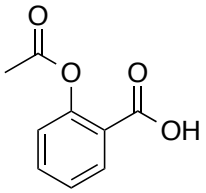
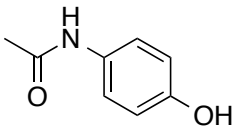
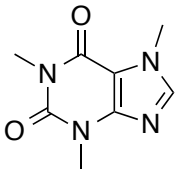
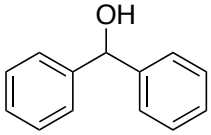
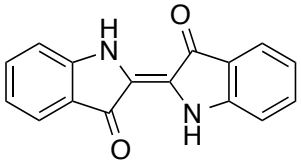
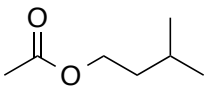
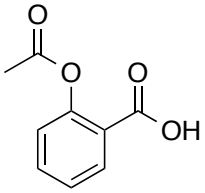




CHEM 8M Workbook

Organic Chemistry Lab II

CONTENTS	
I.	**SAFETY RULES**
II.	**Writing Guidelines: Experimental Methods and Sample from Caitlin's Thesis**
III.	**Safety Scavenger Hunt & Lab Basics Worksheets**
IV.	**** Lecture Note Templates ****
V.	**NMR Problem Sets**
VI.	**IR and NMR Reference Tables**
VII.	**Functional Group Table**

Caitlin Binder, PhD
University of California, Santa Cruz
Department of Chemistry and Biochemistry

Welcome to the CHEM 8M Workbook!

The 8M Workbook is designed to set you up for success in the organic chemistry lab and help you understand our experiments this quarter. Use this workbook for note-taking during *weekly lab lectures* and for *foundational lab activities* such as safety and writing. *Do you find it challenging to take notes while listening to an instructor?* The ***lecture note templates*** in this workbook are intended to let you process the material in class instead of just writing letters and symbols to 'figure out later!'

This **workbook and its contents are available for free on Canvas** for you to print out on your own, copy by hand, or download to a tablet before class. Purchase of the **8M Workbook** and/or **Lab Manual** from the UCSC Copy Center is optional. The benefit is to have all the paper 3-hole punched copies that are 'binder-ready' (pun unavoidable :P). This workbook could also be used re-write notes (learning hack!).

I look forward to passing on my organic chemistry knowledge and learning from you!

Sincerely,
Caitlin Binder, Ph.D.
Follow me on Instagram! @AcroChemist

CONTENTS

The 8M Workbook does NOT contain…

- The course **syllabus**, including
  - **lab & lecture schedule with assignment due dates** – see Canvas
- **Lab Manual** – lab PDFs with background, procedures, pre- and post-lab questions for each lab are posted on Canvas with the option to order a printed **Lab Manual** from Bookstore – see Canvas

Other required 8M materials…

- **Lab Notebook** - any bound, designated notebook for your experiments; duplicate pages NOT required
- **Calculator** – bring to lab each day; no cell phones used in the lab as calculators

Provided, and shared materials in the lab…

- **Safety goggles**
- **Lab Coat** and disposable nitrile **Gloves**

CHEM _____ Section _____ TA _____

LABORATORY SAFETY RULES

Safety First!

The instructors wish students an enjoyable lab experience! The best way to set you up for success is to provide you with lab common sense and etiquette, as much of the surroundings and techniques will be new to you. In general, be respectful of the space and follow instructions and you'll be fine, however, we may need to enforce repeated violations of the rules with point penalties, either for an individual or the whole section, but we hope it won't come to that! Thanks for reading and doing your best as you learn.

1. **Safety goggles must be worn** at all times when anyone in the room is working with chemicals, especially yourself! You are welcome to step outside to defog goggles if necessary.

2. **NO food, drinks, or gum** are allowed anywhere in the labs or in your mouth while you're in the labs. All water bottles, snacks, etc. should be left on the table outside the lab, not hidden in your bag. You may step into the hallway for a quick drink or snack during appropriate times, as long as you're not neglecting the experiment or your partner. Please check with your TA beforehand.

3. **Appropriate lab attire** must be worn at every lab. Students cannot go home to change.
   - **OK LAB ATTIRE:** Pants or long skirt, short or long-sleeve shirt, closed-toe shoes that cover the entire top of the foot. Long hair and loose clothing are confined or tied back.
   - **NOT OK:** Shorts or short skirts (no exposed ankles), *leggings/tights*, cropped pants that expose ankles, ripped pants that expose skin, tank tops, sandals, ballet flats, or any other shoes that expose the tops of the feet (Crocs and Tom's are NOT OK!). High heels, baggy clothing, and dangling jewelry are strongly discouraged.

4. **Lab coats** must be worn over appropriate lab attire (see above).

5. **NO running, fighting, or other acts of mischief**.

6. **NO visitors**, including pets and side-kicks.

7. Know the **locations of emergency equipment** including fire alarms, fire extinguishers, chemical fume hoods, safety showers, and emergency eye washes.

8. **Notify your instructor immediately of any injury, spill, fire, or explosion.** You may clean up small spills (less than a few milliliters) yourself, but let the TA know. You're not in trouble unless you do it on purpose!

9. Keep your lab space **clean and organized throughout the experiment**. Backpacks, purses, jackets, phones, etc. are not allowed where chemicals are being used.

10. **Never leave an ongoing experiment unattended**. If you need to leave the room, be sure a neighbor is watching your experiment.

11. Unless otherwise specified, dispose of broken glassware in broken glassware boxes only, including ceramics and disposable glass pipets. NO paper or other items in the broken glass boxes. **NO PIPETS OR OTHER GLASSWARE IN THE TRASH!** That's not cool to the staff and you'll lose points.

12. **DO NOT TASTE ANYTHING IN THE LAB**. EVER.

13. **Never remove chemicals or equipment** from the labs or stockroom without permission.

14. **NO unauthorized experiments**. Stick to the given procedure.

15. Follow appropriate procedures for inserting glass into a stopper and/or have the stockroom or your TA assist you. Seriously, students have hurt themselves by not paying attention.

16. Wash your hands and arms with soap and water before you leave the lab, no matter what!

CHEM _____ Section _____ TA _____

17. Always know the **hazards** as well as the physical and chemical properties of the materials used. Your lab notebook should include a brief note on the safety hazards for each chemical being used based on the safety table within in the experiment.

18. **Read labels carefully and know the name of chemicals with which you are working**. Read labels twice. Read labels twice.

19. **Label all containers** with chemical/mixture names, your name, and the date **before** anything goes into that container.

20. **Use pluringes and pipet bulbs with glass pipets**. NEVER pipet by mouth. It's gross.

21. Check all **glassware for cracks and cleanliness** before using…or you'll be sorry later that you didn't.

22. **Avoid contamination**. Take only what you need from reagent bottles and NEVER return unused chemicals to the original bottle that other students are sharing.

23. **Fume hoods** are often used to minimize chemical exposure. Handle chemicals six inches into the hood. DO NOT PUT YOUR HEAD IN THE HOOD and DO NOT KNEEL IN FRONT OF THE HOOD, or anywhere in the lab.

24. **Wash all glassware before leaving lab for the day and return all shared equipment to the designated space.** DO NOT WEAR GLOVES WHILE WASHING GLASSWARE.

25. ***Dispose of all waste as instructed in the lab handout or by the TA.*** Read waste container labels carefully to be sure it's going to the right place. Waste containers are typically in the fume hoods. Let your TA know if a waste container is full. DO NOT LET THE WASTE CONTAINERS OVERFLOW! *Seriously, who does that?!*

26. **NO use of flame in the lab**. Nearly everything in the organic chemistry labs is flammable.

27. ***Wear gloves*** when appropriate in the lab and ***change your gloves*** if you get chemicals on them. They're cheap! Gloves are only a first line of protection. They do not make you invincible! Take off gloves and wash your hands before you leave the room. **DO NOT touch door handles, your face, computers, or phones with gloved hands.**

28. ***Minimize chemical exposure*** (ex. keep containers capped) and treat every chemical as if it were hazardous.

29. **No cell phones or electronic devices are allowed to be used in the labs.** If you'd like to take a picture or video of your experiment, ask your TA for permission, but take your gloves off first.

30. **Treat your TA and labmates respectfully.** Please adhere to your TA's instructions and additional safety guidelines announced. Reach out to instructors if you are having interpersonal issues in the lab and we'll help as much as we can.

31. Please restore your locker to its original status. All equipment must be clean and organized in the drawer, whether or not you used those items.

- Check the equipment list and reference the 'perfect drawer' pic on the bulletin board in the lab.
- Replace any missing or broken items with a quick trip the stockroom. Do not bring broken items with you – place them in the glass or solid waste instead.
- **Check for missing, dirty, broken, and extra items** that may have fallen into your drawer.

Writing Guidelines: Experimentals & References

Please review **Parts A-B** of the writing guidelines from CHEM 8L (available on 8M Canvas site) for general format and writing style (passive voice, no personal pronouns).

Part D: Experimental Methods and Compound Characterization

Experimental methods and compound characterization are found at the end of scientific journal articles, dissertations, and other technical documents. This gives the reader instructions on how to recreate the experiment and confirm the structure of the newly synthesized compounds. The format and general content differs depending on the field. Students will include this section at the end of several lab reports using the generally accepted guidelines followed by synthetic organic chemists: one General Methods paragraph followed by one additional paragraph per compound synthesized. ***A sample Experimental Methods section is attached and contains much more information than CHEM 8M students are expected to include.*** *Use passive voice and past tense.*

General Methods

Reagents and by-products do not get full descriptions but are mentioned in the "General Methods" section with the following statement: "**All reagents were commercially available**, unless otherwise stated." Typically researchers would then describe how reagents and solvents were purified, but *this does not apply to 8M students*. Next, list the **specifications for IR** (medium for analysis, such as salt plates or Teflon) only if used in the experiment.

Experimental Methods & Characterization

Following general methods, each organic compound or reaction gets its own paragraph (one paragraph per reaction/compound). Some or all of the following should be included in the experimental methods and compound characterization section. This is based on experimental techniques students utilized in the lab.

- **Reaction scheme** - including reactants, reagents, products, solvent(s), and % yield
  (structures and reaction schemes can be hand-written)
- **Full chemical name of product in bold** (common and/or IUPAC)
- Brief description of **reaction set up** and **workup** including…
  - Names and amounts of each reactant and reagent (mmol and mL or mg)
  - Name and amount of solvent (mL)
  - Order of addition, if pertinent, and reaction conditions (time, temperature)
  - Description, name, and amount of product obtained and % yield:
    - Ex. "Benzhydrol was obtained as a clear liquid (1.00 g, 87% yield)."

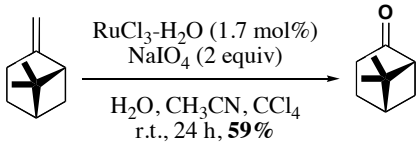
Characterization follows in the same paragraph (after reporting the yield) and includes some or all of the following. There is no characterization for the dye lab.

- Melting point or boiling point
- Distinctive IR stretch(es) – one or two distinguishing peaks, such as carbonyl or O-H stretches

EXPERIMENTAL METHODS AND COMPOUND CHARACTERIZATION

General Methods.

All reagents were commercially available, unless otherwise stated. All air and moisture sensitive reactions were carried out under argon atmosphere using flame- or oven-dried glassware and standard syringe technique. Tetrahydrofuran (THF), dichloromethane (DCM), cyclohexane, triethylamine (Et_3N), morpholine, *tert*-butanol (*t*-BuOH), and dimethyl sulfoxide (DMSO) were distilled over CaH_2. Oxalyl chloride was distilled without drying agent prior to use. Column chromatography was carried out with Silica Gel 60. IR spectra were carried out on NaCl plates with v_{max} in inverse centimeters. Optical rotations were obtained on a digital polarimeter at 20 °C. High resolution mass measurements were obtained on a benchtop ESITOF mass spectrometer.



(+)-Nopinone. $NaIO_4$ (44.96 g, 210 mmol) was added to a 2-L round-bottom flask equipped with a magnetic stir bar and dissolved in water (300 mL), CCl_4 (200 mL), and CH_3CN (200 mL). (–)-β-Pinene (13.88 g, 102.0 mmol) was added followed by $RuCl_3$-$3H_2O$ (457 mg, 1.7 mmol). The reaction was stirred overnight while open to the atmosphere (24 h). The crude reaction mixture was filtered through a pad of celite and rinsed with DCM, creating two distinct layers. The aqueous layer was extracted with DCM (3 x 100 mL). The combined organic extracts were washed with water (2 x 30 mL), dried ($MgSO_4$), filtered, and concentrated *in vacuo* to a black liquid. This was purified by column chromatography (500 mL SiO_2, 100% hexane to elute β-pinene, 4:1 Hexane/EtOAc to elute nopinone) and the nopinone fractions were concentrated to a clear oil (8.3 g, 59% yield). bp 74-76 °C (2 mm Hg), $[\alpha]_D^{22}$ +34.43° (*c* 4, MeOH), IR (neat) 1714 cm^{-1}.

