

EXPERIMENT # 3: *Essential Oils (EO)*

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Department of Chemistry
5.310 Laboratory Chemistry

EXPERIMENT #3 ESSENTIAL OILS¹

I. INTRODUCTION

In this experiment² you will be working with oils prepared from caraway seeds and spearmint leaves. Each oil has a distinct and characteristic odor, yet carvone is the major component in both oils! It is amazing that the difference in odor is attributable solely to a difference in chirality of the carvone in the two oils. Due to chirality of odor receptors in the nose the R-carvone and S-carvone fit into different receptor sites, hence different odor. Can you distinguish between the odors? 8-10% of the population cannot.³ Some physical data⁴ are presented below.

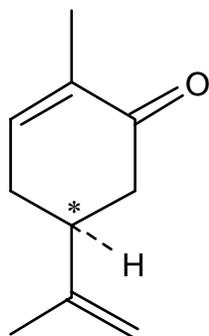
¹ Designed by M. D. Gheorghiu for microscale quantities. The experiment includes contributions from past instructors, course textbooks, and others affiliated with course 5.310.

² Adapted from: Pavia, D. L.; Lampman, G. M.; Kriz, G. S.; Engel, R. G. "Introduction to Organic Laboratory Techniques"; Saunders: Philadelphia, PA, 1990, pp. 96-107.

³ *ibid.* p.103.

⁴ Physical data is taken from Aldrich Chemical Catalog 1998-1999

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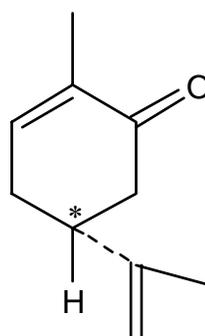
(S) -(+)-Carvone

FW = 150.22; bp 98-100/10 mm
 $n_D^{20} = 1.4970$; $d = 0.9608$ g/mL

$[\alpha]_D^{20} = +61.7^\circ$ (neat 96%)

major component of caraway oil

(*Carum carvi*)



(R) -(-)-Carvone

Fw=150.22; bp 227-230 °C

$n_D^{20} = 1.4990$; $d = 0.9593$ g/mL

$[\alpha]_D^{20} = -62.5^\circ$ (neat 98%)

major component of spearmint oil

(*Mentha spicata*)

All the physical properties should be identical except for the optical rotations of the two isomers (enantiomers), which are of opposite sign. Thus, for both (+)- and (-)-carvone, the infrared, nuclear magnetic resonance spectra, the gas chromatographic retention times, the refractive indexes, and the boiling points should be identical. Hence, the only difference in properties one should observe for the two carvones are the odors and the signs of rotation in a polarimeter. However, some of the physical properties presented above are not identical because of trace impurities.

The * in the formulas below denotes a chiral carbon center. Chiral or asymmetric compounds in nature exist only in living tissue or in matter that was once part of living tissue. Chirality plays a major role in the mechanisms of biological recognition. Yet it is a mystery why caraway plants, *Carum carvi*, produce *S*-(+)-carvone and spearmint plants produce its mirror image (*R*)-(-)-carvone. Other plants such as gingergrass produce racemic carvone. Nature goes one step further; some botanically indistinguishable plants grown in different countries can carry out complete metabolic sequences of mirror-image reactions. Presumably, the enzymes that catalyze the reactions also have a mirror-image relationship. Another example of chiral recognition⁵ is found in the effect these two carvone isomers have on rates of reaction. The toxicity of (+)-carvone in rats is 400 times greater than that of (-)-carvone.

Essential oils are extracts from fragrant plants. They are used extensively in the perfume and flavoring industry. Most components of essential oils are terpenes that contain multiples of a five carbon structural unit, the isoprene unit (Fig. 1).

⁵ The phenomenon in which a chiral receptor interacts differently with each of the enantiomers of a chiral compound is called **chiral recognition**.

