Don't Panic! It's More Organic

Chemistry Lab

ORGANIC CHEMISTRY 12B

LAB MANUAL

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Organic Chemistry References

These references are some sources of organic chemistry information that we will use in Chem 12 lecture and lab. The lab textbooks shown below were used to prepare this lab manual. The lab textbook references listed in the Table of Contents are posted in the Chem 12 website. Please add your own references to this list (and tell me about them too).

Organic Chemistry Textbooks and Online Resources:

1. D. Klein, "Organic Chemistry", 2nd ed., 2014
2. Klein, Organic Chemistry Companion Site: (http://bcs.wiley.com/he-bcs/Books?action=index&itemId=0471756148&bcsId=6581)
3. Virtual Textbook of Organic Chemistry: http://www2.chemistry.msu.edu/faculty/reusch/VirtTxtJml/intro1.htm
4. UC Davis Chem Wiki Organic Chemistry Textbook Maps: http://chemwiki.ucdavis.edu/Textbook_Maps/Organic_Chemistry_Textbook_Maps
5. Daley and Daley Organic Chemistry online textbook: http://www.ochem4free.info/node/1
6. The OCHeM.com website "seeks to provide learning resources for students enrolled in Organic Chemistry": http://ochem.jsd.claremont.edu
7. ChemSpider: the free chemical database: http://www.chemspider.com/
8. WEB-sters' Organic Chemistry is "A Living Document of Internet Resources, Information, and Applications": http://www.chemconnections.org/Websters/ This site has links to other sites for many topics in organic chemistry. Check out the *Synthesis and Reaction Mechanisms* link.
9. The Organic Syntheses is a Publication of Reliable Methods for the Preparation of Organic Compounds: http://www.orgsyn.org
10. Organic Compounds Database: http://www.colby.edu/chemistry/cmp/cmp.html Enter various properties, e.g., m.p., molecular weight, UV wavelengths, chemical types, into this 2500 compound database to identify organic compounds.
11. Organic Chemistry Resources: http://www.chemtopics.com/orgo/orgo.htm
12. Organic Chemistry Directory: http://murov.info/orgchem.htm
13. Organic Chemistry On-Line Learning Center for Carey, Organic Chemistry, 4th ed. http://www.chem.ucalgary.ca/courses/351/Carey5th/Carey.html#4
14. B.S. Furniss, A.J. Hannaford, P.W.G. Smith, and A.R. Mitchell, "Vogel's Textbook of Practical Organic Chemistry", 5th ed., Longman, 1989.
15. Khan Academy: http://www.khanacademy.org/

Organic Chemistry Lab Resources:

1. Organic Chemistry at CU Boulder: Lab Procedures: http://orgchem.colorado.edu/Technique/Procedures/Procedures.html
2. McMaster Univ. Microscale Laboratory Techniques: http://www.chemistry.mcmaster.ca/~chem2o6/labmanual/microscale/complete.html
3. Wired Chemist Lab Tutorials: http://www.wiredchemist.com/chemistry/instructional/laboratory-tutorials
4. OCHeM.com In The Lab tutorials: http://ochem.jsd.claremont.edu/in-the-lab.html
5. Univ. of Nevada, Reno Chemistry YouTube videos: http://www.youtube.com/watch?v=5I1S6evKpe4
6. Not Voodoo: Demystifying Synthetic Organic Laboratory Technique: http://chem.chem.rochester.edu/~nvd/
7. NIST WebBook is a database of properties of substances: http://webbook.nist.gov/chemistry IR spectra for many compounds are included in this site.
8. Williamson, K., "Macroscale and Microscale Organic Experiments", 3rd ed., Houghton-Mifflin, 1999.
9. Pavia, G.M. Lampman, G.S. Kriz, and R.G. Engel, "Introduction to Organic Laboratory Techniques: Small-Scale Approach", 1st ed., Saunders, 1998.
10. Schoffstall, B.A. Gaddis, and M.L. Druelinger, Microscale and Miniscale Organic Chemistry Laboratory Experiments", McGraw-Hill, 2000.
11. Mohrig, C.N. Hammond, T.C. Morrill, and D.C. Neckers, "Experimental Organic Chemistry, A Balanced Approach: Macroscale and Microscale", W.H. Freeman, 1999.

Other Resources:

1. ChemAxon chemistry software (http://www.chemaxon.com/) – chemistry drawing and modeling software (MarvinSketch is free).
2. Chemagic Virtual Molecular Modeling kit: http://chemagic.com/home/

Group and Collaborative Work

The ability to work with people is an important skill that many employers value. A good group or team is able to share their diverse experiences, knowledge, abilities, and opinions to work effectively and efficiently to accomplish goals that one person may not be able to do as well or as quickly. Group or teamwork means members work together in a non-competitive, collaborative atmosphere. Skills include listening to others, being assertive with your input but not dominating the whole group, and taking responsibility for your role on the team and making sure other members are doing their role. It helps to focus on the "big picture", i.e., the overall goal of the group, rather than getting caught up in individual issues.

For most of the labs, you will work with a lab partner in a group of two. For other labs, you will work in a group of four. Working in a larger group requires teamwork and communication. Each group member will be assigned one of the following roles so that duties are shared equally:

Group Leader: responsible for supervising the group and makes sure each member contributes equally to the team.
Communicator: responsible for communicating with the instructor and for completing all materials to be submitted by the team that reflects the thinking of all team members.
Record Keeper: responsible for keeping records of all materials discussed and is for informing absent team members of work missed and progress made.
Counselor: responsible for making sure all members of the team agree on planning, execution, and presentation of work.

Roles should be rotated with each different lab so each member of the group has the opportunity to perform a different function.

General Laboratory Procedures and Conduct

A diagram of microscale equipment is posted on the Chem 12 website.

The following procedures for laboratory safety and practices must be followed by everyone (instructors, students, and staff) using the chemistry laboratory. Disregard of these procedures will result in disciplinary action.
1. Protective goggles or safety glasses with side shields must be worn when performing or observing an experiment or when in the vicinity of others performing experiments.
2. Learn the primary, secondary and handicapped escape routes from the laboratory.
3. Learn the locations of the fire extinguishers, shower, eyewash stations, fire blankets, and hoods.
4. Never perform unauthorized experiments.
5. Eating, drinking, and smoking in the laboratory are forbidden. Do not bring food or drink into the laboratory.
6. Become familiar with the use and operation of laboratory equipment and instruments. A diagram of laboratory equipment is shown below.
7. Never taste a chemical.
8. If instructed to smell a chemical, do so by gently fanning the vapors toward your nose.
9. Never point a test tube that is being heated toward yourself or others.
10. Never pipet by mouth. Pipet filler bulbs are available and their use will be demonstrated when appropriate.
11. Read chemical labels carefully. Be sure that you are using the chemical required.
12. Never return unused chemicals to the stock bottles to avoid contamination.
13. Never discard solid residues or paper into the sinks.
14. Footwear should cover the feet completely. No open-toe shoes. Clothing should cover the body to the knees. Long pants are preferred. Long hair and loose clothing should be secured.
15. When diluting acid, ALWAYS add the acid to the water.
16. When the experiment is completed, wipe the laboratory table; clean and dry equipment; compare the equipment and chemicals in the tray with the check list; when complete, return the tray to the stockroom. Return all ring stands, hot plates, Bunsen burners, etc. to their proper places.

Accidents
1. Clean up all spills immediately.
2. If a thermometer breaks, do not touch the mercury. Notify lab staff immediately.
3. In case of contact with a chemical, wash the affected area immediately and thoroughly with water. Notify lab staff.
4. In case of an injury, no matter how minor, notify lab staff.

Lab Policies
1. Safety glasses or goggles are required in lab. Prescription glasses are an adequate substitute for safety glasses/goggles. For students who wear contact lenses, you will need to wear safety glasses/goggles over your contact lenses. Try to be aware of your safety as well as the safety of others in lab.
2. FAILURE TO CHECK-IN YOUR LOCKER, whether you drop the course or complete it, results in a $25 LAB FEE plus a charge for any broken or missing equipment.
3. All labs must be performed to pass this course.
4. Late lab assignments will be penalized 5% per calendar day.
5. The chemistry lab has 14 computers.
a. You cannot store your lab data and results on the hard drive of a computer you are using. Please bring a floppy disk or flash/thumb drive to store lab files.
b. Each computer is connected to a network printer. You will need to supply your own printer paper. You and your lab partner are asked to donate one ream of paper to lab (you and your lab partner can share the cost of paper) for your use and other student's to use.
c. These computers are connected to the internet so you can look up scientific information. Please do not download images, files, or software onto these computers.

Laboratory Safety Agreement

I have carefully read the instructions on good laboratory safety practices and procedures. I understand the importance of good safety practices for my own welfare and of all people in the laboratory and I, therefore, pledge to follow the safety regulations of the college.

Date: _____ Signature: _____

Drawer Number: _____ Print Name: _____

Microwave Assisted Organic Reactions

"The microwave oven is the Bunsen burner of the 21st century."
- Ajay Bose, microwave chemistry researcher (http://cen.acs.org/articles/90/i39/Chemists-Crank-Heat-Microwaves.html)

General Use of a Microwave Oven:

1. Don't operate an empty microwave oven.
2. Keep the microwave oven clean. Clean up any spills in the oven.
3. Do not use metals in the microwave oven.
4. No sealed containers in the microwave oven. Sealed containers may explode.

Microwave ovens provide intense heating and can replace a long reflux.
Microwaves work by dielectric polarization. This means substances with a non-zero dielectric constant absorb microwave radiation.
Questions:
1. What is dielectric constant?
2. Name two solvents with a non-zero dielectric constant. Give the dielectric constant of each solvent.
3. Does glass heat up in a microwave oven?

