

**BACKGROUND** Chromatography is a powerful technique for the separation and purification of both solids and liquids on relatively small scale (ideally <10g). Chromatographic techniques are also invaluable as analytical techniques for analyzing tiny quantities of material (as little as  $10^{-9}$  g). This is now our fourth purification technique. Advantages for chromatography are its power and generality (not limited to liquids or solids or the need for ionizability). A disadvantage is the limitation in scalability (has problems with hundreds of grams of material).

1. Recrystallization
2. Distillation
3. Liquid/Liquid Separation (Separatory Funnel Separation)
4. Chromatography

Every type of chromatography depends on the distribution of a substance between two phases, a **mobile phase** and a **stationary phase**. (In a river, the running water would be called the mobile phase and the riverbed the stationary phase...) In today's case, the mobile phase will be an organic solvent, the stationary phase a polar surface. A particular chemical will partition between being bound to the surface, where it doesn't move, and being dissolved in the solvent, such that it flows along. Thus different chemicals move at different speeds, depending on adsorption/solubility equilibrium. The more tightly the sample binds to the surface, the less it will move. Anything that impacts the sample's partition between binding to the stationary phase versus dissolving in the mobile phase will impact the sample's mobility.

**Practical Summary: A sample "stuck" to a surface is "washed along" with a solvent. "Less sticky" things move faster!**

Different types of chromatography use different binding principles for "sticking" to the stationary phase, and are useful in different contexts of science.

- Organic Chemistry (today): A polar surface binds polar organics
- Biochemistry
  - Size exclusion: surface pores can fit small molecules, exclude larger molecules
  - Charge: cationic surfaces bind anionic chemicals, anionic surfaces bind cationic chemicals
- Gas/Liquid Chromatography (Organic and Analytical Chemistry): the "stationary phase" is actually a nonvolatile liquid coating on the walls of a tube; the mobile phase is gas passing through the tube. Volatile chemicals are more likely to evaporate from the liquid phase and fly along in the gas phase. Less volatile chemicals are better retained in the liquid phase and thus move more slowly. Polarity can also be used to attract materials to the stationary phases.

### **ANALYTICAL TLC (THIN LAYER CHROMATOGRAPHY)**

TLC chromatography uses glass or plastic plates coated with a thin layer of adsorbent as the stationary phase. Silica gel ( $\text{SiO}_2 \cdot x\text{H}_2\text{O}$ ) and alumina ( $\text{Al}_2\text{O}_3 \cdot x\text{H}_2\text{O}$ ) are the most common solid adsorbents. Both are polar, hydrogen-bonding adsorbents, with lots of polar, hydrogen-bonding "sticky sites". Samples are applied to the surface, and then the organic "eluent" (solvent) is applied and runs up the plate. (The flow of the eluent results from capillary action.)

The mobility of a particular chemical depends on its partition between the mobile phase (the eluent) and the stationary phase (silica gel). The more tightly the sample binds to the silica (the "stickier" it is), the less it will move. The less well it binds, the more it will dissolve in the solvent and flow up the plate.

1. **Sample Polarity and Sample Movement:** A typical ranking of sample polarity in terms of functional groups, all else being equal, is in the order shown. In practice, **a more polar sample will bind to the stationary phase better, and will not move as much.** A more nonpolar, less sticky sample will move faster and farther

- **Polarity Pattern:**  
Carboxylic acids > alcohols > amines > ketones/aldehydes > esters > ethers > halocarbons > arenes > alkanes
- **Adding additional nonpolar hydrocarbon to a given molecule moves it in the non-polar direction (tiebreaker).** For example, C<sub>4</sub>H<sub>9</sub>OH will be more polar than C<sub>7</sub>H<sub>15</sub>OH.
- **Key: More polar sample → moves less. Less polar sample → moves farther.**

2. **Eluent Polarity and Sample Movement:** Eluents have the same order of polarity. But **while a sample's movement decreases with increasing sample polarity, a sample's movement increases with increasing eluent polarity.** A good-binding polar eluent competes for the sticky sites on the silica, and either “displaces” the substrate from the surface or else prevents the sample from binding to the sticky sites on the surface. The result is that the sample will have its adsorption/solubility partition moved away from the adsorbed side toward the dissolved side. The practical result is that increasing eluent polarity means that the substrate will move to a greater degree.