Part E. Format for Literature References (for future reference in lab reports)

There is a standard A.C.S. (American Chemical Society) format for listing references in the chemical literature that you are required to follow (http://pubs.acs.org/books/references.shtml). This format, illustrated below, must be used in the reference section of your report, if appropriate. Be sure to document all assertions and past work described in your reports with a footnote. Footnotes can be referred to more than once. Use superscripts with corresponding numbered references at the bottom of the page or at the end of the report.

Details matter!

- Pay special attention to punctuation (period / comma / semicolon).
- **Years in bold**,
- *Volumes and titles in italics.*

BOOKS

Author's last name, first initial, *Title of Book,* Publisher: City of publication, **Year of pub**.; pages used.

Examples

Crews, P.; Rodríguez, J.; Jaspars, M. *Organic Structure Analysis, 2nd Ed.;* Oxford: New York, **2010**; pp. 67-70.

Palleros, D.R., *Experimental Organic Chemistry;* Wiley: New York, **2000**; pp. 61-70.

JOURNALS

Author's last name, initials.; 2nd author's last name, initials.; (continue for each author). *Journal abbrev.* **Year**, *Vol.,* first to last page of article.

Proper journal abbreviation used in italics*, **year in bold, *volume in italics*, no issue number

Examples

Tansakul, C.; Lilie, E.; Walter, E. D.; Rivera III, F.; Wolcott, A.; Zhang, J. Z.; Millhauser, G. L.; R. Braslau, R. *J. Phys. Chem. C,* **2010**, *114,* 7793-7805.

Sanchez, L. M.; Lopez, D.; Vesely, B. A.; Della Togna, G.; Gerwick, W. H.; Kyle, D. E.; Linington, R. G. *J. Med. Chem.*, **2010**, *53*, 4187-97.

Woehrmann, M. H., Gassner, N. C., Bray, W. M.; Stuart, J. M.; Lokey, S. *J. Biomol. Screen.* **2010**, *15,* 196-205.

WEB SITES

Use full website addresses to allow the reader to locate referenced material on the web. **Be wary of the content. The info on the web is usually not peer reviewed, and can be erroneous!** If you do cite a website, include the date the website was accessed.

Example

http://organicchemistry.wordpress.com/2007/08/18/tips-for-writing-organic-chemistry-lab-reports/ accessed 7-23-09.

Safety Scavenger Hunt

Welcome to the organic teaching labs! We want your time in the lab to be just as enjoyable as it is educational. You'll learn how to handle equipment properly to eliminate or minimize contamination and chemical exposure. Please keep your lab space neat and organized at all times, similar to cleaning the kitchen dishes as you're cooking or baking. Instrumentation is shared with the rest of the class so we'll work together to stay safe.

Student lockers, reagents, equipment, and instrumentation are organized, set up, and otherwise maintained by the stockroom staff, all of which are very nice people. Please value their time, efforts, and kindness by **leaving the lab as you found it or better**.

Lab Orientation Content

A. Lab Safety Scavenger Hunt
B. Equipment Locker

Part A. Lab Safety Scavenger Hunt

Get to know your space!

- Work with your lab-mates to find the following items in the lab and their corresponding tag.
- Make a **lab map** on the next page and mark the locations by number.
- **Fill in the blanks** in this packet with the information on the tags.
- There are some items for which there are multiple locations, such as sinks, but only one tag.
- Other items may not be in the room at all!

Emergency Response	Day-to-Day	Equipment
1. Fire Extinguisher	**9.** Balance Station	**16.** Equipment Room (GC & IR)
2. Fire Alarm	**10.** Sink	**17.** Rota-vap
3. Safety Shower	**11.** Chemical Waste Station	**18.** Water Re-circulation Pumps (water lines)
4. Eyewash Station	**12.** Dry Waste Box	**19.** Ring stands
5. Evacuation Procedure	**13.** Chemical Fume Hoods	**20.** Clamps
6. First Aid Kit	**14.** Reagent Station (Chemical Reacting Agents)	**21.** Vacuum Tubing
7. Broken Glassware Box, Dust Pan & Broom	**15.** Disposable Gloves	**22.** Hot/stir plates
8. Spill Control Center		

Miscellaneous

23. Your TA – go say hi!
24. One-word hazard definitions & precautions
25. NFPA Labels - Copy and color the NFPA label description from the bulletin board then classify the sample labels posted.
26. Lab coats

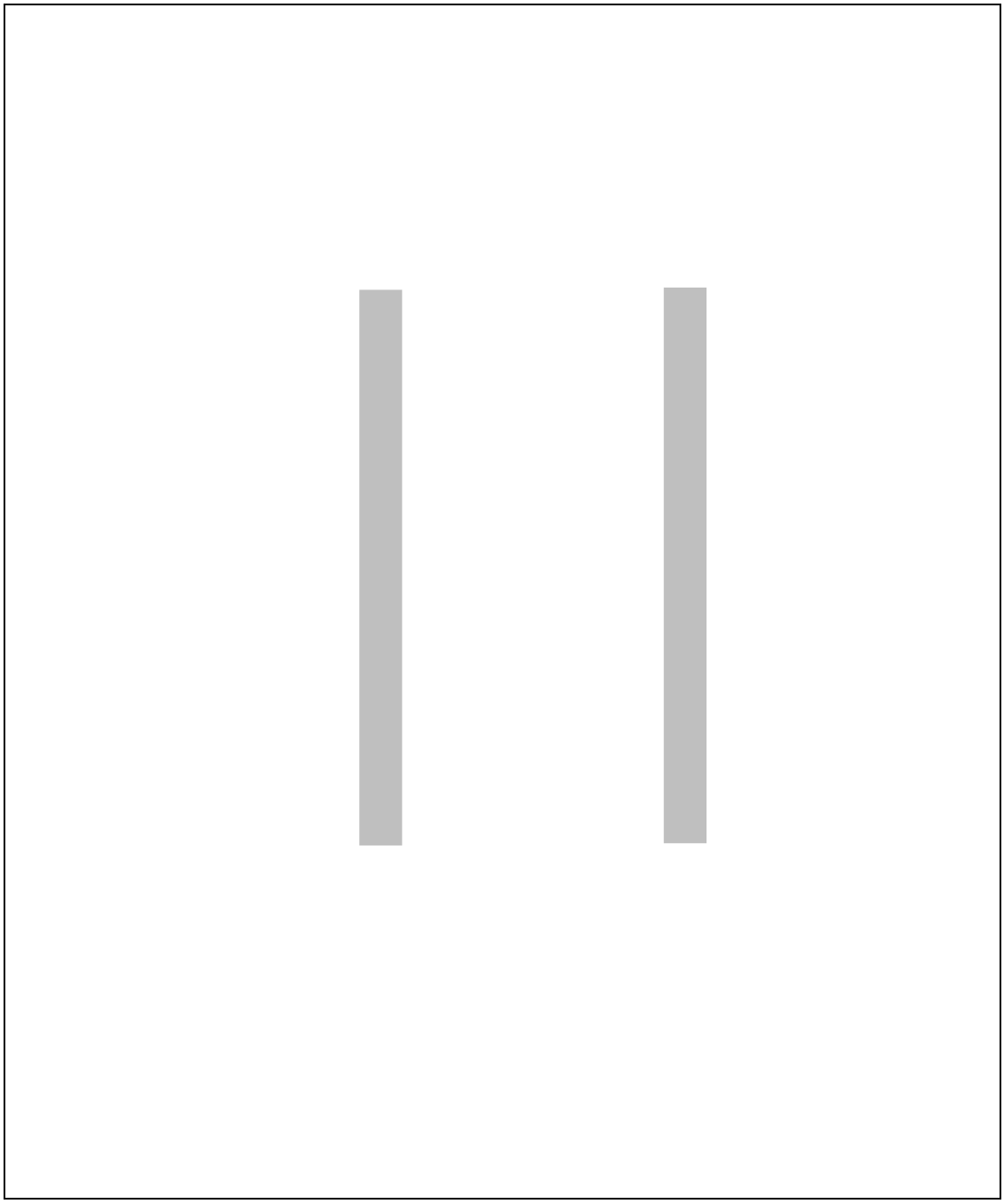
LAB MAP, Thimann Labs

Get familiar with the new lab space by adding the locations of items to **make a map by number (1-26)**.

Keep this map handy for future reference!

Start by adding the DOORS and WINDOWS for reference.

HALLWAY



1. Fire Alarm: find the closest one in the hallway

* Located at the _____building entrance and exit left of the elevator.

* Pull this alarm only if you see a fire. Don't assume someone else has called it in.

* Alert by-standers by yelling "_____**!**"

* Individuals should also notify the fire department by calling _____.

2. Fire Extinguisher: find the closest one in the hallway

* Located in the hallway between rooms ____/_____ and ____/_____.

* Report the fire, _____,_____, and EXIT the building.

* Only _____ should attempt to extinguish a fire

(…so you should probably not be using this, but it's good to know where it is).

3. Safety Shower

* To be used if student is splashed with a considerable amount of _____that cannot be _____.

* DO NOT pull it to test it! Only do it if you need it. It puts out a set, large amount of water.

* If needed, disrobe and stand under the shower for _____ to wash away the chemical and reduce contact (_____).

* Call 911 for severe cases.

4. Eyewash Station

* You shouldn't need this because you should be _____!

* Hold the eyelid open in the running eyebath for _____ min.

* Call _____or go to the _____ if the injury requires further medical attention.

5. Evacuation Procedure

* Take the _____ to evacuate the building instead of the _____.

* Follow the map to the rendezvous point and take a quick spin on the _____.

* Follow the path down the little hill, cross the street, and **take a selfie next to the 'Thimann Laboratories Emergency Assembly Area' sign. Show your TA for credit!**

6. First Aid Kit

* Located in the _____. * Sufficient for _____& _____.

* All injuries must be reported to the TA followed by the completion of an "_____

Form" attained from the stockroom staff.

* For extensive injuries, student is escorted to the _____ before _____ or immediately call

_____ if after _____.

7. Broken Glassware Box, Dust Pan & Broom

* Disposal container for _____ broken glassware.

* Please use the dust pan and broom to sweep up any tiny glass pieces.

* If it's not _____, it doesn't go in here!

8. Spill Control Center

* All spills must be _____.

* _____**(**_____**)** will neutralize solutions that are acidic / basic.

***** _____ should be used for absorbing spilled solvents.

* For spills larger than a few milliliters, it may be necessary to evacuate and call x911.

9. Balance Station

* Read the BALANCE ETIQUETTE SIGN * Use piece of _____ to weigh solids.

* _____ to help the transfer.

* Bring the container you're transferring into – DO NOT walk around the lab with _____

_____**!**

* *Always* _____ the balance pan and _____. NO SNOW

STORMS of chemical powder here!

10. Sink

* After properly disposing of _____, wash glassware with _____ and _____, then rinse twice with DI water.

* This is NOT a waste bin. Only _____ and_____ down the drain!

* Note which sinks in this room, if any, have a flood hose.

11. Chemical Waste Station

* Waste bottles are kept here in _____(bin to catch spills).

* *Read the waste label* – there may be more than one type of liquid waste.

* Pour *into* the waste bottle using the _____provided (not onto the bottle. Yes, someone's done that before. Not cool).

* _____ if a waste bottle is full. Don't let the containers _____.

12. Dry Waste Box

* For solid waste from experiments such as _____, _____, and _____.

* DO NOT put _____in the dry waste box.

* If it's a liquid, it doesn't go in here!

* _____ if you are unsure of what goes in the dry waste box AFTER reading the guidelines above and instructions in lab procedures.

13. Chemical Fume Hoods

* Minimizes your _____to_____

* Work with the chemicals at least _____ into the hood

* Hood cover/sash should be_____to the_____or else!

* DO NOT put _____ in the hood! * Keep surfaces clean – clean up spills

14. Reagent Station

* Take only what you need from bottles * Keep surfaces clean – clean up spills!

* Prevent contamination - DO NOT return _____to_____

* Bring a _____and _____ for transfer – DO NOT walk around with a full pipet!

* Carefully read labels twice * Carefully_____

15. Disposable Gloves

* This is a _____ line of defense * Gloves do not make your hands _____!

* _____gloves if you get chemicals on them

* Let your TA know if a box is _____…also, be a good human and place said empty box in the _____!

16. Equipment Room

* GCs can be hot! Don't leave _____ on top

* Keep GC/IR kits tidy (_____) when in use

* Clean up spills when they happen

* Ask your TA to show you around the instrument room.

17. Rota-vap

* Used to_____samples: Round-bottom flask is attached, rotation prevents boiling over as _____ is applied to remove solvent, which is collected in the _____.

* Your TA will _____ and/or set this up for you the first couple times.

* Please _____ when not in use. * Be respectful – empty that _____!

18. Water Pump & Water Lines

* Don't let pumps _____, check frequently
* Know your in's and out's – _____ is water in, _____is water out
* Water lines run near _____ – watch where you point those things!
* Only use the clamps to adjust flow – please do NOT_____

19. Ring Stands

* Used to secure _____ using _____.
* Stack them in an _____
* Remove all _____before returning

20. Clamps

* Separate clamps from _____
* Do not leave _____ or other items in this drawer
* If the threads on the clamp become worn and no longer work, please bring it to the _____ so we can try to fix it

21. Vacuum Tubing

* _____ tubing for connecting a vacuum line.
* Ask your TA where to connect to the _____.
* Return tubing when you are finished.
* Do not use for_____; vacuum only.