Use polar solvents only, e.g., water, acids, alcohols, and amides.
Polar solvents usually have –OH bonds, which absorb microwave radiation.

Good solvents: methanol, ethanol, isopropanol, 1-butanol, ethylene glycol

Medium solvents: water, acetonitrile, acetone, ethyl acetate, tetrahydrofuran (THF), dimethyl formamide (DMF)

Poor solvents: chloroform, dichloromethane, CCl_4, hexane, toluene, xylene

Questions:
1. How is dielectric constant related to polarity?
2. What makes a solvent a "good" solvent for a microwave reaction? Identify at least two properties of a good solvent.
3. *"Be careful using volatile solvents."* Why?

A commercial microwave oven has a frequency of 2.45 GHz.
This gives a microwave penetration depth of approximately 2 cm.
Question:
1. Based on the microwave penetration depth, what lab container size should you use for a microwave reaction?

To perform organic reactions in a microwave oven, remember glass does not heat up in microwave and will condense vapor (like a reflux condenser). For your reaction vessel,
a. use a test tube.
b. Attach a condenser to your test tube.
c. If you can't use a test tube, use a beaker.
d. **Important**: Place a beaker or flask with water in the microwave with your reaction container.
Questions:
1. Should you seal your reaction vessel? Give reasons.
2. What Power Level or Setting on the microwave oven should you use for a "good" microwave solvent? Give reasons.
3. What Power Level or Setting on the microwave oven should you use for a volatile solvent? Give reasons.
4. How long should you run your reaction in a microwave oven?

Lab 1. Moonshine - Ethanol by Fermentation

How do I make alcohol? Which sugar source produces a higher yield of ethanol?

Objectives

1. Name and classify alcohols; identify their physical and chemical properties, especially reactivity trends.
2. Make ethanol from sugar fermentation.
3. Determine the sugar source that gives the highest yield of ethanol.

References: 1. Ethanol from sugar: http://faculty.tcc.fl.edu/scma/phelpsj/experiments/ethanol.pdf
2. J.L. Epstein, M. Vieira, B. Aryal, N. Vera, and M. Solis, "Developing Biofuel in the Teaching Laboratory: Ethanol from Various Sources," J. Chem. Educ., 2010, **87**, 708-710.

Introduction

The fermentation of sugar is one route to make ethanol. The sugar can come from a variety of sources, e.g., corn, grapes, plums, potatoes. Corn is the largest U.S. crop. In 2010, farmers produced 331 million metric tons (12.1 billion bushels) in the U.S., of which more than half were grown in Iowa, Illinois, Nebraska and Minnesota. 40% of the corn is used for animal feed, 40% is used to make ethanol, and 20% is used for food. (References: http://blogs.scientificamerican.com/plugged-in/2011/10/07/the-u-s-now-uses-more-corn-for-fuel-than-for-feed/, http://www.grains.org/corn)

Glucose is the sugar that undergoes fermentation. One glucose is metabolized to two pyruvates in glycolysis. See Figure 1.

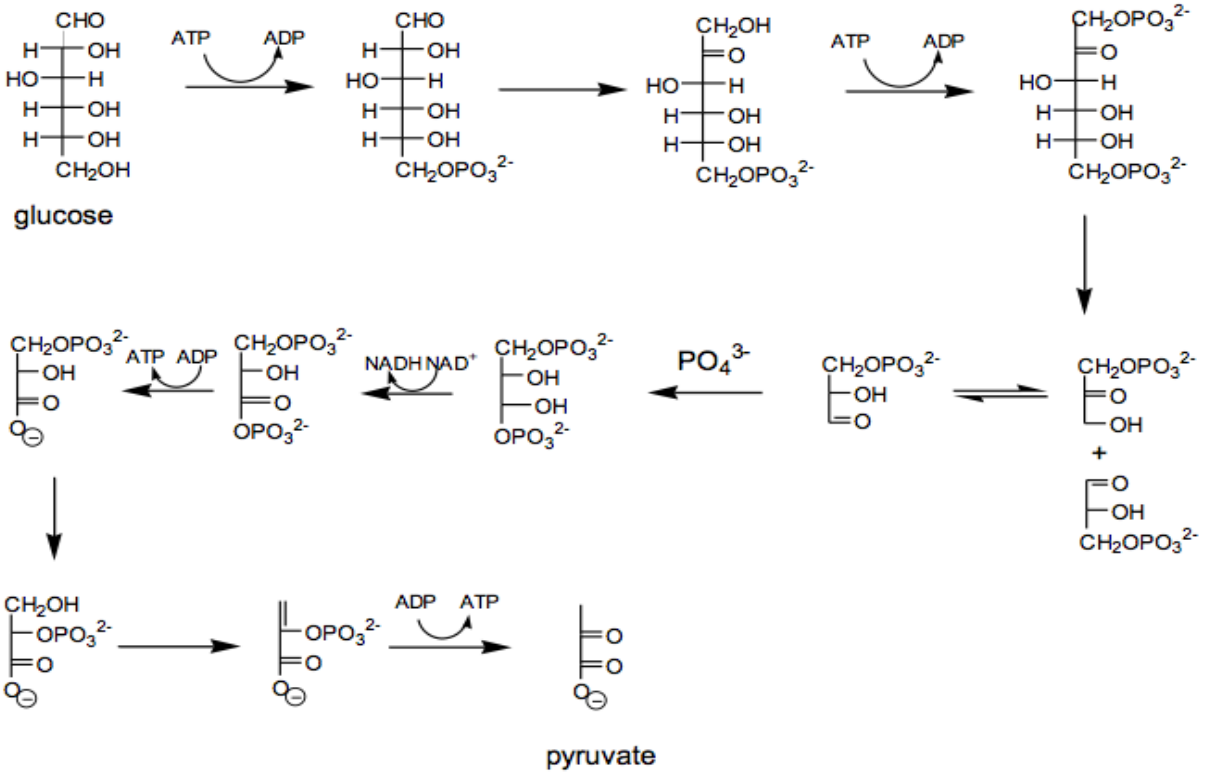


Figure 1. The 10 Steps of Glycolysis

Fermentation occurs in anaerobic organisms. These organisms lack a respiratory chain and must re-oxidize NADH (a biological reducing agent) to NAD^+ so Step 6 of glycolysis can occur. Usually, NADH reacts with pyruvate to form NAD^+ and lactate. Some anaerobic organisms metabolize pyruvate to ethanol, which is excreted as a waste product. Pyruvate is converted to acetaldehyde which is reduced to ethanol. The ethanol in your wine or beer or other adult beverage is actually yeast ____. (www.rpi.edu/dept/bcbp/molbiochem/MBWeb/mb1/part2/glycolysis.htm) See Figure 2. We will learn the organic chemistry of each step of glycolysis and fermentation in CHM 12B.

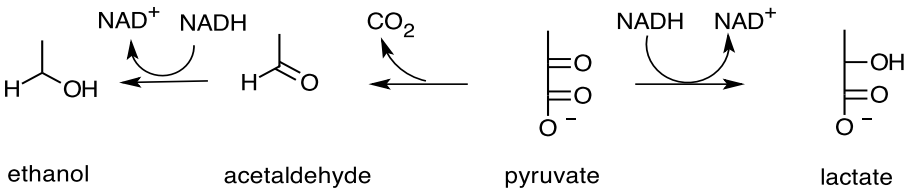


Figure 2. Fermentation Produces Lactate or Ethanol

In this lab, you will make ethanol from sucrose and grape juice. You will determine the concentration of ethanol by measuring the density of this solution. To a portion of this solution, you will perform a distillation. To a second portion of this solution, you will treat it with an oxidizing agent to make an aldehyde and then an acid.

Materials
Sucrose
Students: Bring Grape juice, apple juice, corn starch, potato starch
Yeast
Solid sodium hydrogen phosphate (Na_2HPO_4)
6 M HCl
6 M NaOH
pH 6.2 phosphate buffer (To prepare 0.1 L: 13.6 g KH_2PO_4, 1.42 g Na_2HPO_4)
10X salt solution (To prepare 0.5L: 5 g KH_2PO_4, 0.5 g $CaCl_2$, 2.5 g $MgSO_4$, 50 g Ammonium tartrate, 0.5 g NaCl)
mineral oil or saturated $Ca(OH)_2$ solution
pH paper
glucose test strips

Procedure
Caution: The acids and bases in this experiment are corrosive. Be careful handling these substances.

While you are doing this experiment, try to determine the purpose of each step in the procedure, e.g.,

- Is this reagent reacting with one of the acid, base, or neutral? If so, write a chemical equation that represents the reaction. Is this reagent the limiting reactant or excess reactant?
- If the solvent I just added formed two layers, is the solvent extracting something? Which substance is being extracted?
- What is the reason for heating or cooling?

Record the purpose of each step in your notes.

Work in a group of 4. Each group will be assigned to start with sucrose or grape juice or apple juice. The class will combine data.

1. Fermentation. A typical fermentation takes one week.
a. Measure the mass of starting material (sucrose or grape juice or apple juice or corn starch or potato starch).
(i) For sucrose,

a) Add half an envelope of dry yeast (3.5 g) to 50 mL of water in a beaker. (What does yeast do?)
b) Add 0.35 g of sodium hydrogen phosphate. (What does Na_2HPO_4 do?)
c) Transfer the slurry to a 500-mL round bottom flask.
d) Dissolve 51.5 g sucrose in 150 mL of water. Add this sucrose solution to the slurry in the RB flask.
e) Shake to complete mixing.
f) Go to Step b.

(ii) For grape juice or apple juice, place 200 ml of fruit juice in a 500 ml round bottom flask. Add 3.0 g of dry yeast. Swirl the mixture to dissolve the yeast. Then, go to Step b.

