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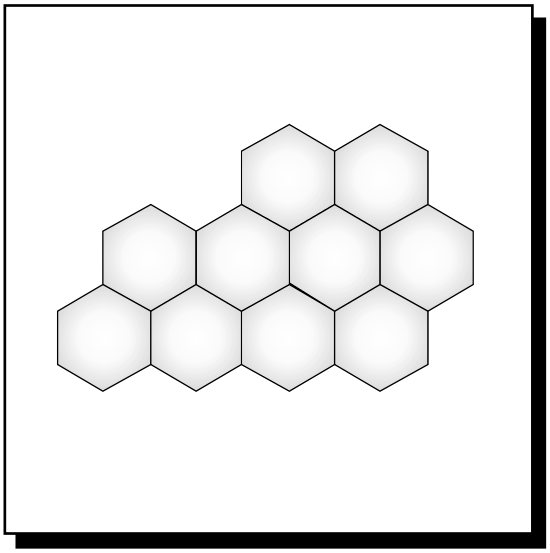
ChemSource Project Principal Investigator:
Mary Virginia Orna, OSU
Department of Chemistry
College of New Rochelle
New Rochelle, NY 10805
Phone: (914) 654-5302
FAX: (914) 654-5387

ORGANIC CHEMISTRY



ChemSource

Instructional Resources for Preservice and
Inservice Chemistry Teachers

Topic Overview

CONTENT IN A NUTSHELL

Organic chemistry is the study of carbon containing compounds. All living things are composed of carbon compounds. Until the early nineteenth century, many chemists believed that organic compounds must have their origin in living organisms, and consequently, could never be synthesized from inorganic material. Today, many compounds of carbon are still obtained from plant and animal sources. However, chemists have devised many processes by which natural and synthetic organic compounds can be prepared. Organic chemistry is a large and important field, and areas within organic chemistry are identified as disciplines themselves—biochemistry, polymer chemistry, synthetic organic chemistry, physical organic chemistry, *etc*. This module is an introduction to organic chemistry.

There are millions of known organic compounds, far more than the number of compounds not containing carbon because carbon atoms can form covalent bonds with one another (**catenation**) to an extent impossible for atoms of other elements. Carbon atoms participating in covalent bonding form four bonds for each carbon atom. Carbon atoms form branched and unbranched chains thousands of atoms long, and rings of different shapes and sizes. Carbon atoms form stable bonds with hydrogen, oxygen, nitrogen, the halogens, sulfur, and phosphorus. Many organic compounds are derived from petroleum.

Initially it might seem impossible to become knowledgeable about the chemistry of such a variety of compounds. Fortunately, there is a systematic approach to studying organic chemistry, allowing for the classification of organic compounds by the type of bond formed between adjacent carbon atoms and with the elements listed above. This systematic study classifies compounds according to "functional groups" contained in their molecular structure. Functional groups are portions of molecules (usually consisting of two to four atoms) responsible for characteristic physical and chemical properties of the substance. A list of names and structures for common functional groups in organic compounds is provided in Figure 1.

One important type of organic reaction is combustion (exhaustive oxidation or burning.) The products of combustion of organic compounds are carbon dioxide and water. The combustion reactions for methane (CH_4, natural gas) and butane (C_4H_{10}, used in Bic™ lighters) are:

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$$

$$2C_4H_{10}(g) + 13O_2(g) \rightarrow 8CO_2(g) + 10H_2O(l)$$

Combustion reactions are useful because they release a large amount of thermal energy. Almost all fuels used today are organic compounds. Other important groups of reactions are those which extend or combine carbon chains, or change a compound's functional group. Organic chemists have developed a wide variety of synthetic reactions used to build organic compounds and interconvert their functional groups. These reactions have enabled chemists to design molecules for specific purposes, as well as to systematically investigate the effect of structural changes on the properties of molecules.

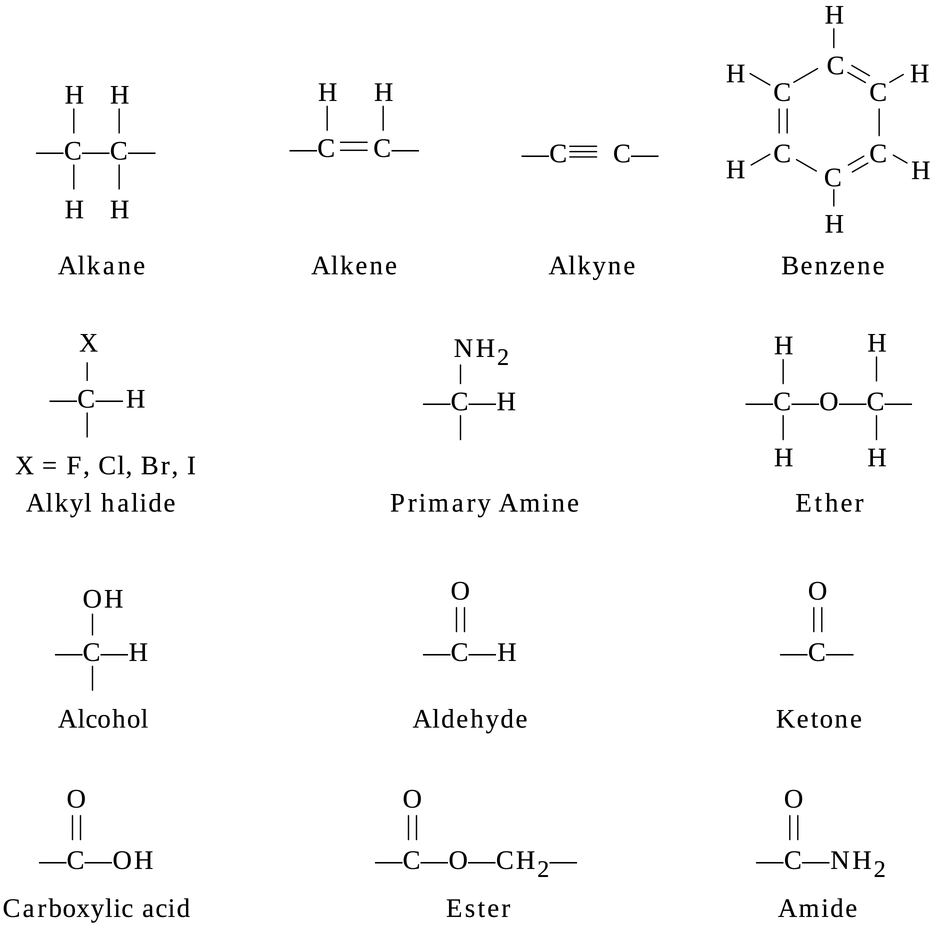


Figure 1. Common functional groups in organic compounds.

PLACE IN THE CURRICULUM

Traditionally, organic chemistry is not a major part of the first year chemistry curriculum. Most high school texts contain at least one chapter on organic chemistry, usually near the end of the book; however, there is no logical reason for this placement. To successfully study organic chemistry students will need as a prerequisite the conceptual understanding of the foundations of chemistry (atoms, molecules, stoichiometry, covalent bonding, phases of matter, *etc.*) The study of organic chemistry requires very little mathematical rigor. A good argument could be made for covering organic chemistry before topics such as acids and bases, oxidation-reduction, thermochemistry, kinetics, and electrochemistry.

CENTRAL CONCEPTS

1. Organic chemistry is concerned with carbon compounds containing covalent bonds. Since carbon atoms have four valence electrons, they form four covalent bonds.
2. The carbon-carbon bond can be a single, double or triple bond.
3. Functional groups are responsible for characteristic reactions of organic compounds.

4. Hydrocarbons are substances containing only carbon and hydrogen. They can exist as chains or rings.
5. Hydrocarbons react with oxygen in combustion reactions, producing energy, forming the basis for their use as fuels. Complete combustion forms carbon dioxide and water.
6. The synthesis of simple organic compounds can be accomplished by addition, substitution, and oxidation-reduction reactions.
7. Other important concepts are nomenclature, isomerism, stereochemistry, reaction mechanisms, and spectroscopy. These are important concepts but are not necessary or appropriate in an introductory course.

RELATED CONCEPTS

1. Atomic Structure
2. Relationship between electron structure and periodicity
3. Lewis-Dot structures
4. Brønsted-Lowry acid-base concept
5. Mole concept
6. Stoichiometry
7. Enthalpy
8. Equilibrium

RELATED SKILLS

1. Balancing equations.
2. Stoichiometric relationships.
3. Laboratory skills such as measuring mass and temperature and making solutions.

PERFORMANCE OBJECTIVES

After completing their study of organic chemistry, students should be able to:

1. define organic chemistry and give examples.
2. identify functional groups.
3. discuss the relationship of organic compound reactivity to functional group.
4. complete and balance hydrocarbon combustion reactions.
5. define the term “isomer” and give examples.
6. describe an organic synthesis that yields a useful product.
7. describe the preparation of esters from alcohols and carboxylic acids.
8. discuss ways in which organic compounds impact the environment.
9. give examples of organic compounds and reactions illustrating previously learned concepts.
10. exhibit safe laboratory practices for dealing with potentially flammable and toxic substances.

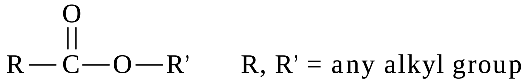
Concept/Skills Development

LABORATORY ACTIVITY: STUDENT VERSION

Activity 1: Synthesis of Esters

Introduction

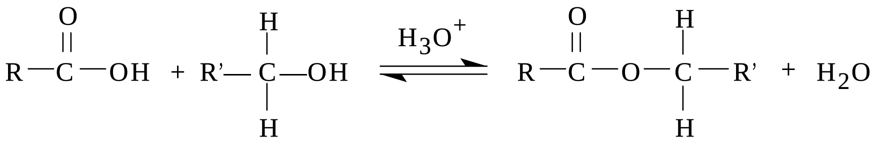
Esters are an important class of organic compounds which are characterized by the following generic formula.



$$R-\overset{\overset{\large O}{||}}{C}-O-R' \qquad R, R' = \text{any alkyl group}$$

Low molecular weight esters have pleasant odors and are responsible for many distinctive odors in fruits and flavorings. Esters can be readily prepared from a carboxylic acid and an alcohol. Generally this reaction is catalyzed by strong acids.

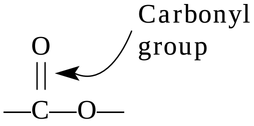
R, R' = any alkyl group



$$R-\overset{\overset{O}{||}}{C}-OH + R'-\underset{\underset{H}{|}}{\overset{\overset{H}{|}}{C}}-OH \xrightleftharpoons{H_3O^+} R-\overset{\overset{O}{||}}{C}-O-\underset{\underset{H}{|}}{\overset{\overset{H}{|}}{C}}-R' + H_2O$$

Carboxylic Acid + Alcohol ⟶ Ester + Water

The equilibrium constant for the reaction between primary alcohols and unhindered carboxylic acids is approximately 4. If equal quantities of acid and alcohol are used, the reaction gives a product yield of only 67%. In order to make esters in high yields, the equilibrium must be shifted toward products. According to LeChatelier's principle, an excess of alcohol or carboxylic acid, or removal of water will produce more ester. Sulfuric acid is used as a catalyst for this reaction because it also serves as a dehydrating agent, shifting the equilibrium toward products. The structures in Figure 2 will assist in determining which acid and alcohol will produce the ester with the desired flavor. The group to the left of and including the carbonyl group belonged to the original carboxylic acid, and the group to the right of the singly bonded oxygen, and including the oxygen atom, belonged to the original alcohol.



Purpose

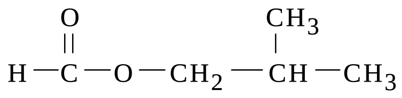
To synthesize an ester from the corresponding carboxylic acid and alcohol, and to identify the characteristic odor of each ester you have made.

Safety

1. Wear protective goggles throughout the laboratory activity.
2. Be very careful with the concentrated sulfuric acid. It can cause serious chemical burns.
3. Your teacher will demonstrate the correct method for testing for odors using a wafting technique; you should never directly smell any chemical used or prepared in the laboratory.

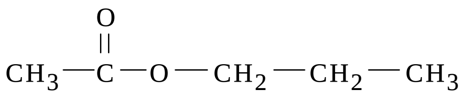
Procedure

1. Place 75 mL water in a 100-mL beaker, add a boiling stone, and set the beaker on a wire screen on a ring stand. Light a burner and place it under the beaker. Bring the water to a gentle boil. (If available, hot plates should be used.)



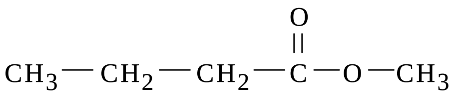
$\mathrm{H-\overset{\overset{O}{\|}}{C}-O-CH_2-\overset{\overset{CH_3}{|}}{CH}-CH_3}$

Raspberry



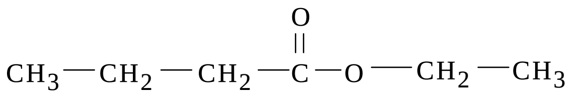
$\mathrm{CH_3-\overset{\overset{O}{\|}}{C}-O-CH_2-CH_2-CH_3}$

Pear



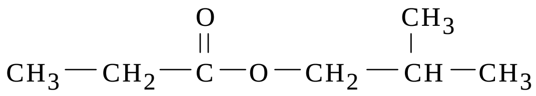
$\mathrm{CH_3-CH_2-CH_2-\overset{\overset{O}{\|}}{C}-O-CH_3}$

Apple



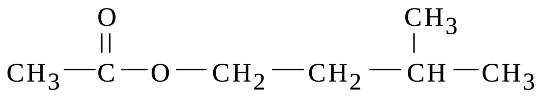
$\mathrm{CH_3-CH_2-CH_2-\overset{\overset{O}{\|}}{C}-O-CH_2-CH_3}$

Pineapple



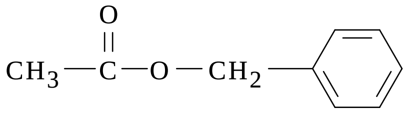
$\mathrm{CH_3-CH_2-\overset{\overset{O}{\|}}{C}-O-CH_2-\overset{\overset{CH_3}{|}}{CH}-CH_3}$

Rum

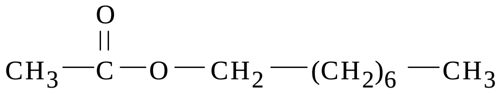


$\mathrm{CH_3-\overset{\overset{O}{\|}}{C}-O-CH_2-CH_2-\overset{\overset{CH_3}{|}}{CH}-CH_3}$

Banana

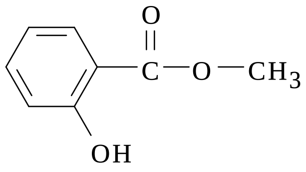


Peach

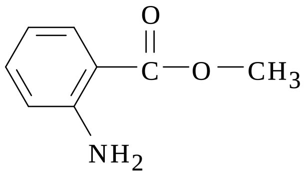


$\mathrm{CH_3-\overset{\overset{O}{\|}}{C}-O-CH_2-(CH_2)_6-CH_3}$

Orange



Wintergreen



Grape

Figure 2. Esters. *NOTE:* $\mathrm{-CH_2-}$ is shorthand for $\mathrm{-\overset{\overset{H}{|}}{\underset{\underset{H}{|}}{C}}-}$ *etc.* (See *Common Student Misconceptions*, p. 22, No. 4.)

2. Examine the structure of the ester you wish to synthesize. Determine which carboxylic acid and which alcohol you need to use in your synthesis.
3. In a 10-cm test-tube obtain one drop of carboxylic acid. If the carboxylic acid you wish to use is a solid, use about the amount that would fit inside this letter "O." Add three drops of alcohol and one drop of concentrated sulfuric acid. *Be very careful with the sulfuric acid. It can cause severe burns if spilled on the skin.*
4. Drop a boiling stone into the mixture.
5. Before heating, wave the fumes from this mixture to your nose and carefully note and record the odor of this reaction mixture.
6. Stopper the test-tube with a one-hole cork stopper and set the assembly in the boiling water. If the test-tube will not "stand up" in the beaker without getting water in the tube, put a test-tube clamp around the tube to hold it upright in the beaker.

7. Turn off the heat and allow mixture to stand in the hot water for 5-10 min.
8. Use a test-tube clamp to remove the reaction assembly from the water bath.
9. Fill a Beral™ polyethylene pipet with cold water and empty its contents into the test-tube. Mix the solution by gently swirling the test-tube.
10. Remove a small quantity of the aqueous mixture from the test-tube with the pipette. One way to do this without exposing yourself to the mixture in the tube is to push the tip of the pipette into the cork until the pipet shaft fills the hole in the stopper. Turn the tube so that the liquid in the tube covers the pipet tip and draw up some of the mixture. Then turn the test-tube right side up and withdraw the pipet.
11. Once the pipet is removed from the tube, invert it to let the liquid flow from the shaft to the bulb. Clear the liquid out of the shaft by lightly tapping the side or by drawing some air into the pipet.
12. With the pipet in the inverted position carefully force out some of the vapor and wave the fumes to your nose. Carefully note and record the odor of the ester you synthesized.
13. Occasionally, the vapor is too concentrated and it will “overpower” your sense of smell. Add more water to the mixture in the test-tube to dilute the odor.
14. If the odor is too faint, place the bulb of your pipette in warm water, wait for a minute, and try again.
15. Thoroughly wash your hands before leaving the laboratory.

Data Analysis and Concept Development

Compare your ester’s odor with the odor you expected from the name (grape, orange, *etc.*) Determine the ester’s structure from the list above. Write a complete balanced equation for the synthesis of your ester.

Implications and Applications

1. In some cases the odor of the synthesized ester does not exactly match the odor of the fragrance found in nature. What might be a possible explanation?
2. Some of the compounds in the list of fragrances have functional groups in addition to the ester group. Identify these compounds and determine the types of functional groups present with the help of the functional group chart posted.

LABORATORY ACTIVITY: TEACHER NOTES

Activity 1: Synthesis of Esters

Major Chemical Concept

In this laboratory activity students will perform a standard organic synthesis—producing esters from alcohols and carboxylic acids. By examining the chemical structure of the desired ester they will choose the appropriate starting materials for their synthesis. They will analyze their reaction mixture for presence of the ester through its characteristic odor.