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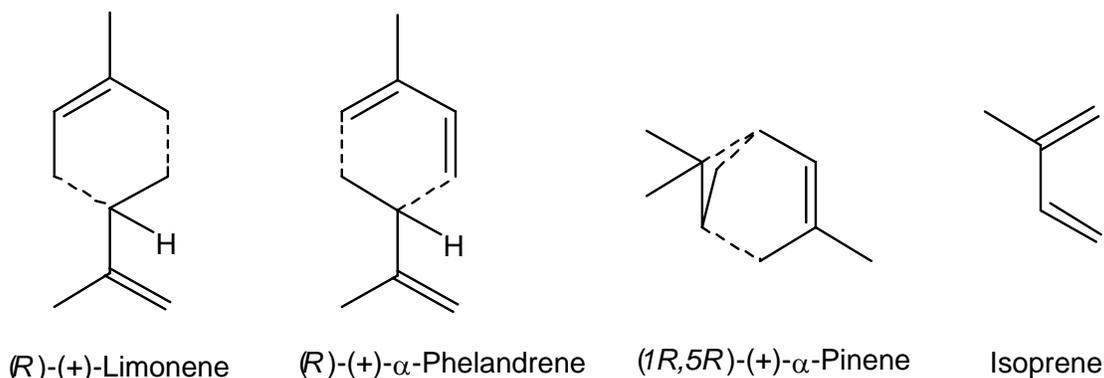


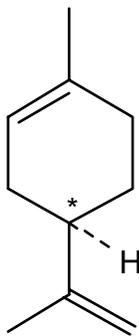
Figure 1. Representative monoterpenes. Isoprene units are shown to indicate the common structural features.

In addition to monoterpenes, compounds derived from two isoprene units, essential oils contain less volatile compounds derived from three and four isoprene units. These higher boiling components will be removed by vacuum distillation of the provided sample to permit facile gas chromatographic separation.

Overview of the Experiment

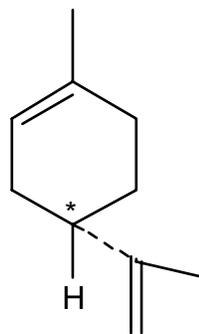
- (A) You will be given a sample of either caraway oil or spearmint oil. The major component of these oils is carvone. You will separate the carvone from the higher-boiling and lower-boiling impurities (such as limonene), via a vacuum distillation.
- (B) You will use gas chromatography and refractometry to check the purity of your distillate and to estimate the relative concentrations of limonene and carvone in the oil.
- (C) You will convert the carvone to its semicarbazone for use in a polarimetric analysis.
- (D) You will obtain infrared spectra of the carvone and limonene fractions and interpret the results.
- (E) You will also characterize the semicarbazone by melting point determination.

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(R)-(+)-Limonene

FW = 136.24; bp 175.5-176 °C
 $n_D^{20} = 1.4730$; $d = 0.840$ g/mL
 $[\alpha]_D^{20} = +123^\circ$ (neat)



(S)-(-)-Limonene

FW=136.24; bp 175-177 °C
 $n_D^{20} = 1.4720$; $d = 0.844$ g/mL
 $[\alpha]_D^{19} = -94^\circ$ (c=10, ethanol)

II. SAFETY

1. **Carvone:** Ketone found in caraway, dill and spearmint oils. The oils are used for flavoring liqueurs, and in perfumes and soaps. Although both enantiomers occur naturally in consumer products, both should be handled with the usual care and not ingested under any circumstances.
2. **Limonene:** Occurs in various oils such as Levant wormseed oil, pine needle oil and other oils. It is used as a solvent, wetting and dispersing agent. It is not considered toxic, but is an irritant. Therefore, keep it off the skin.
3. **Semicarbazide hydrochloride:** Mutagen and cancer suspect agent. Do not inhale or ingest.
4. **Ethanol:** Flammable liquid. The type used in this laboratory is **NOT** safe to drink.
5. **Sodium acetate:** Irritant. Handle with usual caution.

III. BACKGROUND FOR EXPERIMENTAL PROCEDURE

General References

- Distillation **MHSM**, Chapter 11, pp 124-129
- Vacuum Pumps **TM(I)**, Sec. 11C.
- Gas Chromatography **MHSM**, Chapter 16, pp 163-177
- Polarimetry **MHSM**, Chapter 14, pp 140-147

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- Refractometry **MHSM**, Chapter 13, pp 136-140
- Infrared Spectroscopy **MHSM**, Chapter 18, pp 197-219

Distillation

The difference between the boiling points of carvone (230 °C @ 760 torr) and limonene (177 °C @ 760 Torr) is sufficient to permit separation of the two compounds by distillation. However, carvone thermally decomposes at higher temperatures; therefore, a vacuum distillation is necessary.