(iii) For potato starch,

a) Weigh approximately 50 g of potato starch and combine with 100 mL of water. The starch will not dissolve, but swirl to get an even distribution.
b) Add 25-mL of 6M HCl to the mixture and heat to just below boiling for 45 minutes. (What does the acid do?)
c) Remove the mixture from the heat and cool to room temperature. The mixture will be a caramel/brown color.

d) Neutralize the acid by adding 25 mL of 6 M NaOH. (Which acid is neutralized?)
e) Then adjust the pH with 20 mL of 1 M pH 6 phosphate buffer (Why is it important to adjust the pH?). Use a pH test strip to confirm that the pH is about 6.2 (a little lower is OK, but the pH should not exceed 6.5).
f) Test the glucose content with a glucose test strip. The glucose content should be at least 100 mM. If you do not have sufficient glucose, repeat the acid treatment, because you will not obtain sufficient _____ next week. If your glucose concentration exceeds 100 mM, you can obtain a more accurate reading by preparing a dilution of 1 mL of your potato mash in 9 mL of water and measuring the glucose concentration of this $1/10^{th}$ dilution.
g) Place the mixture in a 500 mL round bottom flask and add 20 mL of the 10X salt solution and 3.0 g of yeast. Swirl the mixture to dissolve the yeast. The potato starch has been stripped of all cellular debris, and the 10X salts provide essential salts and a nitrogen source for yeast metabolism.
h) Go to Step b.

(iv) For corn starch, do the same procedure as potato starch.

b. Fermentation set up:
Fit the RB flask with a one-hole rubber stopper containing a bent glass tube that dips below the surface of a saturated aqueous solution of mineral oil in a test tube.
The seal will prevent air and unwanted enzymes from entering flask, but gases will be able to escape.
Place the set-up in a warm place for 1 week, at which time the evolution of CO_2 gas will have ceased.

c. After a week, the fermentation reaction should be complete. Now you want to measure the volume of ethanol you produced and the % ethanol
Separate the liquid (ethanol) from the solid sediment. Try one or a combination of these methods:
(i) *carefully* remove the glass tubing in the mineral oil *without disturbing the sediment*.
Use a pipet to transfer the clear supernatant liquid from the flask to another container.
Avoid drawing any sediment into the pipet.
If you are not able to separate all of the liquid from the sediment, remove the sediment by centrifugation.
(ii) filter the mixture.
Add about 5 g of Celite filter aid for every 100 ml of fermented broth.
Swirl this mixture to wet the Celite.
Yeast cell debris can clog the pores of filter paper; Celite catches yeast cell debris before it reaches the filter paper.
This process is slow. Set up a fitration and allow the liquid to filter for two days.
(iii) if you see large pieces of solid, filter the fermented broth through a cheesecloth.
Then, filter the filtrate as in (ii).

d. (i) Measure the volume of the liquid you collected from Step 1c.
(ii) Measure the density of this liquid.
(iii) Determine the ethanol composition from density (see CHM 1A Lab 2). Use Table 2 to determine % ethanol.
(iv) Calculate the volume of ethanol produced per gram of sugar source you started with.
Hint: use the volume from Step 1d(i), the % ethanol from Step 1d(iv), and the mass of sugar source you used in Step ___.

(v) Share these data from (i) through (iv) with the rest of the class.
(vi) Summarize your data and results in Table 3.

Table 2. Density of Ethanol and Water Mixtures (Reference: D. D. Holmquist and D. Volz, “Chemistry With Computers”, 2000, Vernier Software and Technology, p. 8-3)

% Ethanol	Density, g/ml	% Ethanol	Density, g/ml	% Ethanol	Density, g/ml
0	0.998	34	0.947	68	0.872
2	0.995	36	0.943	70	0.868
4	0.991	38	0.939	72	0.863
6	0.988	40	0.935	74	0.858
8	0.985	42	0.931	76	0.853
10	0.982	44	0.927	78	0.848
12	0.979	46	0.923	80	0.843
14	0.977	48	0.918	82	0.839
16	0.974	50	0.913	84	0.834
18	0.971	52	0.909	86	0.828

20	0.969	54	0.905	88	0.823
22	0.966	56	0.900	90	0.818
24	0.964	58	0.896	92	0.813
26	0.960	60	0.891	94	0.807
28	0.957	62	0.887	96	0.801
30	0.954	64	0.882	98	0.795
32	0.950	66	0.877	100	0.789

2. Compare the class data and results. Determine which sugar source produces the most ethanol. Rank the sugar sources from highest to lowest.

Table 3. Sugar fermentation data and results.

Sugar source	Sucrose	Grape juice	Apple juice	Corn starch	Potato starch
Mass of sugar source, g					
Volume of ethanol solution, ml					
Density, g/ml					
% ethanol					
Volume of ethanol, ml					
Volume of ethanol/g sugar source, ml/g					

3. Do you want wine or moonshine? (If we have time.)
a. Distill your alcohol mixture. (Simple or fractional distillation? At what temperature should you collect distillate?) When the distillation mixture starts boiling, collect 1 ml fractions until the temperature rises above 78^{o}C. At this point, the distillation will slow.
b. Determine the ethanol content in each fraction. (One way is by density.)
c. Did you get pure ethanol?

4. Optional. What happens to ethanol when a person drinks it?
a. To oxidize ethanol, I would use ____. The product of this oxidation reaction is ____.
b. Design an experiment to oxidize ethanol.
See alcohol oxidation with bleach http://ochemonline.pbworks.com/f/03_bleach_oxidation_handout.pdf
http://organic.chem.tamu.edu/Prelab.PowerPoints/Printed%20Slides%20-%20237/Oxidation%20of%20a%20Secondary%20Alcohol-12c.pdf
http://faculty.ycp.edu/~khalliga/Courses/CHM%20236/Spring%202011/Lab/Experiments/Expt%202_Bleach%20Oxidation%20of%20Secondary%20Alcohols%20to%20Ketones.pdf

Waste Disposal: solids – in trash.
Ethanol – in sink.

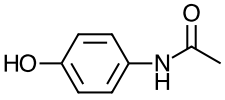
Lab 2. What a Pain! Phenacetin Synthesis from Acetaminophen

What reaction conditions converts acetaminophen to phenacetin? Which functional group reacts? What conditions makes this reaction occur in the reverse direction?

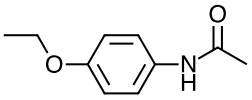
Objectives
1. Convert an alcohol to an ether by substitution reaction.
2. Synthesize phenacetin from Acetaminophen.
3. Analyze your sample by HPLC.
4. Propose a reaction mechanism.

Reference: 1. B.D. Williams, B. Williams, and L. Rodino, "Synthesis of the Sweetener Dulcin from the Analgesic Acetaminophen", J. Chem. Educ., 2000, **77**, 357-359.

Introduction
If you have a headache, you take a pain reliever, such as acetaminophen (Tylenol). In this lab, you will take acetaminophen and convert it into phenacetin, another pain reliever. Phenacetin was banned by the Food and Drug Admininstration (FDA) in 1983 due to adverse side effects including increased risk of certain cancers and kidney damage. Phenacetin is metabolized to acetaminophen. Interestingly, acetaminophen replaced phenacetin in some over-the-counter medications following the ban.



Acetaminophen



Phenacetin

Once you make phenacetin, you will identify the reaction conditions to convert the phenacetin back to acetaminophen and do your experiment. In other words, reverse the reaction.

Materials

Tylenol tablets	ethyl iodide
1 M NaOH in ethanol	1 M HCl (aq)
HPLC	IR

Procedure
While you are doing this experiment, try to determine the purpose of <u>each</u> step in the procedure, e.g.,

- Is this reagent reacting with one of the acid, base, or neutral? If so, write a chemical equation that represents the reaction. Is this reagent the limiting reactant or excess reactant?
- If the solvent I just added formed two layers, is the solvent extracting something? Which substance is being extracted?
- What is the reason for heating or cooling?

<u>Record the purpose of each step in your notes.</u>

<u>Caution</u>: The acids and bases in this experiment are corrosive. Be careful handling these substances.

Synthesize phenacetin from acetaminophen.
1. Synthesis
a. Grind 2 tablets of Tylenol (350 mg of acetaminophen per tablet or an equivalent amount) using a mortar and pestle. Place the powder in a 50-mL round bottom flask with a magnetic stir bar.
b. Add 5.25-mL of 1M ethanolic NaOH solution to the Tylenol.
What does the ethanol or NaOH do?

c. Attach a condenser to the RB flask and bring to a vigorous reflux. Maintain reflux for 15 minutes. Then, remove the flask from its heat source.

While you are refluxing, go to Step 4.

d. To the hot solution, add 0.7 mL of ethyl iodide.
Is the ethyl iodide the limiting reactant?

Reflux for an additional 15 minutes.

2. Workup
a. Filter the **hot** solution under vacuum through a Buchner funnel and into a filter flask containing a mixture of ice and water. The insoluble starches should be collected on the filter paper.
b. The phenacetin precipitates from the filtrate as a white solid upon contact with the cold water.
c. While still cold, collect the solid phenacetin by vacuum filtration.
Wash with cold water. (Why wash with cold water and not hot water?)

d. Dry the solid in the oven at 100 °C for 5 to 10 minutes or by place the sample on a watch glass over a heat source not exceeding 100 °C.
e. The phenacetin prepared by this method is generally pure.
If necessary, you can further purify the phenacetin by recrystallization from hot water. Use decolorizing charcoal if the impure phenacetin is ____. (What does decolorizing charcoal do?)

Waste Disposal: solids – in solid waste.
Ethanolic NaOH – neutralize with acid and dispose in sink.
Any solution containing iodide – in halogenated waste.

3. Characterization
a. Determine the % yield.
b. Characterize the product by:
(i) melting point.
(ii) IR.
(iii) HPLC.
c. Summarize your data and results in Table 3.