Level

Basic, General, or Honors

Expected Student Background

Students should be able to identify the alcohol, carboxylic acid and ester functional groups. They should be familiar with the basic bonding characteristics of organic compounds and understand the concept of chemical synthesis. An understanding of catalysis, equilibria and LeChatelier's principle is desirable but probably not required.

Time

Approximately 30 min.

Safety

Read the *Safety Considerations* in the *Student Version*. A major concern with this laboratory is asking students to "sniff" their products. Because of the small quantities of reagents used in this procedure, this hazard is minimized. Try the technique, described below in the *Pre-Laboratory Discussion* section. It is important to clear the barrel of the pipet before smelling the vapors from the ester solution. *It is mandatory that you demonstrate the proper technique for detecting odors before the laboratory period begins.* All organic compounds used in this laboratory are flammable. It is imperative that reagents be away from heat sources and students use small quantities to minimize fire danger. It is preferable to use hot plates rather than burners.

Materials (For 24 students working in pairs)

12 Test-tubes, 10 cm, fitted with one-hole *cork* stoppers (do not use rubber stoppers)
12 Large-barrel polyethylene pipets (*e.g.,* Beral™)
12 Beakers, 100-mL
12 Ring stands, wire screens and burners or hot plates
Boiling stones
12 Labeled 10-mL bottles of concentrated sulfuric acid (H_2SO_4), with polyethylene pipet
6 Labeled test-tubes, 10-cm with pipets, containing the following alcohols: methanol, ethanol, 1-octanol, 2-methyl-1-butanol, 2-methyl-1-propanol, 1-propanol, 3-methyl-1-butanol, benzyl alcohol.
6 Labeled test-tubes, 10-cm with pipets, containing the following acids: formic acid, acetic acid, propionic acid, butyric acid, salicylic acid, anthranilic acid.

NOTE: Structural formulas should be on the carboxylic acid and alcohol labels. Butyric acid has a very foul odor and should be used with caution and very good ventilation.

Advance Preparation

Set the reagents in a fume hood to keep the background room odor to a minimum. If possible, open your windows to help circulate the room air. It is not necessary to provide the reagents for all of the esters to be synthesized. A subset of three of four esters can be used (*e.g.*, pineapple, banana, wintergreen, orange.) Label both reagent containers *and* dispensers to avoid contamination. A good way to keep the reagent container and dispenser together is to tape a test-tube to the reagent bottle and place the polyethylene pipet used to dispense the reagent in the test-tube. The cork stoppers that are used in this laboratory need to accept the polyethylene pipet with a tight fit. Polyethylene pipets with tapered ends work nicely. You probably will have to dispose of corks after each laboratory because they pick up the odor of the synthesized ester and will confuse the next set of students if recycled. If your cork borer does not drill a small hole, you can clamp the solid cork stoppers in a vise and drill holes in them with an electric drill fitted with a small drill bit. Have a copy of Figure 1 posted to identify functional groups.

Pre-Laboratory Discussion

It is important to demonstrate the proper method for detecting odors. In one hand hold the open test-tube about 15 cm from your nose. Using your free hand sweep the air space above the test-tube toward your nose.

Discuss the concept of organic synthesis, particularly the synthesis of esters (called esterification). The mechanism for ester synthesis is well established but discussing this mechanism is not appropriate for first year students. You might have students try to determine the systematic name for the esters which they make. This would help determine which carboxylic acid and alcohol to use for the synthesis. You will notice that some compounds have common names. To avoid confusion be careful in labeling the compounds.

For basic or general chemistry students, tell them which carboxylic acid to mix with which alcohol to produce a particular ester. Alternatively support student learning by having students predict in the pre-laboratory which ester is produced by particular combinations of carboxylic acid and alcohol, and to compare the structure to the table of esters. Once students have predicted the structure and odor of particular combinations, assign combinations to student laboratory groups to synthesize.

Teacher-Student Interaction

Help students observe physical and chemical changes that take place when the reaction mixture is being heated. Discuss the purpose of the boiling stone *[provides a site for bubbles to form during boiling]*. Discuss the concepts of catalysis, equilibrium and LeChatelier's principle.

Anticipated Student Results

Students should recognize odors like banana and wintergreen. Other odors may be less readily identified. (Undercooking may be better than overcooking.) Students' odor palates are easily overwhelmed and may confuse odors. Students should realize that natural odors are mixtures. Many students will be able to write the reaction equation for any ester after writing the equation for their ester; others will need to see more than one example before they can generalize.

Answers to Implications and Applications

1. The fragrances found in nature are most often due to a mixture of esters rather than a single compound. Fresh ground coffee has at least 200 identifiable esters.
2. $-OH$ hydroxyl, $-NH_2$ amine, $-C_6H_5$ phenyl group (aromatic compound)

Post-Laboratory Discussion

This activity is designed to provide students with hands-on experience in conducting an organic synthesis. Students should be able to discuss the industrial role of organic synthesis in making compounds which are difficult or expensive to isolate from naturally occurring sources. Vanilla is an example of a synthesized flavoring. Aspirin is a familiar example of a synthesized drug (see *Chemistry in Medicine* module). Most of the vanilla and all the aspirin used today are synthesized. Students should also be asked to discuss the benefits and hazards of preparing synthetic compounds not found in nature. Various pesticides, herbicides, and polymeric substances are everyday examples. Discuss benefits and abuses of these substances.

Extensions

1. The ester functional group is very important in the synthesis of polymers. Look up the chemical structure of polyester polymers (see *Polymers* module) and determine the compounds used in their synthesis.
2. Look on the label of common household products to see if you can identify the esters.
3. Suppose you looked on a bottle of fingernail polish remover and found it was composed of ethyl acetate. How would you know it was an ester? How would you prepare this ester? *[Smell. Can be prepared from ethanol and acetic acid.]*
4. Make molecular models of a carboxylic acid, an alcohol, and the ester that can be synthesized from them.

Assessing Laboratory Learning

1. Have students write equations for the formation of esters not synthesized during their laboratory period.

Raspberry	2-methyl-1-propyl formate
Pear	1-propyl acetate
Apple	Methyl butyrate
Pineapple	Ethyl butyrate
Rum	2-methyl-1-propyl propionate
Banana	2-methyl-1- butyl acetate
Peach	Benzyl acetate
Orange	Octyl acetate
Wintergreen	Methyl salicylate
Grape	Methyl anthranilate

2. Have students look up the chemical structure of aspirin (an ester) and write an equation for its synthesis.

LABORATORY ACTIVITY: STUDENT VERSION

Activity 2: Chemical Analysis for the Presence of Halogens

Introduction

Halogens can be substituted for hydrogen in organic molecules to form compounds possessing physical and chemical properties that are different from the original unsubstituted compounds. Since halogens have higher electronegativities than hydrogen, these substituted compounds are frequently polar in nature. These “halogenated hydrocarbons,” or alkyl halides, are used as reagents in several important organic synthesis reactions. Polyhalogenated alkyl compounds (those containing more than one halogen) have practical applications as dry cleaning solvents, insecticides and fire extinguishers. Until recently, chlorofluorocarbons or CFCs have been used as propellants in aerosol spray cans. Unfortunately, these propellants contribute to the decline of ozone in the earth’s stratosphere. Stratospheric ozone absorbs harmful ultraviolet light that is emitted by the sun. The decrease of stratospheric ozone is a critical environmental issue.

Presence of chlorine, bromine and iodine in organic compounds is detected by the Beilstein test. A positive Beilstein test results from the formation of a volatile copper halide when an organic halide is heated with copper oxide. The copper halide imparts a blue-green color to a flame. Since the reaction occurs at a high temperature in a flame, the exact products have not been identified. The Beilstein test does not differentiate between chlorine, bromine and iodine. An additional test using sulfuric acid and sodium hypochlorite can be used to identify which of these halogens is present.

Purpose

To test several unknown organic compounds for the presence of a halogen using the Beilstein test and to identify the halogen.

Safety

1. Wear protective goggles throughout the laboratory activity.
2. Your teacher will demonstrate the proper technique for detecting odors of volatile chemical compounds.
3. Many of the organic compounds used as unknowns are flammable. Since this laboratory uses burners care must be exercised to avoid fires.
4. Care should be exercised in handling the sulfuric acid and sodium hypochlorite solutions.

Procedure

1. Obtain from your instructor an unknown sample of an organic compound. Record the number which identifies the unknown in your laboratory notebook.
2. After bending a small loop (about 2 mm in diameter) in one end of a 5-10 cm length copper wire, insert the other end into a cork stopper (to be used as a holder).
3. Holding the cork, heat the loop end of the wire in a burner flame.
4. After cooling (approximately one minute), dip the wire directly into the sample of the unknown substance.
5. Heat the wire in the burner flame again. The compound will first burn, probably with a yellowish flame. After burning, a green flame will be produced if a halogen is present.

6. If a halogen is not present, record your results and obtain another unknown from your instructor. If a halogen is present, proceed to Step 7.
7. Place 2 mL 1 M sulfuric acid in a 20-cm test-tube.
8. Add 5 drops of your unknown organic halide (for solids, use size of a matchhead) and a boiling stone to the test-tube.
9. Heat this mixture for 5 min in a boiling water bath and allow the test-tube and its contents to cool in a beaker of cold water.
10. Add 10 drops Trichlorotrifluoroethane (TTE) and 3 drops sodium hypochlorite solution to the test-tube.
11. Check to see that the solution is still acidic with a piece of moist blue litmus paper. If it is not acidic, add dropwise 1 M sulfuric acid to make the solution acidic.
12. Stopper the solution and shake it vigorously. Set it aside and allow the layers to separate. Separation should occur within 10 min.
13. Record your observations and interpretation in your laboratory notebook. (The TTE layer will dissolve the colored halogens. An orange to brown color in the TTE layer indicates the presence of bromine. A violet color indicates the presence of iodine. No color or a light yellow indicates the presence of chlorine.)
14. Dispose of your solution in the container marked “halogenated waste.”
15. Thoroughly wash your hands before leaving the laboratory.

Data Analysis

Perform this test on several different unknown organic liquids provided by your teacher. Report your results to your instructor. During the next class period your instructor will tabulate the class results. Compare your results with those of others.

Implications and Applications

Attempt to identify halogenated compounds which are in common use today. Read product labels in grocery, garden and hardware stores to find products which contain halogenated organic compounds. Discuss the use of these products, their toxicity, and the proper means of disposing of them.

LABORATORY ACTIVITY: TEACHER NOTES

Activity 2: Chemical Analysis for the Presence of Halogens

Major Chemical Concepts

This activity is designed to allow students to test for the presence of halogens in organic compounds. The student will be required to make careful observations and to compare these observations for several unknowns. Students will then infer the absence or presence and identity of halogens in their samples.

Level

This laboratory exercise is appropriate for general students late in the academic year or for second year chemistry students.

Expected Student Background

Students should have standard laboratory skills and a general understanding of the structure of organic compounds. You should discuss halogenated hydrocarbons and their properties in class before this laboratory is performed.

Time

40 min

Safety

Read the *Safety Considerations* in the *Student Version*. Check the material safety data sheets (MSDS) or ChemSource*Safety* module, Appendix II for all of the unknowns used in this laboratory exercise. (Many halogenated hydrocarbons are hazardous compounds and should not be used as unknowns. The substances suggested in this guide are nontoxic and noncarcinogenic.) Use small quantities of unknowns to avoid any hazard which could result from spillage. If possible, store all reagents in a fume hood and allow students to take only the amount of sample needed for each activity.

Materials (For 24 students working in pairs)

12 Burners
12 Forceps
36 Test-tubes (15-cm length)
12 Test-tube holders
12 400-mL Beakers
12 Wire gauze
12 Ringstands and rings
Boiling stones
12 Corks
12 Graduated cylinders, 5- or 10-mL size
Copper wire, 12 pieces, 7-8 cm
36 Pipets with bulbs
1 M Sulfuric acid, H_2SO_4, 50 mL (5 mL conc. H_2SO_4 diluted to 50 mL)
l,l,2-Trichloro-l,2,2-trifluoroethane (TTE), 20 mL
Sodium hypochlorite solution, NaClO (use Clorox™ or comparable bleach), 20 mL
Unknown Solutions (see *Advanced Preparation*)
Blue litmus paper
Waste bottle for unknown mixtures

Advance Preparation

Make up unknown solutions as 10% solutions of organic compounds in appropriate solvents (cyclohexane for nonpolar substances and acetone for polar substances). Have sufficient unknowns for students to perform tests on three to five different compounds (1 g/10 mL is enough for 24 students. Use 5-10 drops of unknown per test). Suggested unknowns for halogens are 2-iodobenzoic acid, 2-bromobenzoic acid and 4-chlorobenzoic acid. (These are commonly used as preservatives and can be obtained from Aldrich Chemical Company, 1001 West Saint Paul Avenue, Milwaukee, WI 53233, as well as other suppliers.) Over-the-counter pharmaceutical products can also be used. Examples which are antihistamines include chlorpheniramine (found in Dristan™) which contains chlorine; brompheniramine (found in Dimetane™) which contains bromine; and clioquinol (found in the antifungal product, Vioform™) which contains both iodine and chlorine. Other household products can be tested from paint or hardware stores. Examples include cleaning agents, solvents, white-out, *etc*. Suggested unknowns for nonhalogens are alcohols, esters, and benzoic acid. Be sure to clearly label the unknown containers with A, B, C, D, *etc*. It is advisable to prepare a data table for the students. *NOTE*: Larger amounts of bromide are needed to give a good observable test.

Pre-Laboratory Discussion

Discuss with the class the different functional groups of organic compounds. Explain that halogens form single bonds with carbon atoms in organic molecules.

Teacher-Student Interaction

One approach to teaching this laboratory is to demonstrate the laboratory using two known substances. One known (*e.g.*, benzoic acid) should not contain a halogen, and a second known (*e.g.*, bromobenzoic acid) should give a distinctive positive test. Students can then observe definitive negative and positive tests, respectively. Allow students to perform tests on the known samples as part of their laboratory exercise.

Anticipated Student Results

1. If students use a clean copper wire for each test, a positive or negative halogen test should be apparent.
2. In distinguishing among halides, the colors of I_2 and Br_2 are less apparent. Students may need to hold their TTE extraction tubes against a piece of white paper that is backlighted from a window or a lamp in the classroom.
3. Students will enjoy comparing their analyses of household items such as mothflakes with actual label information.

Answers to Data Analysis

The answers will depend on the type of halogens used.

Post-Laboratory Discussion

1. Help the class compile a list of halogenated organic compounds in common use today. Freon, a refrigerant, is an example.
2. Discuss the use of pesticides in the agriculture industry and the impact of various halogenated compounds on the environment (*e.g.*, polychlorinated biphenyls (PCB's), chlorofluorocarbons—CFCs, halon fire extinguishers, DDT, *etc*.).

Extensions

1. Discuss the principles involved in the reactions used to identify the presence of halogens (conversion of organic halide to inorganic [copper] halide) and the identity of the halogen (conversion of organic halide to inorganic halide and the subsequent oxidation of halide ion to the free halogen by ClO^-). Reactions for the Beilstein test are not well understood; however, the reactions for the identification of the halogen could be researched. The oxidation of halide ion by hypochlorite ion provides an opportunity to review redox reactions.
2. Locate the material safety data sheets (MSDS) that are shipped with chemical orders. Share them with your class and compare the data for several different classes of organic compounds including halogenated compounds. Take special notice of the proper disposal requirements for these substances.
3. The number of double bonds in an unsaturated hydrocarbon can be determined by using the "iodine number." Investigate how the "iodine number" can be used to determine whether oils and lard have single or double bonds.
4. At one time, carbon tetrachloride was used widely as a cleaning agent. It is now considered to be a carcinogenic compound. What halogenated hydrocarbon replaced carbon tetrachloride in the cleaning industry? (*HINT: Have students visit a dry cleaning establishment.*)

Assessing Laboratory Learning

This activity will allow students to develop increased confidence in their powers of observation. They should be capable of drawing conclusions from observations for several different results. Most of this laboratory exercise is designed to teach science process skills. These skills can be assessed only by observing students as they perform the various tasks. Ask students to describe their observations and compare the observations of several students for each unknown tested. It is important that students be allowed to repeat their tests on many different unknowns. Both negative and positive Beilstein results should be obtained in order to allow students to differentiate between them. Encourage students to perform a test together whenever there is disagreement regarding a particular observation. The emphasis should not be on "right answers" in this activity. Rather than post the "answers" to the unknown solutions, see if the class can agree upon the results of their experimentation.

DEMONSTRATIONS

CAUTION: Use appropriate safety guidelines in performing demonstrations.

Demonstration 1: Methane Bubbles

Purpose

This demonstration shows the reactivity of saturated hydrocarbons.

Materials

Methane gas (natural gas) outlet
Glass funnel, 5-7 cm diameter, with 1 m length of rubber tube
Glycerol, 10 mL, mixed with 10 mL liquid detergent in a 100-mL beaker
Candle attached to the end of a meter stick
Matches
Safety goggles

Safety

CAUTION: Methane is a flammable gas. Make sure students stand back and that the gas jet is turned off before igniting the bubble. Designate one student as the fire control officer with the fire extinguisher readily available.

Procedure

Connect the tubing to a natural gas outlet with the other end attached to the end of a glass funnel. Dip the funnel in the detergent/glycerol mixture and form a bubble by opening the gas tap slightly. Turn off the gas. Turn the funnel right-side up and shake it gently to allow the bubble to rise. Light the candle and touch it to the bubble. Observe the reaction and ask students to name the products. *NOTE*: An alternate procedure is to bubble methane directly through detergent solution to form a "tower of bubbles" that can be scooped aside and ignited.