Two problems are encountered in a vacuum distillation. The volume of vapor formed from a given amount of liquid is pressure dependent; i.e., the volume of vapor formed from one drop of liquid will be about 30 times as great at 25 torr as it was at 760 torr. As a result, serious bumping may occur. Boiling chips generally do not help much at the reduced pressures. Some of the bumping can be overcome with the use of a magnetic stir bar. The second problem is also related to the larger volume of vapor at lower pressure. The velocity of the vapor entering the column is greatly increased. This creates a greater pressure in the column than is registered on the manometer. Maintaining a slow, steady rate of distillation can minimize this difference in pressure.

Gas Chromatography and Refractometry

In Gas Liquid Chromatography a mixture of vapors is carried in a stream of helium (carrier gas) through a column. The vaporized sample components move through the column that is lined with a liquid stationary phase. The different components in the sample are retained on the stationary phase for different characteristic relative times. Each component ultimately reaches the Flame Ionization Detector, the most commonly used detector in GC (Air + Hydrogen gas, ratio 10:1). They are detected by their ability to form ions when they are burned in the H₂ / air mixture. The area under a peak in a gas chromatogram is proportional to the amount of that substance in the sample.

Among the factors that influence the separation of compounds by gas chromatography are selection of liquid phase, column temperature, and flow rate of carrier gas. Two common liquid (stationary) phases are silicone oil, which separates components on the basis of boiling point, and carbowax (polyethyleneglycols), which separates components on the basis of polarity. The effect of increased column temperature is to decrease the retention time of a component. As a rough approximation, a 10-15 °C decrease in column temperature corresponds to a doubling in the retention time. For most samples, the lower the column operating temperature, the higher the partition coefficient in the stationary phase and hence the better the separation. Too low a column temperature can lead to broad, asymmetric peak shapes. The criterion for resolution of the sample is simply achieving baseline separation of the components. Varying the column temperature and selecting the appropriate liquid phase will achieve resolution of the sample into its components. Identification of retention time can be accurately obtained using a pentane peak as a standard. There will always be enough pentane in the syringe to leave a small peak on the chromatogram. The retention time of

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the other peaks can be calculated using the pentane peak. The relative amounts of carvone and limonene in each fraction and the original oil maybe calculated by using the area under the appropriate peaks.

By measuring the refractive index of the original oil, limonene and carvone fractions, you can estimate the purity of the respective fractions and the composition of the original oil. Assuming that the actual refractive index, n , measured for the two-component mixture (limonene and carvone) is linear in the molar fraction, x , of any of the components, then one can write:

$$n = (1 - x_{\text{carvone}}) * n_{\text{limonene}} + x_{\text{carvone}} * n_{\text{carvone}}$$

Plug in your data and determine the value of x_{carvone} for the limonene and carvone distillation fractions and the oil itself. Compare these results with those obtained by GC.

IV. EXPERIMENTAL PROCEDURE

DAY 1: Distillation and Gas Chromatography: WORK in PAIRS. Split evenly the limonene and carvone fractions for the derivatization step.

Part A. Distillation

Before setting up the glassware as shown in Fig. 2 have your teaching assistant demonstrated how to connect to the vacuum pumping manifold. You should be able to reduce the pressure to 3-5 Torr (or less) in a closed system. At this pressure, limonene should vaporize at a temperature between 34 °C and 38 °C, while carvone should distill at about 70-80 °C. Carefully assemble the glassware as shown in Fig. 2. **Lightly grease all joints as demonstrated by your TA.** Be sure to include a heating mantle, a stirring plate and an ice-bath in the setup. **Do not proceed until your TA has checked your setup.**

Pour 10 mL (save a small portion, about 5 drops, for gas chromatography and refractive index measurements) of your essential oil into the round bottom flask, and add a 1" stir bar.