Table 3. Phenacetin synthesis data and results.

	Run 1	Run 2
Method	reflux	microwave
Mass of acetaminophen		
Moles of acetaminophen		
Volume of 1 M NaOH		
Moles of NaOH		
Limiting reactant		
Moles of Phenacetin		
Theoretical yield of Phenacetin, g		
Actual yield of Phenacetin, g		
% yield of Phenacetin		
Experimental melting point range, ^{o}C		
True melting point, ^{o}C		

4. Repeat the experiment except this time use the microwave oven to heat your reaction mixture instead of doing a reflux.

Lab 3. Eat Your Vegetables: Solar Cell from Plant Pigments

What chemical causes the color of plant pigments? What structural feature causes the color of the pigment? How can I change the pigment color?

Objectives

1. Name and classify conjugated dienes; identify their physical and chemical properties, especially reactivity trends.
2. Make a dye sensitized solar cell (DSSC).
3. Measure and interpret UV-VIS spectra of lycopene, raspberry, and blueberry.
4. Use Woodward-Feiser rules to predict λ_{max}.

Table 1. Chemical Properties of Lab 3 Compounds.

Compound	Structure	Functional Group(s)	Acid/Base/ pK_a	Nu^-/E^+	Molar mass	density	b.p./m.p., ^oC	Polar or non-polar?

References: 1. D. Klein, "**Organic Chemistry**", 2nd ed., 2014, Ch. 17
2. Fieser-Kuhn rules: http://pharmaxchange.info/press/2013/05/ultraviolet-visible-uv-vis-spectroscopy-%E2%80%93-fieser-kuhn-rules-to-calculate-wavelength-of-maximum-absorption-lambda-max-of-polyenes-with-sample-problems/
3. Y.R. Smith, E. Cone, V. Subramanian, "A Simple Photocell to Demonstrate Solar Energy Using Benign Household Ingredients", J. Chem. Educ., 1013, 90, 1358-1361. DSSC using raspberries.
4. DSSC using blueberries: http://zenofstem.com/project/diy-solar-cells-with-blueberry-juice/
5. DSSC using blackberries: http://sciencegeekgirl.com/activities/Blackberry%20solar%20cell.pdf

Introduction

"MORE ENERGY—in the form of sunlight—strikes Earth in one hour than all of the energy consumed by humans in an entire year." -- Nathan Lewis, Cal Tech

Currently, on a global scale, **energy usage is on the order of 14 terawatts** (14 trillion W or 14 trillion joules per second), of which roughly **85% is generated by burning fossil fuels**. (CEN, 8/27/07, p. 16) The sun showers Earth with an energy flow of some 120,000 TW. Energy from the sun is ____ but we haven't figured out a way to cheaply convert sunlight to electricity. So far, polysilicon solar cells are 14% efficient and thin film solar cells are 8% efficient. The latest prototypes DSSC are 15% efficient with current DSSCs at 11%. DSSCs are lower cost and have higher power conversion efficiencies than silicon-based solar cells.

In this lab, you will make a DSSC using different dyes. We will see which dye works best. Many plant pigments have a conjugated system of alternating carbon-carbon single bonds and carbon-carbon double bonds over which the pi electrons are delocalized. The color arises from $\pi \rightarrow \pi^*$ transitions.

DSSC Operation: A solar cell is a type of electrochemical cell (see CHM 1B). Oxidation occurs at the anode; reduction occurs at the cathode. Sunlight enters the cell through the transparent conductive glass slide (ITO – indium tin oxide) top contact, striking the colored dye on the surface of the TiO_2. Photons with enough energy are absorbed by the dye to create an excited state of the dye, from which an electron can be "injected" directly into the conduction band of the TiO_2 (see valence band and conduction band in band theory). From there it moves by diffusion (as a result of an electron concentration gradient) to the clear anode on top.
Meanwhile, the dye molecule has lost an electron and the molecule will decompose if another electron is not provided. The dye strips one from iodide in electrolyte below the TiO_2, oxidizing it into triiodide. This reaction occurs quite quickly compared to the time that it takes for the injected electron to recombine with the oxidized dye molecule, preventing this recombination reaction that would effectively short-circuit the solar cell.
The triiodide then recovers its missing electron by mechanically diffusing to the bottom of the cell, where the counter electrode re-introduces the electrons after flowing through the external circuit.

Materials

Students: Bring one of the following fruits:

Tomato juice | Raspberry tea or raspberries | Blueberries | Blackberries

Conductive glass slides (ITO)
Pencil/graphite rod
Rubbing alcohol or 95% ethanol
Parafilm or wax paper or scotch tape
Bunsen burner or candle
Ceramic crucible
Multimeter (Voltmeter/ammeter/ohmeter)
UV-VIS spectrometer
TiO_2 (anatase)
Iodine tablets
Vinegar
Binder clips
hot plate
mortar/pestle
variable resistors

Procedure
Caution: Ethanol and rubbing alcohol are flammable and hazardous. Iodine is an oxidizer.

While you are doing this experiment, try to determine the purpose of each step in the procedure, e.g.,

- Is this reagent reacting with one of the acid, base, or neutral? If so, write a chemical equation that represents the reaction. Is this reagent the limiting reactant or excess reactant?
- If the solvent I just added formed two layers, is the solvent extracting something? Which substance is being extracted?
- What is the reason for heating or cooling?

Record the purpose of each step in your notes.

1. Prepare a solution of the fruit dye.
Raspberry tea: Immerse a few tea bags in ~100 mL of boiling water after it was removed from the heat source.
Dip and steep the bags several times to make a dark red colored solution.
Cool the dye solution to room temperature.

Blackberries or Blueberries: blend or crush fresh or frozen blackberries or blueberries in a blender or by hand, adding a tablespoon (15 ml) of water for every 10 blackberries.
Or take the juice from the bottom of frozen berries after they have thawed.

Tomato: filter tomato juice and use the filtrate (should not have any solid).

Anode preparation.
1. ID and clean the conductive glass slide.
a. Identify the conducting side of the glass slide.
Check the resistance of each side of the glass slide with a multimeter operated in the resistance mode.
The conducting side will have the ___ (higher or lower?) resistance, typically 10-40 Ω.

b. Clean the conducting side by swabbing with alcohol and drying in air.
Care should be taken, once cleaned, not to touch the conducting slide.
Use tweezers or hold the slide by the edges. Finger grease can increase resistance hence wearing gloves is recommended.

2. Deposit TiO_2 onto a conductive glass slide
a. Place a few grams of TiO_2 into a mortar. Add a small amount of vinegar, a few mL's at a time, to the TiO_2 and use the pestle to grind the mixture into a uniform paste. (It should be smooth and free of lumps.)
The final ratio of vinegar to TiO_2 is approximately 5 mL to 3 g.
b. Cast (drop) a few drops of this slurry onto ~25 mm of the conducting side of the ITO plate.
Deposit (distribute) a thin film of the TiO_2 slurry uniformly by "painting" with a glass rod (a paint brush may also be used). (See Reference 4 for pictures.)
c. Allow the anode to dry. You can expedite this process by using a hotplate at 80^{o}C for about 10 min.

3. Staining the Anode
Fresh or frozen fruit or tea can be used as the dye to sensitize the anode. Dye pigments in fruits, such as blackberries, raspberries, or pomegranate, that contain several =O or –OH groups are capable of chelating the Ti^{4+} sites on the titania surface are desirable. Although several colored fruits, e.g., strawberries, and leaves contain anthocyanins, they may not chelate to the titania surface if they do not possess the aforementioned functional groups.

We will test different dyes. Your instructor will assign your group to use a specific fruit.

After you have prepared your organic dye solution,
a. Drop cast the dye onto the titania-coated glass plates and allow the dye to dry over a hot plate at ~80°C.
Repeat this procedure several times until the white TiO_2 is visibly red on the reverse side of the glass plate.
b. Store your dye filmed conductive glass slide in the dark until you are ready to use it.

c. Measure the UV-VIS spectrum of your leftover dye solution.
Record the wavelength(s) of light absorbed by your fruit pigment dye. λ = _____ nm.
Identify the chromophore (the substance that gives the fruit its color).
Draw the structure of the chromophore.
Apply the Woodward-Feiser or Feiser-Kuhn rules to determine the peak wavelength. Does this wavelength match the experimental wavelength?

Alternate Method: Soak the anode in the dye solution until the white TiO_2 is visibly colored on the reverse side of the glass plate.

4. Counter electrode preparation
Prepare the counter electrode can be prepared while the drying the dye in the staining process of the titania anode (previous step).
a. With another clean ITO glass plate (cleaned by swabbing alcohol), use a pencil or graphite rod to apply a light carbon film on the entire conducting side of the ITO plate. Do not remove the ITO from the conductive glass slide!
b. A heat treatment can be carried out for a more stable electrode (350°C for 30 min in air), but this step is not critical.

Alternate method: hold the ITO glass slide above a candle flame until it is coated black.