Remarks

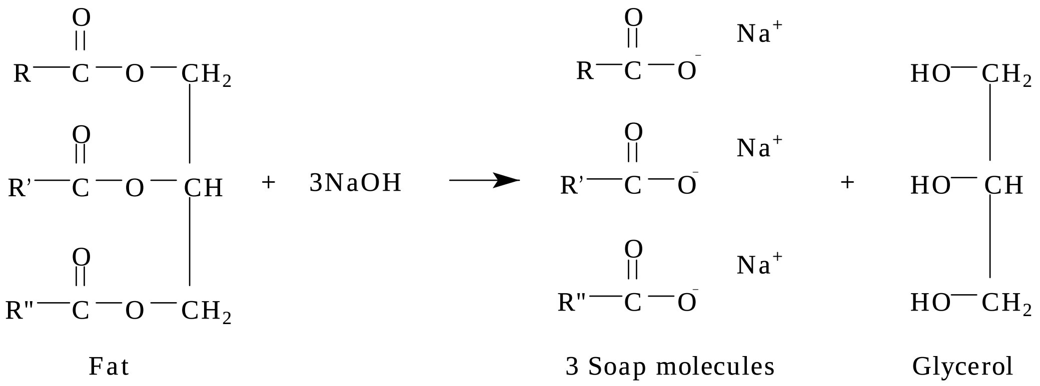
Glycerol lends structural stability to the bubble.

Demonstration 2: Making Soap

Introduction

This demonstration will require one to three days for completion, but you should be able to conduct other activities during these class periods.

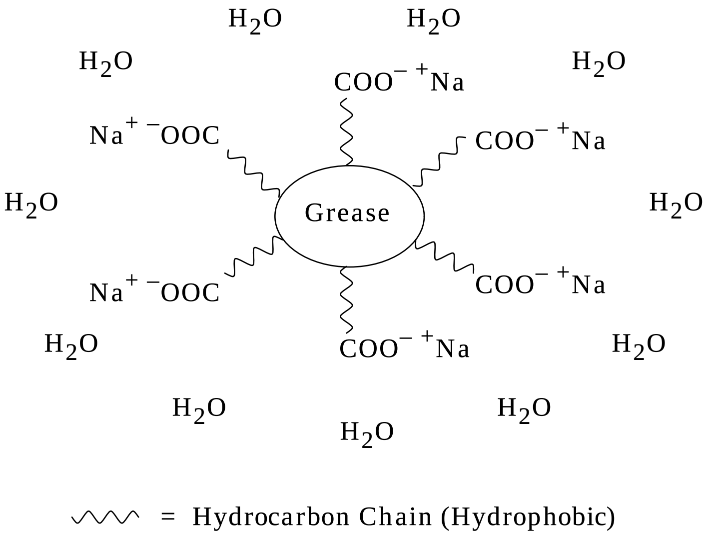
Soap has been known at least since 600 B.C. when the Phoenicians reported making a curdy material by boiling animal fat with wood ashes. Soap is prepared by allowing sodium or potassium hydroxide to react with fats and oils (esters of long chain carboxylic acids with glycerol).



(R, R', R" represent long-chain hydrocarbons)

The soap curds produced contain both glycerol and excess base. Failure to remove the base makes homemade soap harsh. However, soap can be purified by boiling it with plenty of water, followed by precipitating the dissolved soap with sodium chloride. (The process of precipitating a substance by dissolving another substance that is more soluble is called "salting out.") The precipitated soap can be dried and pressed into cakes. Perfumes and dyes are usually added to soap intended for household use; antiseptics are added to make medicinal soap; pumice is added to make scouring soap; and air bubbles are blown into soap to make floating soap. Despite advertising claims, soaps are quite similar; the main difference is the kind of fat or oil used in their synthesis.

Soap works as a cleanser because the ends of soap molecules have different properties. The carboxylic acid salt, or carboxylate, end is ionic and dissolves in water, a property described as hydrophilic or water-loving. The long hydrocarbon chain part of the molecule is not soluble in water (hydrophobic), but it is soluble in other nonpolar substances such as fats and greases. Even though the greasy dirt won't dissolve in water, the addition of soap provides a mechanism for water to carry greasy dirt away. Each little glob of grease is surrounded by soap molecules which have their hydrocarbon chains dissolved in the grease glob. Water then surrounds and dissolves the carboxylate ends of the soap molecules which are sticking out on the surface of the grease glob. The net effect is that the grease glob is now soluble in water.



Commercial cleansers, are made of synthetic detergents rather than natural soaps. Detergents are not the same as soaps derived from fats, although they are frequently referred to as "soaps." Modern detergents are typically mixture of compounds called surfactants that have a hydrophilic "head" and a hydrophobic "tail." Detergents typically contain polyphosphate groups that serve to soften hard water and to adjust the pH. Laundry detergents also include fluorescent "whiteners" that absorb ultraviolet light and then emit visible light to make clothing appear cleaner.

Purpose

This activity demonstrates the preparation of soap using ordinary household materials.

Materials

Oil, shortening, or lard, 20 mL (a mixture of lard and olive oil works quite well)
6 M Sodium hydroxide, NaOH. (To a 125-mL or 250-mL pyrex flask add 24 g NaOH and 100 mL H_2O. Dissolve the NaOH by stirring. Be careful. Dissolving NaOH liberates heat.)
Ethanol, C_2H_5OH
2 Beakers, 100-mL
Thermometer
Hot plate *(Do not use an open flame for this activity!)*
Wooden or plastic spoon
Paper cup
25% Sodium chloride, NaCl (25 g NaCl in 75 mL H_2O)
Beaker, 600-mL
Beaker, 1000-mL (optional)
Sodium chloride, NaCl, 50 g (optional)
Perfume (optional)
Food coloring (optional)
Ice bucket and ice (optional)
pH paper (optional)

Safety

Ethanol is flammable. Do not use open flames. Sodium hydroxide is caustic; protect your skin from splashes and wash off immediately if a splash occurs. Unpurified soap is often too basic for human use. Test the product with pH paper. If the pH is above 8, don't let students wash with it. Wear an apron, goggles, and gloves. If you have a face shield, wear that instead of goggles.

Procedure

1. In a 100-mL beaker, prepare about 20 mL fat mixture by melting lard or shortening. If liquid oil is used, measure out 20 mL in a graduated cylinder.
2. Allow the heated mixture to cool to about 45 °C.
3. While the liquid fat is cooling, heat a mixture of 10 mL 6 M NaOH and 10 mL ethanol to about 35 °C in a separate 100-mL beaker. Use care; do not splatter this solution—6 M NaOH is quite caustic. While the liquid fat is cooling and the ethanol and NaOH are heating, pour the aqueous NaCl into the 600-mL beaker.
4. When the ingredients are at the desired temperature, slowly pour the ethanol solution of NaOH into the melted fat while stirring continuously with a wooden or plastic spoon.
5. Stir constantly until a thick substance in which the spoon will stand upright is produced. If the reactants were at the right temperature, this will take 5-10 min. [If soap does not form, heat the solution in a water bath made by heating water in a 250 or 400-mL beaker and placing the 100-mL reaction beaker in it. Heat the reaction in simmering water for about 20 min. Then pour the warm reaction mixture into the 25% NaCl solution that was previously put in the 600-mL beaker.] As the mixture cools, the hardened soap will float to the top where it can be skimmed off and placed in a separate container. If soap forms readily, omit the step with NaCl. Go to either Step 6 or 10 next. Step 10 begins the purification procedure.
6. Add perfume and color at this point. Just stir it in. (Optional)
7. Pour the mixture slowly and evenly into the paper cup—the soap mold.
8. Test the sudsing power of prepared soap by washing out the beaker in which it was prepared.
9. Let the soap settle for a few days and dry into the shape of the cup.
10. To purify soap, heat to 50-80 °C approximately 500 mL of water in the 1000-mL beaker. Then pour the soap in to dissolve it. Let it cool.
11. Add 50 g NaCl and stir until dissolved. The soap should precipitate out. To increase the amount and rate of soap precipitation, cool the solution in an ice bucket.
12. Pour off excess water, stir in perfume and color, and proceed as in Steps 7-9.
13. If time permits, prepare two samples of soap, one with and one without purification. Use pH paper to test the pH of both samples. This is a good way to determine whether soap is still too basic for washing skin. Avoid using soap at pH > 8.

Questions

1. Describe the reaction in terms of reactants and products. What functional groups are involved? *[An ester of glycerol and carboxylic acids with long alkyl chains reacts with sodium hydroxide to produce glycerol and the sodium salt of the carboxylic acid. The ester functional group reacts with the hydroxide ion.]*
2. What was the pH of soap? Why? How could it be purified further to alter the pH? *[The pH of the soap will vary. pH is high because of sodium hydroxide impurity. It can be lowered by dissolving the soap in water and re-precipitating it by salting out. The NaOH contaminant remains dissolved in the water.]*
3. A popular drain cleaner is a concentrated solution of sodium hydroxide. How do you think it works to remove grease from the drain? *[The sodium hydroxide in drain cleaner reacts with grease in the drain to turn it into soap. The soap formed dissolves in water and washes down the drain.]*

GROUP AND DISCUSSION ACTIVITIES

Key Questions

1. What is the role of carbon-carbon bonding in organic chemistry? *[Provides for a variety of organic compounds (open-chain and cyclic) with a multitude of uses.]*
2. What is the role of functional groups in organic chemistry? *[Provides the major route for converting one organic compound into another.]*
3. What are some reactions of organic compounds that lead to new products? *[Substitution reactions lead to the formation of artificial flavors (*Activity 4*) and soaps (*Demonstration 2*).]*
4. What role does combustion of organic compounds play in modern society? *[Combustion reactions of organic compounds is exothermic providing large quantities of heat. This heat can be used to warm buildings, boil water, run automobile engines,* etc.*]*
5. How are structure of an organic compound and its physical and chemical properties related to each other? *[The structure of an organic compound and its physical and chemical properties are related in terms of water solubility or insolubility, density, physical state, and reactivity.]*

Counterintuitive Examples

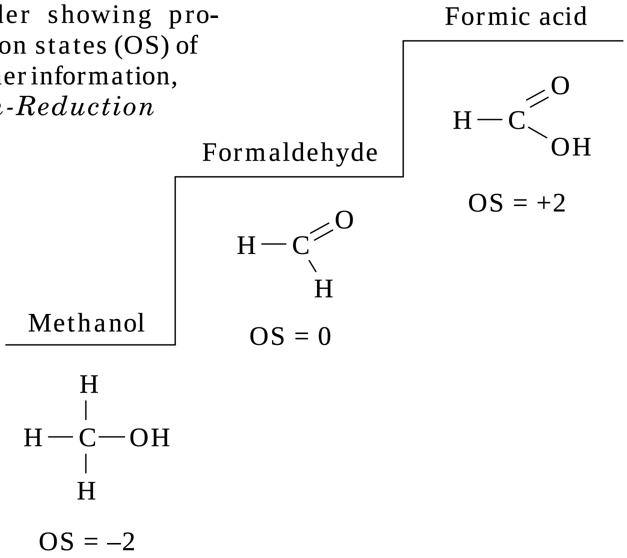
1. Small changes in structure produce large changes in perceived properties, such as odor. For example, esters have small structural differences yet quite varied odors. Compare the structures responsible for the grape and wintergreen odors in *Activity 1*.
2. That all organic molecules come from living sources is a common (and incorrect) belief. However, as a chemical term, *organic* just means having a carbon-chain backbone, which can be synthesized from *inorganic* substances.
3. Most of what is taught in first-year chemistry is inorganic chemistry. However, most of the chemistry around us—fuels, dyes, detergents, plastics, biological processes—is organic chemistry.

Analogies and Metaphors

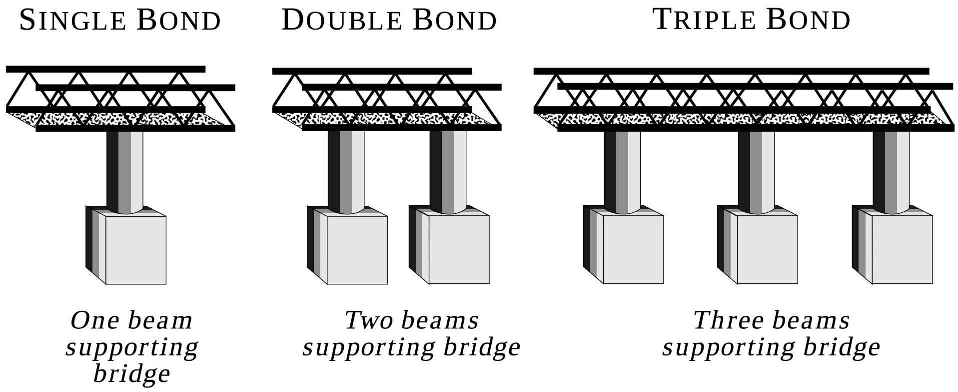
1. Some types of carbon compounds are like a linked chain—all connected together.
2. Organic synthesis is like building with LEGOs™ or CAPSELA™ kits. A few basic components are used to produce many end-structures.

Pictures in the Mind

1. Oxidation ladder showing progressive oxidation states (OS) of carbon. For further information, see *Oxidation-Reduction* module.



2. Bond strength and bridges. Remember that bond *strength* refers to how strongly two atoms are held together, *not* to how *reactive* those bonds are.



TIPS FOR THE TEACHER

Language of Chemistry

Much emphasis is placed on naming organic compounds in most introductory chemistry texts. Such emphasis is misplaced, and the emphasis in introductory chemistry should be determining chemical and physical properties through the presence of functional groups. Ask students to learn to recognize and name a few important functional groups such as alcohols, aldehydes, carboxylic acids, *etc*. The focus should then be on what these functional groups will do chemically because of the electron distribution in the group. Rather than focusing on language in the organic chemistry module, use organic compounds and reactions to illustrate the fundamental principles of chemistry.

An important term for students to learn is *isomer* because isomerism is very important in determining a compound's physical and chemical properties. Isomers that differ in identity of functional groups are clearly different from each other chemically and physically. However, even if the functional groups remain the same, as in *cis-trans* isomerism, a small change in geometry sometimes greatly alters the overall shape of the molecule, the distribution of electrons within the molecule, and/or the location of functional groups in space with respect to each other. Therefore, even *cis-trans* isomers can differ profoundly from each other. A number of isomeric puns are provided in the *Humor* section to illustrate some of the language of isomerism. Isomerism is also discussed in Links and Connections to the Contemporary World section.

Distilled alcoholic beverages (ethyl alcohol) are often described by their "proof." Since this term may be familiar to students, the history of this term is outlined. "Proof" refers to a test used to determine the alcohol content of whiskey. To "prove" that whiskey was not watered down, gunpowder and the whiskey in question would be mixed to form a paste, usually in a shot glass or even just in a pile on the bar. A lighted match would be placed on this paste. If the whiskey was much less than 50% alcohol, the match would just go out. If the whiskey was much more than 50% alcohol, the mixture would explode. (Whether this whiskey was considered good or bad to drink is not recorded in folklore.) If the whiskey was 50% alcohol and 50% water, the mixture would burn steadily. Such whiskey was usually called 100 proof. Later, when it became easy to determine the percentage of alcohol in an aqueous alcohol solution, it was discovered that 100 proof whiskey was 50% alcohol. ("Proof" is twice the percent alcohol.)

Pattern Recognition

Properties and biological activity are related to functional groups. To emphasize the functional group nature of organic compounds, make overheads of line structures and/or models of complex organic molecules like the porphyrin center of hemoglobin, or a steroid, or quinine, *etc*. You can find structures for such interesting molecules in college organic chemistry texts. Have students identify the various functional groups and predict chemical properties from them. For example, they can predict that quinine will be basic because of the amine groups with unshared electron pairs that can act as Lewis or Brønsted-Lowry bases (see *Acids and Bases* module). Given that it is predicted to be a base, you can then give students some quinine water in paper cups to taste and discuss the name "bitters," which is sometimes given to quinine water.

Students can identify the Lewis base amine centers in hemoglobin and show the complex with iron is formed by donating pairs of electrons to bond with iron.

The number of biologically important and/or interesting molecules that can be used to play this game are practically infinite, and your ability to use this exercise with students will be limited only by your own research and imagination.

Common Student Misconceptions

1. **"'Organic' means 'natural' or 'good'."**

   The word "organic" is used in many different contexts and with many different connotations. Advertisers sometimes take advantage of this confusion. For example, in the early 1970s, during the beginning of the environmental movement, one shampoo manufacturer advertised that their product was made from "pure one hundred percent organic chemicals." Of course, some of the most potent carcinogens known are "pure organic chemicals." As a chemical term, *organic* simply means having a carbon chain backbone.

2. **“All carbon containing compounds are organic.”**

   Carbonates, bicarbonates, carbon dioxide and carbon monoxide are not organic compounds. Some inorganic compounds can produce an organic molecule, as indicated in the following reaction in which calcium carbide (inorganic) is hydrolyzed to acetylene (organic).

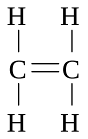
   $$CaC_2(s) + H_2O(l) \rightarrow C_2H_2(g) + Ca(OH)_2(s)$$

3. **“Formalin and formaldehyde are the same.”**

   Formaldehyde is a gas at standard temperature and pressure. It is a very reactive molecule and is a carcinogen. However, *formalin* is an aqueous solution of formaldehyde. Because formaldehyde is so reactive, it reacts with the water to form a molecule that is not carcinogenic. The molecule in formalin solutions is so stable that formaldehyde is not present in its vapor. Formalin in high concentrations is used as a preservative for biological specimens. Although the odor of formalin is unpleasant, current evidence indicates that formalin is not a health hazard.

4. **“When a formula is written in one line such as $CH_2{=}CH_2$, the hydrogen atoms are bonded to the carbon atom to their left.”**

   This shorthand notation may be misleading, but it is essential to be able to read it properly. The carbon on the left is bonded to two hydrogens. Since carbon has four covalent bonds, the double bond to the immediate right of the two hydrogens must apply to the left hand carbon as well. Furthermore, since each hydrogen only has one bond, then the hydrogens can’t possibly be bonded to any other atoms but the carbon. The right side of the molecule is less ambiguous. The double bond applies to the right hand carbon, which must also be bonded to the two hydrogens on the right. An expanded version of this formula can be drawn out as shown.