22. Hot / Stir Plates

* Note that there are separate dials for '_____' and '_____' and that different hotplates have different types of _____ settings.
* Mind where the cord lies to prevent_____
* Set heat on or below _____ setting. These hot plates get ridiculously (unsafely) hot on ___.
* When finished, put them away neatly, no leaning towers of hot plates please.

23 – What is one of your TA's hobbies or interests?_____

Share something similar with your TA 😊

*** 24 & 25 are on the following pages ***

26. Lab Coats

* Worn over _____.
* Must be worn with _____ during all experimentation and cleaning.
* Contaminated lab coats are considered waste. Notify your TA and bring the coat to the _____ if you spill on your lab coat.
* Lab coats are shared with many sections – be considerate and do not leave _____in the pockets!
* Hang up coats neatly on the hanger labeled with the _____.

24. Hazard Definitions

In the case of exposure to any chemical, rinse the affected area immediately for _____and _____.

Copy the following precautions to be taken when handling the following types of chemicals then find the HAZARD TERMS below.

- *Irritant* – irritates the_____; minimize_____, wear _____ &_____
- *Flammable* – keep away from_____& potential_____, handle in_____ with_____ & _____
- *Lachrymator* – induces_____; wear _____&_____
- *Carcinogen* – linked to_____; minimize_____, wear _____&_____, handle in_____
- *Corrosive* – _____ and _____ the skin; minimize_____; wear_____& _____.

HAZARD TERMS

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

CARCINOGEN CORROSIVE FLAMMABLE

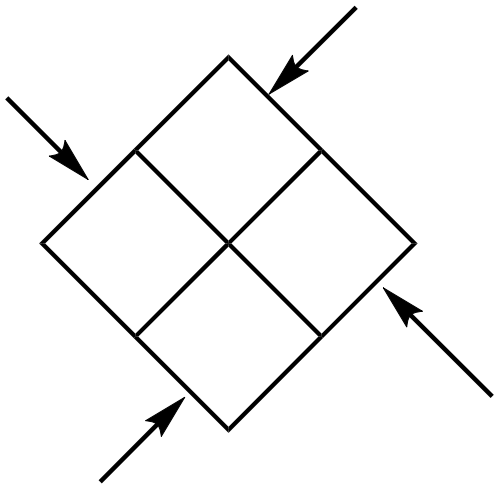
HYGROSCOPIC IRRITANT LACHRYMATOR

SAFETYFIRST SLUG TOXIC

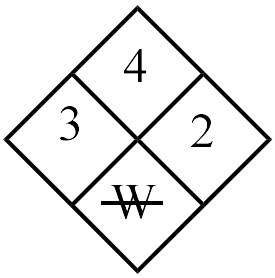
25 – NFPA Labels - Copy the NFPA label description from the bulletin board. Color them in if you have the equipment!

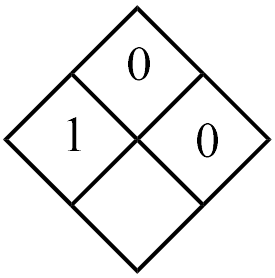
What does NFPA stand for? _____

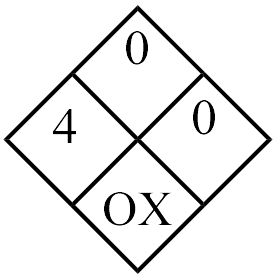
Hazard Classifications



Classify each of the examples below using the ratings above. Forgive the lack of color, feel free to add your own!







Health Hazard			
Fire Hazard			
Specific Hazard			
Instability			

Part B. Equipment Locker

Clean & Organized Drawer = Safe & Orderly Experiments 😊

- Find the locker **equipment list** in addition to pictures of glassware and the pictures of the drawers.
- Check that all your equipment is present in your drawer.
- There should be **no missing, extra, dirty, or broken items** after lab.
- At the end of each lab, pick up each item from your drawer to make sure there are no cracks or chemicals present, even if you didn't use that equipment that day (things can fall into your drawer!).

Sketch and name at least **three items** from your drawer that are new to you

Lab Basics – Balances, Pipets, & Solutions, oh my!

Part C. Making Solutions

1. Find the molecular mass, boiling point, melting point, density, and safety hazards in the Material Safety Data Sheet (MSDS) in the lab.
2. Enter the chemical name and amount measured for the solid in milligrams and for the liquid in milliliters.
3. GO TO THE PROCEDURE. Enter data on the following pages AND below.

	Chemical Name	**Amount**	**Molecular mass (g/mol)**	**Moles (mmol)**	**Boiling or melting point (°C)**	**Density (g/mL)**	**Safety Hazards**
Solid **Part C.1**		mg					
Liquid **Part C.2**		mL					

Part C.1. PROCEDURE - Measuring Solids

- The digital balances read in grams (g) so you'll need to convert to milligrams (mg).
- There are 1000 milligrams in every gram (10^3 mg / 1 g) or (1 g / 10^3 mg).
- **Convert 50 mg into grams:** 50 mg = _____ g

Use the "Balance Etiquette" on next page - weigh **approx. 50 mg (± 10 mg)** of your assigned solid…

- Note (± 10 mg) means your measurement can be 10 mg higher or lower than 50 mg.

40 mg = _____ g 60 mg = _____ g

- **Record the exact mass measured**: _____ mg
- **Convert mass (mg) to millimoles (mmol)** using the molecular mass of the solid.

_____ mmol

- Copy relevant data to the table above.
- **Transfer the solid** into a small beaker or Erlenmeyer flask labeled with chemical name.

PROCEDURE - Balance Etiquette

Line at the balance? Introduce yourself to the person in front of you and they'll tell you when they're done!

1. Bring a **spatula** or **scoopula** & **labeled container** into which to transfer the solid.
2. **Fold the weigh paper** in half on the diagonal and place on the balance pan
3. **Tare (zero) the balance**
4. **Add the solid** onto the paper and record the mass
5. **Place extra solid** on separate weigh paper, *not back into the original container*
6. **Close the container**
7. **Transfer the solid** into the labeled container (ex. Erlenmeyer flask or beaker)
    - **DO NOT walk around the lab with solid on weigh paper!**
8. **CLEAN**! Brush spilled solids onto **separate weigh paper** then transfer to the **solid waste**.
    - **Dispose of weigh paper** in the trash
    - **Wipe down the counter** with a wet sponge or paper towel

Part C.2. PROCEDURE - Measuring Liquids and Making Solutions

Use the steps below to measure 15.0 mL of deionized water (diH_2O) and mix with your solid...

1. **Label** the 25-mL graduated cylinder from your drawer (diH_2O).
2. Locate the diH_2O reagent bottle in the **fume hood**.
3. **Pour a little under 15 mL** from diH_2O reagent bottle into the large grad cylinder in your drawer.
4. **Use a glass pipet and bulb** to remove or add smaller volumes of water to get to exactly 15.0 mL.
    - Transfer any excess water into a separate container, NOT back into the reagent bottle.
5. **Convert volume (mL) to millimoles (mmol)** using the density and molecular mass of water.

_____ mmol

6. **Make the solution:** Transfer the diH_2O into the container with the weighed solid from **Part C.1**.
    - Swirl to dissolve completely.
    - *What's happening at a molecular level as the solid seems to disappear?*
        - **Sketch diagrams** of the following forces:

Solid: ionic bonds	**Liquid:** Hydrogen-bonding	**Solution:** Ion-dipole interactions

7. **Calculate the solution concentration**.
    - Molarity = (mmoles solute) / (mL of solution) = _____ M

<u>Part C.4. PROCEDURE - Mixing Solutions</u> – pluringe and graduated cylinder practice

What's a pluringe and how do I use it? A pluringe is a disposable glass pipet connected to a reusable syringe with rubber tubing (pluringe). This allows the synthetic chemist to obtain small volumes of liquids with reasonable accuracy and precision. The pipet needs only be inserted into the rubber tubing enough to stay put, not all the way, as it becomes difficult to remove later. The pluringe is re-usable as long as it does not come into contact with liquids. It is easy to avoid pluringe contamination:

- **DO NOT turn the pluringe upside-down when liquid is in the pipet.**
- **Obtain only volumes smaller than the pipet or pluringe itself.**

Only the glass pipet touches liquid, not the rubber tubing or syringe. Pipets can go in the glass waste if the pipet was only used for water. Broken syringes can be exchanged in your lab – find the little plastic cup with spare good syringes.

Part C.4. PROCEDURE - Mixing Solutions

- Pair up with another student to share solutions.
- Transfer their solution into yours using each of the following tools from your drawer. Record the volume.

Instrument	Volume from instrument (mL)	New volume after mixing (mL)
1-mL pluringe		
3-mL pluringe		
10-mL grad cylinder		

***Group Discussion*: What would happen if…**

…you quickly pulled back the syringe to obtain liquid? Or if you quickly pushed the syringe to transfer?

…you were transferring a second portion of liquid into a container and dipped the tip of the pipet into the liquid in that container?

…you dispensed more liquid into the pluringe than the capacity of the pipet? What is the volume of a short-stem glass pipet?

…you threw away a glass pipet in the regular trash?

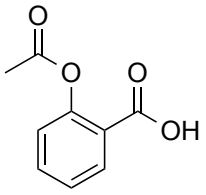
Part C.5. CLEANUP - Keep lab coat, goggles, and mask ON

1. Dispose of chemicals in appropriate **waste container**. Throw away your **gloves** in the regular trash.
2. **Wash glassware** with soapy water and brush. Rinse with diH_2O. Leave to dry on paper towel.
3. **Wipe down the counter** at your workstation with a wet sponge then dry with a paper towel.
4. Ask your TA for a **community cleanup task**.
5. **Put away glassware** in your drawer, leaving upside-down to dry if necessary and possible!
6. **Wash your goggles** with soapy water. Rinse with diH_2O, blot to dry, then hang on the pegs for goggles.
7. Take off your **lab coat**, empty the pockets, and place on the appropriate hanger by size.
8. **Wash your hands.**
9. Double check with your TA that it's ok to leave then say bye to your lab buddies!

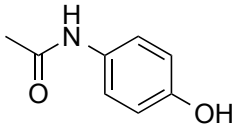
CHEM 8M, Experiment 1
Separation of Excedrin Ingredients *via* Column Chromatography
- TLC Analysis & Percent Recovery

Exp's 1 & 2 = Column Chromatography & Acid-Base Extraction for Excedrin Separation
Revell, K. D. *Journal of Chemical Education.* **2011**, *88*, 1413.

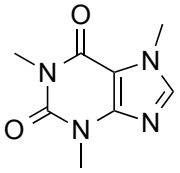
Aspirin (ASP)



Acetaminophen (ACE)

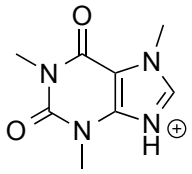


Caffeine (CAF)

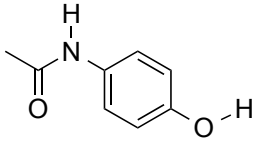


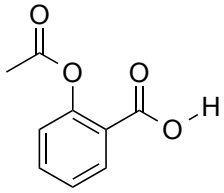
Functional Groups, Intermolecular Forces (IMFs), & Polarity

- Ion-dipole

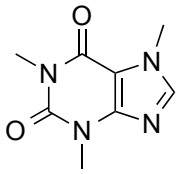


- Hydrogen bonding (H-bond)





- Dipole-dipole



CHROMATOGRAPHY →

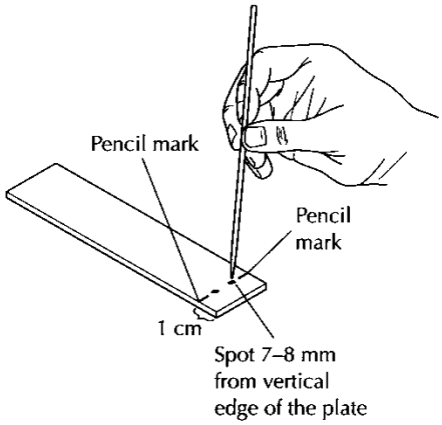
(S) Stationary Phase = SiO_2

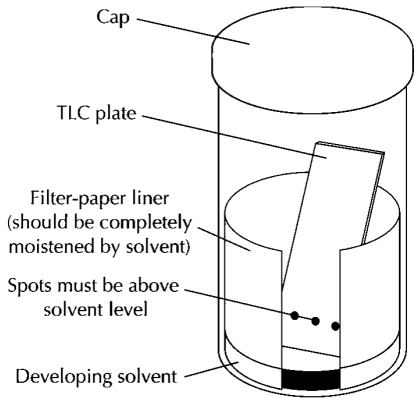
(M) Mobile Phase = Organic Solvents
Hexanes, Ethyl Acetate (EtOAc), & Acetone