- **Eluent factor: The more polar the eluent, the faster and farther samples will move**

3. **Response Factors:** Movement is quantified by "R<sub>f</sub>" (**R**esponse<sub>f</sub>actor) values: relative to where the sample begins, this is the distance the sample travels divided by the distance that the eluent travels. For a given surface, substrate, and eluent, the R<sub>f</sub> is characteristic and is useful for identification. For a series of substrates, their relative R<sub>f</sub>'s reflect their relative polarities.
4. **Sample Visualization:** Visualizing samples is crucial, since most organics are colorless. UV (ultraviolet light) or a chemical colorizing dip will be used. (UV is ideal, but is only applicable to molecules with extensive systems of sp<sup>2</sup> atoms that are able to absorb UV light.)

Summary: For silica gel surfaces, which are polar, the following relationships are true:

1. When two samples are run under identical conditions, **the more polar sample will move less and have the lower R<sub>f</sub>; the less polar sample will move more and have the higher R<sub>f</sub>.**
2. When the same sample is run under two different solvent conditions, **any sample will have a higher R<sub>f</sub> with the more polar eluent, and a lower R<sub>f</sub> with the less polar eluent.**

## COLUMN CHROMATOGRAPHY

While TLC is useful as an analytical tool, chromatography can also be used as a purification technique. But to separate larger than analytical quantities of chemical, a larger amount of solid surface material must also be used, and larger volumes of solvents must also be used.

The general idea is that if sufficient quantities of solvent are used, solutes will eventually “wash off” of the surface. The differential mobilities of different compounds allow them to come off at different speeds. Individual collection of the different fractions, followed by reconcentration, enables isolation of pure compounds from initial mixtures.

**Eluent Polarity Ramping:** In practice solvent polarity “ramping” is commonly used. In this technique, a relatively nonpolar solvent is used first, which is only able to selectively wash off mobile, nonpolar substrates, while leaving polar substrates behind (“stuck” to the solid surface). Then a more polar solvent is applied which is able to wash off the more polar substrate. In today's lab we will do a very abrupt increase in solvent polarity to make things go faster. But often this is done gradually.

Pressure is frequently used to push solvent through more quickly and speed up the process. We will use modest pressure in today's experiment.

In today's experiment, the samples will be colored, so it will be relatively easy to see them separating and moving. Most ordinary organics are colorless. When colorless organics, a series of different solvent fractions are collected in test tubes or flasks. Then the same visualization techniques that are used for TLC are applied to determine which fractions actually have chemicals

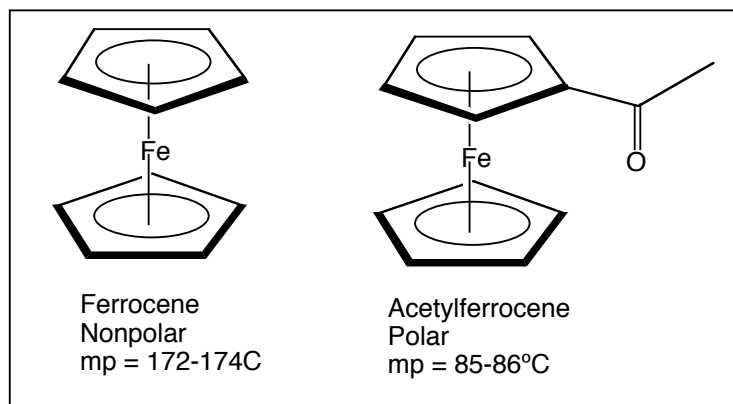
## The Experiment

### Part I: COLUMN CHROMATOGRAPHY

#### **Separation of nonpolar Ferrocene(mp 172-174°C) from polar Acetylferrocene (mp 85-86°C).**

#### Overview

In this experiment, a small-scale chromatographic separation of non-polar ferrocene (mp 172-174°) and relatively polar acetylferrocene (mp 85-86°) will be attempted. These structurally interesting iron-containing molecules have been chosen for the experiment specifically because they are colored (unlike most organics). So their visible color will enable you to see the separation and chemical movement as it happens. The



