoms in their molecules. Increased intermolecular attractions are related to the greater molecule-molecule contact possible for larger alkanes.

For example, consider the boiling points of some isomers

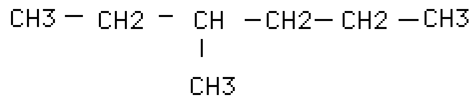
1. Boiling points for two sets of isomers are listed below:



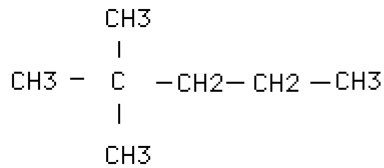
2. Within a given series, how does the boiling point change as the number of carbon side-changes increase?

3. Match each boiling point to the appropriate C_7H_{16} isomer: 98.4 °C, 92.0 °C, 79.2 °C.

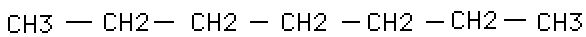
a.



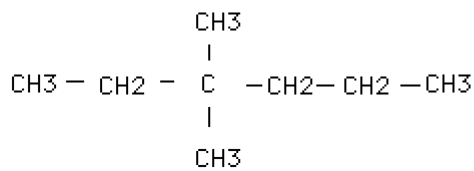
b.



c.



4. This is a C_8H_{18} isomer.



- a. Compare it to each C8H18 isomer listed in table 3. Predict whether it would have a higher or lower boiling point than each of these other C8H18 isomers.
- b. Would the C8H18 isomer shown above have a higher or lower boiling point than each of the three C5H12 isomers shown in table 3?

4. Write a summary paragraph explaining what you have learned in activity one, two and three with regards to the following terms:

- Hydrocarbons
- Boiling Point
- Isomers

Adopted from:
Chem Com: Chemistry in the Community, second edition, 1995, American Chemical Society

Assessment Ideas

Students can answer the questions on the worksheet.

Organic Molecules

Activity #2 – Synthesizing Esters

Questions to be investigated

Can a molecule with a good smell be synthesized from odorless molecules?

Objectives

Students will learn a basic organic synthesis and observe the smells of esters.

Teacher Notes

A fume hood is highly recommended for this activity.

You can remove the data table or the procedure to extend this inquiry activity and make more challenging for students.

Materials

salicyclic acid (#1) wintergreen	2 mL methyl alcohol (#1)	8 -10 drops
acetic acid (#2) orange	octyl alcohol (#2)	10 -15 drops
formic acid (#3) rum	ethyl alcohol (#3)	20 drops
butyric acid (#4) pineapple	ethyl alcohol (#3)	15 -20 drops
butyric acid (#4) apple	methanol (#4)	15 -20 drops

7 10 x 75 mm test tubes
1 test tube rack
1 test tube holder
1 stirring rod
14 pieces of filter paper (or strips of paper towel)
1 250 mL beaker (to be use as a hot water bath)
boiling chips

Safety Concerns

Nearly all of the compounds used in this lab are flammable. Concentrated sulfuric acid is EXTREMELY dangerous. Great care and proper ventilation are required for this lab.

Real-World Connections

Perfume and food manufacturers regularly use many of these esters in food and perfumes / colognes.

Sources

Instructor Homepage: Susan Hovde, Instructor:

http://www.hartnell.cc.ca.us/faculty/shovde/chem12b/esters.htm

Procedure / Description of Lesson:

ESTERS Name ______________________________

Esters are a class of compounds widely distributed in nature. They have the general formula

$$R\text{-}\overset{\overset{\displaystyle O}{||}}{C}\text{-}OR'$$

The simple esters tend to have pleasant odors. In many cases, although not exclusively so, the characteristic flavors and fragrances of flowers and fruits are due to compounds with the ester functional group. An exception is the case of essential oils. The organoleptic qualities (odors and flavors) of fruits and flowers may often be due to a single ester, but more often the flavor or aroma is due to a complex mixture in which a single ester predominates.

Some common flavor principles are listed below.

Ester	Odor
isoamyl acetate	banana
ethyl acetate	fingernail polish remover
methyl salicylate	wintergreen
ethyl butyrate	pineapple
benzyl butyrate	cherry
ethyl propionate	rum
ethyl benzoate	fruity
benzyl acetate	peach
methyl butyrate	apple
octyl acetate	orange
n-propyl acetate	pear
ethyl phenylacetate	honey

Food and beverage manufacturers are thoroughly familiar with these esters and often use them as additives to spruce up the flavor or odor of a dessert or beverage. Many times odors do not have a natural basis, as is the case with the "juicy fruit" principle, isopentenyl acetate. An instant pudding that has the flavor of rum may never have seen its alcoholic namesake—this flavor can be duplicated by the proper admixture, along with other minor components, of ethyl formate and isobutyl propionate. The natural flavor and odor are not exactly duplicated, but most people can be fooled. Often only a trained person with a high degree of gustatory perception, a professional taster, can tell the difference.