- Order of Separation

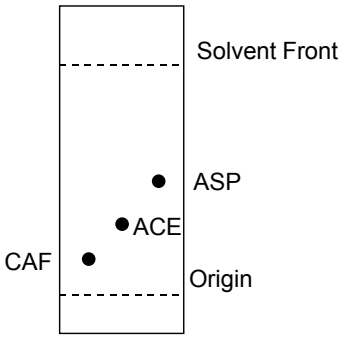
- Degree of Separation

Thin-Layer Chromatography (TLC) Analysis – ACE, ASP, & CAF Standards





TLC Analysis of Standards

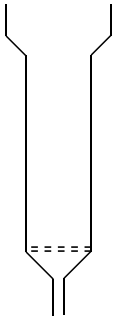


highly conjugated compounds are "UV active"

components absorb UV radiation, easy to visualize TLC plates

TLC analysis of fractions
after column chromatography
(Example from Revell article)

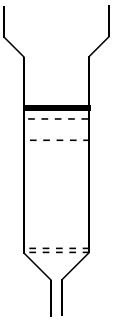
Prepare Solvent, then Pack & Load the **Column for Liquid Chromatography**



3. Sand

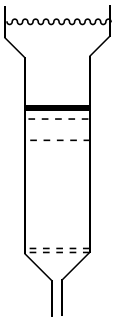
2. Excedrin - coated SiO_2

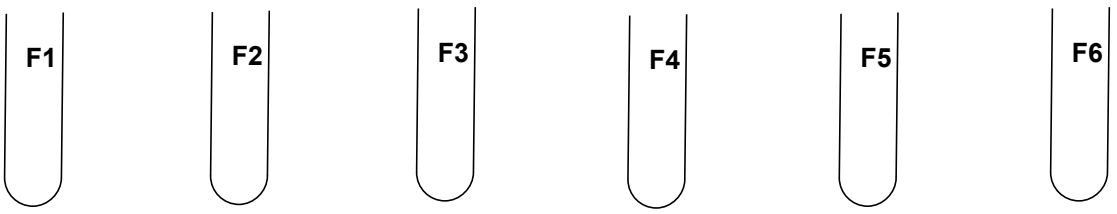
1. SiO_2



4. Carefully add first portion of 1:1 Hex / EtOAc

Run the Column





5. Elute 30 mL of 1:1

6. Elute 30 mL of 1:2

7. Elute 30 mL of Acetone

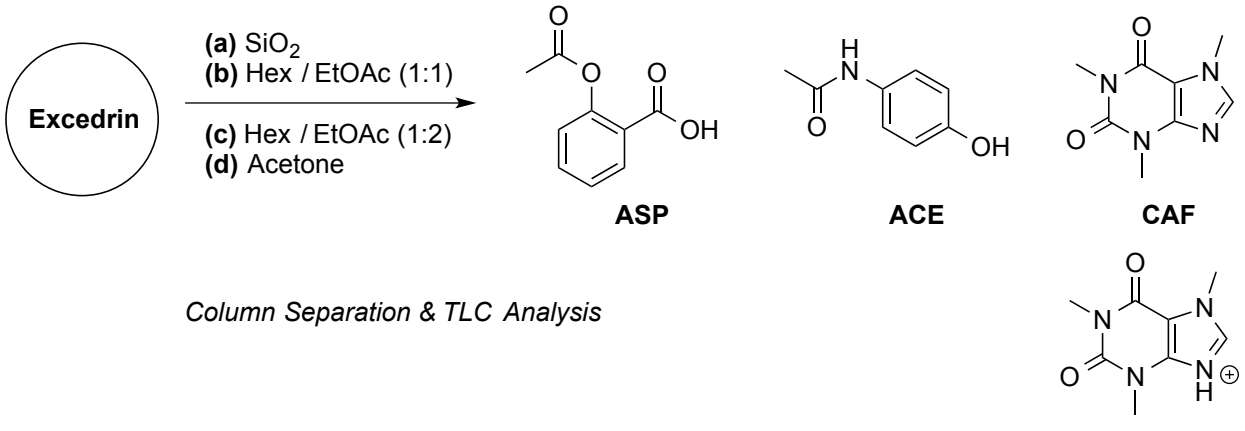
8. TLC Analysis of Column Fractions

9. Combine & concentrate appropriate fractions *in vacuo* (rotary evaporator, rota-vap)

10. Percent (%) Recoveries from Excedrin tablet (~675 mg)

1 tablet = 250 mg ACE, 250 mg ASP, 65 mg CAF, plus inactive ingredients

Experiment Overview



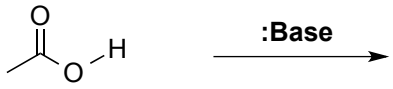
CHEM 8M, Experiment 2 – Two-Base Extraction of Excedrin Components

(1) Extraction / separation (2) Analysis: TLC & IR

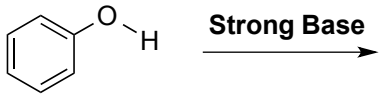
ACIDIC & BASIC FUNCTIONAL GROUPS (FGs) **vs.** **NEUTRAL FGs**

(accepts or donates protons, H^+) (not acidic or basic)

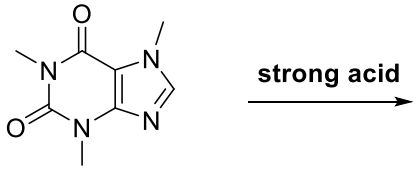
- Carboxylic acids, phenols, amines - Esters, alcohols, hydrocarbons



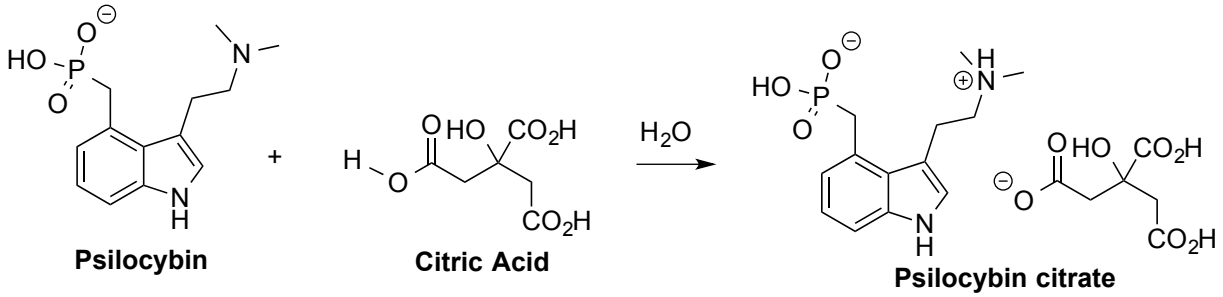
- Phenols



- Amines

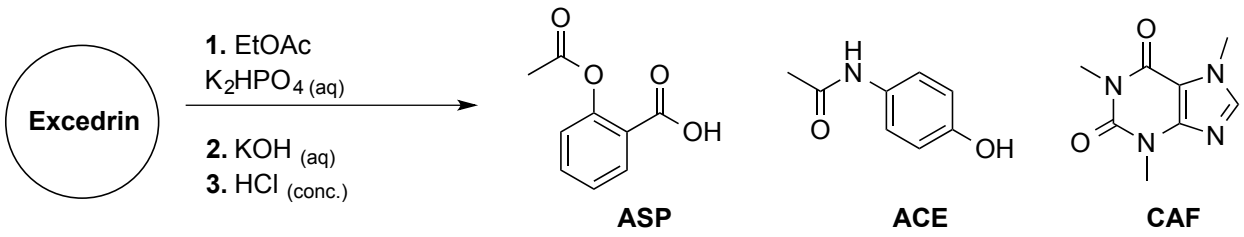


CAF



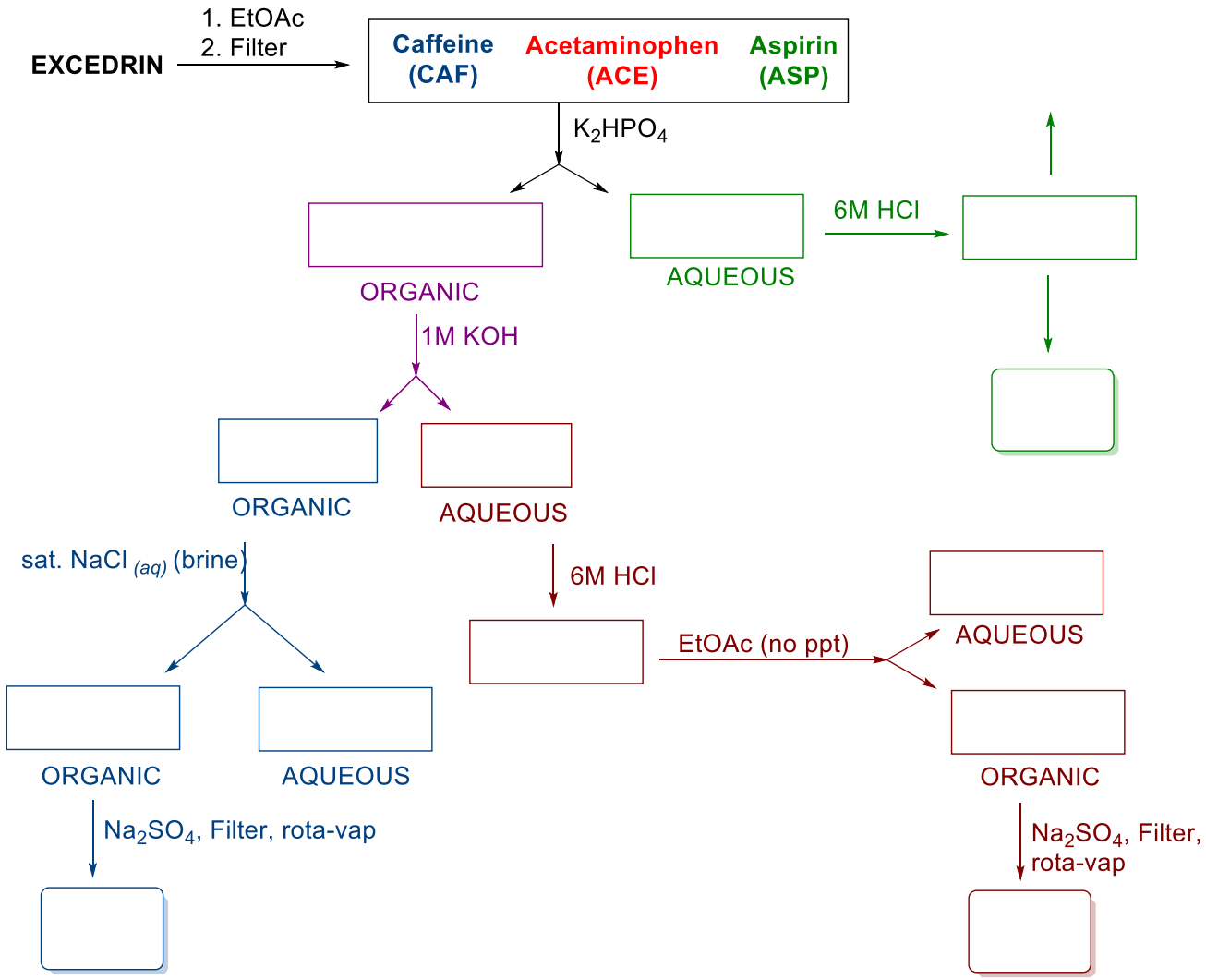
Psilocybin **Citric Acid** **Psilocybin citrate**

Two-Base Extraction of Excedrin's Active Ingredients



Extraction Flow Chart

- What's where and when?!