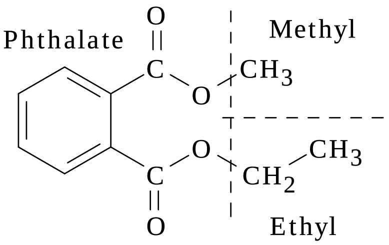
   $$\begin{array}{ccc} H & & H \\ | & & | \\ C & = & C \\ | & & | \\ H & & H \end{array}$$

   Obviously, the expanded formula is clearer, but it takes up space in textbooks that publishers can ill afford to waste. Hence, you will see condensed formulas in print for the most part.

Problem Solving

Routes to Chemical Synthesis

Once students learn a few reactions (oxidation of aldehydes, esterification of carboxylic acids, hydrolysis of esters) it can be fun to write an unfamiliar structure on the blackboard and imagine what you can make with it. If the structure has more than one functional group, it might undergo more than one reaction, enabling you to prepare several interesting compounds. The heart of this synthesis game is recognizing the functional groups and remembering their reaction patterns.



When students have played this synthesis game a few times, it is fun to provide a product and ask them what reactant molecules they need to prepare it. Organic chemists specializing in synthesis do this by taking the desired product and visually breaking it into pieces to see if they can imagine molecules with functional groups that will enable them to prepare the product. (This procedure, called retrosynthesis, is described in detail in most college-level organic chemistry texts.) For example, suppose you asked students to propose compounds to be used in the synthesis of methyl ethyl phthalate.

Although recognizing potential reactants is a trivial problem (see the following note) for an organic chemist, having high school students recognize that methanol, ethanol, and phthalic acid are necessary for the preparation is not at all obvious, even after they have prepared simple esters themselves.

Once students have proposed a reasonable set of starting materials and synthetic steps for the compound, ask them to predict other compounds formed, again based on the functional group properties. In the above example, if one reacted ethanol with phthalic acid first, one would expect to get some diethyl phthalate and unreacted phthalic acid in the mixture as well as the desired product in which one carboxylic acid group had formed an ethyl ester while the other remained unreacted and therefore available to react with methanol. Such pattern recognition is more like solving crossword or picture puzzles than the quantitative problems typically presented to first year chemistry students, but it is critical for all organic chemists. For additional examples, see college-level organic chemistry texts.

[*NOTE: The actual laboratory preparation of a pure sample of methyl ethyl phthalate from phthalic acid, methanol and ethanol is not a trivial problem, even for a synthetic organic chemist. In fact, an organic chemist might proceed from quite different starting materials in order to avoid undesired products like diethyl and dimethyl phthalate. Those who become professional synthetic organic chemists will learn in later coursework some of the problems and exceptions not hinted at in the above exercise. However, the purpose of the above exercise is for students to recognize patterns, and the exercise is valid for that reason.*]

Decision Making

A societal issue related to organic chemistry that students can use for practice in decision-making is petroleum uses. Typically, people think of some sort of fuel when the word “petroleum” is used, but petroleum is also an important chemical feedstock, *i.e.*, it can be used to provide builder molecules for synthesis of drugs, dyes, or plastics important to our lives and lifestyles. Once students have prepared esters, they will be aware that organic chemicals can be used to prepare fragrances and flavors. Chemicals that make excellent fuels—alcohols—are also used for synthesizing fragrances and flavors by reacting with the appropriate carboxylic acid. The hydrocarbon group in alcohols makes these compounds good fuels, but the hydroxy (alcohol) functional group makes them good molecular building blocks.

The same principles apply to compounds derived from petroleum. Functional groups are developed during the cracking process. As petroleum supplies dwindle, society will be forced to decide whether to convert petroleum into CO_2 and H_2O by burning it as fuel, or to convert it into other kinds of molecules—drugs, plastics, dyes, fragrances, flavors, and so forth. An outstanding resource is the *Chemistry in the Community (ChemCom)* curriculum developed under the auspices of the American Chemical Society (1993). A unit in that curriculum is entitled “Petroleum: To Build or to Burn.” A shorter resource that makes many of the same points is an article by Seymour (1989)—see *References* section). Also consider the following poem (Kolb & Kolb, 1979) that appears in another excellent article about petroleum chemistry.

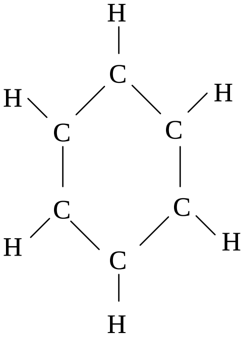
Petroleum

That viscous, tarry liquid nature laid beneath the ground
  A hundred million years before people came upon the scene
Can be transformed to marvelous new products we have found—
  Like nylon, orlon, polyesters, polyethylene,
Synthetic rubber, plastics, films, adhesives, drugs, and dyes,
  And other things, some that we now can only dream about.
Who knows what wondrous products people might some day synthesize
  From oil! Except, alas, that our supplies are running out.
The time is near when earth's prodigious flow of oil may stop,
  (We've taken so much from the ground with no way to return it);
Meanwhile we strive to find and draw out every precious drop, . . .
  And then, incredibly, we take the bulk of it and burn it.

HISTORY: ON THE HUMAN SIDE

Friedrich August Kekulé (1829-1896) was one of several important German chemists in the 1800's. It was perhaps fortuitous that his fame endures as a great teacher and chemist for he began his university days as a student of architecture and later turned to chemistry after hearing some dynamic lectures by Justus von Liebig.

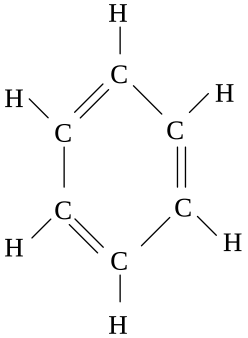
In 1858, Kekulé left his first teaching post at Heidelberg, Germany and went to Ghent, Belgium as professor of chemistry. That same year, both he and Archibald Scott Couper, a Scottish chemist, independently proposed that in all organic compounds, carbon always has four "affinity units," *i.e.*, carbon is tetravalent; it forms four bonds when it joins elements to form compounds. Perhaps it was because the German chemists in the 1800's were receiving wide recognition in organic chemistry while the Scottish chemists were not as well known that fame was heaped on Kekulé rather than Couper for this proposal. Even today, structural formulas where two electron covalent bonds are indicated simply by a line drawn between two atoms are called "Kekulé structures." Before 1858, organic chemists had been working without a mental picture of substances at the molecular level. The Kekulé-Couper theory of molecular structure of carbon compounds shed light on the structural basis of organic chemistry.



Benzene structure
proposed by Kekulé

Kekulé went on to propose that carbon atoms can bond together to form extended chains of atoms linked together. He is quoted as coming to that conclusion after a dream he had while napping on the top deck of a bus while visiting London. In the dream, he saw carbon atoms uniting in chains and whirling in a giddy dance with smaller atoms (hydrogen, *etc.*) connected to the chains.

Benzene posed a major problem for chemists in the 1800s because of its unusual properties. The molecular formula was known to be C_6H_6, but no one had been able to suggest a suitable structural formula. In 1865, Kekulé proposed a concept for benzene's structure as presented to him in a dream. While working on a textbook in his study his thoughts wandered, and he dozed before a warming fire, seeing atoms dancing before his eyes—long rows of atoms twining and twisting in snake-like fashion. Suddenly, one of the snakes turned and seized hold of its own tail and the form whirled before his eyes. He awoke and spent the rest of the night working out the cyclic structure of benzene.



Modern structure
of Benzene

Some writers have doubted Kekulé's account of the "dream" in developing structural formulas of organic compounds, but none can deny the importance of his work. The development of dyes, drugs such as sulfanilamides and aspirin, high octane gasoline, plastics, fabrics such as Dacron, are all outgrowths of the aromatic chemistry for which Kekulé helped lay the foundations with his structural formula for benzene. Kekulé died in 1896 before the first Nobel prizes were given. However, he is recognized as one of the greatest teachers of chemistry in the nineteenth century. Three of the first five Nobel prizes in chemistry were awarded to his students.

Ira Remsen (1846-1927) was the person most responsible for elevating the reputation of American universities to those of their European counterparts in the late 1800's and early 1900's by incorporating laboratory research into the instruction process.

Born in New York, Remsen was educated in the public schools and went on to receive an M.D. from Columbia University at the age of 21. He was much taken by chemistry, however, after hearing lectures on the subject. Finding no U.S. institution with a reputable graduate chemistry program, Remsen went to Munich to study under Liebig. Eventually, he went to the University of Göttingen to study in the laboratory of Rudolph Fittig, where he received his Ph.D. in 1870.

After two years of postgraduate work in Germany working on the oxidation of substituted benzene rings, Remsen returned to New York to seek an academic appointment. He was named professor of chemistry and physics at Williams College and remained there four years performing his own research, but he was unable to offer coursework in laboratory research for his students. In 1876, at the age of thirty, Remsen was offered a professorship of chemistry at the new Johns Hopkins University in Baltimore. There, he was able to introduce to his teaching the laboratory research component which had influenced him so greatly in Germany. Remsen's approach was so successful that he was able to attract large numbers of students from both the U.S. and Europe, particularly at the graduate level, marking the beginning of the rise in reputation of American institutions in chemistry.

In 1879, an event occurred that was to bring more fame to Remsen's laboratory. Constantine Fahlberg, a Ph.D. from Germany, was invited to work in Remsen's laboratory and continue the study of the oxidation of substituted benzene rings, which Remsen had started in Europe. At Remsen's suggestion, Fahlberg oxidized *ortho*-toluenesulfamide and accidently spilled some of the product on his hand. He noticed it tasted unusually sweet. (Chemists often tasted and inhaled new materials they worked with and were not nearly as cautious as they are today.) Fahlberg saw the importance of this substance as a commercial product and took out a patent on it in 1885. He called it saccharin from the Latin word for sugar, *saccharum*. It had a potency relative to sucrose of about 300 to 1. Remsen apparently felt some grievance about Fahlberg's behavior concerning the patent, and there was some ill will between the two for several years.

The achievements in Ira Remsen's laboratory were many. During this time he founded the American Chemical Journal, the first publication devoted to American chemical research. In 1901, Remsen became the president of Johns Hopkins University while also remaining chairman of the chemistry department. In 1908, he retired from the department but remained president of the institution until 1911. Ira Remsen is renowned as one of the most influential American chemists and educators of the 19th century.

HUMOR: ON THE FUN SIDE

1. **Student response on exam**: Organic chemistry is the chemistry of the organs; inorganic chemistry is the chemistry of the inner organs.
2. **Signs on bumper stickers**:
   a. It takes *alkynes* to make a world.
   b. It is *amino world* without chemists.
   c. Organic chemists do it naturally.
   d. We're *alkene* chemists!
3. **Organic Chem Gems** *(CHEM 13 NEWS, November 1976, p. 1099 and March 1985, p. 5)*
   a. What did the triple-bonded hydrocarbon say to the other hydrocarbons when they threatened to kick him out of gasoline?

      It takes alkynes!

   b. What did the first man to synthesize an organic compound yell when he did it!

      Urea! I've done it!

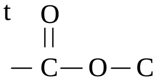
   c. What did the patient say when he was put under?

      Ether that's anesthetic or I'm crazy!

   d. What kind of car does an organic chemist drive?

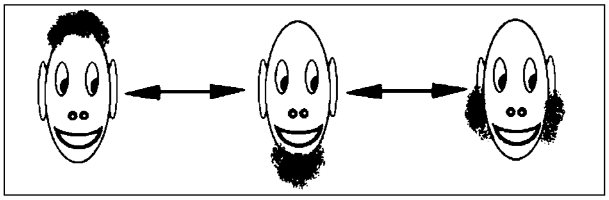
      A Mercedes Benzene

   e. **Professor**: Well, class, next lecture we will talk about containing compounds.
      Class: You mean. . .?
      Professor: Yes, tomorrow is esterday.



$-\overset{\overset{O}{||}}{C}-O-C$

4. **Resonance** *(CHEM 13 NEWS, October 1988, p. 15)*



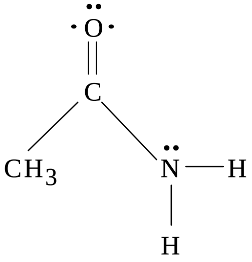
5. **THE ESTER SONG** *(CHEM 13 NEWS, December 1987, p. 4)*

(To the Oscar Meyer Bologna song)

My ester has a first name
that comes from alcohol.
My ester has a second name
from acids one and all.
Ester compounds smell so nice;
Flavoring our food precise.
Even though their names are long,
the world without them would be wrong.

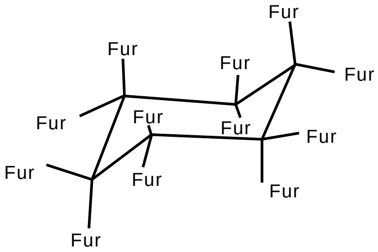
The trick to naming esters
is to find the acid part.
The carbon has two oxygens
right there in its heart.
Drop the ic, add A T E.
It's as easy as can be.
So we sing our little song;
our names for esters are not wrong.

6.



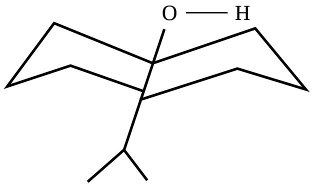
Be very careful with this chemical. It has amide of its own.

CHEM 13 NEWS, October 1985, p. 12



Expensively covered chair

CHEM 13 NEWS, January 1982, p. 8



“Alcoholic” pterodactyl

CHEM 13 NEWS, November 1984, p. 10

7. **LAMENT OF THE ORGANIC CHEMISTRY STUDENT**
(CHEM 13 NEWS, April 1979, p. 13)

Oh what a pleasure life would be
Without organic chemistry.

No one to take it out of my hide
When I don’t know thioacetamide.

Alcohols, acids, phenones, and ketones,
Baffle the student who wails and bemoans;

I study for hours before major tests!
In organic chem. class nobody rests!

While taking this course, one bonds to his book,
That’s 1.5 angstroms with a single hook.

The book that we use weighs nearly five pounds.
From twelve hundred pages its mighty word sounds;

What would life be without C, H, and O?
What a disordered place; world full of woe!

Bodies without enzymes, carbohydrates, or fat,
It would be hard to survive without things like that!

To top it all off what would be missed most of all,
That which keeps us all going, Blessed Alcohol!

Straight chains, branch chains, cyclic compounds;
To an ordinary student this surely confounds.

There’s a special fraternity of O. C. students,
For together they’ve suffered through these events.

Though it’s only been months, it seems like years,
I’ve been saturated with O. C. till almost in tears.

The nerve racking tension, the labs that one dreads,
Deep into the soul it seeps and spreads.

You think, eat, and sleep organic chemistry,
Finally synthesizing compounds are all that you see.

Marked for life by this course with which you vie,
By the tremble in your voice, and the glaze in your eye.

It’s tough for sure and it won’t get any easier;
And as the semester proceeds your stomach gets queasier.

Till the end of the semester you’re ready to die,
And hope with a “D” you’ll finally slide by.

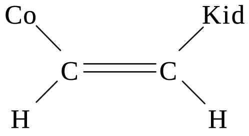
Perhaps the world would be no special place,
Without this science which we all face.

Do you feel that your mind is off in space?
Ah, you’re rapidly becoming a basket case!

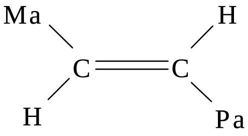
But such is the course of organic chemistry,
Which makes it not for you and me.

8. **Structural puns**. Many puns based on *cis* and *trans* isomerism of aliphatic compounds, *ortho*, *meta,* and *para* isomerism of aromatic compounds, and general nomenclature of organic compounds are possible. Challenge students to make up some new ones and share them with the teaching community by sending them to the *Journal of Chemical Education* or *The Science Teacher*.

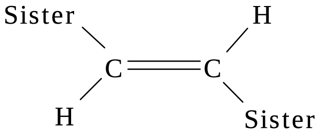
a. ***Cis-trans* isomerism**. (***Cis*** means "on the same side of a double bond." ***Trans*** means "on opposite sides of the double bond."



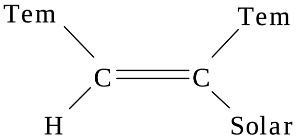
Cisco Kid
(a famous cowboy)



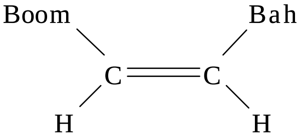
Transparence
(Transparents)



Electronics
Components
(trans-sisters)

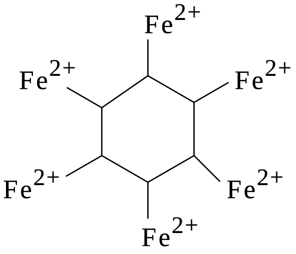


Solar System
(Solar cis-tem)

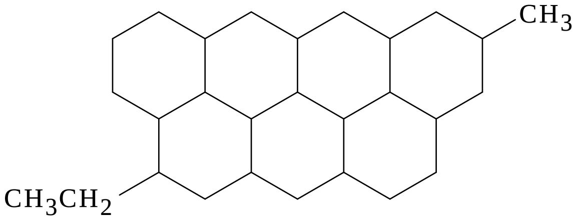


Football Cheer
(cis-boom bah)

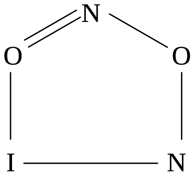
b. **Other**



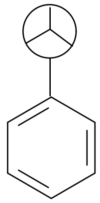
Ferrous wheel
(Older name for iron (II))



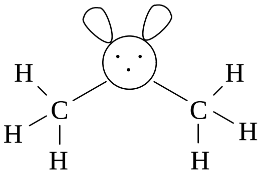
Ethylmethyl chicken wire



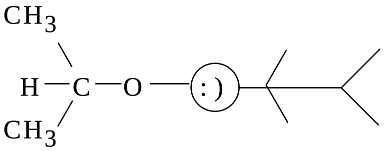
Onion ring



Mercedes
Benzene

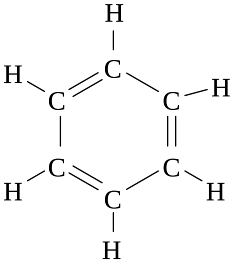


Dimethyl ether bunny

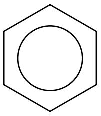


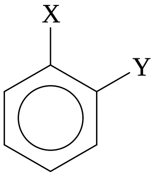
Isopropyl people ether

c. **Aromatic isomerism**. For substituted benzenes, where...