A single compound is rarely used in good-quality imitation flavoring agents. A formula for imitation pineapple flavor that might fool an expert includes 10 esters and carboxylic acids that can easily be synthesized in the laboratory, and 7 essential oils that are isolated from natural sources.

Flavor is a combination of taste, sensation and odor transmitted by receptors in the mouth (taste buds) and nose (olfactory receptors). There are four different tastes (sweet, sour, salty, and bitter). The perception of flavor, however, is not so simple. The human actually possesses 9000 taste buds and odor plays a big role in the perception of taste.

Although the "fruity" tastes and odor of esters are pleasant, they are seldom used in perfumes or scents that are applied to the body. The reason for this is that the ester group is not as stable to perspiration as the ingredients of the more expensive essential oils. The later are usually hydrocarbons (terpenes), ketones and ethers extracted from natural sources. Esters are only used for the cheapest toilet waters; since on contact with sweat they hydrolyze, giving organic acids. These acids, unlike their precursor esters, generally do not have a pleasant odor.

$$R\text{-}\overset{O}{\overset{\|}{C}}\text{-}OR' + H_2O \rightarrow R\text{-}\overset{O}{\overset{\|}{C}}\text{-}OH + R'OH$$

Butyric acid, for instance, has a strong odor like that of rancid butter (of which it is an ingredient) and is a component of what we normally call body odor. Ethyl butyrate and methyl butyrate, however, are esters that smell like pineapple and apple, respectively.

In this experiment you will note the odor of five carboxylic acids and four alcohols. Then, you will prepare seven esters using various combinations of these carboxylic acids and alcohols. From the odor of the esters and the list above you will identify the ester and then the carboxylic acid and alcohol from which it was made.

Materials

Each student will need:

1 gram acid(#1)	2 mL alcohol (#1)	8 -10 drops
3 mL acid (#2)	2 mL alcohol (#2)	10 -15 drops
4 mL acid (#3)	2 mL alcohol (#3)	20 drops
2 mL acid (#4)	2 mL alcohol (#3)	15 -20 drops
2 mL acid (#4)	2 mL alcohol (#4)	15 -20 drops

7 10 x 75 mm test tubes	1 stirring rod	boiling chips
1 test tube rack	14 pieces of filter paper (or strips of paper towel)	
1 test tube holder	1 250 mL beaker (to be use as a hot water bath)	

Procedure:

1. Put on goggles.
2. Put one drop of carboxylic acid and one drop of alcohol on opposite sides of a piece of filter paper. Waft the vapor toward your nose and describe the odor of the acid and alcohol. If the acid is solid, open the cap of the container and waft the vapors toward your nose. Record the odor is the appropriate space in the following data table.
3. Repeat until the odor of all carboxylic acids and alcohols has been recorded in the following data table.
4. Read the label on the bottle and add the indicated number of drops/quantity of each reagent to a micro test tube. Swirl gently to mix the contents.
5. Add a drop of concentrated sulfuric acid to the test tube. (Sulfuric acid acts as a catalyst.) Add a boiling chip.
6. Using the test tube holder, place the test tube in a boiling water bath for one minute. Watch the contents carefully to avoid boiling over. If the reaction mixture begins to boil too quickly, remove it from the water bath for a few seconds and slowly return it. Each test tube must be in the water bath for one minute.
7. Use a stirring rod to transfer a drop of the reaction mixture to a clean piece of filter paper (or strip of paper towel). Waft the vapors toward your nose and record the odor of the new compound. If the mixture solidifies, waft the vapors from the solid material on the end of the stirring rod.
8. Identify the ester by the odor of the ester produced. Use the identification of the ester to identify the carboxylic acid and alcohol used in the reaction to produce the ester.
9. Repeat steps 4 through 8 until each of the seven esters has been prepared.

Data Table

TRIAL	Acid	Quantity	Odor	Acid Name	Alcohol	Quantity	Odor	Alcohol Name	Ester Name	Odor
A	#1	10 drops			#2	20 drops				
B	#1	10 drops			#3	20 drops				
C	#2	0.4 gram			#2	20 drops				
D	#3	10 drops			#1	12 drops				
E	#3	10 drops			#2	8 drops				
F	#4	20 drops			#2	15 drops				
G	#5	0.1 gram			#4	15 drops				

Larger data table is shown on next page
(Print out larger table in excel titled "Esters Lab Report")

Questions

1. Write equations for each of the esters formed above:
   A.

   B.