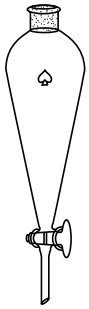
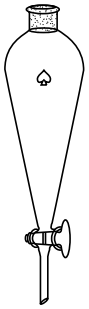
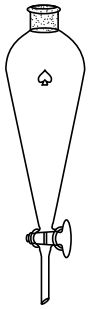


LIQUID-LIQUID EXTRACTION

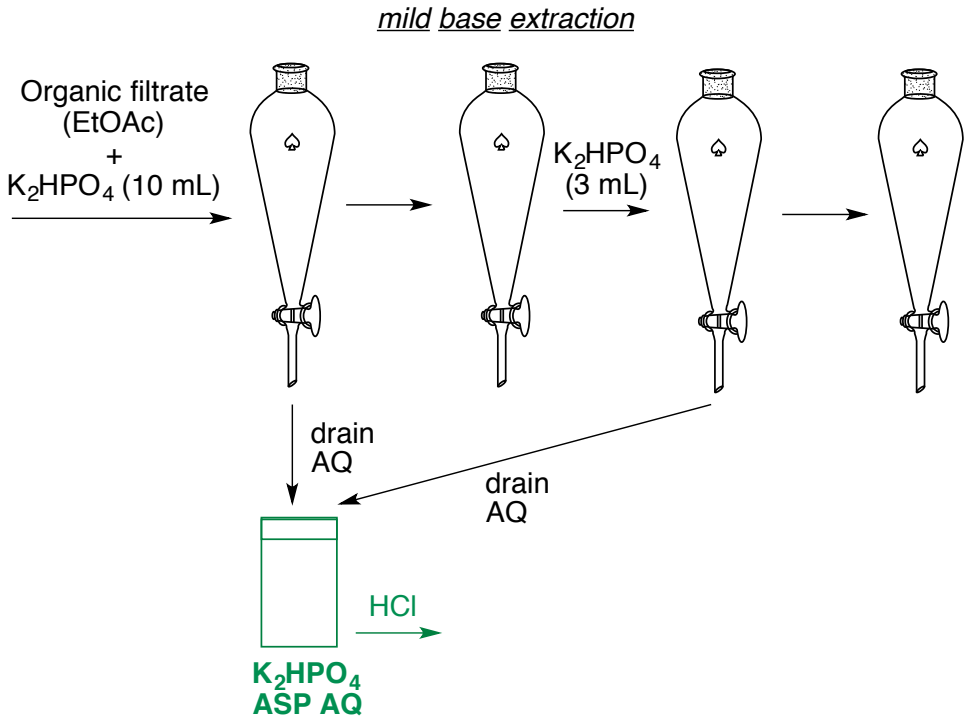
- 2 immiscible liquids have distinct densities and polarities
- Component(s) have a solubility preference for one layer: aqueous (AQ) & organic (ORG)
    - PARTITION COEFFICIENT = ratio of solubilities in 2 solvents

Procedural Lingo…

Basic Extraction	***Acidic Extraction***	***Washes***
"*Extract the ORG layer w/ AQ base"*	*"Extract the AQ layer w/ ORG solvent"*	*"Wash the ORG layer with sat. NaCl (brine)"*

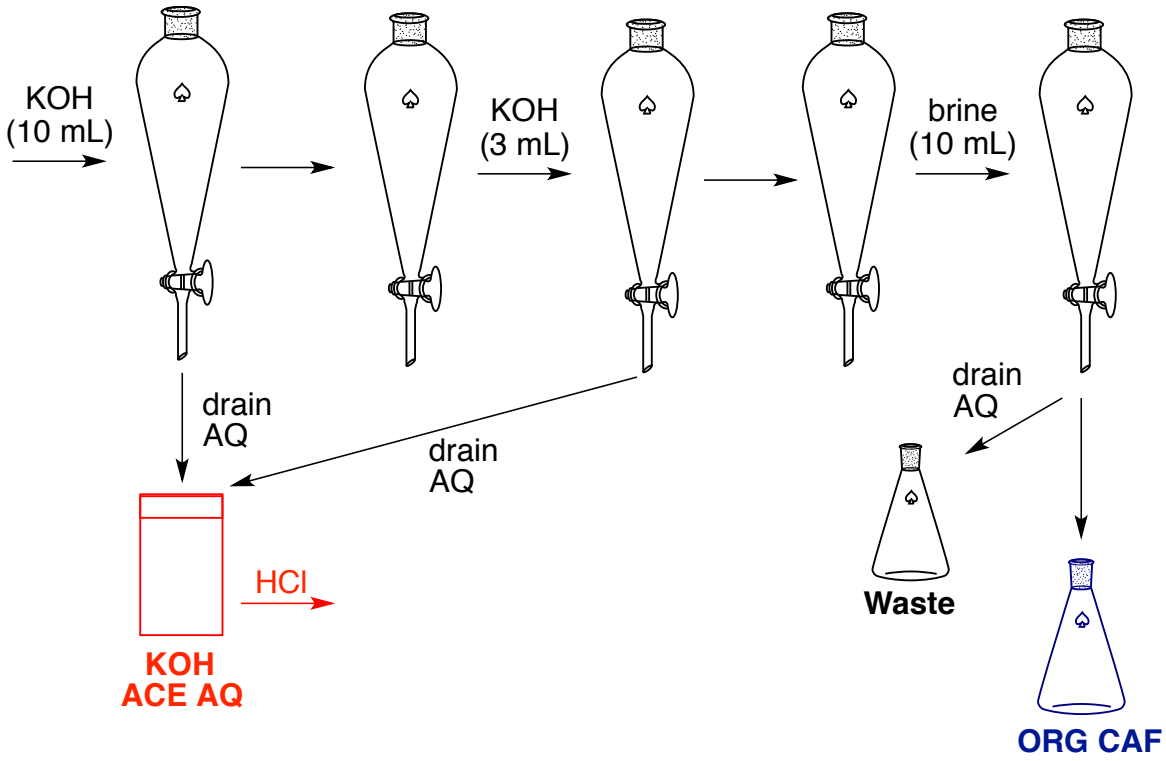




1. Isolation of Aspirin



2. Separation of Acetaminophen & Isolation of Caffeine

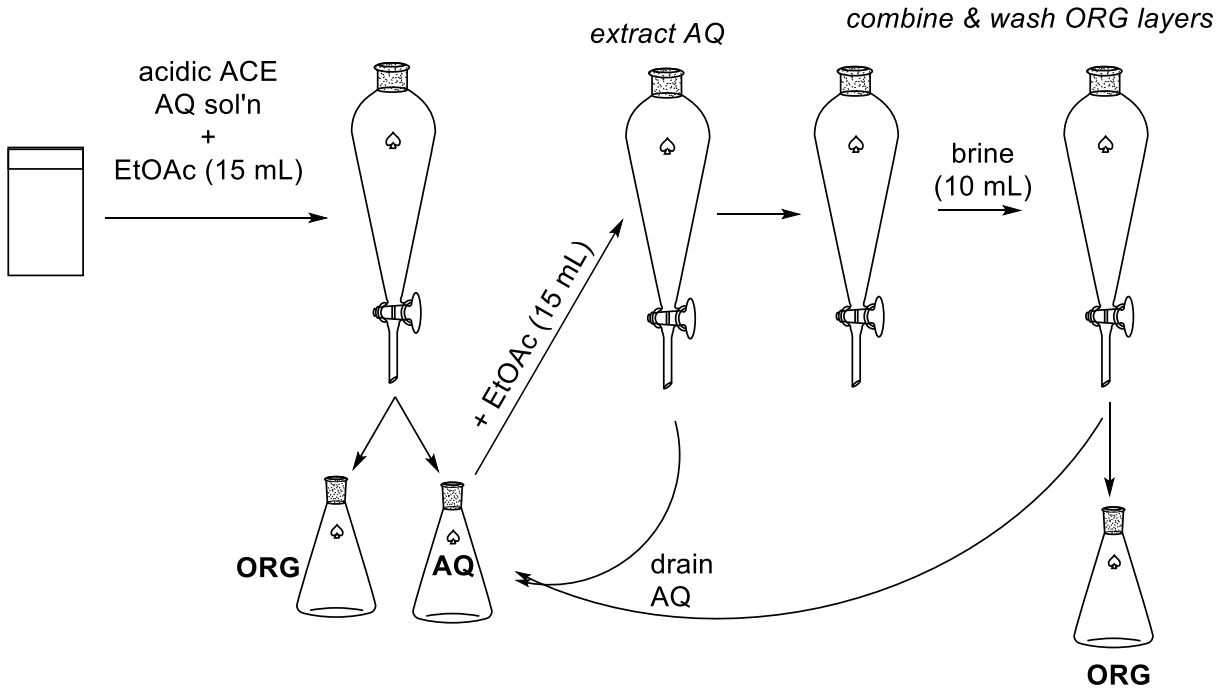
strong base extraction



3. Isolation of Acetaminophen

- ACE typically does not precipitate upon addition of HCl

Acidic aqueous extraction of ACE



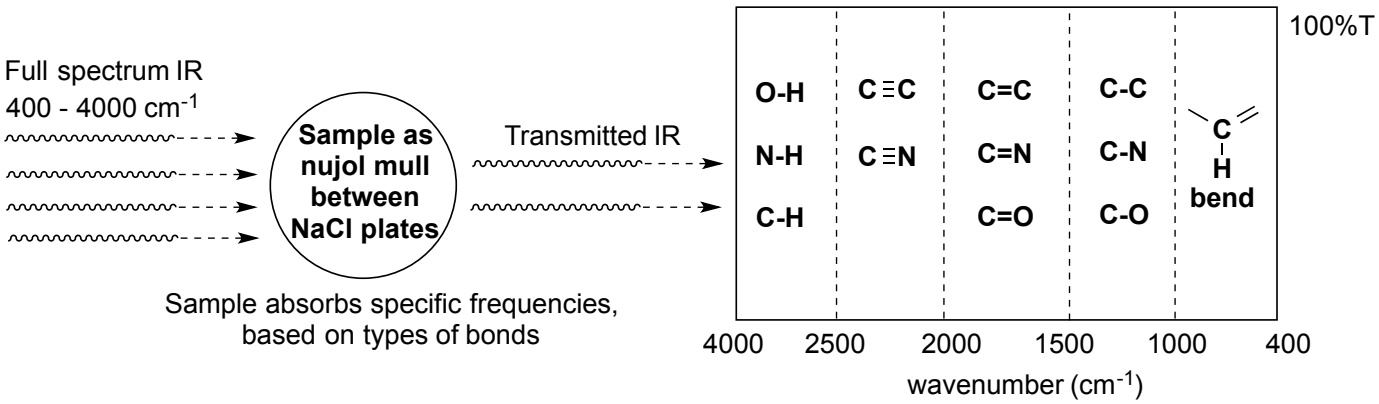
Analysis of Excedrin Components *via* TLC and IR Spectroscopy

1. TLC – same as Exp 1! TLC mobile phase = 1:2 Hex / EtOAc w/ 1% HAc

- dilute solids & check for purity before IR analysis

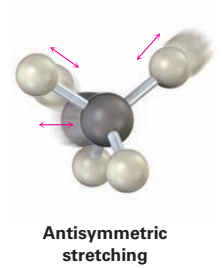
ASP **ACE** **CAF**

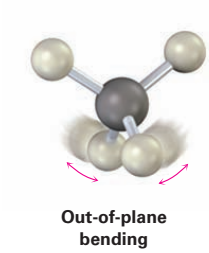
2. IR analysis = detection of bonds within specific functional groups



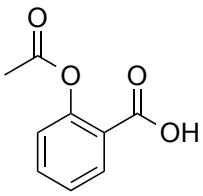
- Frequency of vibration depends on **bond length**

- **Longer bonds** have greater distance to expand/contract = **slower frequency,** ⇓ν

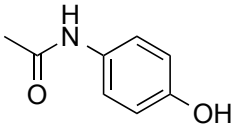

Antisymmetric stretching


Out-of-plane bending

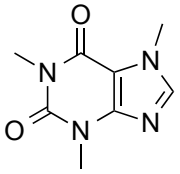
Identify the **functional groups** and **expected IR ranges** from IR table on Canvas.



ASP



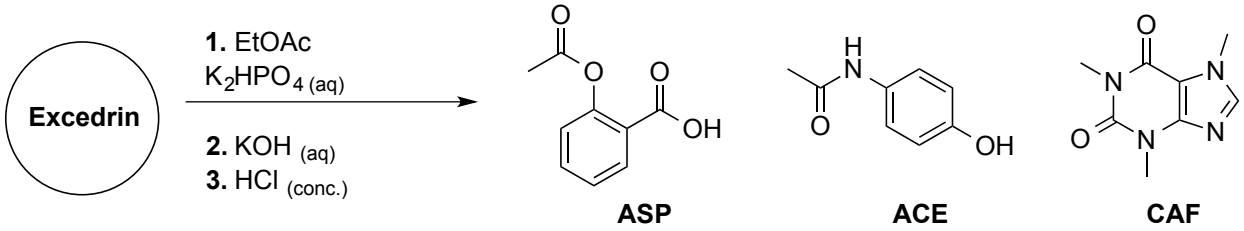
ACE



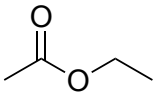
CAF

Conjugated vs. saturated double bonds

Exp 2 Overview



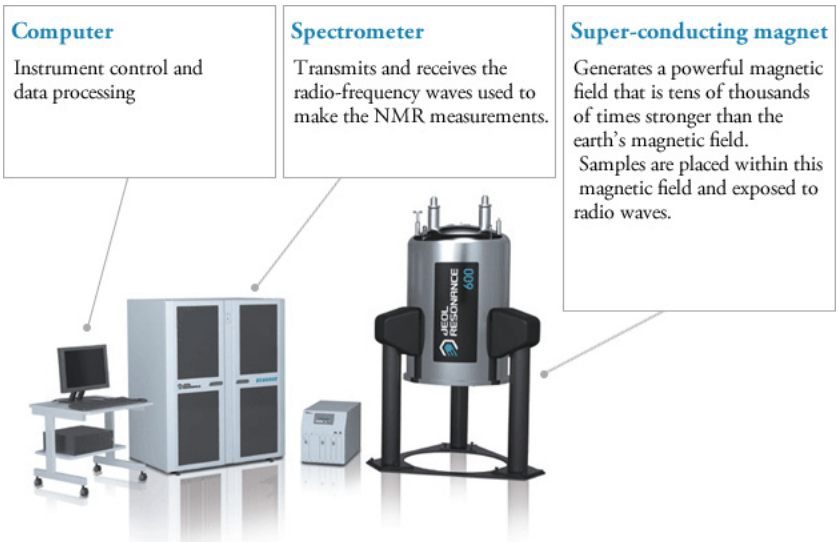
CHEM 8M, NMR Spectroscopy for Structure Determination



ethyl propanoate … says who?!