5. Assemble the device
A schematic of the device assembly is given in Figure 1 (from Reference 3).

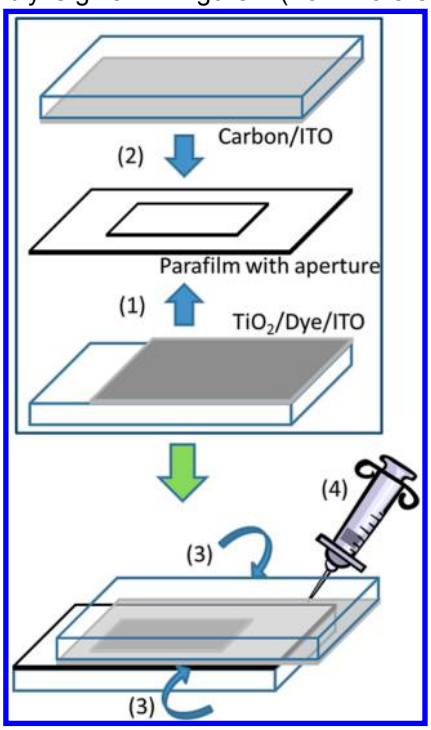


Figure 1. The scheme explaining the steps in assembling the DSSC: (1) lay the parafilm/tape with an aperture on top of the TiO_2-dye/ITO plate; (2) place the carbon/ITO plate with the carbon side facing the TiO_2-dye/ITO with the slides slightly offset; (3) attach binder clips to the edges of the assembly; (4) add a few drops of the iodine mixture (electrolyte) to the side, gently working out any air bubbles.

a. Prior to assembly, take a piece of parafilm or wax paper or folded tape ~20 x 20 mm. This serves as a separator between the anode and cathode of the solar cell. Cut an aperture or window in the middle of the separator to an arbitrary size and note the area.

b. Next, lay the TiO_2-dye/ITO plate flat with the TiO_2-dye facing up. Overlay the parafilm/wax paper/tape separator followed by the carbon/ITO plate facing down.
c. "Sandwich" the assembly together using two binder clips on the long edge of the plates. The plates will need to be slightly offset as shown in Figure 1 for contact point for the positive and negative electrodes of a potentiostat or multimeter.
d. A solution prepared with a few iodine tablets in ethanol or water serves as the electrolyte. One to a few drops of this solution can be placed at the edges of the plates. Opening each binder clip, alternately, will ensure the electrolyte fills the void via capillary action. Once the device is assembled, it is ready to be tested.

6. Test the device
Test the device either inside (simulated light) or outside (direct/diffuse sunlight).
a. Connect an alligator clip and wire to each slide and to a multimeter.
b. Place the DSSC under light.
c. Measure the voltage and current.
d. Turn off or remove the DSSC from the light.
What happens to the voltage?

e. Repeat the dark/light cycle.
Does the voltage change with each cycle?

Note: During prolonged or continuous operation, the electrolyte may dry up; add few drops to the edge of the cell to "revive" the device.

f. Share your data and results with the class in Table 2.
g. Compare the class data and results.
(i) Which fruit produced the highest voltage?
(ii) Which fruit worked the best as a DSSC?

Recycle the cell: Disassemble the cell.
TiO_2 coated glass slide: If the TiO_2 film is undamaged, wash the electrolyte off the glass slides with ethanol. Burn the old dye off the TiO_2 coated slide by sintering (heating) for 30 minutes at 450°C. Cool to room temperature and store in a cellophane (glassine) envelope to prevent scratching or damage.
If the TiO_2 film is damaged, wipe off the TiO_2 off the glass slide with a tissue dampened with isopropanol or ethanol.
Carbon coated glass slide: wash the carbon coated slide with ethanol, then dry and store in the cellophane (glassine) envelope.
TiO_2 and vinegar suspension: save in a labelled and sealed bottle for reuse.
Electrolyte: keep free of water and seal the electrolyte bottle using wax paper.
Pipettes: recycle by rinsing in water and then isopropanol or ethanol.

Table 2. DSSC data and results. Tomato, raspberry, blueberry, blackberry. Try 3 light/dark cycles.

Group	Fruit	Color	Experimental λ_{max}, nm	Calculated λ_{max}, nm	Chromophore	Voltage, 1st cycle	Voltage, 2nd cycle	Voltage, 3rd cycle

Optional: Additional testing of solar cell properties.
Plot I-V curve using potentiostat to vary resistance (or use fixed resistors in circuit)
Measure Power = I x V.
Fill factor
Power conversion efficiency

Waste Disposal: fruit juice – in sink.

Lab 4a. Ring Around: Rates of Electrophilic Aromatic Substitution Reactions

How does a side group affect the rate of EAS? Does a pi bond in benzene react the same way as a pi bond in an alkene?

Objectives
1. Name and classify arenes; identify their physical and chemical properties, especially reactivity trends.
2. Measure rate of EAS reactions.
3. Determine which groups make EAS go faster. Propose a reaction mechanism.
4. Determine which groups make EAS go slower. Propose a reaction mechanism.

References: 1. D. Klein, "**Organic Chemistry**", 2nd ed., 2014, Ch. 18 and 19
2. Schoffstall, et al., "Microscale and Miniscale Organic Chemistry Laboratory Experiments", McGraw-Hill, 2000 p. 289-294.

Introduction
Alkenes and conjugated dienes undergo addition reactions. Aromatic compounds undergo electrophilic aromatic substitution reactions (EAS). The rate of a EAS reaction depends on the substituent on the aromatic ring. Electron-donating substituents donate electron density to the benzene ring making the pi electrons more nucleophilic, thus activating the ring and speeding up the rate of an EAS reaction. Electron-withdrawing substituents withdraw electron density from the benzene ring making the pi electrons less nucleophilic, thus de-activating the ring and slowing down the rate of an EAS reaction.

Materials

toluene	acetanilide	acetophenone
aniline	anisole	phenol
phenyl acetate	bromobenzene	

0.05 M bromine in acetic acid
15 M acetic acid

Procedure
While you are doing this experiment, try to determine the purpose of <u>each</u> step in the procedure, e.g.,

- Is this reagent reacting with one of the acid, base, or neutral? If so, write a chemical equation that represents the reaction. Is this reagent the limiting reactant or excess reactant?
- If the solvent I just added formed two layers, is the solvent extracting something? Which substance is being extracted?
- What is the reason for heating or cooling?

<u>Record the purpose of each step in your notes.</u>

<u>Part 1.</u> Use reaction rate to determine whether a group activates or deactivates the aromatic ring in EAS (adapted from Reference 2).
<u>Caution</u>: The organic compounds in this experiment are flammable. Some are toxic and are irritants.
Bromine is an oxidizing agent. Be careful handling the Br_2 in acetic acid.
1. a. Using the substituted benzene compounds assigned to your group, do a microscale bromination of substituted benzene derivatives. You will measure the time elapsed for each bromination reaction to determine the relative EAS rate.
(i) For the liquid aromatic compounds, prepare 1 ml of 0.2 M solution using glacial acetic acid as the solvent.
Sample calculation: volume of liquid aromatic compound = 0.2 M x 0.001 l x molar mass / density
Measure this volume of liquid aromatic compound and add enough glacial acetic acid to make 1 ml of solution.

(ii) For the solid aromatic compounds, prepare 1 ml of 0.2 M solution using glacial acetic acid as the solvent.
Sample calculation: mass of liquid aromatic compound = 0.2 M x 0.001 l x molar mass
Measure this mass of liquid aromatic compound and add enough glacial acetic acid to make 1 ml of solution.

(iii) Calculate the moles of reactants, determine the limiting reactant, and calculate the theoretical yield of product.

b. Prepare a 40°C water bath.
Should the temperature of this bath be constant?

c. Obtain the number of test tubes equal to the number of substituted benzene compounds assigned to your group **plus one**.
To your first test tube, add 1.0 ml of 0.2 M toluene.
To the other test tubes, add 1.0 ml of 0.2 M solution of each assigned substituted benzene compound.
d. Place each test tube in the 40°C water bath. Allow the solutions to reach thermal equilibrium.

2. a. Add 1.5 ml of 0.05 M Br_2 in acetic acid all at once (not dropwise) to the test tube with the 0.2 M toluene.
Swirl the contents of the test tubes to mix.
Start timing.
When the red Br_2 color disappears (the solution turns colorless or light yellow), record the _____.

b. Repeat this process with the other substituted benzene compounds.

Note: we want to determine how fast or slow each reaction is relative to toluene, i.e., reaction is faster than toluene or slower than toluene.

3. a. The class will combine their data.
Which substituted benzene compound undergoes bromination the fastest?
Slowest?
Rank the substituted benzene compounds in order of fastest to slowest.
Based on the data and results, identify the groups that activates the ring. Identify the groups that deactivates the ring.

b. Summarize your data and results in Table 2.

Table 2. EAS data and results.

Compound	time	Activating or Deactivating?

Waste Disposal: Bromine is a halogen so any solution that contains bromine – in halogenated waste.

Lab 4b. Ring Around: Bromination of Acetanilide

How does a side group determine the position of substitution in EAS?

Objectives
1. Predict EAS product of monosubstituted benzene.
2. Describe reaction mechanism.

References: 1. D. Klein, "**Organic Chemistry**", 2nd ed., 2014, Ch. 18 and 19
2. S. Tantayanon, "Small Scale Laboratory: Organic Chemistry at University Level", p. 73
(http://www.unesco.org/science/doc/Organi_chem_220709_FINAL.pdf)

Materials

Acetanilide	glacial acetic acid	
Potassium bromate, $KBrO_3$ (or sodium bromate)	48% HBr	10% $NaHSO_3$

Procedure
While you are doing this experiment, try to determine the purpose of each step in the procedure, e.g.,

- Is this reagent reacting with one of the acid, base, or neutral? If so, write a chemical equation that represents the reaction. Is this reagent the limiting reactant or excess reactant?
- If the solvent I just added formed two layers, is the solvent extracting something? Which substance is being extracted?
- What is the reason for heating or cooling?

Record the purpose of each step in your notes.

Note: instead of using concentrated Br_2 solution, which is very corrosive, you will generate Br_2 in situ from HBr and BrO_3^-:

$$6\ H^+ + 5\ Br^- + BrO_3^- \text{ ---> } 3\ Br_2 + 3\ H_2O$$

1. Synthesis
a. Weigh 200 mg (1.5 mmol) of acetanilide, 85 mg (0.5 mmol) of potassium bromate in the appropriate microscale round bottom flask and 2 mL of glacial acetic acid to the flask and swirl the mixture until all the solid has dissolved.
b. Add 0.3 mL of 48% HBr and stir the mixture at room temperature for 30 minutes.
Caution: Acetanilide is toxic and an irritant. Avoid skin and eye contact. HBr is corrosive and causes burns.
How many moles of Br_2 are produced?