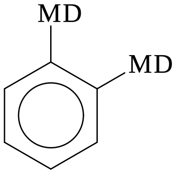


is

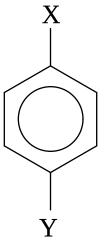




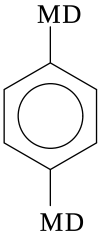
Ortho-



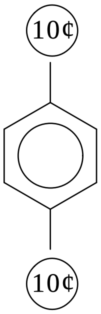
Orthodox
(ortho docs)



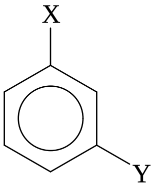
Para-



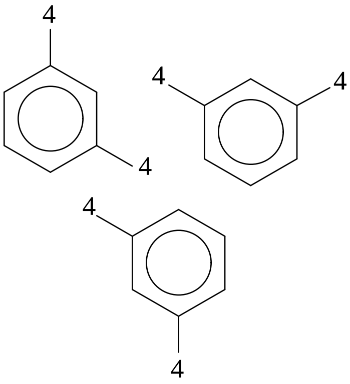
Paradox
(para docs)



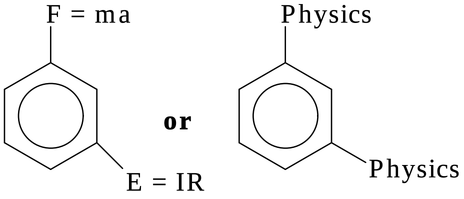
Paradigms
(para dimes)



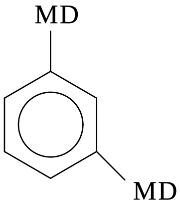
Meta-



Mixed metaphor

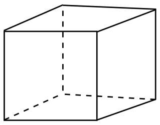


Metaphysics

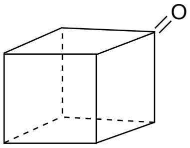


Metaphysicians

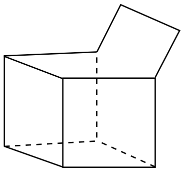
d. **SHAPE-DERIVED NAMES**



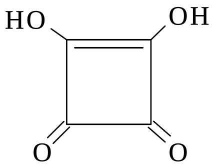
CUBANE



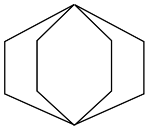
OXOCUBANE



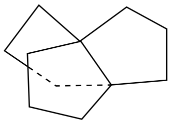
BASKETANE



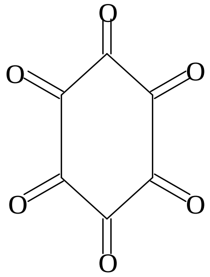
SQUARIC ACID



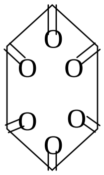
PADDLANE



PROPELLANE



CYCLONE



ANTICYCLONE

(CHEM 13 NEWS, March-April 1986, p. 8, 12)

9. Word Search (see *Appendix* for master copy)

L	N	U	G	C	W	N	R	Q	W	L	N	J	Y	I	V	X
W	Q	G	T	I	O	V	G	S	N	O	E	R	F	J	M	V
G	I	O	L	L	H	V	L	B	B	K	H	W	G	O	D	P
H	S	A	N	I	K	G	U	R	F	U	J	T	X	A	E	Y
Q	O	F	X	H	J	L	A	L	B	L	H	Y	G	V	E	O
Y	M	Q	Y	P	E	C	C	A	B	Z	G	C	C	U	D	C
J	E	M	D	O	O	E	S	V	I	E	P	Q	K	U	I	G
Y	R	J	I	R	G	E	N	O	N	Y	W	J	U	H	M	P
Q	K	I	D	D	N	E	S	H	H	Q	N	X	E	O	A	E
D	T	Y	Y	Y	J	U	E	T	H	Y	L	Z	L	U	G	A
D	H	V	K	H	I	N	O	H	E	S	T	E	R	S	C	A
X	Z	L	O	G	Q	D	A	O	K	I	Z	V	P	Y	G	K
F	A	E	J	F	B	U	V	G	B	C	Y	I	Z	R	Q	Q

Words about the concepts in this module can be obtained from the clues given. Find these words in the block of letters:

1. Organic compound that contains a carbon-carbon triple bond.
2. Organic compounds that have pleasant odors and are responsible for odors of fruits and flavorings.
3. Water-loving.
4. Word part meaning “on the same side of a double bond.”
5. Another name for chlorofluorocarbons.
6. Predominant type of organic bond in proteins.
7. In a carbonyl compound, this atom is doubly bonded to carbon.
8. Organic compound that contains only carbon and hydrogen.
9. Term that describes structural relationship of ethanol and dimethyl ether.
10. Alkyl group containing two carbon atoms.

Answers: 1. ALKYNE 2. ESTERS 3. HYDROPHILIC 4. CIS 5. FREONS 6. AMIDE 7. OXYGEN 8. HYDROCARBON 9. ISOMER 10. ETHYL

10. Crossword Puzzle (see *Appendix*)
11. See cartoons at end of module.

MEDIA

1. Software published by *JCE: Software*, a publication of the *Journal of Chemical Education,* Department of Chemistry, University of Wisconsin-Madison, 1101 University Avenue, Madison, WI 53706-1396: (608) 262-5153 (voice) or (608) 262-0381 (FAX).
   a. *Alkane Isomers,* by Richard R. Hiatt. Vol. VI B, No. 1, for IBM PS/2 PC-compatible computers.
   b. *Organic Spectroscopy,* by Richard Hiatt. Vol. II A, No. 2, for the Apple II computer.
   c. *Proton NMR Spectrum Simulator*, by Kersey Black. Vol. II C, No. 1, for the Apple Macintosh.
2. Software published by Falcon Software, Box 200, Wentworth, NH 03282; (603) 764-5788.
   a. *SpectraBook for Windows and SpectraDeck for Macintosh – An Annotated Collection of IR, NMR, CMR and Mass Spectra*, by Paul F. Schatz. $95 for individual copies.
   b. *The Schatz Index for Macintosh* , by Paul F. Schatz. The IR and NMR spectra, physical information, references, synonyms and safety data for 400 organic compounds. $200 for individual copies.
   c. IR and NMR Simulators of Macintosh and MS-DOS. These simulators are low-cost and easy to use; they are no-maintenance simulations of the real instruments. Data sets for 300 compounds are available separately. $95 for individual copies of NMR simulator, $75 for individual copies of IR simulator, $200 for IR data set, $250 for NMR data set.
   d. *Organic Reaction Mechanisms*, by J.R. Buell and A.F. Montana. For the Macintosh computer. $75 for individual copies.
   e. *OGRE–Organic Reaction Drills*, by V.I. Bendall. For IBM computers. $75 for individual copies.
   f. *Introduction to Organic Chemistry*, by Stanley G. Smith. For IBM PC, IBM PS/2, Apple II and Macintosh computers. 7-9 single disks at $60 per disk.
3. Software published by Project SERAPHIM, Department of Chemistry, University of Wisconsin-Madison, 1101 University Avenue, Madison, WI 53706-1396: (608) 263-2837 (voice) or (608) 262-0381 (FAX).
   a. For the Apple II computer running on ProDOS: AR 702, AR 705.
   b. For the Apple II computer: AP 701, AP 702, AP 704, AP 705, AP 706, AP 707, AP 717, AP 727.
   c. For IBM PCs and PC-compatibles: PC 3501, PC 3504.
4. Videodiscs published by *JCE: Software*, a publication of the *Journal of Chemical Education,* Department of Chemistry, University of Wisconsin-Madison, 1101 University Avenue, Madison, WI 53706-1396: (608) 262-5153 (voice) or (608) 262-0381 (FAX).
   a. “Carbon and its Bonds,” “Making Aspirin,” “Perkin’s Experiment,” “Chiral Molecules and Polarized Light,” “Making Polyethylene,” and “Polyethylene,” six chapters on *The World of Chemistry: Selected Demonstrations and Animations*: Disc II (double sided, 60 min.), Special Issue 4.
   b. *Demonstrations in Organic Chemistry* (double sided, 60 min.). Special Issue 6.
5. World of Chemistry Videocassettes, “Number 21: Carbon” and “Number 22: The Age of Polymers.” Annenberg/CPB Project, P.O. Box 1922, Santa Barbara, CA 93116-1922; (800) 532-7637; World of Chemistry Series, Atlantic Video, 150 South Gordon Street, Alexandria, VA 22304; (703) 823-2800 or QUEUE Educational Video, 338 Commerce Drive, Fairfield, CT 06430; (800) 232-2224.

EQUIPMENT AND INSTRUMENTATION

Modern organic chemistry is dependent on instrumentation. Organic chemists have extensive laboratory instrumentation at their disposal. These instruments are used to obtain detailed information about the presence of certain functional groups and the overall structure of organic compounds. In fact, chemists routinely use instruments and identify them by their initials—GC for gas chromatography, IR for infrared spectroscopy, and NMR for nuclear magnetic resonance (see *Instrumentation* module).

Links/Connections

WITHIN CHEMISTRY

1. **Halocarbons and environmental chemistry.** Although halogen substituted hydrocarbons pose unique environmental problems, they also provide solutions to a wide range of problems.

   a. **Halocarbon pesticides.** Some of the earliest effective pesticides (*e.g.*, DDT and Chlordane) are halocarbons. Their widespread use has allowed humans to temporarily conquer insect-borne diseases (such as malaria) and to increase agricultural productivity. However, the amount of such halocarbons used and their chemical stability resulted in their being spread throughout the ecosystem. The functional group reactivity that made them toxic for insects also made them toxic for some other species such as birds. It is a misconception that only humans make toxic halocarbons. A number of organisms have been discovered that produce such substances. The problem with halocarbons of human origin is one of scale and concentration, not the "un-naturalness" of the compounds.

   b. **Carcinogenic halocarbons.** Some halogenated hydrocarbons that were industrially useful were later found to be carcinogenic in animals, or to have other negative effects. For example, one kind of halocarbon, polychlorinated biphenyls or PCBs, were used as dielectric fluids in power line transformers until researchers discovered many of them were carcinogenic.

   c. **CFCs and the Ozone layer.** Another kind of halocarbon causing problems recently is the group of compounds known as **freons** or CFCs (chlorofluorocarbons). CFCs are essentially inert at the earth's surface. They have been used as coolants in refrigerators, freezers, and air conditioners. Unfortunately, their lack of reactivity at the earth's surface and their high volatility made it easy for CFCs to float higher up in the atmosphere. Once in the upper atmosphere, they undergo a characteristic reaction of halogen as a functional group—that is, they absorb UV light and break into pieces called free radicals that contain unpaired electrons. The unpaired electrons give the free radical breakdown products of CFC just exactly the right chemical properties to react with ozone (O_3) occurring naturally in the upper third of the atmosphere. Unfortunately, O_3 is needed there to absorb UV radiation that would otherwise reach the earth's surface damaging us and other living systems.

2. **Fuels and Thermodynamics.** Concepts learned by applying thermodynamics to the exothermic reaction of NaOH with HCl can be applied to hydrocarbons. Burning either petroleum or coal supplies most of the world's energy. The enthalpy of reaction for combustion of hydrocarbons can be experimentally determined. For example, see the experiment (*References* section) for determining the heating value of fuels reported by Rettich, Battino, and Karl (1988). Thermodynamic problems can focus on the burning of organic compounds.

3. **Reaction Kinetics**. The majority of synthetic organic reactions occur in solutions at temperatures below 150 °C. In addition, most reactions can be considered complete in just a few minutes. These kinds of chemical reactions lend themselves to kinetic studies. Reactions which consume or liberate acids or bases can be followed by adding a small amount of acid-base indicator to the reaction solution. An excellent example of just such a reaction is the hydrolysis of a methyl ester in a base solution. See *References* section for Rodig, Bell, and Clark (1990). Many organic reactions occur in a stepwise fashion and can be described by a series of equations called a reaction mechanism. One of the best ways of testing a proposed reaction mechanism is to see if it fits an experimentally determined rate equation. Finally, there are numerous examples of catalysis in organic chemistry. Some reactions are catalyzed by species in solution and some are catalyzed by surfaces in contact with solutions.

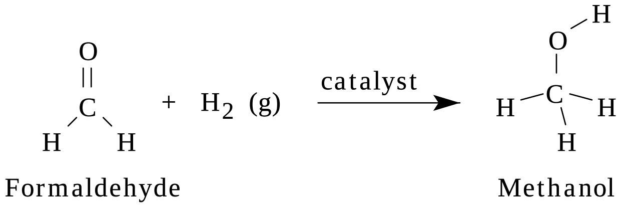
4. **Molecular Geometry**. The geometry of organic compounds is an important consideration in predicting their reactivity (see the discussions of isomerism in *Links and Connections to the Contemporary World*). Most organic compounds have a number of tetrahedral centers, and other centers that are trigonal or linear. Since each atom is bonded to carbon by an electron cloud, counting the number of atoms around a particular carbon atom in a molecule permits prediction of the number of electron clouds around that carbon. VSEPR theory can then be used to predict the geometry around the carbon (see *Molecular Geometry* module). If there are four atoms attached to carbon, there are four clouds, and they form a tetrahedral arrangement. If there are three atoms attached to a carbon (three clouds), they form a planar trigonal arrangement. If there are two atoms (two clouds), there will be a linear arrangement.

5. **Polymer chemistry**. Although progress has been made in recent years to synthesize useful polymers from inorganic materials, most commercially useful polymers are made from organic chemistry builder molecules. In addition to synthetic polymers, there are many naturally occurring polymers based on organic chemicals. DNA and proteins are just two obvious examples. In teaching polymers, emphasize the functional group chemistry that serves to link monomers to form polymers.

   A polymer that students may find interesting is supernylon, which appears ready to assume a dominant role in the marketplace. Stanyl™, developed in the Netherlands, reportedly has a higher melting point and greater toughness and temperature stability than traditional nylon polymers. These properties should make it ideal for the manufacture of molded parts and fibers. For additional information on organic polymers, refer to the *Polymer* module.

6. **Biochemistry**. Biomolecules are organic compounds such as DNA and proteins. Another example is lignins, which provide structural support for plant cells. Large numbers of organic compounds are critical for biochemical functioning. Many of these compounds are mentioned in various contexts in this module.

7. **Biochemical reactions with an aldehyde.** An aldehyde reacts with H_2, in the presence of an appropriate catalyst, to form an alcohol. Hydrogen adds across the carbon-oxygen double bond, placing a hydrogen atom on each of the atoms comprising the carbonyl group.



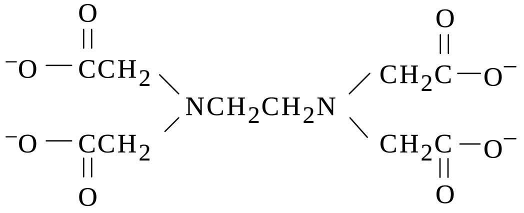
Your body processes alcohol via a mechanism that is the reverse of this process. Whereas adding H_2 to something is called hydrogenation, taking H_2 away is called dehydrogenation. In your body, and in many other species, alcohol is processed by an enzyme called alcohol dehydrogenase. Ingested ethanol reacts with alcohol dehydrogenase in the liver to form acetaldehyde. The aldehydes have characteristic odors. People who have been drinking a lot but quit a few hours earlier have a characteristic odor—not of alcohol but of acetaldehyde, as the body expels it via perspiration and breathing.

Acetaldehyde is reactive because of its aldehyde functional group. It is able to sneak into systems like the ends of nerve cells because of its small size. Acetaldehyde may be the molecule that actually causes drunken behavior rather than alcohol itself.

Aldehydes are very easy to oxidize. The human body oxidizes acetaldehyde to acetic acid. If large quantities of alcohol are ingested, enough may be converted to acetaldehyde which is then oxidized to acetic acid to cause a drop in blood pH. If the pH drops far enough, enzymes necessary for vital functioning begin to precipitate and the individual dies of alcohol poisoning. One of the medical treatments for alcohol poisoning is to add sodium bicarbonate solution to the patient's bloodstream, helping to raise the pH back to normal levels because the bicarbonate anion is the conjugate base of a weak Brønsted-Lowry acid.

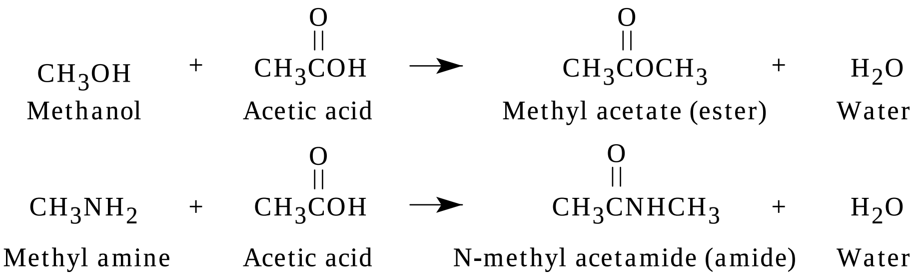
A similar reaction series occurs when methanol (wood alcohol) is ingested because alcohol dehydrogenase can also work on methanol. In this case, formaldehyde is produced by the dehydrogenation of methanol. Formaldehyde is quite reactive and reacts with just about any biomolecule that happens to be in the neighborhood when it is formed. For example, it is known to be a carcinogen, indicating that it can disrupt the cell's genetic machinery. Methanol ingestion, even in fairly small quantities, can lead to blindness, paralysis, and death. Patients who have ingested methanol are treated with ethanol because alcohol dehydrogenase reacts preferentially with ethanol. Maintaining a relatively high concentration of ethanol in the body pushes the equilibrium of the reaction in which enzyme-ethanol complex is formed to the right, effectively preventing oxidation of methanol into formaldehyde. Once analysis of the patient's urine indicates that methanol is no longer being excreted, then the ethanol treatment is removed (see *Chemistry in Medicine* module).

8. **Complex ion formation.** The biological example of hemoglobin as a complex ion in which iron is bound as a Lewis acid to the nitrogen bases in heme was discussed above. Another application of the same principle is the use of EDTA to complex metal ions. EDTA stands for ethylenediamine tetraacetate, and this is its structure.