NMR = Nuclear Magnetic Resonance

INSTRUMENTATION



ATOMIC NUCLEI, ex. ^{1}H atoms

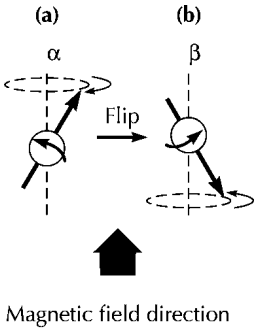


FIGURE 22.3 Nuclear magnetic dipole (a) aligned with an external magnetic field (α) and (b) opposed to an external magnetic field (β).

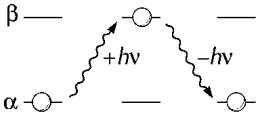
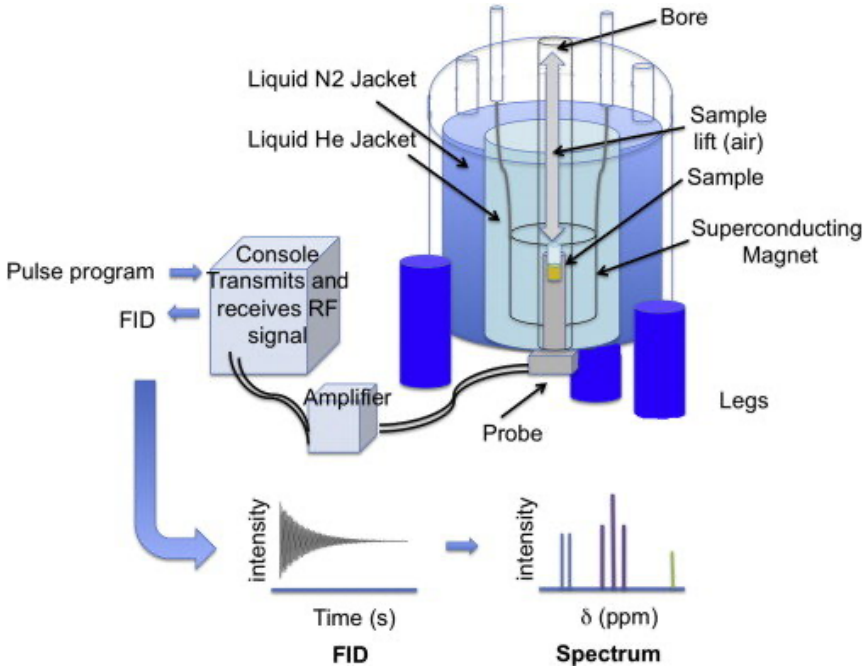


FIGURE 22.2 Excitation of a nucleus from its low-energy state to its high-energy state and emission of energy upon relaxation of the nucleus.



^{1}H NMR is used determine or confirm a chemical structure

- **Chemical Equivalence***:* How many different types of protons are in the molecule?
- **Chemical shift:** What is the chemical environment of those protons?
- **Integration:** How many H's are represented by each signal?
- **Splitting:** How many H's are nearby?

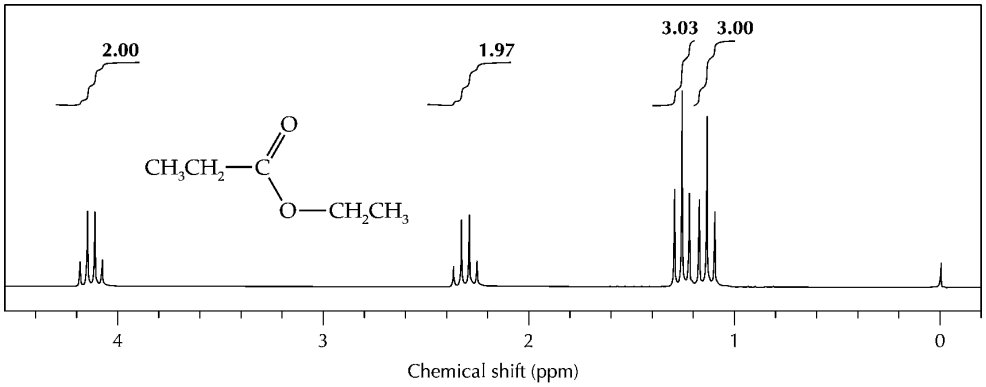


FIGURE 22.11 ^{1}H NMR spectrum of ethyl propanoate at 200 MHz.

One type of "NMR-active" nucleus can be observed in an experiment at a time: ^{1}H, ^{13}C, ^{11}B

- **^{1}H NMR = "proton NMR"** is most common / useful because **^{1}H isotope > 99% abundance**.
  - Small amount of sample (< 10mg)
  - Quick run time (< 5 min).
  - Chemical shift range: 0 – 12 ppm
- **^{13}C NMR = "carbon NMR"** is also widely used.
  - **^{13}C isotope < 1% abundance**
    - more sample (< 30mg)
    - longer run time (30+ min)
  - Chemical shift range: 0 – 220 ppm

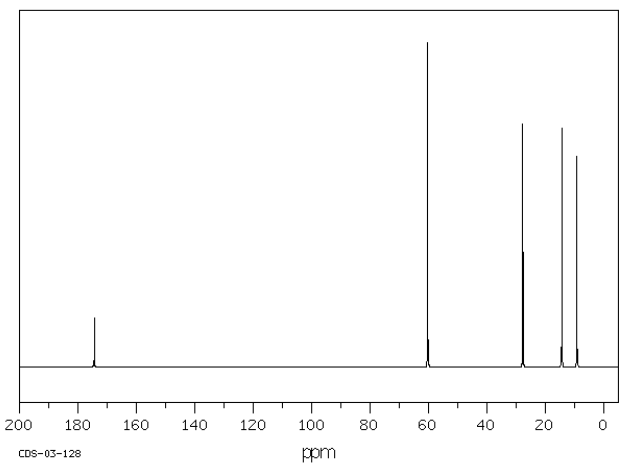


TABLE 21.1 Deuterated solvents for NMR spectroscopy

Solvent	Structure	Residual ^{1}H signal (ppm)	^{13}C chemical shift (ppm)
Chloroform-d	$CDCl_3$	7.26 (singlet)	77.0 (triplet)
Acetone-d_6	$CD_3(C{=}O)CD_3$	2.04 (quintet)	29.8 (septet), 206.5 (singlet)
Deuterium oxide	D_2O	4.6 (broad singlet)	—
Dimethyl sulfoxide-d_6	$CD_3(S{=}O)CD_3$	2.49 (quintet)	39.7 (septet)

^{1}H NMR = “Proton NMR”

CHEMICAL SHIFTS, EQUIVALENCY, & CHEMICAL ENVIRONMENTS

- Nearby atoms / FG’s cause the chemical shift to be **higher (deshielded)** or **lower (shielded)**
  - **Shielding** = electron clouds ‘protecting’ the nucleus from experiencing the magnetic field of the NMR instrument
- Pi bonds, electron-withdrawing groups (EWG’s), & electronegative (EN) atoms cause **deshielding**

Deshielded H’s

Strong δ^+

↑Chemical shift

Shielded H’s

Weak δ^+

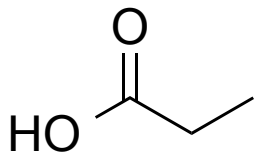
↓ Chemical shift

CH_3OCH_3

$Si(CH_3)_4$

Relate the terms below to propanoic acid…

- Chemical Equivalence



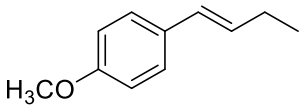
- Integration

- Chemical Shifts

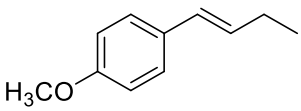
12 0

Chemical Shift (ppm)

How to Predict ^{1}H NMR Spectra



1. **Chemical Equivalence**: How many **^{1}H NMR absorptions** are expected?
    - How many **types of non-equivalent protons**?
2. **Integration:** What is the ratio of peak areas expected upon **integration** of the spectrum?
3. Approximate the **chemical shift** for each type of proton using the NMR correlation tables.
    - **Table 22.2…H**-C-("Group") used to assign most appropriate **chemical shift range**
    - **Tables 22.3 and 22.4** are used to calculate an expected chemical shift based on nearby atoms
        i. Use **Table 22.4** for H's connected to a benzene ring; use **Table 22.3** for all other H's
4. **Splitting & (n+1) rule:** Number of H's adjacent to each set of H's

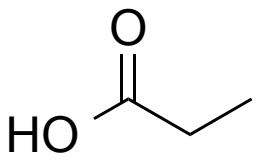


12 0

Chemical Shift (ppm)

Proton Splitting aka **^{1}H-^{1}H Coupling** and the **"n+1 Rule"**

- *Non-equivalent signals (neighboring proton nuclei) effect each other's* ***peak shape****.*



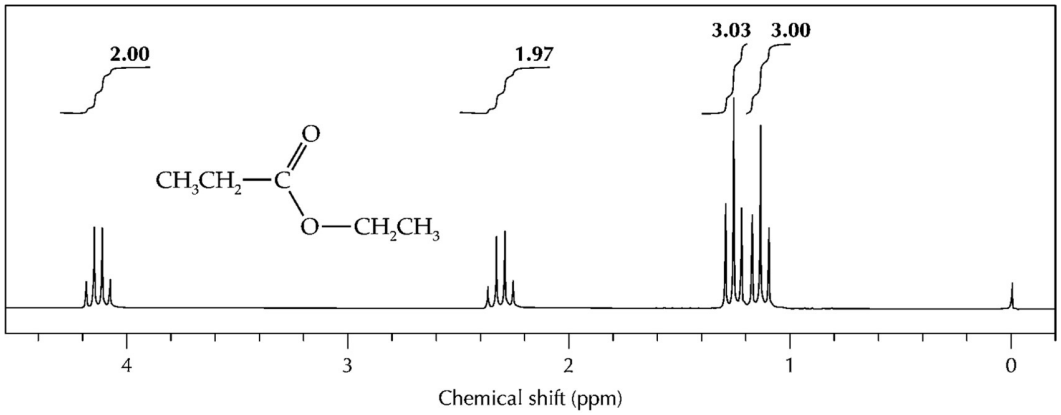
N = number of hydrogens on adjacent carbons (neighbors)

N	N+1	Relative intensities of peaks	Typical pattern
0	1	1	Singlet
1	2	1 1	Doublet
2	3	1 2 1	Triplet
3	4	1 3 3 1	Quartet
4	5	1 4 6 4 1	Quintet
5	6	1 5 10 10 5 1	Sextet
6	7	1 6 15 20 15 6 1	Septet

FIGURE 21.23 Pascal's triangle can be used to predict the multiplicity and relative intensities of the signal of any magnetically active nucleus coupled to N equivalent nuclei of spin 1/2. It applies to both ^{1}H and ^{13}C spectra.

Mohrig, J. R.; Hammond, C. N.; Schatz, P. F. *Techniques in Organic Chemistry, 3rd Edition*. 2010. Freeman.

^{1}H spectrum of **ethyl propanoate** has two **2H quartets** (**B**&**C**) and two **3H triplets** (**A**&**D**).



Signal **D** is a **3H triplet** at **1.3 ppm**: "δ 1.1 (3H triplet)"

- All **D** nuclei spin *against B field* with central chemical shift @ **1.3 ppm**
- **D** has **2** neighbors (signal **C, n = 2**) that are *50 / 50 with & against B field*
  - The random spins of **C** effect the *peak shape* of signal **D**
    - **n = 2; n+1 = 3, triplet**

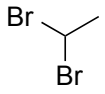
Before splitting

After splitting

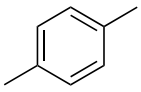
Preparing for NMR Problem Set

- watch the “How to do the NMR problem set” video (Canvas) and use the template below to follow along with the problem-solving process.

…Predict the number signals, integration, splitting, and chemical shift (range and calculated)



Signal	Integration	Splitting	Chemical Shift Range (ppm)	Calculated Chemical Shift (ppm)*



Signal	Integration	Splitting	Chemical Shift Range (ppm)	Calculated Chemical Shift (ppm)*

Structural Elucidation - Propose a structure from chemical formula, IR, & ^{1}H NMR
Watch the "How to do the NMR problem set" video (Canvas) and use the template below to follow the problem-solving process.

- Calculate **degrees of unsaturation** (total number of pi bonds and/or rings) from the molecular formula
- use IR to identify possible **functional group(s),**
- draw structure **fragments** based on signal information (2H doublet = C**H$_2$**CH),
- then put the fragments together in the **final structure**.
- Check your work by calculating chemical shifts of the proposed structure.

C_3H_6O; **IR** 1720 cm^{-1}, 2900 cm^{-1}; **^{1}H NMR** – δ 2.0 ppm (3H singlet)

$C_5H_{12}O$; **IR** 3300 cm^{-1}, 2900 cm^{-1}; **^{1}H NMR** – δ 4.0 ppm (1H broad singlet), δ 3.5 ppm (2H triplet), δ 1.6 (1H nonet), δ 1.5 ppm (2H quartet), δ 0.9 (6H doublet)

What's the resonance frequency, Kenneth?

See optional/supplemental video (Canvas) on what a chemical shift really is.