- Check if the water-in and water-out connections are set correctly (see Fig. 2).
- Turn the water on in the condenser.
- Immerse the four pear shaped receivers flasks (connected to cow and secure with yellow Keck clamps) into a mixture of ice and water.
- Turn on the magnetic stirrer and fully open the vacuum valve (note: pressure cannot be controlled with this valve. If an adjustment is necessary, please see the Instructor). The pressure should read less than 10 mm Hg (10 Torr) on the manometer. Determine the temperature the limonene and carvone fractions should begin to distill based on

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the pressure reading on the manometer, using the chart at the end of this experiment. Feel free to verify your answers with your TA.

- Use the Variac dial (starting at setting 30), increase the temperature slowly. Although some “explosive” bumping is expected, do not allow the heat to reach such a level that the column is flooded since this will dramatically decrease the efficiency of the separation.

Note: On a warm day the room temperature may be at or above the boiling point of limonene (ca 32 °C). If the laboratory is warm be sure to check for limonene distillation before turning on the heat source. Limonene condensation will occur efficiently due to the condenser and the ice bath in which the receiver flask is placed (ca. 0 °C).

When carvone begins to distill, the condensation can be seen inside the thermometer adapter, thus the progress of carvone distillation can be readily monitored. The rate at which the temperature changes at the top of the column is also extremely significant. Be sure to record temperature information in your lab notebook.

To ensure an optimal separation, three fractions should be collected: **the limonene fraction**, **an intermediate fraction** that forms during the rapid increase in temperature after collection of the limonene fraction, and the **carvone fraction**.

To collect each fraction, rotate (under vacuum) the cow adapter such that the end of the bent outlet sits above the next empty receiver flask. Label flasks, for example, with letters **A, B, and C**.

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Figure 2. Apparatus used for Vacuum Distillation

- | | |
|----------------------|---------------------------------------|
| 1. Thermometer | 9. 25 mL round bottom flask |
| 2. Adaptor | 10. Heating mantle |
| 3. Water-out | 11. Variac |
| 4. Vigreux column | 12. Stirring plate |
| 5. Condenser | 13. 10 mL pear-shaped receiving flask |
| 6. Vacuum connection | 14. Bucket with ice and water |
| 7. Water-in | 15. Keck clamps |
| 8. Cow | |

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Part B. Gas Chromatography: Run only three GC's:

- (a) the **original oil**
- (b) **fraction 1 (limonene).**
- (c) **fraction 3 (carvone).**

Read the general references on Gas Chromatography in the *Techniques Manual* (TM) or *Technique in Organic Chemistry (MHSM)*. Detailed instructions for use of the Hewlett-Packard 5890-II gas chromatographs are provided in the Appendix at the end of this experiment.

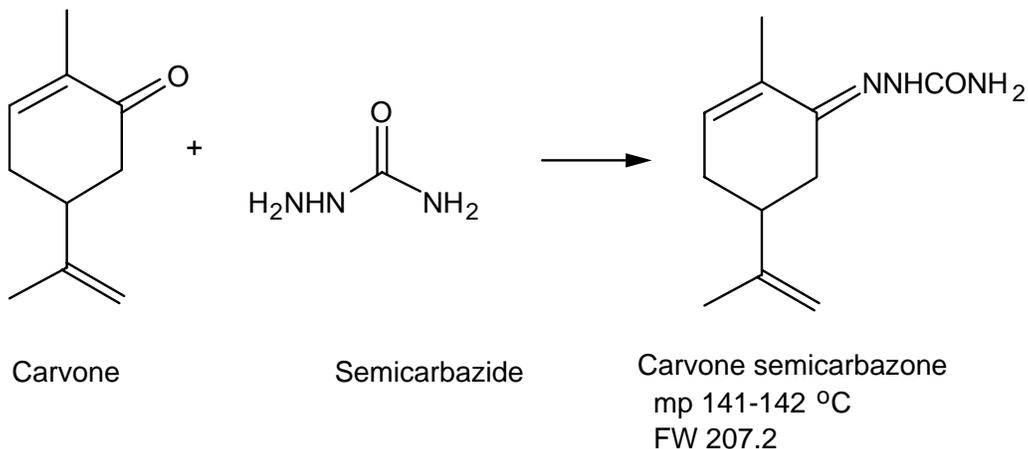
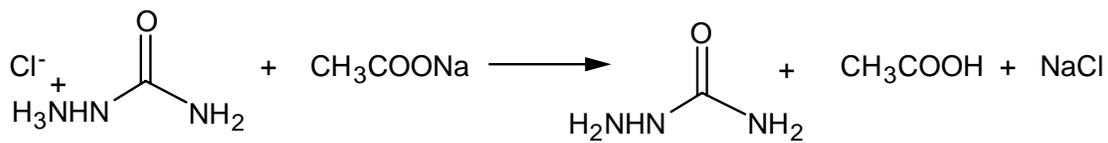
Save a small portion (5 drops) of your original essential oil sample and of the distilled limonene and carvone fractions for Gas Chromatography and Refractive Indexes measurements. The composition of these samples will be analyzed to determine the effectiveness of the separation. Follow the procedures **carefully** for preparation of the gas chromatograph samples.