The four carboxylate groups are free to rotate or flop around, allowing them to adopt a number of different positions in space with respect to the amine nitrogens. The amine nitrogens and the carboxylate groups are Lewis bases that can donate an electron pair to bond with a Lewis acid in complex formation. Consequently, EDTA is able to form complexes with a wide range of metal ions. EDTA is used in analytical chemistry to complex the ion of interest and sometimes to remove a competing ion. It is also used in a variety of other contexts in which forming an organic complex of a metal ion is useful (as in lead poisoning treatment). Have students read food and/or over-the-counter (OTC) drug package labels to see if they can find EDTA as an ingredient.

9. **Formation of amides.** A reaction similar to the formation of esters, described earlier in this module, is the formation of amides. In amide formation, a carboxylic acid reacts with an amine to produce the amide and water. Compare the reactions for ester and amide formation:

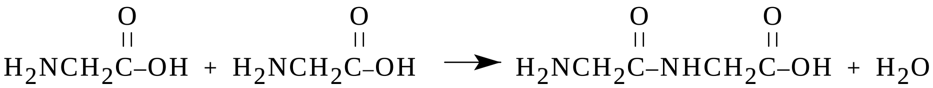


$$\underset{\text{Methanol}}{\mathrm{CH_3OH}} + \underset{\text{Acetic acid}}{\mathrm{CH_3}\overset{\displaystyle \mathrm{O}}{\overset{\|}{\mathrm{C}}}\mathrm{OH}} \longrightarrow \underset{\text{Methyl acetate (ester)}}{\mathrm{CH_3}\overset{\displaystyle \mathrm{O}}{\overset{\|}{\mathrm{C}}}\mathrm{OCH_3}} + \underset{\text{Water}}{\mathrm{H_2O}}$$

$$\underset{\text{Methyl amine}}{\mathrm{CH_3NH_2}} + \underset{\text{Acetic acid}}{\mathrm{CH_3}\overset{\displaystyle \mathrm{O}}{\overset{\|}{\mathrm{C}}}\mathrm{OH}} \longrightarrow \underset{\text{N-methyl acetamide (amide)}}{\mathrm{CH_3}\overset{\displaystyle \mathrm{O}}{\overset{\|}{\mathrm{C}}}\mathrm{NHCH_3}} + \underset{\text{Water}}{\mathrm{H_2O}}$$

These reactions are very similar. The carboxylic acid functional group reacts in an essentially identical fashion in both reactions. However, the difference in electronegativity between O and N makes the reaction rates and extent of reaction very different. Consequently, the preparation of amides in the laboratory is usually conducted with different starting materials. Biochemically, amide bonds are formed from amines and carboxylic acids with the help of enzyme catalysts.

Amides, like esters, are biologically important and the amide bond is the principal bond in protein formation. Amino acids are organic compounds with two functional groups—an amine group, and a carboxylic acid group. In forming proteins, amino acids are linked *via* an amide bond. An example of a simple amide bond between two amino acids is shown.



$$\mathrm{H_2NCH_2}\overset{\displaystyle \mathrm{O}}{\overset{\|}{\mathrm{C}}}\mathrm{–OH} + \mathrm{H_2NCH_2}\overset{\displaystyle \mathrm{O}}{\overset{\|}{\mathrm{C}}}\mathrm{–OH} \longrightarrow \mathrm{H_2NCH_2}\overset{\displaystyle \mathrm{O}}{\overset{\|}{\mathrm{C}}}\mathrm{–NHCH_2}\overset{\displaystyle \mathrm{O}}{\overset{\|}{\mathrm{C}}}\mathrm{–OH} + \mathrm{H_2O}$$

The newly formed amide still has an amine group on one end and a carboxylic acid group on the other, enabling it to form other amide bonds. The manufacture of polyamides such as nylon is dependent on this principle.

10. **Acids and Bases.** Many applications of organic chemistry to acids and bases exist. A few have been mentioned previously. Some weak acids and bases are organic compounds. Carboxylic acids, *e.g.,* acetic and propionic acids, are typical weak acids, whereas amines, *e.g.*, methylamine and ethylamine, are typical weak bases. In teaching acid-base equilibria, organic as well as inorganic examples can be used.

BETWEEN CHEMISTRY AND OTHER DISCIPLINES

1. **Biology.** The links between organic chemistry and biology and its related disciplines such as medicine are obvious. Specific examples are found throughout this module.
2. **Literature.** Detective fiction utilizes numerous chemical clues. Stories by A. Conan Doyle and Dorothy Sayers are especially good examples. In *A Study in Scarlet* a protagonist is (or at least may have been) slowly poisoned.
3. **Art.** Organic chemistry has a great impact on the art world. Many of the paints and dyes—acrylics, for example—are organic in origin. The instrumental techniques used by organic chemists are often used in determining whether paintings are forgeries. Organic chemistry is also used in color photography.
4. **History.** History is likewise not immune to organic chemistry. The Phoenicians may have based their trading empire on similar technology three millennia ago with their knowledge of the production of dyes and the interaction of dyes with fabrics. It is possible to overemphasize the importance of politicians and military men and to ignore the importance of trade, including new industrial processes, that influence the patterns of history. One of the reasons for Germany's rise to power in the nineteenth century was its industrial prowess in organic chemistry. German companies held so many patents that the American chemical industry found it difficult to grow and prosper. During World War I, the Americans took over many of the German patents and began to manufacture substances like aspirin.

TO THE CONTEMPORARY WORLD

Careers

Organic chemists are employed in large numbers in industry. The pharmaceutical industry employs organic chemists to conduct research to find new and different compounds for medical applications. New areas of research, such as gene splicing, continue to develop. The petrochemical industry has long been a major employer of organic chemists. Many of the top twenty-five chemicals produced in the U.S. are made from petroleum cracking. Fifty percent of industrial chemists in the U.S. work in some area of organic polymer chemistry. Organic chemists are also needed in such fields as environmental protection, the health sciences, including toxicology, the biological sciences, transportation industries and the semiconductor industry. In addition to industrial positions, organic chemists are employed as researchers in government and academic laboratories. Because a basic knowledge of organic chemistry is also required for professionals in such diverse areas as medicine and materials engineering, numerous organic chemists are also employed as teachers. Many organic chemists combine more than one professional description—teacher and researcher, or academic researcher and industrial consultant just to name two possibilities.

Community

Many industries are involved with organic chemistry, from petroleum refining or pharmaceuticals to treatment of wooden poles with creosote, the production of pine oil cleansers, and the treatment of coal or other fuels prior to burning. A potential field trip site includes a visit to the local propane/butane/natural gas distributor, or a swampy area where anaerobic decomposition is producing methane bubbles, or local beauty colleges where knowledgeable representatives of the industry can discuss and demonstrate the various beauty products used. (For example, permanents require the use of an agent that denatures the protein in hair.) You might also wish to contact your county extension agent, who should be knowledgeable in the area of pesticides.

Most areas have a local section of the American Chemical Society. If you don't know where or when yours meets, contact chemistry teachers at the nearest college or university or call the ACS in Washington, DC. By attending a meeting, you can meet chemists in your area who are involved in all sorts of professions. Each local ACS section typically has several organic chemists who will willingly talk with students.

Personal

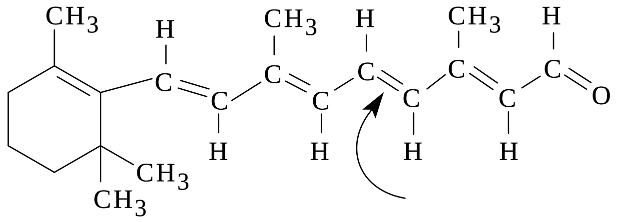
1. **The Chemistry of Vision involving *Cis* and *Trans* Rhodopsin.**

Vision is actually a very complex chemical phenomenon. When light enters the opening in the front of the eye, it travels through the eye and falls on the rear surface (retina) lined with cone-shaped and rod shaped cells. Each eye contains 7 million cones for detecting color and 120 million rods to detect white light and to provide sharpness of visual images. The molecules responsible for vision are attached to the tops of the rods and cones.

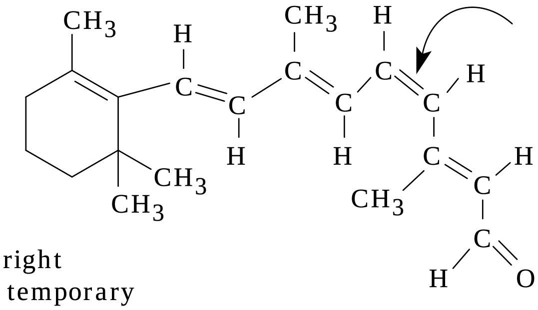
Rhodopsin is one of the molecules responsible for vision. It has two parts: a protein portion called "opsin," and a small aldehyde portion called "retinal." The structure of retinal can occur in the *trans* form where all substituents around the double bonds are *trans*. It can also be noted that vitamin A, a substance known to aid vision—especially night vision, has the same structure as retinal except that the terminal aldehyde functional group is replaced by an –OH group to give an alcohol. Retinal can occur in other isomeric forms, one of which is called the 11-*cis* form because of the *cis* arrangement at carbon 11. It is in this *cis* form that retinal is bound to opsin. When rhodopsin absorbs light, the retinal is isomerized to the all-*trans* form, which separates from the opsin.

The retinal portion of rhodopsin: (a) the *trans* form; (b) the 11-*cis* form.

(a)



(b)



When the two portions separate, the natural reddish-purple color of rhodopsin is lost. In addition, the cell to which rhodopsin is attached becomes excited. This receptor cell then excites other cells and sends a message to the brain.

After the activation of rhodopsin and the separation of the *trans* form of retinal, the retinal returns to the 11-*cis* form and reconnects to opsin. This process is relatively slow, which is one reason our eyes need time to adapt to low-light conditions. Also, intensely bright light causes saturation of the light receptors, causing temporary blindness since there is no attached retinal to absorb additional photons. [See *References*, *Chemical and Engineering News* (1992, April 6) for the article describing isolation of the visual pigments for the first time.]

2. **Optical Isomerism and Drug Specificity**. Stereoisomers have the same bonds but different spatial arrangements of atoms. One type of stereoisomer is called an optical isomer because the isomers have opposite effects on plane-polarized light. The isomer that rotates light to the right (when viewed down the beam of oncoming light) is said to be dextrorotatory, or *d*. The isomer that rotates the plane of light to the left is called levorotatory or *l*. Optical isomers are mirror images of each other (like left and right hands); they cannot be arranged in space so that they completely overlap.

   Many biomolecules are optical isomers, and their reactions are highly dependent on structure. For example, a drug might have a particular effect because it can bind with a specific isomer in the body. In order to bind correctly, the correct optical isomer of the drug must be administered. Thalidomide is a drug which has two optical isomers. Unfortunately, when the incorrect isomer, or a mixture of both isomers, was administered to pregnant women, it caused terrible birth defects in the children born to these women. (See *Chemistry in Medicine* module for another example—amphetamines.) Many naturally synthesized compounds are a given optical isomer rather than a mixture of the two possible isomers (a 50/50 mixture is called a "racemic mixture"). When a living creature dies, slow racemization of the optically active molecules in the organism begins. Archaeological organic chemists have measured the average rate of this process, thereby developing a method for fixing the date of death of the organism or compounds derived therefrom. This method promises to be a much more sensitive and less limited dating technique than radiocarbon dating.

SCIENCE/ TECHNOLOGY/ SOCIETY

1. **Methane**. Methane, along with carbon dioxide, water vapor and other substances, helps control the earth's temperature. Scientists have noted that the atmosphere's methane content seems to be increasing 2% annually. Although most people don't consider "naturally occurring" methane a problem for society, many of the sources are human-related in origin.

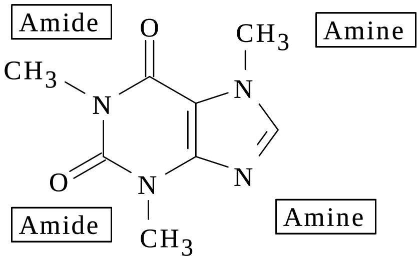
   One source of this increase appears to be termites. When termites consume wood, cellulose is broken down into methane, carbon dioxide and other compounds by microorganisms in termites' digestive systems. It is estimated that termites produce 165 million tons of methane and 55 million tons of carbon dioxide annually. These amounts of methane and carbon dioxide are very significant and are due to environmental changes favoring termite multiplication. One such change is deforestation, which leaves large numbers of felled trees and branches, a perfect environment for termites. The additional methane can contribute to the Greenhouse Effect, possibly increasing global warming.

   Methane gas is also given off by cows as they belch when chewing their cud. In Oregon, this gas has even been collected by some farmers and used as a fuel. Again, that sounds quaint and interesting until one considers the number of cattle raised every year to provide beef, milk, and leather for a growing human population. Bacteria in a cow's stomach is not the only way cattle produce methane. Manure is another methane source. In fact, decomposing manure is such a potent source of methane, it can kill. Experienced farmers in Menominee, MI entered a manure pit and were overcome and later died from methane gas poisoning.

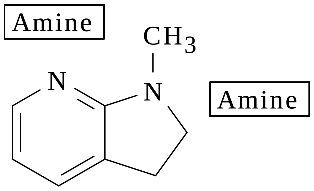
Rice is the major food staple for much of the world, and rice paddies are major sources of methane.

No one knows for sure how much of the methane in the atmosphere results from nonhuman sources and how much results from human activity. It is true, however, that our production of CO_2 and CFCs are not our only contributions to the Greenhouse Effect.

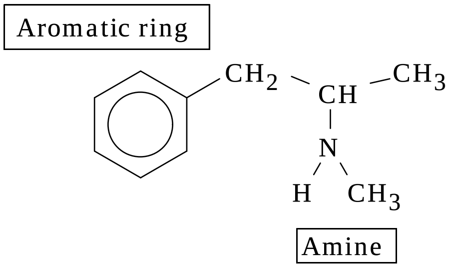
2. **Drugs: Licit and Illicit.** Most drugs, both legal and illegal, are organic compounds, and most of the currently known psychoactive drugs are amines. A few of those currently used by society are caffeine, cocaine, methamphetamine, and nicotine. Important functional groups are indicated in their structures.



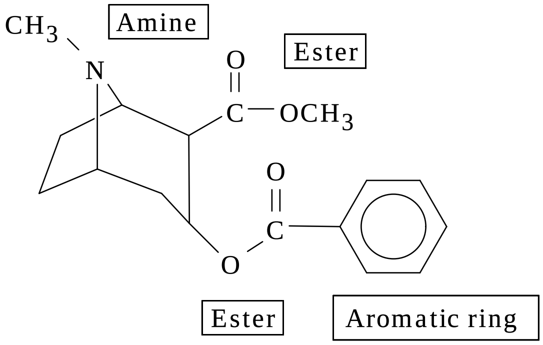
Caffeine



Nicotine

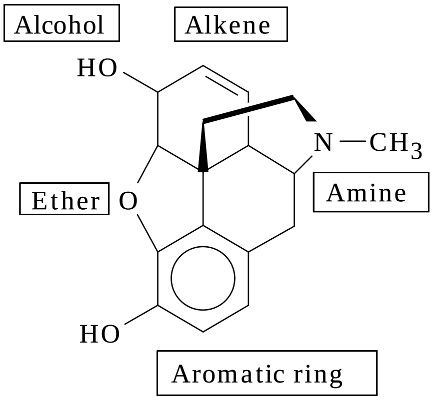


Methamphetamine

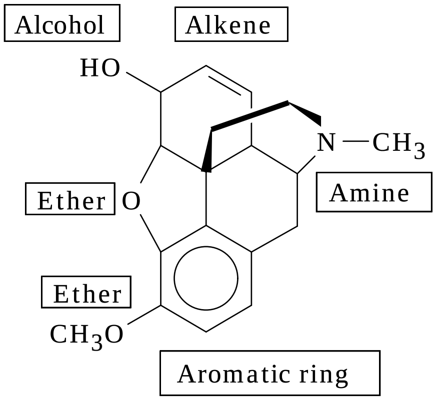


Cocaine

Some scientists have proposed that ethanol, causing most problems of substance abuse in the United States, does not directly cause all symptoms associated with it. Rather, the acetaldehyde formed via alcohol dehydrogenase oxidation of ethanol reacts with one or more naturally occurring brain amines to form products similar to other psychoactive substances in the way they fit receptors on nerve cells. One very well understood group of psychoactive substances that illustrate the way such substances seem to work is the group called the morphine alkaloids. Morphine itself was discovered when chemists began investigating the chemical basis of the pain-killing properties ofextracts of the opium poppy. Two naturally occurring cousins of morphine are codeine, which is often used in cough syrups, and thebaine, a pain-killer. Structures for these compounds appear here with important functional groups indicated.

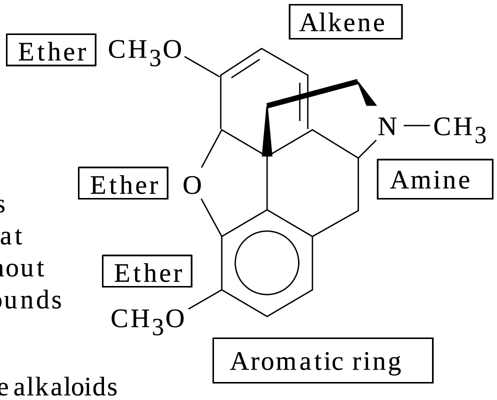


Morphine

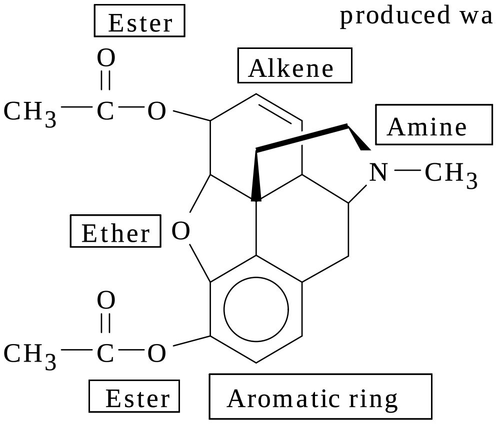


Codeine

Although these compounds may be useful in medicine, they have generated social problems because they are addictive. A systematic investigation of derivatives of morphine was carried out in the late nineteenth and early twentieth centuries in an attempt both to understand morphine's mechanism and to produce chemicals that had morphine's pain-killing properties without its addictive properties. One of the compounds produced was heroin.