Which reactant is the limiting reactant?

While your reaction is occurring, go to Step 5.

2. Workup
a. Pour the mixture into a 100-mL beaker containing 25 mL of water (Why use water instead of ethanol?) and stir the mixture rapidly for 15 minutes. You should see a precipitate form.
b. Collect the solid product by _____ filtration. (What type of mixture are you trying to separate?)
What is this solid?

Wash the precipitate with several drops of 10% $NaHSO_3$ and water to remove any residual bromine.
c. Recrystallize the crude product from ethanol.
d. After crystallization is complete, collect the crystals by _____.
Wash the product with cold ethanol (Why use ethanol instead of water?) and continue suction to dry.

3. Characterization
a. Weigh the dry product. Determine % yield.
b. Measure the _____ of the solid.

Look up the melting points of:
ortho-bromoacetanilide (2-bromoacetanilide) = _____^oC
meta-bromoacetanilide (3-bromoacetanilide) = _____^oC
para-bromoacetanilide (4-bromoacetanilide) = _____^oC

4. Summarize your data and results in Table 3.

Table 3. Bromination of acetanilide reaction data and results.

	Run 1	Run 2
Method	reflux	microwave
Mass of acetanilide		
Moles of acetanilide		
Mass of potassium bromate		
Moles of potassium bromate		
Volume of 48% HBr		
Moles of HBr		
Moles of Br_2		
Limiting reactant		
Moles of product		
Theoretical yield of product, g		
Actual yield of product, g		
% yield of product		
Experimental melting point range, ^oC		
True melting point, ^oC		

5. Repeat the experiment except this time use the microwave oven to heat your reaction mixture instead of doing a stirring at room temperature for 30 minutes.

Waste Disposal: Treat the filtrate with 10% $NaHSO_3$ to destroy the left over HBr – in halogenated waste.
Solids – in solid waste.

Alternate Procedure (use Br_2 in glacial acetic acid)
Caution: Acetanilide is toxic and an irritant. Avoid skin and eye contact. Br_2 is corrosive and causes burns.
1. Synthesis
a. Weigh 200 mg (1.5 mmol) of acetanilide in the appropriate microscale round bottom flask.
Add 1 mL of glacial acetic acid to the flask and swirl the mixture until all the solid has dissolved.
b. Slowly add 1.8 mL of 1 M Br_2 in glacial acetic acid and stir the mixture at room temperature for 30 minutes.
How many moles of Br_2 are produced?
Which reactant is the limiting reactant?

2. Workup
a. Pour the mixture into a 100-mL beaker containing 15 mL of water (Why use water instead of ethanol?) and stir the mixture rapidly for 15 minutes. You should see a precipitate form.
b. Collect the solid product by _____ filtration. (What type of mixture are you trying to separate?)
What is this solid?

Wash the precipitate with several drops of 10% $NaHSO_3$ and water to remove any residual bromine.
c. Recrystallize the crude product from ethanol.
d. After crystallization is complete, collect the crystals by _____.
Wash the product with cold ethanol (Why use ethanol instead of water?) and continue suction to dry.

3. Characterization
a. Weigh the dry product. Determine % yield.
b. Measure the melting point.

Waste Disposal: Treat the filtrate with 10% $NaHSO_3$ to destroy the left over Br_2 – in halogenated waste.
Solids – in solid waste.

Lab 4c. Ring Around: Nitration of Salicylic Acid

How do two side groups determine the position of substitution in EAS?

Objectives
1. Predict EAS product of disubstituted benzene.
2. Describe reaction mechanism.

References: 1. D. Klein, "**Organic Chemistry**", 2nd ed., 2014, Ch. 18 and 19
2. Green Chemistry Task Force Committee, DST, "Monograph on Green Chemistry Laboratory Experiments", p. 26

Introduction
This method for the nitration of salicylic acid is a "green" reaction. In this reaction, nitration is rapid and regioselective and is ecofriendly the reaction is done without nitric acid. In addition, the reagents and byproducts (calcium acetate) are useful agrochemicals and environmentally benign.

Green chemistry principles (Anastas, P. T.; Warner, J. C., "Green Chemistry: Theory and Practice," Oxford University Press: New York, 1998, p.30)
1. Prevention
It is better to prevent waste than to treat or clean up waste after it has been created.
2. Atom Economy
Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.
3. Less Hazardous Chemical Syntheses
Wherever practicable, synthetic methods should be designed to use and generate substances that possess little or no toxicity to human health and the environment.
4. Designing Safer Chemicals
Chemical products should be designed to effect their desired function while minimizing their toxicity.
5. Safer Solvents and Auxiliaries
The use of auxiliary substances (e.g., solvents, separation agents, etc.) should be made unnecessary wherever possible and innocuous when used.
6. Design for Energy Efficiency
Energy requirements of chemical processes should be recognized for their environmental and economic impacts and should be minimized. If possible, synthetic methods should be conducted at ambient temperature and pressure.
7. Use of Renewable Feedstocks
A raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable.
8. Reduce Derivatives
Unnecessary derivatization (use of blocking groups, protection/ deprotection, temporary modification of physical/chemical processes) should be minimized or avoided if possible, because such steps require additional reagents and can generate waste.
9. Catalysis
Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.
10. Design for Degradation
Chemical products should be designed so that at the end of their function they break down into innocuous degradation products and do not persist in the environment.
11. Real-time analysis for Pollution Prevention
Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.
12. Inherently Safer Chemistry for Accident Prevention
Substances and the form of a substance used in a chemical process should be chosen to minimize the potential for chemical accidents, including releases, explosions, and fires.

Materials
Salicylic acid glacial acetic acid Calcium nitrate tetrahydrate

Procedure
While you are doing this experiment, try to determine the purpose of each step in the procedure, e.g.,

- Is this reagent reacting with one of the acid, base, or neutral? If so, write a chemical equation that represents the reaction. Is this reagent the limiting reactant or excess reactant?
- If the solvent I just added formed two layers, is the solvent extracting something? Which substance is being extracted?
- What is the reason for heating or cooling?

Record the purpose of each step in your notes.

1. Synthesis
a. Dissolve 1.5 g of calcium nitrate in 5 ml of warm acetic acid.
The calcium nitrate reacts with acetic acid:

$Ca(ONO_2)_2 + 2\ CH_3COOH \text{ ---> } 2\ CH_3COONO_2 + Ca(OH)_2$

Think of CH_3COONO_2 as $(CH_3COO^-)(NO_2^+)$. The electrophile is _____.
b. Add 1 g of salicylic acid to the calcium nitrate in acetic acid solution.
c. Heat the reaction mixture in a boiling water bath (maintained at > 80°C) for 1 min.
You should see the salicylic acid dissolve completely and the solution turn dark red.

2. Workup
a. Immediately pour this mixture into a 10 ml of ice cold water. Place this mixture in an ice bath. After an hour, you should see yellow crystals. If you do not, keep the mixture in the ice bath.
b. Separate the yellow crystals from the liquid by ____.
c. Wash the yellow solid with minimum amount of ice cold water to remove the acid. (Why use water instead of ethanol?)
d. What should you do with the solid?

Caution: The yield of the reaction mainly depends on temperature of the reaction and solubility (since products are soluble in water). Very minimum amount of water should be used for washing of acetic acid as well as the byproducts like calcium acetate and calcium nitrate.

3. Characterization
a. Measure the yield. (Typical yield = 50%.)
b. Measure the ____ of the solid.

From Sigma-Aldrich:
melting point of 3-nitrosalicylic acid = 142-147°C
melting point of 4-nitrosalicylic acid = 235-239°C
melting point of 5-nitrosalicylic acid = 228-230°C
In salicylic acid, Carbon 1 is bonded to the acid group.

Note (A. K. Bose,* S. N. Ganguly, M. S. Manhas, S. Rao, J. Speck,U. Pekelny and E. Pombo-Villars, *Tetrahedron Lett.* , 2006, *47,1885*): This nitration procedure is very efficient with salicylic acid and may be used for making derivatives of salicylic acid in identification of organic compounds. However, it may not give equally good results for nitration of all aromatic compounds and thus should not treated as a general method of nitration.

Lab 5. Making Big from Small: Grignard(-like) Reaction

What happens when a carbonyl carbon reacts with a base? What functional group is produced?

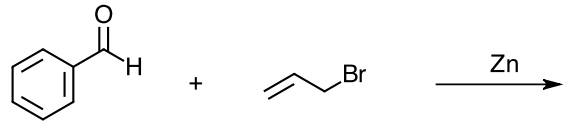
Objectives:
1. Synthesize an alcohol from a carbonyl compound by a nucleophilic addition reaction.
2. Make a big molecule from a small molecule and form a C-C bond using a Grignard-like reaction.

References: 1. D. Klein, "**Organic Chemistry**", 2nd ed., 2014, Ch. 20
2. "A Grignard-like Organic Reaction in Water," G.W. Breton and C. A. Hughey, J. Chem. Educ. 1998, 75, 85.
3. "Small Scale Laboratory: Organic Chemistry at University Level," Supawan Tantayanon, p. 101
(http://www.unesco.org/science/doc/Organi_chem_220709_FINAL.pdf)

Introduction

The Grignard reaction is a very common synthetic method to make a C-C bond. This reaction requires scrupulously dry conditions. Any water present reacts with ___ and stops the reaction.

In this lab, you will perform a reaction that is similar to the Grignard reaction but can be done in aqueous conditions. In this reaction, benzaldehyde reacts with allyl bromide in the presence of Zn to form a ___. A C-C bond forms to make a bigger molecule from smaller molecules.