Chemical shift (ppm) = $\frac{\text{frequency of proton relative to TMS}}{\text{Maximum operating frequency of instrument (MHz)}}$

Ex. *tert*-butyl acetate is dissolved in a solution of $CDCl_3$ (w/ 0.1 % TMS) and ^1H NMR spectra are run on two different instruments.

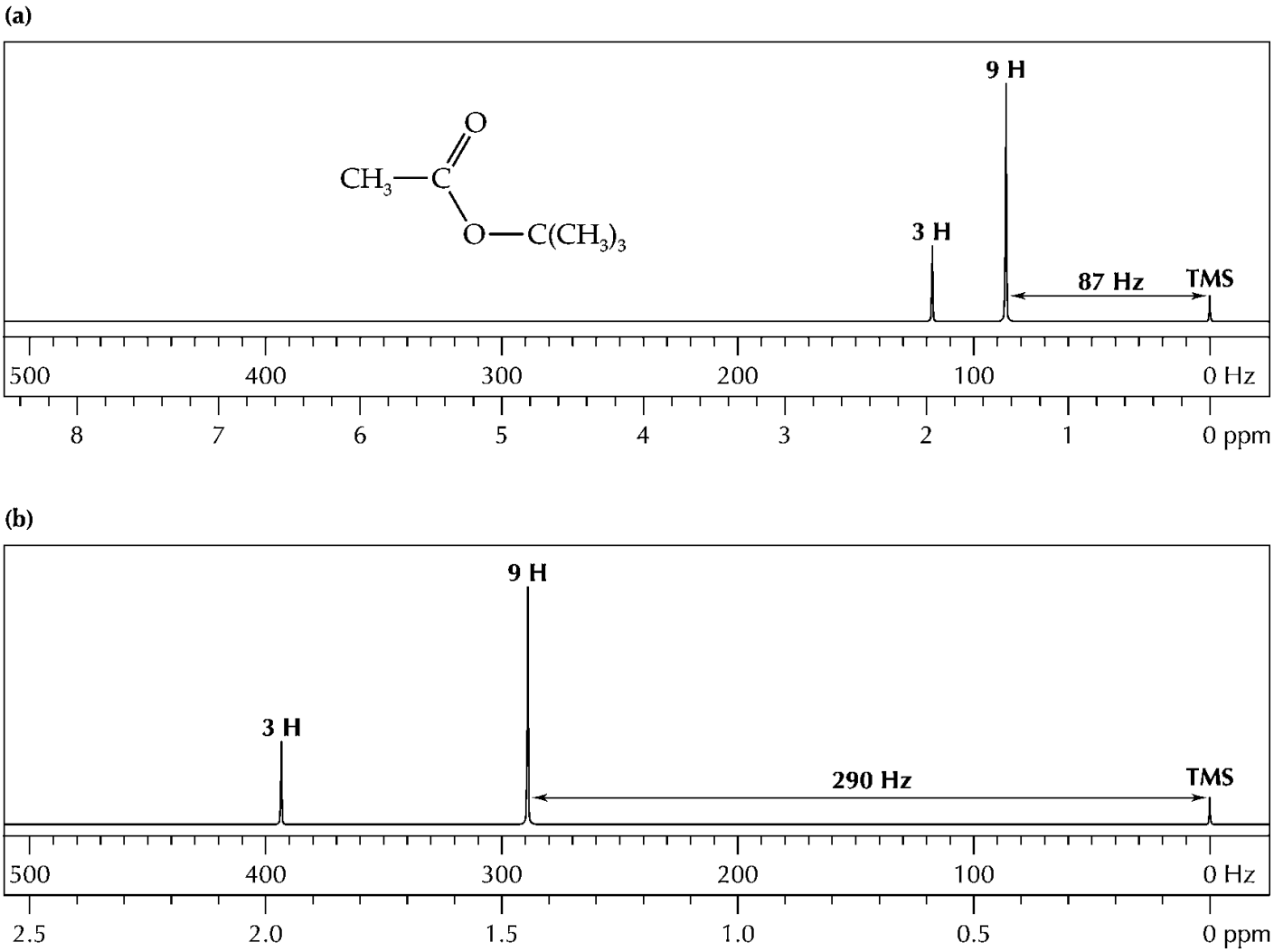


FIGURE 22.12 ^1H NMR spectra of *tert*-butyl acetate in the region from 0 to 500 Hz at (a) 60 MHz and (b) 200 MHz. The chemical shift of each signal is the same regardless of the spectrometer frequency.

^{1}H NMR Introductory Problems

1. How many ^{1}H NMR absorptions are expected for each compound? In other words, how many non-equivalent protons are in each compound? *Pro-tip: Draw the skeletal structure then add H's.*

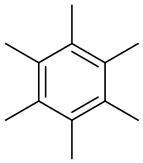
(a) CH_3CH_2Cl **(b)** $(CH_3)_2CHOCH_3$ **(c)** $NO_2CH_2CH_2CH_3$

(d) Benzene **(e)** 2-Methyl-1-butene **(f)** *trans*-3-hexene

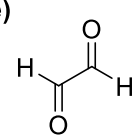
2. Each compound below has only 1 peak in its ^{1}H NMR spectrum. Use the NMR tables to predict the chemical shift range (ppm) where each compound should absorb.

(a) 

(b) 

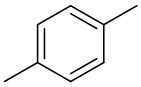
(c) 

(d) CH_2Cl_2

(e) 

(f) CH_3OCH_3

3. Consider the structure of ***p*-xylene** below to answer the following.



***p*-xylene**

(a) How many peaks (absorptions) should *p*-xylene have in its ^{1}H NMR spectrum?

(b) What ratio of peak areas would you expect on integration of the spectrum?

(c) Use the NMR tables to approximate the chemical shifts of the signals in ***p*-xylene**.

4. Summarize in your own words *how* to find the number of signals, integration, and chemical shift(s) in any given molecule.

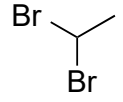
5. Draw (invent) or look up a molecule you know by name online (ex. medicine). Draw that structure below. Predict the number of ^{1}H NMR signals, integration, and chemical shifts of that molecule! Share your findings to your labmates.

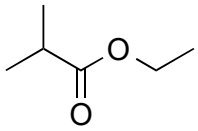
NMR Problem Set

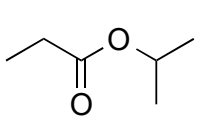
Pages 1-4	Pages 5-8	Page 9
#1 Predict spectra from given structure	**#2-4** Structure elucidation from given spectra	**#5** Summary / Overview

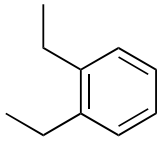
1. Predict the ^{1}H NMR spectrum for compounds **(b)** – **(f)** below.

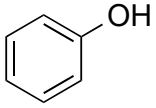
- **Add in the missing hydrogens**
- Determine the **number of ^{1}H NMR signals** in each compound below.
- Label each **type of proton** (A, B, etc.) and fill in the tables provided on the following page with a row for each type of proton (signal).
- Predict the **integration** (#H's), the **chemical shift range** (ppm), and **calculated chemical shift** (ppm), that you would expect for each signal.
    - Determine the **splitting pattern** for each signal using the *n+1 rule*, where *n* is the number of H's on adjacent carbon atoms.
        - Splitting patterns: singlet, doublet, triplet, quartet, pentet, sextet, heptet, or multiplet.
        - There is no splitting through heteroatoms (O, N, S, etc.) – all OH's are singlets!
- **Sketch the predicted ^{1}H NMR spectrum of each compound** and use nmrdb.org to check your work
    - *Approximate* the central chemical shift of the signal on the x-axis and *draw* each splitting pattern.
    - Don't worry about incorporating integration (peak size).

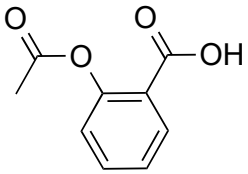
(a) 

(b) 

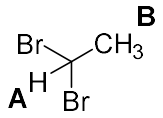
(c) 

(d) 

(e) 

(f) 

(1a) Worked example: Watch the "**How to do the NMR Problem Set**" video on Canvas



Signal	Integration	Splitting n+1 rule	Chemical Shift Range (ppm)	Calculated Chemical Shift (ppm)*
A	*1H*	*quartet*	*2.1 – 4.5*	*5.7*
B	*3H*	*doublet*	*0.8 – 1.9*	*2.3*

Calculate expected chemical shifts using *Table 22.3 of NMR tables – alkyl H's

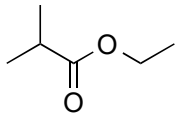
Calculation of Signal **A**

Methine (CH) + 2 x Br (alpha substituent)
1.5 ppm + *(2 x 2.1)* = *5.7 ppm*

Calculation of Signal **B**

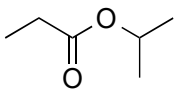
Methyl (CH_3) + 2 x Br (beta substituent)
0.9 ppm + *(2 x 0.7)* = *2.3 ppm*

Tables for #1 – create as many rows as the number of signals in each compound, read page 1 for more!

(1b) 	Signal	Integration	Splitting	Chemical Shift Range (ppm)	Calculated Chemical Shift (ppm)*

Sketch of ^{1}H NMR spectrum:

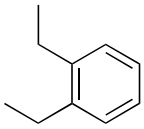
12 **Chemical Shift (ppm)** **0**

(1c) 	Signal	Integration	Splitting	Chemical Shift Range (ppm)	Calculated Chemical Shift (ppm)*

Sketch of ^{1}H NMR spectrum:

12 **Chemical Shift (ppm)** **0**

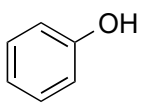
Tables for #1 – create as many rows as the number of signals in each compound, read page 1 for more!

(1d) 	Signal	Integration	Splitting	Chemical Shift Range (ppm)	Calculated Chemical Shift (ppm)*

Note: Use correlation Table 22.4 for aromatic H's and Table 22.3 for alkyl H's

Sketch of ^{1}H NMR spectrum:

12 **Chemical Shift (ppm)** **0**

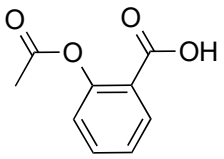
(1e) 	Signal	Integration	Splitting	Chemical Shift Range (ppm)	Calculated Chemical Shift (ppm)*

Note: Use correlation Table 22.4 for aromatic H's; no calculation for OH

Sketch of ^{1}H NMR spectrum:

12 **Chemical Shift (ppm)** **0**

Tables for #1 – create as many rows as the number of signals in each compound, read page 1 for more!

	Signal	Integration	Splitting	Chemical Shift Range (ppm)	Calculated Chemical Shift (ppm)*
(1f) 					

Sketch of ^{1}H NMR spectrum:

12 **Chemical Shift (ppm)** **0**

2. Structural Elucidation: **Draw structures** for compounds that meet the following descriptions.

1. Calculate **degrees of unsaturation** from the **molecular formula** to determine the number of pi bonds or rings
2. Use **IR** to identify potential **bonds & functional group(s)**
3. Draw structure **fragments** for each ^{1}H NMR signal using the **integration & splitting**
    a. Ex. **2H doublet** = C**H$_2$**CH, where the bold H's are determined by integration (2H) and the neighboring CH group is determined by splitting (doublet)
    b. Incorporate functional groups into fragments where possible using **chemical shifts**
        i. Ex. δ 4.0 (2H doublet) = OC**H$_2$**CH
        ii. the 2H's are deshielded by the electronegative oxygen, resulting in a higher chemical shift
4. Put the **fragments** together in the final structure.