   C.

   D.

   E.

   F.

   G.

2. Pick one of the equations above and write the mechanism for the formation of the ester.

Assessment Ideas

Students can answer the questions on the worksheet.

Organic Molecules

Activity #3 – Separation by distillation

Questions to be investigated

Can a mixture of different compounds be separated by boiling?

Objectives

Students will understand the basics of distillation as well as how distillation can separate compounds.

Teacher Notes

Distillation apparatuses are expensive; this might be a good demo.

Materials

Isopropyl alcohol	water	distillation apparatus.

Safety Concerns

Isopropyl alcohol is flammable and has strong fumes. Care and proper ventilation should be used.

Real-World Connections

Petroleum is separated in exactly the same way as in this lab.

Sources

Chemistry in the Community 5th Edition

Procedure / Description of Lesson

Unit 3

A.2 Investigating Matter: Separation by Distillation

Introduction

You know that you can often separate substances by taking advantage of their different physical properties. One physical property commonly used to separate liquids is their density. However, density differences will work only if substances are insoluble in each other, which is not the case with petroleum; its components are soluble in each other. Another physical property chemists often use is boiling point. The separation of liquid substances according to their differing boiling points is called **distillation.**

As you heat a liquid mixture containing two components, the component with the lower boiling point will vaporize first and leave the distillation flask. That component will then condense back to a liquid as it passes through a condenser—all before the second component begins to boil. See Figure 3.6 (page 215 of your textbook). Each condensed liquid component, called the **distillate,** can thus be collected separately.

In this investigation, you will use distillation to separate a mixture of two liquids. Then you will identify the two substances in the mixture by comparing the observed distillation temperatures with the boiling points of several possible compounds listed in Table 3.1 (page 212 of your textbook).

The following Procedure provides guidance about when you should collect and record data (consider Step 8). Create a data table with columns to record time and temperature data. Remember to include proper units for each data column. Before you begin, carefully read the Procedure to learn what is involved, note safety precautions, and plan for your data collecting and observations.

Procedure

(***Caution:*** *This distillation should only be completed with a hot plate or other electric heating source. The presence of open flames near the distillation apparatus represents a fire hazard.*)

1. Construct data tables to record your observations and measurements.
2. Assemble an apparatus similar to that shown in Figure 3.6. Label two beakers *Distillate 1* and *Distillate 2.*
3. Using a clean, dry, graduated cylinder, measure a 50-mL sample of the distillation mixture. Pour the mixture into the distillation flask and add a boiling chip.
4. Record your observations of the starting mixture.
5. Connect the flask to a condenser, as indicated in Figure 3.6. Ensure that the hoses are attached to the condenser and to the water supply as shown. Position the Distillate 1 beaker at the outlet of the condenser so it will catch the distillate, as shown in Figure 3.7 (page 216 of your textbook).
6. Ensure that all connections are tight and will not leak.
7. Turn on the water to the condenser, and then turn on the hot plate to start gently heating the flask. (***Caution:*** *The substances, other than water, are volatile and highly flammable. Be sure that no flames or sparks are in the area.*)
8. Record the temperature every minute until the first drop of distillate falls into the beaker. Then continue to record the temperature every 30 seconds. Continue to heat the flask and collect the distillate until the temperature begins to rise again. At this point, replace the Distillate 1 beaker with the Distillate 2 beaker.
9. Continue heating and recording the temperature every 30 seconds until the second substance just begins to distill. Record the temperature at which the first drop of the second distillate falls into the beaker. Collect 1 to 2 mL of the second distillate. (***Caution:*** *Do not allow all of the liquid to boil from the flask.*)
10. Turn off the hotplate and allow the distillation apparatus to cool. While the apparatus is cooling, test the relative solubility of solid iodine (I_2) in Distillate 1 and Distillate 2 by adding a few crystals of iodine to each beaker and stirring. Record your observations. (***Caution:*** *Iodine is corrosive on contact. It will stain skin and clothing.*)
11. Disassemble and clean the distillation apparatus, and dispose of your distillates as directed by your teacher.
12. Wash your hands thoroughly before leaving the laboratory.

Data Analysis
Plot your data on a graph of time (*x*-axis) versus temperature (*y*-axis). As you observed, heating the liquid mixture raised its temperature. However, once the first component began to boil and vaporize from the mixture, the temperature of the liquid remained steady until that component completely distilled. Continued heating then caused the temperature to rise again, this time until the second component began to boil and distill. Because the liquid temperature does not change appreciably during distillation of a particular component, those graph-line portions should appear flat (horizontal).