solid surface will be silica; the nonpolar solvent will be "petroleum ether" (a misnomer, it is a mixture of low-boiling alkane isomers); and the polar solvent will be 50/50 diethyl ether/petroleum ether. The column will be packed with silica gel. Then a 50/50 mixture of ferrocene and acetylferrocene will be poured on top. Nonpolar petroleum ether will wash off the nonpolar ferrocene while leaving the polar acetylferrocene behind. More polar 50/50 diethyl ether/petroleum ether will then be used to wash off the acetylferrocene. Both wash solutions will then be concentrated to give the purified samples.

#### Preparing the sample:

1. Weigh out approximately 0.1g of 50/50 pre-mixed ferrocene/acetylferrocene material onto some weighing boat. (Record the exact weight of the mixture).

#### Preparing the column:

2. Plug the end of a 4-mL "monster" pipette (the "column") with glass wool. A long-nosed regular pipette serves as a good ramrod.
  - Note: This is a special pipet, with thicker glass and a larger diameter than you normally use. Make sure you get the correct pipet.
3. Weight out 1g of silica and add this to the pipet. (Use weighing boat to try to funnel it in). Your column should be approximately half full.
4. Securely clamp the column, and tap it to try to level the surface of the silica.
5. Get 25 mL of petroleum ether.

#### Applying the sample to the column:

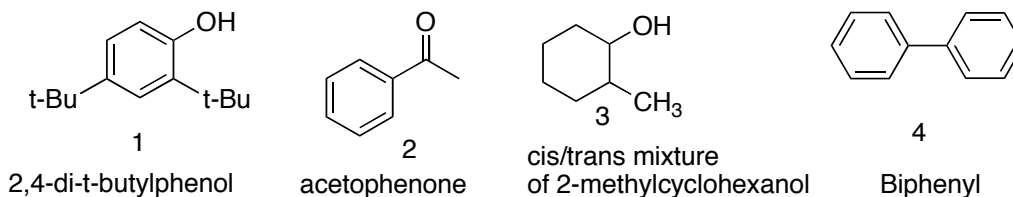
6. Take your dry sample (see above) and pour it (carefully!) into the column, again using the weighing boat. Again tap the surface to try to level the material.

**Eluting the Nonpolar Substrate:**

1. Clamp down your 50-mL round-bottomed flask
2. Use 15 mL of petroleum ether to wash the mobile, nonpolar substrate off from your column into the round-bottomed flask. Hopefully by the end the bottom portion of your column should be essentially white and there should be no yellow color coming off anymore.
  - Note: while using the pre
3. Concentrate the solution by rotary evaporation.
4. Take a melting point for your ferrocene. (You may need to use a bent microspatula to scrape off enough solid material to do the melting point.)

**Eluting the Polar Substrate:**

5. Clamp down your 25-mL round-bottomed flask, or if working with a partner use your partner's 50-mL round-bottomed flask.
6. Now use 10-15 ml of 50/50 diethyl ether/petroleum ether solvent to wash the more polar acetylferrocene off of the column and into your second round-bottomed flask. You should be able to see the colored band as it moves through the column. There will be some residual gray or brown color that will not wash off; these are impurities that we don't want anyway.
7. Concentrate the solution by rotary evaporation.
8. Take a melting point for your acetylferrocene. (You may need to use a bent microspatula to scrape off enough solid material to do the melting point.)

**Part II: TLC (Thin Layer Chromatography)**4 Substrates, Unknown CandidatesGoals

1. Use TLC mobility to observe the TLC behavior and rank the "TLC polarity" of the 4 reference substrates, from least polar to most polar. (Some may be essentially tied).
2. Determine how each substrate can be visualized. Which are UV active, and which appear only when using a visualizing "dip"?
3. Observe the dependence of TLC mobility on solvent polarity.
4. Calculate  $R_f$  values
5. Identify two unknowns by TLC.
6. Learn general analytical TLC techniques.

Procedure

Work with a partner on this experiment. Each of you will need at least 4 TLC plates (two for each eluent). Each of you will identify two unknowns. Do not do the same unknowns as your partner.