The two biggest problems with sample preparation are:

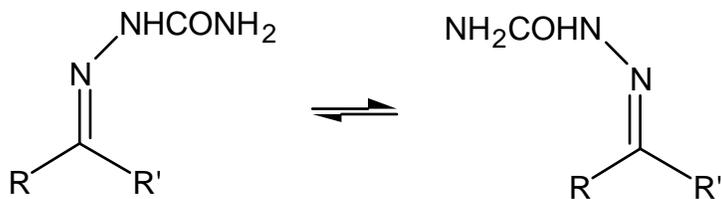
- 1) **not carrying out the double dilution** (use disposable test tubes) for the GC analysis (thus the sample is too concentrated to get clean separation with minimal background noise and may overload the column)
- 2) **not placing the barcode label in exactly the right spot** for the instrument to read the label (thus causing the instrument to shutdown). Be sure to record barcode numbers as well as vial positions in the GC line-up.

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DAY 2 Part C. Synthesis of Semicarbazone



There are two diastereoisomers for the semicarbazone of (-)-carvone and (+)-carvone. They result from the restricted rotation about $>\text{C}=\text{N}$ -bond. The α -isomer of (-)



or (+)-carvone melts at 162-3 °C, the β -isomer at 141-2 °C. The β -semicarbazone forms under our experimental conditions. On some occasions students may have observed the α -isomer when conditions have varied. Because the limonene does not have a carbonyl group, the small amount of it which remains in the carvone fraction will not form a semicarbazone derivative. The limonene will remain liquid and be washed away during filtration.

In a large test tube, dissolve 0.5 g (4.5 mmole) of semicarbazide hydrochloride and 0.5 g of anhydrous sodium acetate (or 0.8 g of sodium acetate trihydrate) in 4 mL of distilled water and 7 mL of ethanol. Add 0.5 mL (0.48 g, 3.2 mmole, ca. 7 drops) of your carvone fraction. Stopper and shake your tube vigorously. Remove the stopper, place a

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boiling chip in the test tube and place in a beaker of warm water (ca. 80 - 90 °C) for 30 minutes. Careful! Contents of the test tube will boil. Beware of splashing!

There are two ways by which you can isolate the crystals of your semicarbazone derivative:

- (1) You can add 3 mL of water and then set the reaction mixture aside to cool slowly at room temperature. Under these conditions, crystallization may take 45 minutes or longer. Slow crystal formation gives quite pure crystals that probably need not be recrystallized for the optical activity studies.
- (2) Alternatively, after allowing the reaction mixture to cool for ten minutes or so, you can add three grams of ice or cold water and cool the mixture to 0-5 °C with water-ice bath. If no crystals form, scratch the sides of the flask with a glass rod in order to induce crystallization.

Collect the crystals by suction filtration using your Hirsch funnel and wash them with a few milliliters of cold water (do not forget to remove the boiling chips).

Dry the semicarbazone in your desk until the next laboratory session.

DAYS 3 and 4 Instrumental Analysis of the Limonene and Carvone

Part D. Melting Point of Semicarbazone Derivative

Take the melting point of the dry solid semicarbazone derivative and record the yield. If it is necessary to recrystallize the semicarbazone derivative, you may do so from an ethanol/water mixture. Repeat measurement of the melting point to verify the success of the recrystallization.