Questions
1. a. Using your graph, identify the temperatures at which Distillate 1 and Distillate 2 were collected.

Distillate 1_________°C

Distillate 2_________°C

b. How well do the horizontal plateaus in your graph match the temperatures at which you collected the first drops of each distillate?

____

____

2. Use data in Table 3.1 (page 216 of your textbook) to identify each distillate sample.
Distillate
1____
Distillate
2____

3. Combine your data with the data of students who distilled the same mixture:
   a. Examine the combined data, and find the average temperature (*mean*) and the most frequently observed temperature (*mode*) for each of the two plateaus you observed.

   Mean Temperature _________°C

   Mode Temperature _________°C

   b. All laboratory teams investigating the same mixture did not observe the same distillation temperatures. Describe some factors that may contribute to this inconsistency.

   ____

   ____

4. In which of the distillates was solid iodine more soluble? What observational evidence leads you to that conclusion?

   ____

   ____

   ____

5. What laboratory tests could you complete to decide whether the liquid left behind in the flask is a mixture or a pure substance?

   ____

   ____

   ____

6. Of the substances listed in Table 3.1 (page 215 of your textbook), which two would be most difficult to separate by distillation? Why?

____

____

____

7. a. How would a graph of time vs. temperature look for the distillation of a mixture of all four substances listed in Figure 3.4 (page 214 of your textbook?

____

____

b. Sketch the predicted graph and describe its features.

____

____

____

Unit 3

A.2 Investigating Matter: Separation by Distillation
Starting Mixture Observations

____

____

____

Time	Temperature

Temperature when first drop of second distillate falls into beaker:

____________°C

Organic Molecules

Activity #4 – Synthesis of Soap

Questions to be investigated

How can the properties of a substance be modified by modifying the intermolecular forces within a molecule? Can these changes be beneficial?

Objectives

Students will be able to determine the relationship between various intermolecular forces and the properties of substances.

Teacher Notes

Soap making can be very messy. Make sure to clear all non-essential materials.

Materials

Fat or Oil   Sodium Hydroxide   Ethanol   Water   Glassware

Safety Concerns

This lab uses concentrated sodium hydroxide, which is EXTREMELY caustic and dangerous. Extreme caution should be exercised.

Real-World Connections

Soap is a major industrial product today and its manufacture is accomplished in much the same way as is performed in this lab. The possibility of scaling this reaction up to industrial scale can be discussed.

Sources

LBS 172L Principles of Chemistry II - Reactivity /Spring 2007 :
https://www.msu.edu/course/lbs/172l/Lab1-S06-soapmaking.pdf

Procedure / Description of Lesson

Laboratory Goals

In this lab, you will:

- Learn how soap is prepared
- Test some properties of soap

Safety Notes

The sodium hydroxide solution used in this lab is extremely concentrated. Be sure to avoid any contact with skin and especially eyes as it can cause serious burns. All spills MUST be immediately reported to the LA and cleaned.

Introduction

The process of soap-making goes far back in history. Most people who have made soap throughout the centuries have had no idea what is occurring; they simply made soap through trial and error, lots of luck and governing superstitions.

The process (similar to what we will be doing in lab) involved combining some form of fat with an alkali (basic) material. Most commonly the alkali was in the form of potash and pearlash, which contain KOH. Potash and pearlash soaps were used by everyone from the reigning monarchs to the peasant or cottager, who made their own soap from the waste fats and ashes they saved.

The First Soap

It is recorded that the Babylonians were making soap around 2800 B.C. and that it was known to the Phoenicians around 600 B.C. These early references to soap and soap-making were apropos the use of soap in the cleaning of textile fibers such as wool and cotton in preparation for weaving into cloth.

The Romans and Celtics

The first definite and tangible proofs of soap-making are found in the history of ancient Rome. Pliny, the Roman historian, described soap being made from goat's tallow and causticized wood ashes. He also wrote of common salt being added to make the soap hard. The ruins at Pompeii revealed a soap factory complete with finished bars.

While the Romans are well known for their public baths, generally soap was not used for personal hygiene. To clean the body the Greeks (and later the Romans) would rub the body with olive oil and sand. A scraper, called a strigil, was then used to scrape off the sand and olive oil, also removing dirt, grease, and dead cells from the skin, which was left clean. Afterwards the skin was rubbed down with salves prepared from herbs.

Throughout history, people have taken baths in a variety of bathing mediums, with herbs and other ostensibly beneficial additives. It is well known that Cleopatra, who captivated the leaders of the Roman world, attributed her beauty to her baths in mare's milk. During the early centuries of the Common Era, soap was used by physicians in the treatment of disease. Galen, a second century physician, recommended bathing with soap for the amelioration of some skin conditions. Soap for personal cleansing became popular during the later centuries of the Roman era.