Preparing the Plates:

1. Prepare the two plates for your first eluent: Use a pencil to mark 4 spots.
  - Give at least a 1 cm margin from the bottom. **Otherwise the sample may subsequently submerge, get dissolved away, and not get drawn up the plate.**
  - Avoid placing spots within 0.8 cm of the sides.
  - Use a pencil to mark placement of your original spots.
2. On plate 1, write **1**, **X** (the letter for your first unknown), **Y** (the letter for your second unknown) and **2**.
3. On plate 2, write **3**, **X** (the letter for your first unknown), **Y** (the letter for your second unknown) and **4**. (Both unknowns should be on each plate).
4. Then use the capillary tubes to apply your chemical solutions onto your TLC plates.
  - Spots should be neither too heavy nor too light (strong enough to be able to visualize, but **light enough to avoid overlap and chemical "tailing"**).
  - Before running your plates, check your second plate by UV. Biphenyl (**4**) should be easily visible. If not, your spot sizes may be too small. [Note: some spots are not very UV active, and may not appear. The point here is that if you don't even see #4, which is strongly visible, something is wrong. But don't worry if some of your spots show little or nothing by UV.]

**To run the TLC's:**

1. Place 3 full pipets of eluting solvent into a 50-mL beaker, and put a watch-glass on top to prevent solvent evaporation.
  - The eluent choices are 2% ethyl acetate/hexane, 10% ethyl acetate/hexane, and 20% ethyl acetate/hexane.
  - One partner should run both the 2% and 10% solutions. The other partner should run both the 10% and 20% solutions. (I want both of you to run 10% just to see how much scatter there is or isn't between two different scientists.)
  - You don't want to put in so much eluent that your spot will get submerged, in which case it will get dissolved away and not get drawn up the plate.
  - Ethyl acetate is an ester. The more ethyl acetate is present in the mixture, the more polar the eluent should be.
2. **Carefully** put your two TLC plate(s) into the beaker, and put the watch-glass back on top. The eluent will creep up the plate.
  - You can easily put both plates 1 and 2 in at the same time.
  - Avoid putting plates in crooked, or touching the walls.
  - You'd like the solvent line on the bottom to be level.
  - Note: the spots must not be submerged in solvent, or they will simply dissolve and not be drawn up the plate.
3. After the eluent has risen a significant distance, (it should **not** be allowed to get all the way to the top), remove the plate(s) and **immediately** mark with pencil the top distance that the eluent went.
  - If the solvent reaches the top, your sample can keep creeping up the plate and you will get falsely high  $R_f$ 's.
  - Note: It's important to keep the cover on your beaker. Otherwise evaporation competes with elution and you will get falsely high  $R_f$ 's.

**Eluent choice:** You will test two different solvent mixtures, as will your partner. One of you should run both the 2% and 10% ethyl acetate/hexane solvents; the other should run both the 10% and 20% ethyl acetate/hexane solvents. Since each of you will test two solvents, and for each solvent you will need 2 plates, that means each of you will be running 4 plates total.

**Visualizing the spots:**

1. Look at your plates under UV light, and circle with pencil the spots that you can see.
  - Spots may seem weaker than before; during the process the sample gets "stretched" out, so the signal intensity essentially gets diluted.
  - Not all samples will give UV spots.
2. After marking the UV active spots, take your plate to the "p-Anisaldehyde Dip" station. (Caution: 5% sulfuric acid!)
  - Dip your plate into the solution, using forceps
  - Try to let the excess liquid drain off
  - Then dry the plate with a heat gun.
3. Circle the new spots that appear, and record their color. (Some spots may differ in color, and the colors may have diagnostic value).

**Calculate the  $R_f$  Values for All Your Spots:** This will be the ratio of the distance traveled by your spot relative to the distance traveled by the solvent. You can qualitatively do this just by eye-ball analysis to get values to nearest tenth. (Ex. 0.1 vs 0.2 0.3 vs 0.4, etc.)

- Do not measure relative to the bottom of the plate. Measure relative to where the samples were applied. That's the starting line, because when the eluent climbs that far is when the race between eluent and sample to climb the plate begins.