Benzaldehyde Allyl bromide

This Grignard-like reaction is "green" and hopefully more reproducible.

Materials

Zn powder	saturated NH_4Cl (aq)
Benzaldehyde	allyl bromide
THF	diethyl ether
Na_2SO_4	

Caution: Benzaldehyde is considered a hazardous substance by the EPA.
Allyl bromide has an intense, acrid, and persistent smell – use in the fume hood.
THF and diethyl ether are flammable.

Procedure

While you are doing this experiment, try to determine the purpose of each step in the procedure, e.g.,

- Is this reagent reacting with one of the acid, base, or neutral? If so, write a chemical equation that represents the reaction. Is this reagent the limiting reactant or excess reactant?
- If the solvent I just added formed two layers, is the solvent extracting something? Which substance is being extracted?
- What is the reason for heating or cooling?

Record the purpose of each step in your notes.

1. Synthesis
a. Mix 0.256 g of zinc powder with 2 mL of a saturated aqueous NH_4Cl solution.
b. To a 25-mL round-bottomed flask fitted with a condenser, add 2 mL of THF and 0.21 mL of benzaldehyde.
c. Add the Zn/NH_4Cl mixture to the benzaldhyde/THF solution.
d. While stirring this mixture vigorously, dropwise add 0.21 mL of allyl bromide using a calibrated pipet through the condenser. Make sure each drop is falls directly into the stirring mixture. (Your % yield will be lower if the allyl bromide runs down the side of the condenser.)
What reacts with the allyl bromide?

What is the limiting reactant?

b. Stir the mixture for 30 minutes.

While your reaction is going, consider doing this reaction in a microwave. Go to Step 4.

2. Workup
a. Add 2 mL of ether to the reaction mixture.
b. Filter this mixture through a plug of glass wool to remove excess zinc and any precipitate (zinc salts) that may have formed.
(Here's a quick way: Wrap the Pasteur pipette tip with a small piece of cotton wool. Immerse the pipette into the solution until the pipette tip reaches the bottom of the flask while squeezing the rubber bulb. Draw the solution up into the pipette by releasing the rubber bulb. Take off the cotton wool and expel the solution in the pipette into the proper container).
If any precipitate is present, rinse the precipitate is with 1 mL of fresh ether.
Which should you do with the rinse ether?

c. Separate the two phases.
The top layer is the organic phase because _____.

The bottom layer is the aqueous phase because _____.

Your product is in the organic phase because _____.

d. Wash the aqueous phase once with a 2 mL of ether.
Separate the layers.
Combine the ether layer with the ___ layer from the previous step.

e. Dry the combined organic phases over Na_2SO_4.
Then, _____ to separate the solid from liquid.

f. At this point, the organic phase contains the desired product and ___.
Your product is a colorless liquid. How will you remove the ___ to obtain the product? (Hint: how do you separate a mixture of liquids?)

3. Characterization
a. Measure the yield of product.
b. Measure the IR spectrum of your product.

4. Summarize your data and results in Table 2.

Table 2. Grignard-like reaction data and results. What else goes in Table 2?

	Run 1	Run 2
Method	reflux	microwave
Mass of _____, g		
Limiting reactant		
% yield		

5. Repeat the experiment except this time use the microwave oven to heat your reaction mixture instead of doing a reflux.

Waste Disposal: any liquid containing zinc without Br – in heavy metals waste.
Liquid containing Br – in halogenated waste.

Lab 6. Acids Rock!

What happens to the charge and solubility of an acid as pH changes? How can I make a smelly compound from non-smelly compounds? Which functional groups react?

Objectives:
1. Predict ionic charge and structure with pH change based on pK_a.
2. Synthesize an ester from an acid and alcohol using a nucleophilic acyl substitution reaction.

References: 1. D. Klein, "**Organic Chemistry**", 2nd ed., 2014, Ch. 21

Part A. MSG

Introduction

Many substances, including proteins, drugs, and natural products, behave like acids or bases or both. When pH changes, the charge of an acid or base changes and changes their properties. For example, the protein in milk is soluble in water at pH 7 because the milk protein is an ion at that pH. However, when an acid, such as vinegar, is added to milk, the milk protein ionic charge changes (becomes neutral) and is no longer soluble in water and forms a solid precipitate. This solid milk protein are the curds that are used to make cheese.

Materials

Monosodium glutamate (MSG) solid
1 M HCl 1 M NaOH (s) pH paper

Procedure

While you are doing this experiment, try to determine the purpose of each step in the procedure, e.g.,

- Is this reagent reacting with one of the acid, base, or neutral? If so, write a chemical equation that represents the reaction. Is this reagent the limiting reactant or excess reactant?
- If the solvent I just added formed two layers, is the solvent extracting something? Which substance is being extracted?
- What is the reason for heating or cooling?

Record the purpose of each step in your notes.

1. Prepare 10 ml of an aqueous 0.1 M MSG solution. Pour this solution into a test tube. Measure the pH.

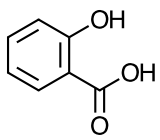
2. a. Pretend MSG enters your stomach. Dropwise, add 1 M HCl to the MSG solution. Continue to add HCl until you see a precipitate form. Measure the pH. What is the charge on the MSG at this pH?
b. The MSG has passed through your stomach and into your intestines. Dropwise, add 1 M NaOH to the solution from Step 2a. Continue to add NaOH until you see the precipitate dissolve. Measure the pH. What is the charge on the MSG at this pH?

Solubility: MSG = 740 g/liter of water, glutamic acid = 7.5 g/liter of water

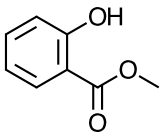
Part B. Wintergreen and Aspirin Synthesis

Introduction

The wintergreen taste in Wintergreen Lifesavers is methyl salicylate. It is produced naturally by certain plants to defend against bug attack and in the lab for use as a fragrance and flavoring agent in gum and mints, in liniments (Bengay) as a rubefacient and analgesic, as an antiseptic in Listerine mouthwash, and other uses. You may have done this before - when a Wintergreen Lifesaver is mechanically crushed, it emits blue-green light – a phenomena called triboluminescence – very cool!



Salicylic acid



Methyl salicylate

Materials

Salicylic acid	methanol
H_2SO_4 (conc.)	glacial acetic acid

Procedure

While you are doing this experiment, try to determine the purpose of each step in the procedure, e.g.,

- Is this reagent reacting with one of the acid, base, or neutral? If so, write a chemical equation that represents the reaction. Is this reagent the limiting reactant or excess reactant?
- If the solvent I just added formed two layers, is the solvent extracting something? Which substance is being extracted?
- What is the reason for heating or cooling?

Record the purpose of each step in your notes.

Caution: H_2SO_4 and glacial acetic acid are corrosive. Methanol is flammable.

While you are doing this experiment, try to determine the purpose of each step in the procedure, e.g.,

- Is this reagent reacting with one of the acid, base, or neutral? If so, write a chemical equation that represents the reaction. Is this reagent the limiting reactant or excess reactant?
- If the solvent I just added formed two layers, is the solvent extracting something? Which substance is being extracted?
- What is the reason for heating or cooling?

Record the purpose of each step in your notes.

1. Synthesis of methyl salicylate from salicylic acid.

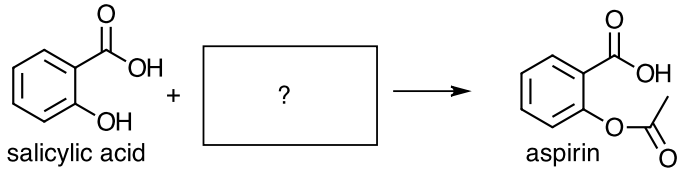
a. In an appropriate size test tube, mix 0.1 g (1 small scoop) of salicylic acid with 15 drops of methanol. Carefully add 2 drops of concentrated H_2SO_4.

b. Heat this mixture in a boiling water bath for 1 minute.

c. Use a stirring rod to transfer 1 drop of the reaction mixture to a piece of filter paper. Carefully waft the vapors toward your nose. Does it smell like wintergreen?

d. Repeat the experiment except this time use the microwave oven to heat your reaction mixture instead of doing a reflux. Note: microwave heating time should be shorter than a reflux. How long should you heat your reaction mixture in the microwave? Remember to place a separate beaker or flask of water in the microwave oven.

2. Synthesis of aspirin (acetylsalicylic acid) from salicylic acid.



a. Identify the organic compound that reacts with salicylic acid to produce aspirin. CHECK with your instructor to see if you identified the correct compound.

b. Do you want to use a catalyst like in the previous reaction?

c. In an appropriate size test tube, mix 0.1 g (1 small scoop) of salicylic acid with 10 drops of the substance you identified from part a. Carefully add 2 drops of concentrated H_2SO_4.

d. Heat this mixture in a boiling water bath for 3 minutes.

e. Cool your reaction mixture to room temperature and then in an ice bath. You should see a white solid form. This solid should be ____.

f. Separate the solid from the liquid by ____.

g. Dry the solid.

h. Measure the melting point. Look up the melting points of salicylic acid and aspirin.

Waste Disposal: Salicylic acid or methyl salicylate solution – in non-halogenated waste.
H_2SO_4 and acetic acid – dilute with water and neutralize with NaOH – in sink.

Lab 7. Multistep Synthesis of a Sunscreen

How do I make sunscreen? Is the sunscreen effective? Which functional groups react in each step? What functional group is produced?

Objectives: Name and classify acids, acid derivatives, and amines; identify their physical and chemical properties, especially reactivity trends.
1. make PABA from p-toluidine
2. make a PABA derivative
3. measure the UV-VIS spectrum of PABA and the derivative to determine their effectiveness as a sunscreen

References: 1. D. Klein, "**Organic Chemistry**", 2nd ed., 2014
2. Schoffstall, et al., "Microscale and Miniscale Organic Chemistry Laboratory Experiments", McGraw-Hill, 2000 p. 419-427.