The Celtic peoples are also believed by some historians to have discovered soap-making; their soaps were used for bathing *and* washing. Perhaps due to increased contact with the Celtics by the Romans, using soap for personal cleansing became popular.

There is an interesting legend surrounding the discovery of soap-making. This legend accords the discovery of soap to the Romans, so it might have been fabricated to confront the Celtic claim to soap-making. Probably both of these inventive peoples discovered soap-making independently. The legend asserts that soap was first discovered by women washing clothes along the Tiber River at the bottom of Sapo Hill. The women noticed their wash became cleaner with far less effort at that particular location. What was happening? The ashes and the grease of animals from the sacrificial fires of the temples situated on the top of Sapo Hill mixed with the rain; the resulting soap--which ran down the slope in the streams of rain water--give the women a wash day bonus. One can see at a glance that "saponification", the chemical name for the soap-making reaction, bears the name of that hill in Rome long ago, which caused one washer-women to comment to another, "My wash is cleaner than yours".

The Chemistry of Soapmaking

As stated earlier, the chemistry behind soap-making was not understood for many years. It is now known that saponification of soaps proceeds by the conversion of the triglycerides, which are the components of fats and oils, to fatty acid salts and glycerol as show in Figure 1. The R groups in the figure represent long carbon chains with the accompanying hydrogens. For each specific triglyceride, these specific R groups can be determined. For example tristearin gives the reaction shown in Figure

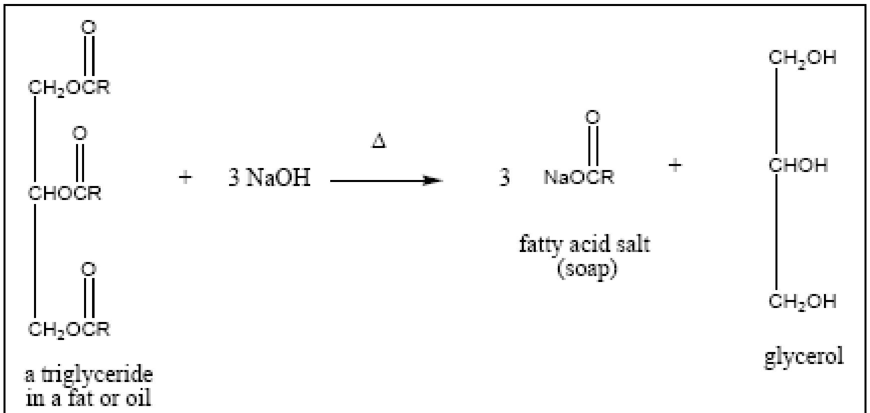


Figure 1: Reaction of a triglyceide with sodium hydroxide

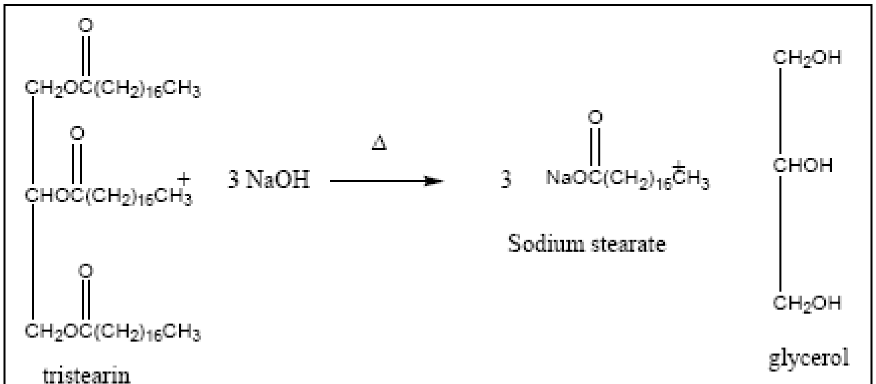


Figure 2: Reaction of tristearin with sodium hydroxide.

Typically, fats and oils have different more than one different R group in the same molecule so a variety of sodium salts are produced. In order to separate out the salts from the rest of the reaction products, a saturated NaCl solution is added. This forces the soap to coagulate without dissolving in the water. It can then be collected by filtration and washed to remove the excess base.

Table 1 lists the different carboxylic acids that originally reacted with glycerol to yield the triglycerides found in the fats and oils. It shows the relative ratio of the acids for a variety of fats and oils.

Table 1: Percent by weight of total fatty acids.