Part E. Measurement of Optical Rotation by Polarimetry

Make up a 1.5-3% (w/v) solution⁶ of your semicarbazone in 3 mL of ethanol. Add this to a polarimeter tube obtained from the stock room. Measure the optical rotation of the semicarbazone derivative solution in the polarimeter, following the procedure outlined in the *Techniques Manual* (TM). This technique is very dependent on the interaction of light with a clean sample. Be sure the cell is clean. If there is any particulate matter or cloudiness to the solution filter it first. Finally check that no air bubbles have formed which will also interfere with the analysis.

Part F. Infrared spectroscopy of limonene and carvone

Run infrared spectra of the limonene and carvone fractions obtained by distillation. The infrared spectrum may be run using neat liquid on salt plates or by spotting several drops of liquid (disposable pipet!) on the window area of an IR card.

⁶ Approximately 0.15 g to 0.3 g sample in 10 mL of solution

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Run IR spectra of each sample on the Perkin-Elmer FTIR⁷ located in Room 4-448. If the peak absorbances are low, place an additional few drops of the limonene or carvone on the IR card, and re-record the spectrum.

Part G. Refractometry

Measure the refractive indexes of pure limonene, pure carvone, original oil, limonene fraction and carvone fraction as described in *The Organic Chem Lab Survival Manual* (JWZ) Calculate x_{carvone} , and compare with the GC data.

V. ANALYSIS & DISCUSSION

Be sure to incorporate your answers into your written report (discussion section).

1. Using the refractive index data determine the approximate composition of your oil, your carvone fraction and your limonene fraction with respect to limonene and carvone.
2. From the gas chromatography, report the percentages of limonene and carvone in your original sample and in the fractions following distillation. How effective was the distillation in separating these components? Are there any other (minor) components in any of the fractions? If so, how much of the sample do they constitute? Can you identify any of the minor components?
3. Compare the results obtained from gas chromatography and refractive index measurements. How closely do they agree? If they are not in good agreement can you provide an explanation?
3. Which isomer of carvone do you have? Is it *R* or *S*? How do you know? What is the association between the chirality and the odor of the carvone isomers?
4. Calculate the **specific rotation** of the semicarbazone derived from carvone,

$$[\alpha]_D^{25} = \frac{\alpha}{C * l}$$

where α is the rotation angle read on the polarimeter, C is the concentration of the semicarbazone solution in grams per milliliter of solution, and l is the path length of the polarimeter tube in decimeters (these units are employed for historical, rather than rational reasons). Include a propagation of errors!

5. (a) Which features in the IR spectrum can be assigned to limonene? to carvone? Identify as many functional groups as you can in each sample.

⁷ Fourier-Transform Infrared

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- (b) Do the spectra of the samples suggest the presence of a mixture of these two components, and if so, are they consistent with the GC data?
 - (c) Can you use IR spectroscopy to distinguish between (*R*)- carvone and (*S*)-carvone?
6. Your well written discussion should address the following (within the text, NOT as a numerical series of answers to questions):
- 1. Comparison of your distillation results (temperature ranges) with your chromatographic results.
 - 2. Explanation of how the separation of components could be improved.
 - 3. Comparison of your results (boiling points, compositions, m.p., of semicarbazones, optical rotations) with literature values.
 - 4. Discussion of what information gas chromatography provides.
 - 5. Discussion of what information infrared spectroscopy provides.
 - 6. Discussion of what information these techniques do NOT provide.
 - 7. Discussion of what the identity of the carvone enantiomer tells you (if anything) about the identity of the limonene in your sample.

VI. ADDITIONAL READING

- 1. Ernest L. Eliel and Samuel H. Wilen, "*Stereochemistry of Organic Compounds*"; Wiley: New York, 1994, p 202.
- 2. S. Robinson and E.R. Gilliland, "*Elements of Fractional Distillation*," 4th ed.; McGraw-Hill: New York, 1950.
- 3. G. Guiochon, G; Guilleman, C. L. *Gas Chromatography Rev. Sci. Instrum.* **1990**, *61*, 3317.
- 4. D.L. Sayers and R. Eustace, "The Documents in the Case" (1930): a particularly nasty murder is solved by using polarimetry to distinguish between natural and synthetic muscarine [C₉H₁₈NO₂.HCl].
- 5. "Looking Glass Chemistry," *Science*, **1992**, *256*, 964.