Name:

## Chromatography Lab Report

**Part 1: Column Chromatography**

## 1. Part 1 Yields and Melting Ranges:

Nonpolar Ferrocene melting range:

Polar Acetylferrocene melting range:

**Part 2: TLC**2. Fill out the R<sub>f</sub> data in the chart below for the two columns that you ran yourself (either first two, or last two).

- You are not required to fill in the “distance traveled” information, but many students like to write it down if they have a ruler or something. However, an eyeball estimate is satisfactory, given the qualitative nature of this experiment. Only one significant figure is probably appropriate (0.2, 0.3...)
- Remember that the R<sub>f</sub> value for a spot will be fall somewhere from  $0.0 \leq R_f \leq 1.0$ , and is the ratio of the distance traveled by the spot (middle of the spot) relative to the distance traveled by the solvent, relative to where the spot began.
- Put a star above each of the two columns that you did yourself.
- Copy R<sub>f</sub> data from partner and fill in those two columns.
- Note: There is a high likelihood that the R<sub>f</sub>'s that you and your partner got for the same chemicals in the same solvent will differ noticeably, due to experimental variance. But the relative ordering should be analogous.

	2% Ethyl <u>Acetate/Hexane</u>	10% Ethyl <u>Acetate/Hexane</u>	10% Ethyl <u>Acetate/Hexane</u>	20% Ethyl <u>Acetate/Hexane</u>
<u>Substrate</u>	<u>R<sub>f</sub></u>	<u>R<sub>f</sub></u>	<u>R<sub>f</sub></u>	<u>R<sub>f</sub></u>
2,4-di-t-Butylphenol <b>1</b>				
Acetophenone <b>2</b>				
2-Methylcyclohexanol <b>3</b> (this is a cis/trans mixture, and may perhaps separate into two spots)				
Biphenyl <b>4</b>				
First Unknown				
Second Unknown				

3. Rank the observed polarity of the 4 samples **1-4**. In case of a close race, your eyes will be best for seeing which is a little faster. You may need to look at the results using more than just one eluent strength in order to be sure. Some might be too close together to tell with certain eluent strengths.

Most Polar: \_\_\_\_\_ &gt; \_\_\_\_\_ &gt; \_\_\_\_\_ &gt; \_\_\_\_\_ Least Polar

4. Identify your two TLC Unknowns:

First Unknown: Letter \_\_\_\_\_ Identity \_\_\_\_\_

Second Unknown: Letter \_\_\_\_\_ Identity \_\_\_\_\_

5. Did increasing the polarity of your eluent increase or decrease your  $R_f$ 's?

6. Given that the solid surface is polar, explain why polar **samples** have lower  $R_f$  values than less polar ones.

7. Explain why increasing **eluent** polarity increases the  $R_f$  value for a given sample?

8. What problem happens if the spot is placed so low on the plate and the eluent pool is so deep that the spot is actually submerged under the solvent?

9. If the TLC beaker is left uncovered, will the resulting  $R_f$  be fine, too high, or too low?

10. In what order, from top to bottom, would you expect to see the spots for naphthalene ( $C_{10}H_8$ ), butyric acid ( $CH_3CH_2CH_2CO_2H$ ), and phenyl acetate ( $CH_3CO_2C_6H_5$ )?

Top

Middle

Bottom

11. In what order, from top to bottom, would you expect to see the spots for the following:

- |  |                 |
|--|-----------------|
| • acetic acid= $CH_3CO_2H$                     | Top             |
| • butanal= $CH_3CH_2CH_2CHO$ ;                 | 2 <sup>nd</sup> |
| • 2-octanone= $CH_3COCH_2CH_2CH_2CH_2CH_2CH_3$ | 3 <sup>rd</sup> |
| • decane= $C_{10}H_{22}$ ;                     | 4 <sup>th</sup> |
| • 1-butanol= $CH_3CH_2CH_2CH_2OH$              | Bottom          |

12. If an eluent of too low polarity is used for the development of a TLC plate, will the sample spots be somewhere in the middle, way at the bottom, or way at the top of the plate?

13. If a eluent of too high polarity is used for the development of a TLC plate, will the sample spots be somewhere in the middle, way at the bottom, or way at the top of the plate?