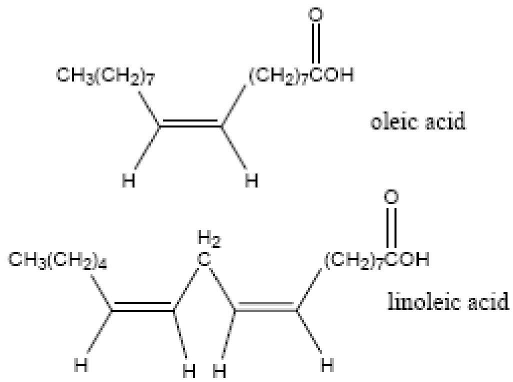
Oil or Fat	Unsat/ Sat ratio	Saturated					Mono unsat	Poly unsaturated	
		Capric Acid C10:0	Lauric Acid C12:0	Myristic Acid C14:0	Palmitic Acid C16:0	Stearic Acid C18:0	Oleic Acid C18:1	Linoleic Acid (ω6) C18:2	Alpha Linolenic Acid (ω3) C18:3
Almond Oil	9.7	-	-	-	7	2	69	17	-
Beef Tallow	0.9	-	-	3	24	19	43	3	1
Butterfat (cow)	0.5	3	3	11	27	12	29	2	1
Butterfat (goat)	0.5	7	3	9	25	12	27	3	1
Butterfat (human)	1.0	2	5	8	25	8	35	9	1
Canola Oil	15.7	-	-	-	4	2	62	22	10
Cocoa Butter	0.6	-	-	-	25	38	32	3	-
Cod Liver Oil	2.9	-	-	8	17	-	22	5	-
Coconut Oil	0.1	6	47	18	9	3	6	2	-
Corn Oil (Maize Oil)	6.7	-	-	-	11	2	28	58	1
Cottonseed Oil	2.8	-	-	1	22	3	19	54	1
Flaxseed Oil	9.0	-	-	-	3	7	21	16	53
Grape seed Oil	7.3	-	-	-	8	4	15	73	-
Lard (Pork fat)	1.2	-	-	2	26	14	44	10	-
Olive Oil	4.6	-	-	-	13	3	71	10	1
Palm Oil	1.0	-	-	1	45	4	40	10	-
Palm Kernel Oil	0.2	4	48	16	8	3	15	2	-
Peanut Oil	4.0	-	-	-	11	2	48	32	-
Safflower Oil	10.1	-	-	-	7	2	13	78	-
Sesame Oil	6.6	-	-	-	9	4	41	45	-
Soybean Oil	5.7	-	-	-	11	4	24	54	7
Sunflower Oil	7.3	-	-	-	7	5	19	68	1
Walnut Oil	5.3	-	-	-	11	5	28	51	5

Percentages may not add to 100% due to rounding and other constituents not listed.

Human depot fat, usually found in the abdomen of men and around the thighs and hips of women, has a composition similar to lard.

Included under the name of each acid is the number of carbons in the molecule along with the number of double bonds (e.g. C12:0 represents 12 carbons with no double bonds.)

The structures for oleic acid and linoleic acid are shown below:



In this lab you will both make soap as well as test some of its properties. You can either use the provide fats and oils, or you can bring in your own sample to make a different soap from everyone else in lab (with which you can subsequently taunt them J). Note that each of these are shown in the *cis-* configuration. The human body tends to deal with these in a much better way than the *trans*-fatty acids.

Prelab
Write a purpose for the lab in you notebook. You might also wish to think about the following questions. They will help you prepare for the lab, but you need not turn them in at the beginning of class.

What reaction is described by the word saponification? What are the products from this reaction and what are the required reactants?

Draw out the full structure for three of the carboxylic acids listed in table 1. Identify all of the polar bonds, and find the polar and non-polar regions of the molecule.

What is the most dangerous part of the lab? Why is it critical to clean up all spills immediately?

Procedure
First you will have to select the type of fat or oil that you wish to use to make soap. Olive oil, vegetable oil, sesame oil and lard will be provided. You are welcome to use any other type of oil or fat, but you will have to provide it (looking at other oils can give you drastically different soaps that provide an interesting comparison.) Start with 20 mL of the selected oil (or about 16 g of the lard) and put it in a clean 400 mL beaker. Add in 20 mL of ethanol followed by 25 mL of 20 % sodium hydroxide (remember this is very concentrated. If any of it is spilled it should be reported to immediately to the LA and then cleaned up. It is concentrated enough to cause serious chemical burns and irreversible eye damage if it comes in contact with you.) Stir the mixture with a glass rod.