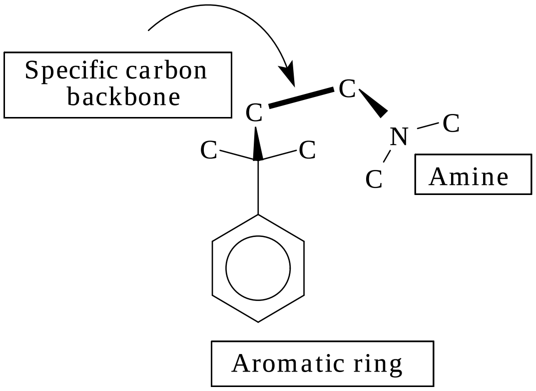
Thebaine



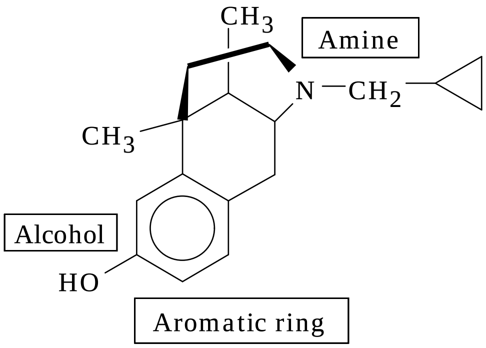
Heroin

Further study of the morphine alkaloids determined that the key structure included an aromatic ring attached to a 3-carbon backbone, the nearest carbon of which was also attached to two carbons and the other end of which was attached to a tertiary amine. (Tertiary amines have three carbons attached to the nitrogen.)

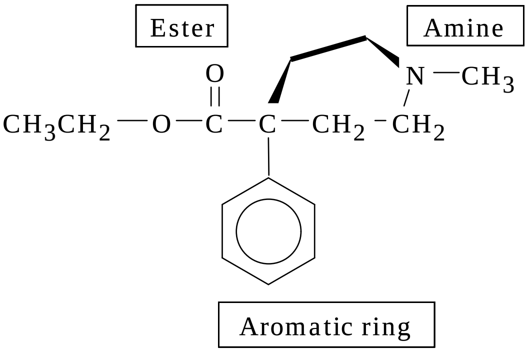
Other research indicated that the mechanism of morphine action was that morphine alkaloids bound to the surface of nerve cells in the brain, in spots called "opiate receptor sites" (named after the original source of morphine alkaloids). The opiate receptor sites normally bind to small proteins such as b-endorphins that occur naturally in the brain. Because morphine alkaloids are a slightly different shape from b-endorphins that usually bind to opiate receptor sites, they alter the shape of the receptor site, thereby altering the way the brain perceives pain. The addictive morphine alkaloids like morphine and heroin also apparently cause long-lasting changes in the brain that result in addiction.



From these clues, compounds that have morphine's pain-killing properties but greatly decreased addictive properties were synthesized. Two of these include cyclazocine and meperidine.



Cyclazocine



Meperidine

Examining the structures of all morphine alkaloids, including the nonaddictive synthetic substitutes, shows they fit the general structure allowing binding to the opiate receptor sites. If you have the time to put these structures on the board, you might wish to ask students which feature(s) of morphine, codeine, and heroin might be responsible for the addictive properties. Such a question would comprise a good exercise in pattern recognition.

3. **Pesticides.** A serious problem in providing food for the world's populations is pests: weeds, fungi, insects, worms, rodents, *etc*. Two modes of attack have been made on this problem: breeding hardier plant species and developing chemical pesticides.

A pesticide that kills weeds is an herbicide. The first chemical herbicides were inorganic compounds, but they often killed the crop they were intended to protect. In the early 1940's, a major breakthrough in weed control occurred with the discovery of 2,4-dichlorophenoxyacetic acid or 2,4-D. This substance selectively kills broad leaf weeds. 2,4-D has been widely used to control weeds in wheat, rice, corn and sugar cane, as well as in lawns. A close relative is 2,4,5-trichlorophenoxyacetic acid or 2,4,5-T, first marketed in 1948 and used in controlling brush along roads and fences. 2,4,5-T has been the focus of controversy because of its use in Vietnam to defoliate trees to destroy the cover of enemy soldiers. The substance used was actually a 50:50 mixture of the butyl esters of 2,4-D and 2,4,5-T and was called Agent Orange because it was stored in orange drums. Agent Orange has been implicated in causing a wide range of symptoms in humans. Many American soldiers were exposed to Agent Orange during the spraying, and some of them later joined in suing the U.S. government for damages suffered as a result. Many scientists feel that any damage to humans as a result of the spraying was probably due to an impurity, dioxin, in the mixture. Even so, restrictions have been placed on the use of 2,4,5-T because of the possible toxic effect on humans. Whether Agent Orange caused damage to U.S. soldiers and others is still under dispute. Other herbicides, such as atrazine, alachlor and trifluralin are now being used for similar applications. The herbicides act by interfering with mechanisms important to plant survival. Atrazine disrupts photosynthesis, alachlor inhibits the synthesis of proteins and trifluralin interferes with cell division.

Compounds that kill insects are known as insecticides. Approximately one-third of agricultural produce grown worldwide is consumed or destroyed by insects. The first insecticides were inorganic compounds but most modern products are organic compounds. The first highly successful insecticide was DDT. However, numerous environmental problems were associated with DDT and other chlorinated hydrocarbons. They are toxic and remain a long time in the ecosystem without being chemically degraded to less toxic forms. Chlorinated hydrocarbons have gradually been replaced by other classes of compounds such as organic phosphates, which are much more readily biodegraded. Most of these compounds are closely related to nerve gases developed for human warfare and are quite toxic. Parathion is very toxic to humans, but malathion is less toxic and is widely used because it biodegrades in a few weeks. Another class of insecticides is derived from carbamic acid. The carbamates, of which the compound Sevin is an example, are generally safer to handle but more expensive to produce.

Extensions

1. Compounds containing the carbonyl functional group, $C=O$ (the remaining bonds are to hydrogen or alkyl groups), are called aldehydes ($RCHO$) or ketones ($RCOR'$). The chemistry of these compounds is primarily due to the chemistry of the carbonyl functional group. Most aldehydes and ketones give a yellow-to-red precipitate when mixed with 2,4-dinitrophenylhydrazine. However, only aldehydes will reduce Ag^+. The Tollens' test for aldehydes (silver mirror) is based on the reduction of Ag^+ by an aldehyde. (Directions for the Tollens' test can be found in most organic chemistry laboratory manuals; see *References*.) Methyl ketones (ketones where one alkyl is a methyl group) will react with iodine in a basic solution to give a yellow iodoform precipitate. By this difference in behavior you can classify and differentiate aldehydes and ketones—see Pavia, Lampman, Kriz, and Engel (1990) in *References*. Students can devise a set of chemical tests to identify various aldehydes and ketones. In recommending this extension to students, pay special attention to safety features.

2. An excellent independent study project would be to investigate the oxidation of alcohols by $KMnO_4$(s). Apparently the reactions on the solid surface are different from permanganate oxidations in solution. Parameters not fully investigated include potential for transition metal catalysis (Cu^{2+} has been studied, but not in depth), inhibition by carboxylic acids, and the role of trace quantities of water. Students could isolate the ketones by precipitating as dinitrophenylhydrazone derivatives—see Fieser and Williamson (1979, p. 354) in *References*—identify them by melting point, and/or determine the amount produced per unit time by determining the number of moles of dinitrophenylhydrazone produced. If students had access to a gas chromatograph (most analytical and university laboratories have gas chromatographs), following the course of a reaction would be even easier. Menger (1982) has written an excellent review article for interested students.

3. When alcohols are mixed with solutions of cerium salts, colored complexes (typically orange or red) are often formed. Can the rate of the reaction be studied with a spectrophotometer like a Spectronic 20, a Coleman Junior, a Sargent-Welch Chem Anal, *etc.*? Can students devise a method to follow the reaction by its color change even if they don't have access to a spectrophotometer? Are there any patterns to the colors formed or the reaction rates that can be explained because the alcohols are primary, secondary, or tertiary alcohols, or by the number of carbons in the backbone? Do secondary alcohols that are linear behave differently from secondary alcohols that are cyclic? Can the complex (probably a solid) be isolated? A recipe for the cerium solution is found in Fieser and Williamson (1979), see *References*. They recommend 90 g cerium(IV) ammonium nitrate, $Ce(NH_4)_2(NO_3)_6$ in 225 mL 2 M HNO_3. The idea for this project came from Dr. Archie Moore, Southeastern Louisiana State University, Box 385, Hammond, LA 70402.

4. Do microwaves affect hydrolysis reactions? The production of soap (see *Demonstration 2*) is a hydrolysis reaction. In the demonstration, the reactants were heated on a hot plate. Recent evidence indicates that heating in a microwave oven may cause effects that are not due just to the heat—see Jahngen, *et al.* (1988) in *References*. They reported that microwave heating caused a compound to hydrolyze as much as ten times faster than equivalent hot plate heating. The authors suggest that this “nonthermal” heating may account for observed damage by microwaves to biological systems. Students could replicate Jahngen’s study by seeing whether microwave oven treatment produced soap faster than hot plate treatment. They would need to be careful in setting up experimental controls to ensure that thermal heating was equivalent. Many replicates of experiments would be necessary for appropriate statistical analysis of the data.
5. Students who are interested in soaps can prepare them with potassium hydroxide, KOH, as well as with sodium hydroxide, NaOH, using the directions in *Demonstration 2*. In order to compare properties all conditions would have to be carefully duplicated.

References

Module developed by William Becker, Beatrice Epperson, and William Lamb, the Oregon team.

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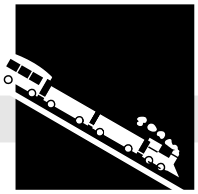
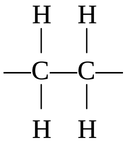
Appendix



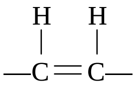
- **Transparency Masters**
  1. Common Functional Groups in Organic Compounds
  2. Esters
  3. Organic Chemistry Crossword Puzzle
  4. Word Search
- **Humor**

Common Functional Groups in Organic Compounds



$-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-$

Alkane

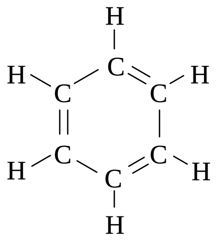


$-\overset{H}{C}=\overset{H}{C}-$

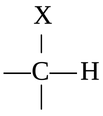
Alkene

$-C\equiv C-$

Alkyne



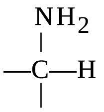
Benzene



$-\overset{X}{C}-H$

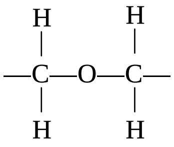
X = F, Cl, Br, I

Alkyl halide



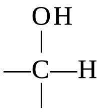
$-\overset{NH_2}{C}-H$

Primary Amine



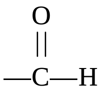
$-\overset{H}{\underset{H}{C}}-O-\overset{H}{\underset{H}{C}}-$

Ether



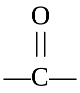
$-\overset{OH}{C}-H$

Alcohol



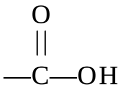
$-\overset{O}{\overset{\|}{C}}-H$

Aldehyde



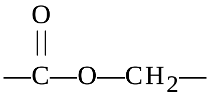
$-\overset{O}{\overset{\|}{C}}-$

Ketone



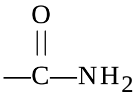
$-\overset{O}{\overset{\|}{C}}-OH$

Carboxylic acid



$-\overset{O}{\overset{\|}{C}}-O-CH_2-$

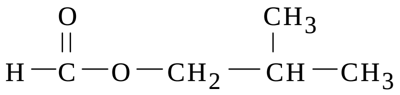
Ester



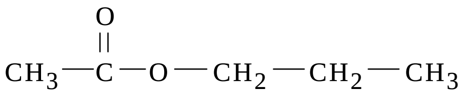
$-\overset{O}{\overset{\|}{C}}-NH_2$

Amide

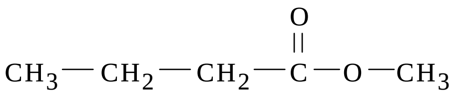
Esters


$H-\overset{O}{\overset{\|}{C}}-O-CH_2-\overset{CH_3}{\overset{|}{CH}}-CH_3$

Raspberry


$CH_3-\overset{O}{\overset{\|}{C}}-O-CH_2-CH_2-CH_3$

Pear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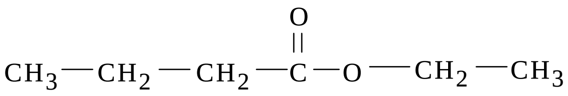
Apple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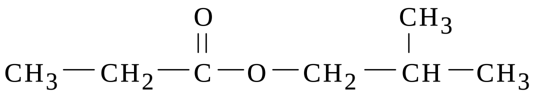
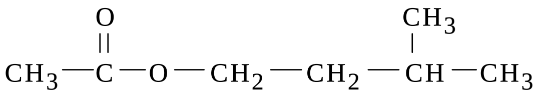
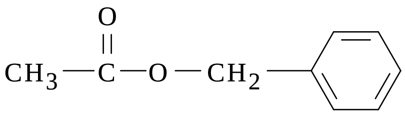
Pineapple


$CH_3-CH_2-\overset{O}{\overset{\|}{C}}-O-CH_2-\overset{CH_3}{\overset{|}{CH}}-CH_3$

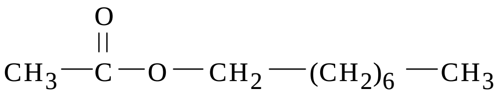
Rum


$CH_3-\overset{O}{\overset{\|}{C}}-O-CH_2-CH_2-\overset{CH_3}{\overset{|}{CH}}-CH_3$

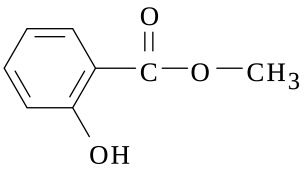
Banana



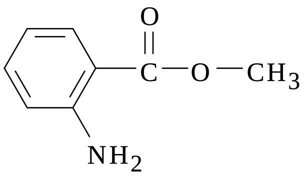
Peach


$CH_3-\overset{O}{\overset{\|}{C}}-O-CH_2-(CH_2)_6-CH_3$

Orange

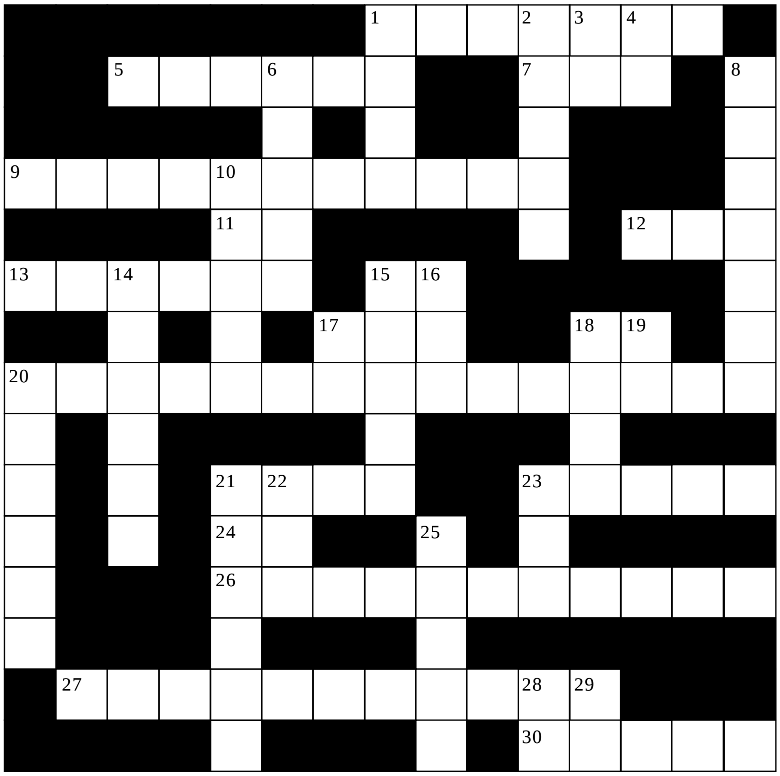


Wintergreen



Grape

Organic Chemistry Crossword Puzzle



Down

1. Product of length and width.
2. Organic compounds with the general formula RCOOH.
3. Element 28 (Symbol).
4. Element 99 (Symbol).
6. Device used to control certain types of computers.
8. ________ point, temperature at which a pure organic compound is suddenly transformed from a solid to a liquid.
10. Pertaining to the periodic ebb and flow of ocean waters.
14. Water ________, description of a hydrophilic compound.
15. Organic compound produced by the reaction between a carboxylic acid and an alcohol.
16. Where the synthesis in 15-Down takes place, for short
17. Prefix meaning “not.”
18. Physical property characteristic of 15-Down.
19. Element 3 (Symbol).
20. Element that all organic compounds must contain.
21. Organic compounds containing a bridging oxygen between hydrocarbon groups and formerly used as an anesthetic.
22. Path or road.
23. Pie ________ mode.
25. Element contained in boric acid.
28. Common pronoun.
29. Element 24 (Symbol).

Across

1. Saturated hydrocarbons.
5. One of several species with the same formula but with different structure and properties.
7. Configuration applied to geometric isomers denoting an arrangement in which the substituent groups are on the same side of the double bond.
9. Type of organic compound with one or more double or triple bonds.
11. Common verb containing the symbols for Elements 53 and 16.
12. Type of organic compound associated with obesity.
13. Alkyl _______, type of compound in which a hydrocarbon group is bonded to a halogen.
15. Public transportation in Chicago.
17. Country where the organic compound, nylon, was invented (Abbrev.).
18. Suffix for an alcohol.
20. Type of bonding where electrons are shared by atoms and typical of organic compounds. (2 words)
21. Pitcher containing the symbols for Elements 74 and 68.
23. Cyclic, unsaturated hydrocarbon such as benzene.
24. Element 73 (Symbol).
26. Compound composed of carbon and hydrogen.
27. Adjective for compound not soluble in water.
30. Configuration applied to geometric isomers denoting an arrangement in which the substituent groups are on opposite sides of the double bond.