Introduction

Synthesis is the heart of chemistry. Chemists have designed and created molecules with different and unique properties for a variety of uses and applications. Usually, substances are not synthesized in one or two steps, as you have done in most of the experiments in this course, but often require several or many steps to make. The raw materials or feedstocks to make these substances are usually readily available and cheap. Many raw materials are based on petroleum. As you have seen from this course so far, there are many organic reactions that can be used to make new substances.

In this lab, you will make a common sunscreen p-aminobenzoic acid (PABA) starting from p-toluidine (p-aminotoluene) in three steps as shown in Figure 1. From PABA, you will make benzocaine or a benzocaine analog. You will test the effectiveness of this substance and PABA as a sunscreen.

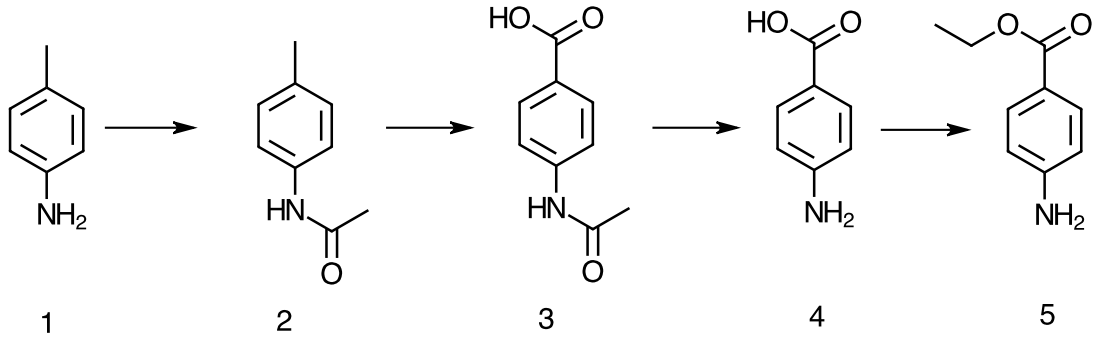


Figure 1. Sunscreen synthesis overview. 1 = *p*-toluidine, 2 = *p*-methylacetanilide (*p*-acetotoluidide), 3 = *p*-acetamidobenzoic acid, 4 = *p*-aminobenzoic acid, 5 = benzocaine.

Materials

Part A. *p*-toluidine	$NaC_2H_3O_2 \cdot 3H_2O$ (s)	HCl (conc.)	acetic anhydride
Part B. $KMnO_4$ (s)	$MgSO_4 \cdot 7H_2O$ (s)	ethanol	H_2SO_4 (20%)
Part C. HCl (6 M)	NH_3 (aq, 6 M)	acetic acid (glacial)	
Part D. ethanol	H_2SO_4 (conc.)	Na_2CO_3 (10%)	CH_2Cl_2

Procedure

Caution: the inorganic acids and bases and acetic anhydride are corrosive.
$KMnO_4$ is a strong oxidizer.
CH_2Cl_2 is volatile, flammable, and may be a carcinogen.
Ethanol is flammable.

While you are doing this experiment, try to determine the purpose of each step in the procedure, e.g.,

- Is this reagent reacting with one of the acid, base, or neutral? If so, write a chemical equation that represents the reaction. Is this reagent the limiting reactant or excess reactant?
- If the solvent I just added formed two layers, is the solvent extracting something? Which substance is being extracted?
- What is the reason for heating or cooling?

Record the purpose of each step in your notes. After each Part, draw a flow chart of the procedure. The Flow Chart is not a rewrite of the procedure in boxes.

Part A. Synthesis of *p*-methylacetanilide (*p*-acetotoluidide) from *p*-toluidine.

1. Synthesis

a. Prepare a solution of sodium acetate by combining 2.15 g of sodium acetate trihydrate ($CH_3CO_2Na \bullet 3\ H_2O$) and 5-6 mL of water in a 10-mL Erlenmeyer flask. Swirl vigorously to dissolve. Set the sodium acetate solution aside.

b. In a 125-mL Erlenmeyer flask, dissolve 1.61 g of p-toluidine in 40 mL of water. With stirring (use a stir bar), add 1.3 mL of concentrated HCl. Stir for 2 minutes.

c. With stirring, add 2.1 mL of acetic anhydride and immediately add the sodium acetate solution. (Which reactant reacts with the p-toluidine? Which reactant is limiting?) Stir vigorously to mix the reagents. Cool the solution in an ice bath and continue to stir vigorously while the product crystallizes.

2. Workup

a. Isolate the product by vacuum filtration, washing the crystals with several small portions of ice-cold water.

b. Let the crystals air dry or place in a warm drying oven.

c. Weigh the product. Save at least 25 mg of the product for characterization and spectral analysis. The remainder may be used without purification in the next step.

d. Summarize your data and results in Table 2.

Table 2. Multistep synthesis data and results.

	Run 1	Run 2
Method	reflux	microwave

Part B. Synthesis of *p*-acetamidobenzoic acid from *p*-methylacetanilide.

This procedure is designed for use of 1 g of p-methylacetanilide.

1. Synthesis

a. Dissolve 2.6 g $KMnO_4$ in 14 mL of boiling water. Set this solution aside. (What do you want $KMnO_4$ to do?)

b. To a 250-mL Erlenmeyer flask fitted with a stir bar, add 1 g of dry *p*-methylacetanilide (or all of the remaining solid from part A), 2.6 g of $MgSO_4 \bullet 7H_2O$, and 64 mL of water.

c. Heat to 85°C on a steam bath or water bath. While vigorously stirring the solution of *p*-methylacetanilide, slowly add via pipet a hot solution of potassium permanganate. The addition should take approximately 30 minutes. It is important to add the permanganate solution slowly and uniformly to avoid local build up of the oxidant.

d. After all of the oxidant has been added, add 2 mL of ethanol, stir vigorously, and bring to a boil. (What does the ethanol do?) Check to make certain that no purple color remains, then filter over a pad of Celite using vacuum filtration, washing with water to dissolve any adsorbed product.

2. Workup

a. Transfer the clear solution to an Erlenmeyer flask. Cool the filtrate in an ice bath and acidify with 20% sulfuric acid until the pH is 3-4. (For what reason do you want to lower the pH?)

b. Collect the product using vacuum filtration, rinsing the crystals with small amounts of ice-cold water.

c. Dry the crystals as much as possible by continuing suction. The product does not need to be completely dry for the next step. Measure the yield. Save at least 25 mg of the product and let it dry thoroughly for characterization and spectral analysis.

d. Summarize your data and results in Table 2.

Part C. Synthesis of *p*-aminobenzoic acid from *p*-acetamidobenzoic acid.

1. Synthesis

a. Add 1.0 g of *p*-acetamidobenzoic acid and 5 mL of 6M HCl to a 10-mL round-bottom flask containing a stir bar. (Which group in *p*-acetamidobenzoic acid reacts with HCl?)

b. Attach a reflux condenser to the round-bottom flask and reflux gently, with stirring, for 30 minutes.

c. After the heating time is over, let cool to room temperature. Transfer the contents of the flask to a 50-mL Erlenmeyer flask, rinsing with 2.5 mL of cold water. Add the rinses to the flask.

2. Workup
a. Add concentrated (15 M) ammonia dropwise until the pH is between 7 and 8. Do not go beyond pH 8. During the addition, precipitates will form and redissolve. (What is the reason for adding ammonia?)
b. Estimate the volume of the solution: then add 1 mL of glacial acetic acid for every 30 mL of solution to induce crystallization. Stir vigorously and cool the solution in an ice bath. It may be necessary to add more glacial acetic acid, to add a seed crystal or to scratch the inside surface of the flask with a glass rod.
c. Suction filter the product and let air dry until the next lab period. Measure the yield. Save 25 mg of product for analysis and use the remainder in Part D.
d. Summarize your data and results in Table 2.

Part D. Synthesis of benzocaine from *p*-aminobenzoic acid.
1. Synthesis
a. To a 10-mL round bottom flask fitted with a stir bar, add 0.33 g of dry *p*-aminobenzoic acid and 2.5 mL of the assigned alcohol.
b. While stirring, add 0.25 mL of concentrated H_2SO_4 dropwise. The precipitate that forms upon the addition of sulfuric acid should dissolve when the solution is heated.
c. Reflux, with stirring, for 1 hour.
d. Cool to room temperature, then transfer the solution into a centrifuge tube.

2. Workup
a. Neutralize cautiously with dropwise addition of 10% Na_2CO_3 until the pH is approximately 8. (Gas evolution will be vigorous. What is the gas? What reacts with Na_2CO_3 to form this gas?)
b. Extract with two 3-mL portions of methylene chloride. (What substance are you extracting?)
c. Wash the combined methylene chloride layers with two 8-mL portions of water. (What does the water wash out?)
d. Dry the methylene chloride solution over anhydrous sodium sulfate.
e. Gravity filter into a clean Erlenmeyer flask containing a boiling stone.
f. Evaporate the methylene chloride under the hood on low heat.
g. Recrystallize the whitish residue using as a solvent pair, the assigned alcohol and water. Suction filter the product, and let air dry.
h. Measure the yield.
d. Summarize your data and results in Table 2.

Part E. Sunscreen effectiveness. Measure the UV-VIS spectrum of:
a. PABA
b. PABA derivative

Prepare a Table that summarizes your data and results.

Waste Disposal: halogenated compounds – in halogenated waste.
Solids – in solids waste.
Acids and bases – neutralize with base or acid – in sink.
$KMnO_4$ – if oxidizing agent solution is still purple, add ethanol until no purple color remains – in heavy metals waste.