Turn on a hot plate and place the beaker atop it. Periodically stir the mixture during heating. During the heating the mixture may foam up. Stirring will help prevent this, but if the foam climbs up the beaker you will need to remove it from the heat momentarily until the foaming subsides. The mixture should be heated until all of the ethanol is removed. When is that? It will be when ethanol vapors are no longer being released from the heated mixture. Being college students we will assume that you are familiar with the smell of ethanol (please don't test this by sticking your head over the beaker. This is just asking for trouble.) The loss of the ethanol will likely coincide with the increase in the amount of foaming that is occurring in your beaker.

Once the ethanol is gone remove the beaker from the heat and turn off the hot plate. After allowing the mixture to cool most of the way to room temperature, add in 100 mL of saturated sodium chloride and mix thoroughly. The soap should coagulate into a solid mass and can now be filtered to remove the by-products. Our filtering will be done using a wire screen (instead of filter paper). To do this put the wire screen on top of a large beaker and pour the soap containing liquid onto the gauze (some soap may get through, but the majority will collect on the gauze.) The soap should then be washed at least twice with 10 mL of ice water (ice can be obtained from the biology lab) to remove the excess NaOH. It may be more effective to put the soap back into the original beaker and add the ice water and filter again. Once the rinsed soap has drip dried, move it to a paper towel to finish drying.

Testing the Soap

Take a pea sized piece of the newly formed soap and put it in a 125 mL Erlenmeyer flask and add about 50 mL of distilled water. Repeat this in a second and third flask using either a commercial soap or soap made by another lab group starting from a different fat or oil. Stopper the flasks and shake them vigorously for 20-30 seconds and observe the results paying attention to the solubility of the soaps and the foaming action. The ability to create foam indicates the presence of the soap. The amount of foaming and the length of time until deflation both relate to the surface tension of the solution.

Once you have been able to compare the rate of deflation of the foam, take a clean glass rod and dip it into a solution and then touch a piece of pH paper. Test the other solutions as well as the pH of distilled water. This will give a feeling of how well you were able to remove the excess NaOH.

Next add two drops of mineral oil to the solutions. To another flask add 50 mL of distilled water and 2 drops of mineral oil. Cover and shake the flasks for about 10 seconds and compare how well the soaps were able to emulsify the oil (prevent it from immediately separating out.)

Last, clean out the flask and rinse with distilled water. Put a pea sized piece of your soap and another group's soap in a flask and add in 10 drops of a 5% solution of calcium chloride. Calcium is one of the common components in hard water. Shake the flask for about 10 seconds and observe the changes. This reaction leads to "ring around the tub" and a dull grey on clothes.

Questions

1. What is an emulsion? Which mixture was the better at maintaining an emulsion, oil and water or soap, oil and water? Explain why on a molecular level.
2. How can soap remove oil or dirt from clothes?
3. What was the role of the ethyl alcohol that was originally added to the reaction mixture?
4. Explain chemically what happens when soap is added to hard water and the problems that can occur when washing.

Writing

This lab report will be a formal lab report written with a partner. Try to answer the above questions as a part of your discussion or introduction section, rather than in independent "question" section. It will both make the lab report flow better as well as really give you something to "discuss" in your discussion section.

Chemicals:

20% NaOH, ethanol, saturated NaCl, 5% calcium chloride, vegetable oils, mineral oil, soap

Chemical Disposal

All liquid chemicals may be disposed of down the drain. NaOH should be washed down the drain with lots of water. Any solid waste (excess lard or soap that you don't want to keep) should be discarded in the trash.

References

1. "Fats, Oils, Fatty Acids, Triglycerides - Chemical Structure" a webpage by ScientificPsychic.com accessed Nov 2, 2004 at http://www.scientificpsychic.com/fitness/fattyacids.html
2. "Colonial Soap-making" a webpage by Alcasoft http://www.alcasoft.com/soapfact/history.html accessed Nov 2, 2004.
3. Paul Kelter, Jim Carr and Andrew Scott, Laboratory Manual to accompany Chemistry a World of Choice, McGraw-Hill, Boston, 1999.

Special thanks to Anna Wasson for grammatical editing.

Assessment Ideas

Students can compare and contrast the soaps made from various sources. This lends itself well to a cross-curricular activity with English or Social Studies either for writing or for the history of soap.

Organic Molecules

Activity #5 – The Organic Drawing Game!

Questions to be investigated

How many Lewis Structures can you draw?

Objectives

Students will get large amounts of practice drawing Lewis structures for hydrocarbons.

Teacher Notes

Using organic shorthand instead of full Lewis Structures can be a valuable addition to this lab.

Materials

None

Real-World Connections

Modern informational research is investigating the total number of isomers of many compounds. For more information, visit:
http://www.research.att.com/~njas/sequences/A134818

http://www.research.att.com/~njas/sequences/A134819

Sources

David Consiglio, Southfield-Lathrup High School Chemistry Teacher

Procedure / Description of Lesson

See next page.