Across

1. Alkanes
5. Isomer
7. Cis
9. Unsaturated
11. Is
12. Fat
13. Halide
15. El
17. USA
18. Ol
20. Covalent bonding
21. Ewer
23. Arene
24. Ta
26. Hydrocarbon
27. Hydrophobic
30. Trans

Down

1. Area
2. Acids
3. Ni
4. Es
6. Mouse
8. Melting
10. Tidal
14. Loving
15. Ester
16. Lab
17. Un
18. Odor
19. Li
20. Carbon
21. Ethers
22. Way
23. A La
25. Boron
28. It
29. Cr

Word Search

L N U G C W N R Q W L N J Y I V X
W Q G T I O V G S N O E R F J M V
G I O L L H V L B B K H W G O D P
H S A N I K G U R F U J T X A E Y
Q O F X H J L A L B L H Y G V E O
Y M Q Y P E C C A B Z G C C U D C
J E M D O O E S V I E P Q K U I G
Y R J I R G E N O N Y W J U H M P
Q K I D D N E S H H Q N X E O A E
D T Y Y Y J U E T H Y L Z L U G A
D H V K H I N O H E S T E R S C A
X Z L O G Q D A O K I Z V P Y G K
F A E J F B U V G B C Y I Z R Q Q

Words about the concepts in this module can be obtained from the clues given. Find these words in the block of letters:

1. Organic compound that contains a carbon-carbon triple bond.
2. Organic compounds that have pleasant odors and are responsible for odors of fruits and flavorings.
3. Water-loving.
4. Word part meaning “on the same side of a double bond.”
5. Another name for chlorofluorocarbons.
6. Predominant type of organic bond in proteins.
7. In a carbonyl compound, this atom is doubly bonded to carbon.
8. Organic compound that contains only carbon and hydrogen.
9. Term that describes structural relationship of ethanol and dimethyl ether.
10. Alkyl group containing two carbon atoms.

"Relax Professor relax, you'll be ok. You gave me an A in your organic course."

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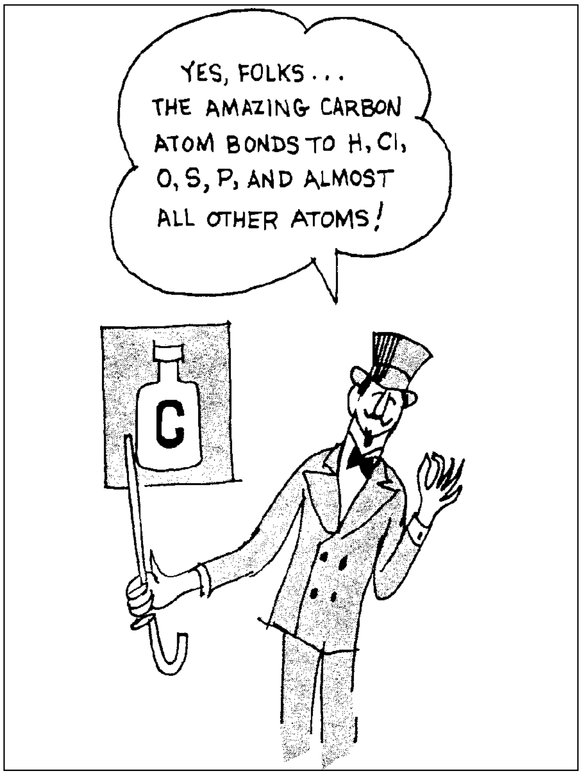

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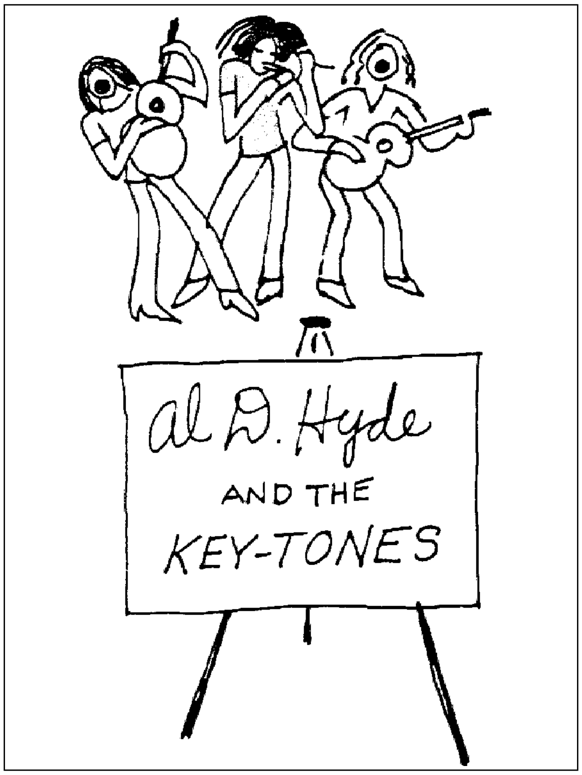

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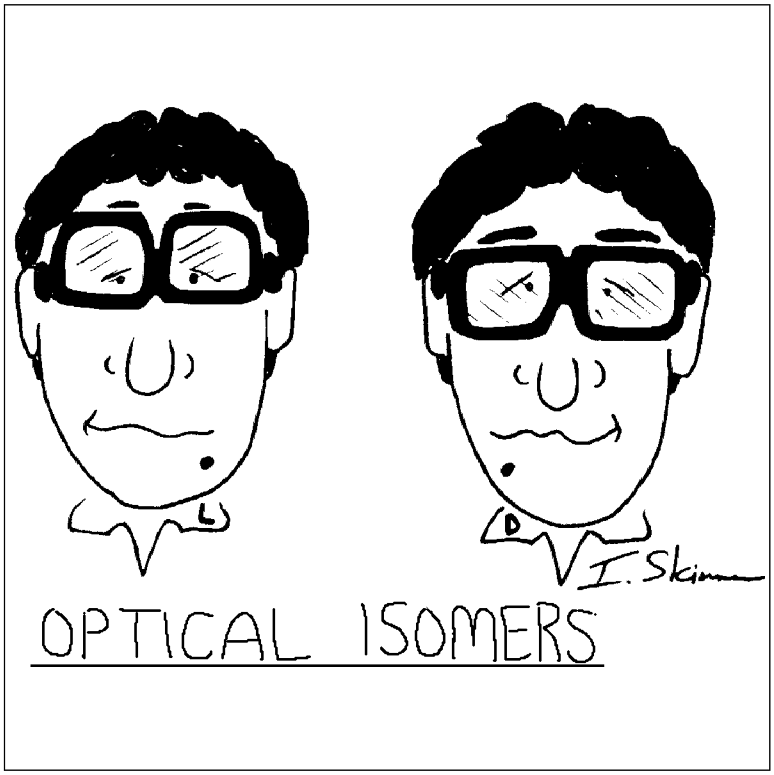

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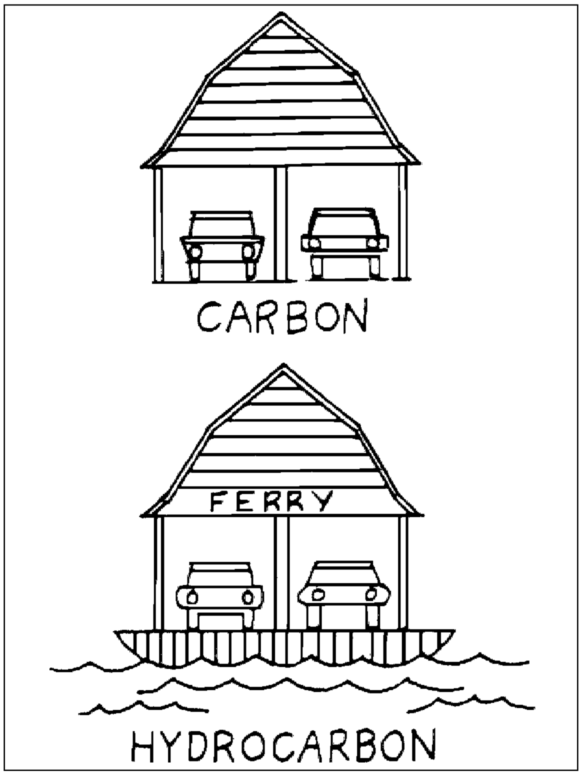

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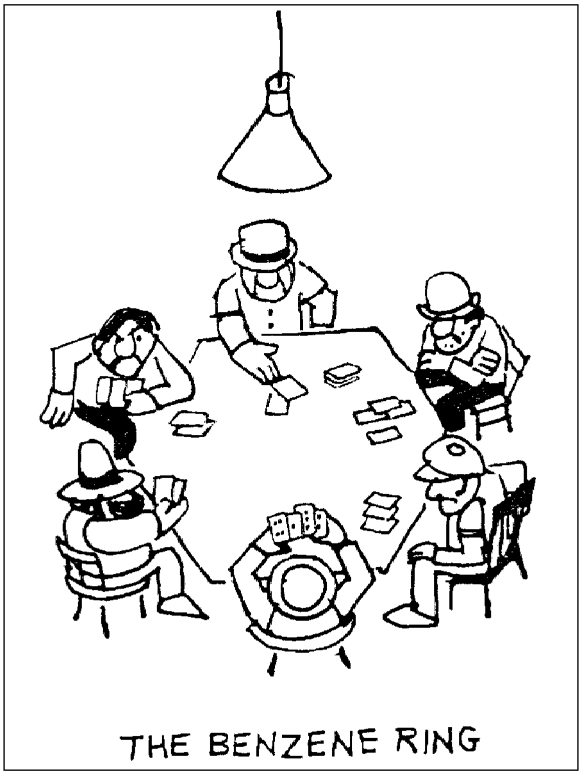

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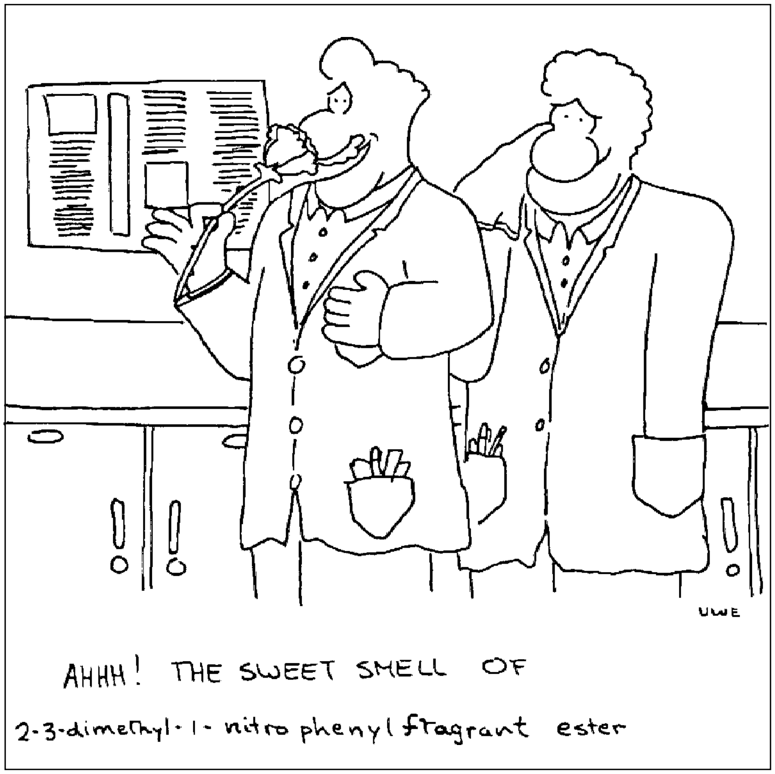

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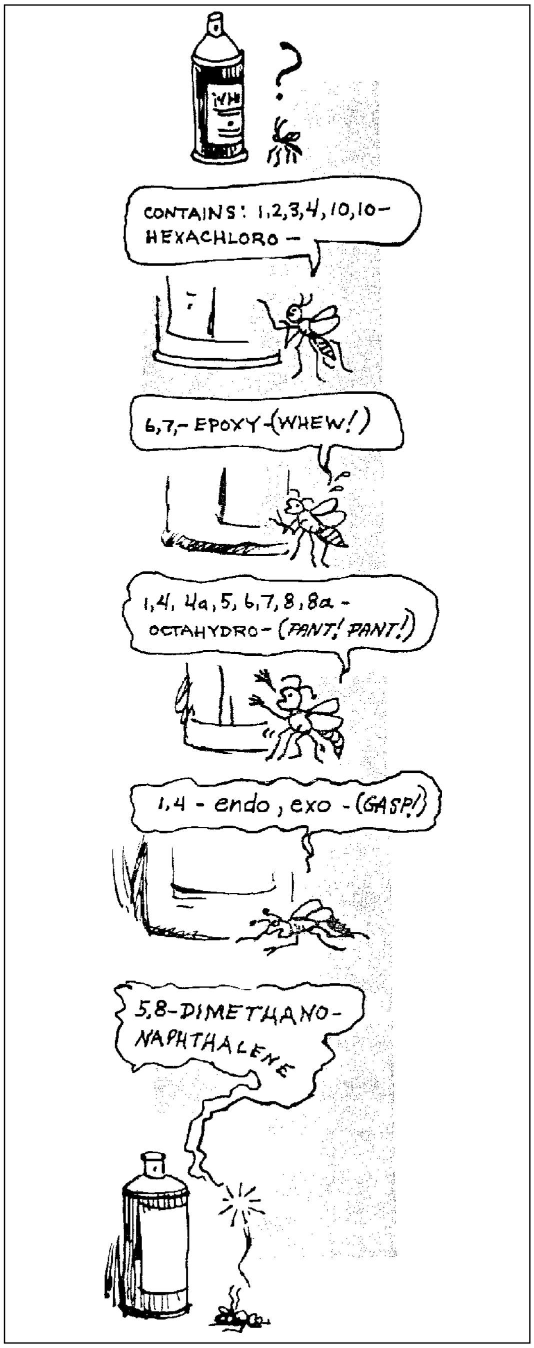

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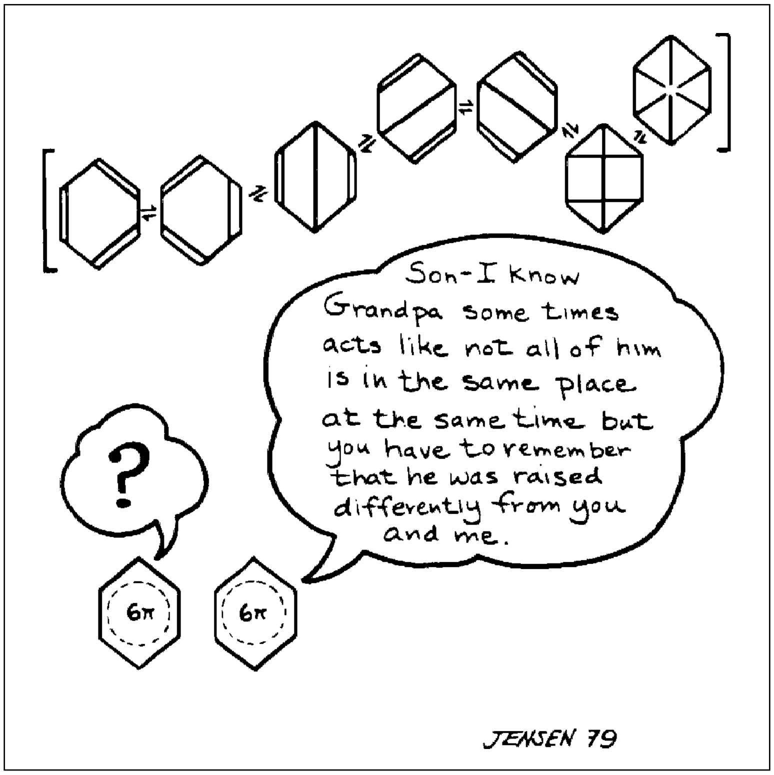

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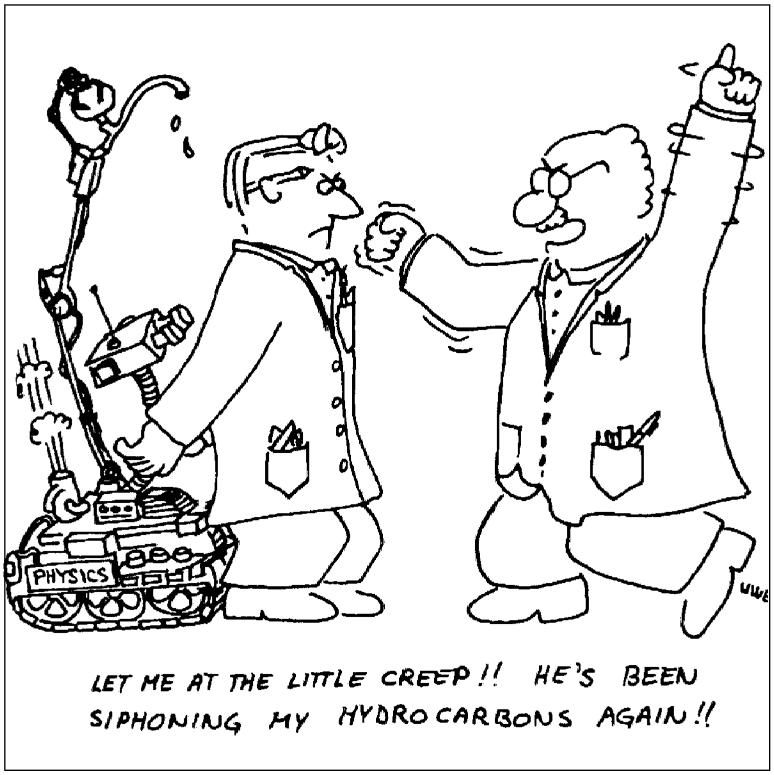

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