Name:__________________________________Date:_____________Hour:_________

The structure drawing game

Instructions:

1. You must determine the number of different structures that can be drawn according to the criteria on the chart below.
2. Write that number in the chart.
3. Draw the "cleaned up" version of all of those structures on a separate sheet of paper.

Drawing Rules:

1. Each carbon must have 4 total bonds.
2. Each hydrogen must have 1 bond.
3. There can be 1, 2, or 3 bonds between two carbon atoms.
4. There can be 1 bond between a carbon atom and a hydrogen atom.

Example:

One carbon and hydrogens only (first box)

```
          H
          |
H------C--------H
          |
          H
```

This is the only structure that can be drawn.
Notice that each hydrogen has one bond.
Notice that the carbon atom has 4 total bonds.

Other Atoms	One Carbon	Two Carbons	Three Carbons
Hydrogens Only	**1**		

Extra Credit:

Level 1: (Hard) How many structures are possible with 4 carbons and hydrogens only?

Level 2: (Very Hard) How many structures are possible with 5 carbons and hydrogens only?

The team that gets closest to the answers *without going over* and has acceptable structures to go with their claim earns extra credit.

ANSWERS:

Other Atoms	One Carbon	Two Carbons	Three Carbons
Hydrogens Only	**1**	**3**	**9**

Extra Credit:

Level 1: (Hard) How many structures are possible with 4 carbons and hydrogens only? **37**

Level 2: (Very Hard) How many structures are possible with 5 carbons and hydrogens only? **146**

Assessment Ideas

Students can answer the questions on the handout.

Organic Molecules

Activity #6 – Organic Model Building

Questions to be investigated

How can molecules be represented using models?

Objectives

Students will use molecular modeling kits to build models of many organic compounds.

Teacher Notes

If you don't have molecular models, you can use foam balls and pipe cleaners available at most craft stores.

Materials

Modeling kits

Real-World Connections

Modeling is now done on the computer. If you want to build 3-d molecular models on the computer, try:

http://www.chemaxon.com/marvin/download-user.html

Sources

Chemistry in the Community, 5th edition

Procedure / Description of Lesson

Unit 3

A.9 Investigating Matter: Alkanes Revisited

Introduction

The alkane molecules you have considered so far are **straight-chain alkanes,** where each carbon atom is only linked to one or two other carbon atoms. In alkanes with four or more carbon atoms, other arrangements of carbon atoms are possible. In **branched-chain alkanes,** one carbon atom can be linked to three or four other carbon atoms. An alkane composed of four or more carbon atoms can have either a straight-chain structure or a branched-chain structure. In this activity, you will use ball-and stick molecular models to investigate such variations in alkane structures—variations that can lead to different properties.

Before starting, read the following procedure to learn what is involved and plan for your data collecting and observations.

Procedure

1. a. Assemble a ball-and-stick model of a molecule with the formula C_4H_{10}.
   b. Compare your model with those built by others. How many different arrangements of atoms in the C_4H_{10} molecule did your class construct?

   ____

Molecules that have identical molecular formulas but different arrangements of atoms are called structural isomers. By comparing models, convince yourself that there are only two structural isomers of C4H10. The formation of isomers helps to explain the very large number of compounds composed of carbon in chains or rings.

2. a. Draw a Lewis-dot structure for each C_4H_{10} isomer.

b. Write a structural formula for each C_4H_{10} isomer.

3. As you might expect, alkanes containing larger numbers of carbon atoms also have larger numbers of structural isomers. In fact, the number of different isomers increases rapidly as the number of carbon atoms increases. For example, chemists have identified three pentane (C5H12) isomers, as shown in Table 3.4 (page 230 of our textbook). Try building these structural isomers. Then draw them in the spaces below.

4. Now consider possible structural isomers of C_6H_{14}, hexane.
   a. Working with a partner, draw structural formulas for as many different C_6H_{14} isomers as possible. Compare your structures with those drawn by other groups. Show your drawings below

   b. How many different C_6H_{14} isomers were found by your class?

      ____

5. Build models of one or more C_6H_{14} isomers, as assigned by your teacher.
   c. Compare the three-dimensional models built by your class with corresponding structures drawn on paper.
   d. Based on your careful examination of the three-dimensional models, how many different C_6H_{14} isomers are possible? ____________________________

ANSWERS: There are 5 C_6H_{14} isomers:
Hexane
2-methylpentane
3-methylpentane
2,2-dimethylbutane
2,3-dimethylbutane

Assessment Ideas

Students can answer questions on the worksheet.