Worked examples: Watch the "**How to do the NMR Problem Set**" video on Canvas

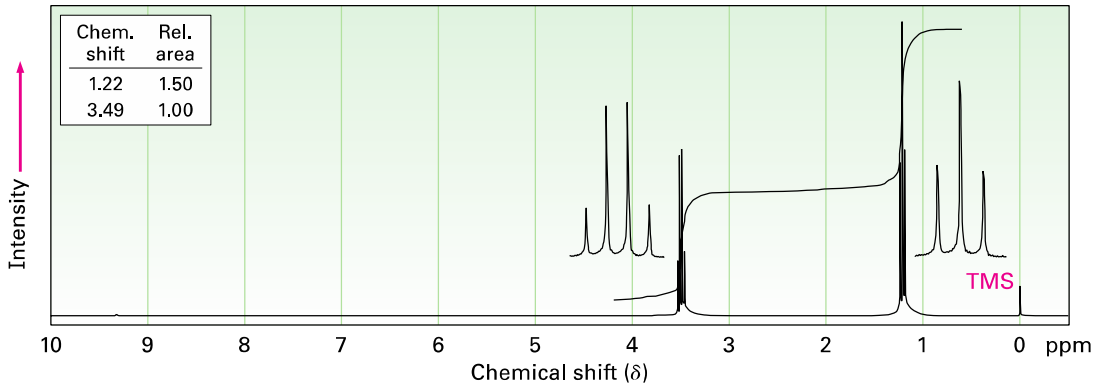
Formula	Degrees Unsat.	Suspected bonds / FG(s) from IR	Fragment(s) from ^{1}H NMR	Final Structure
C_3H_6O	**1**	1720 cm^{-1} **C=O** 2900 cm^{-1} **Alkane sp^3 C-H**	δ 2.0 ppm (6H singlet) 6H's are next to 0 H's C**H$_3$**C$_{(no\ H's)}$ Symmetry - 2 x CH_3 groups	
C_3H_7Cl	**0**	2900 cm^{-1} **Alkane** 800 cm^{-1} **C-Cl bond**	δ 3.7 (6H doublet) ^ next to Cl Doublet = 6H's next to one H (C**H$_3$**)$_2$CHCl δ 1.4 (1H septet) ^ farther from Cl Septet = 1H next to 6 H's (CH$_3$)$_2$C**H**Cl	$(CH_3)_2CHCl$

Formula	Degrees Unsat.	Suspected bonds / FG(s) from IR	Fragment(s) from ^{1}H NMR	Final Structure
(2a) $C_5H_{10}O_2$		1760 cm^{-1} 2900 cm^{-1}	δ 4.1 (2H quartet) δ 2.3 (2H quartet) δ 1.3 (3H triplet) δ 1.1 (3H triplet)	
(2b) $C_4H_8O_2$		1760 cm^{-1} 2900 cm^{-1}	δ 4.0 (2H quartet) δ 2.0 (3H singlet) δ 1.4 (3H triplet)	
(2c) C_3H_8O		3300 cm^{-1} 2900 cm^{-1}	δ 3.8 (1H septet) δ 2.0 (1H broad singlet) δ 1.2 (6H doublet)	

Formula	Degrees Unsat.	Suspected bonds / FG(s) from IR	Fragment(s) from ^{1}H NMR	Final Structure
(2d) Bonus Problem: $C_{10}H_{12}O$		3050 cm^{-1} 1675 cm^{-1} 1620 cm^{-1} 850 cm^{-1}	δ 7.85 (2H doublet) δ 7.28 (2H doublet) δ 2.9 (2H quartet) δ 2.0 (3H singlet) *benzylic δ 1.5 (3H triplet)	

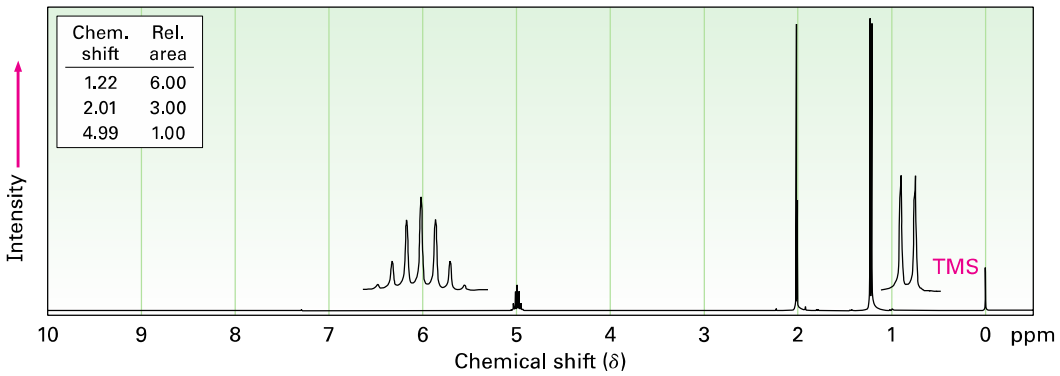
3. Determine the **structure** of a compound with molecular formula $C_4H_{10}O$ and the integrated ^{1}H NMR spectrum below (**rel. area** gives the *ratio* of H's per signal). Identify the splitting pattern from the expanded shapes in the spectrum (**m = n + 1**, where **m** = multiplicity, triplet or quartet and **n** = number of neighboring H's).

- Show your work: **draw fragments** of the molecule in addition to the **full structure**.
  ↓ This box gives the relative area (integration or ratio of H's) of both peaks, identified by chemical shift.



4. Propose a structure for a compound with formula $C_5H_{10}O_2$ and a sharp IR absorbance at 1735 cm^{-1}. Identify the splitting pattern from the expanded shapes in the spectrum (**m = n + 1**, where **m** = multiplicity, triplet or quartet and **n** = number of neighboring H's). The signal at 2.0 is a singlet.

- Show your work: **draw fragments** of the molecule in addition to the **full structure**.
  ↓ This box gives the relative area (integration) of all peaks, identified by chemical shift.



5. *<u>Summarize your process</u>* for (a) predicting spectra and (b) elucidating / solving a structure from spectral data.

(a) Predicting Spectra

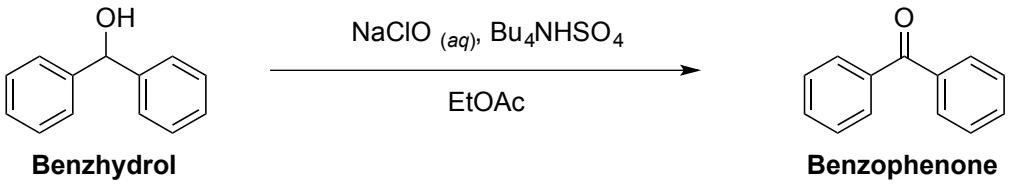
(b) Structural Elucidation

CHEM 8M, Experiment 3 – Oxidation of Benzhydrol

- Reactions using Phase Transfer Catalysts (PTC)
- TLC, IR, and ^{1}H NMR Analysis of Benzhydrol & Benzophenone

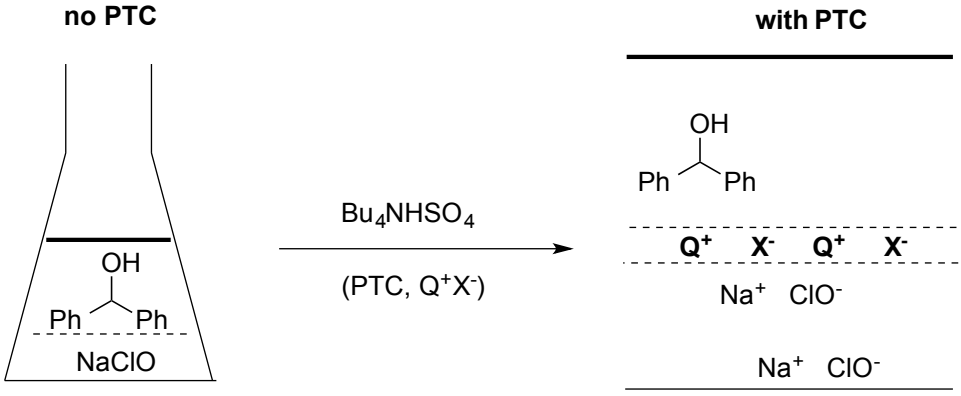
---

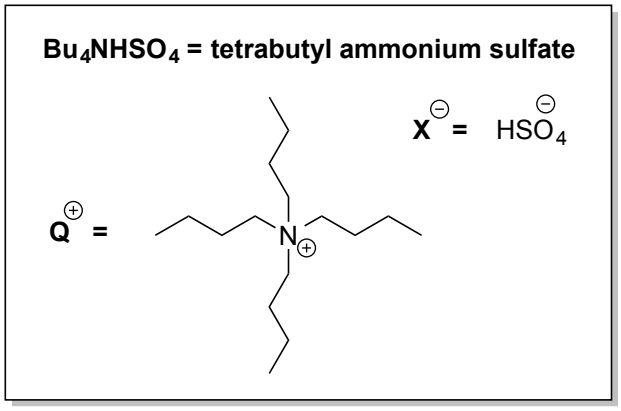
Oxidation of Benzhydrol with Bleach using Phase Transfer Catalyst



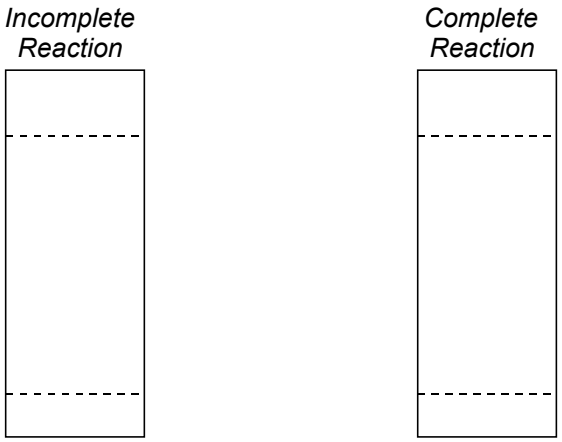
Benzhydrol **Benzophenone**

Phase Transfer Catalysis (PTC)



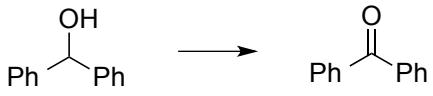


Monitoring Reaction Progress by TLC



Reaction Work-up: remove AQ, wash with brine then water, dry, filter, rota-vap

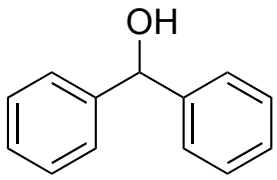
IR Analysis

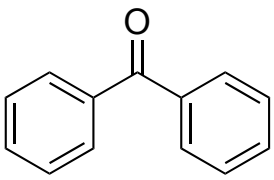


^{1}H NMR Analysis = assign each set of protons on structure to signal on spectrum

Predict spectrum

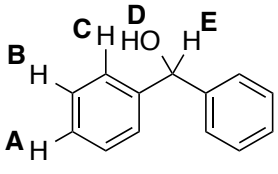
1. Look for symmetry – **equivalent protons** and for asymmetry – **non-equivalent protons**



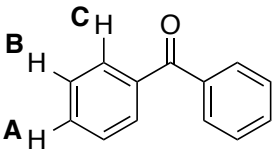


2. Integration: How many of each type of proton?

3. Identify **chemical shift ranges** in benzhydrol & benzophenone



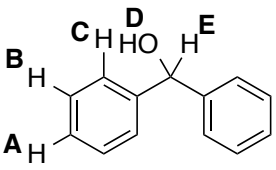
Benzhydrol



Benzophenone

4. Calculate **expected chemical shifts** using chemical shift correlation tables or online predictor tool

Table 3. ^{1}H NMR Analysis of Benzhydrol

 **Benzhydrol**	Signal	Integration (# of H's)	Expected Chemical Shift (ppm)	Observed Chemical Shift (ppm)
	A			
	B			
	C			
	D			
	E			

Correlate / assign to signals on given spectrum

- *Integration lines = Curves on or above peaks, height = relative ratio of H's*

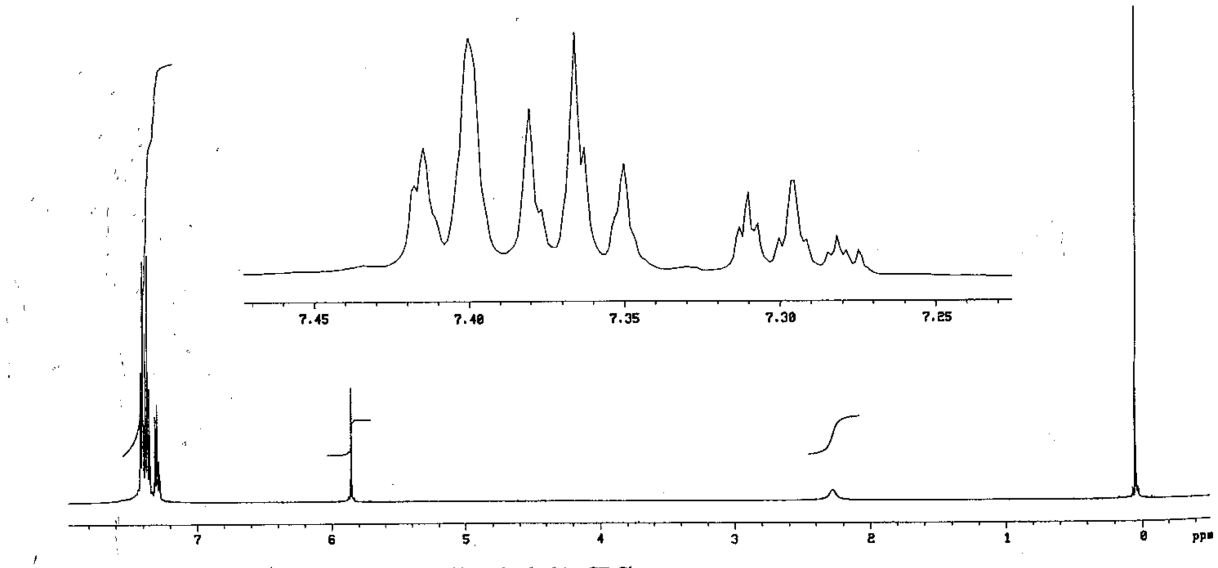
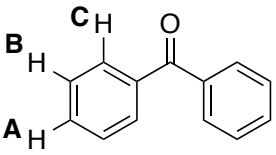


Figure 21.6 500-MHz ^{1}H-NMR spectrum of benzhydrol in $CDCl_3$.

Table 4. ^{1}H NMR Analysis of Benzophenone

 Benzophenone	Signal	Integration (# of H's)	Expected Chemical Shift (ppm)	Observed Chemical Shift (ppm)
	A'			
	B'			
	C'			

Correlate / assign to signals on given spectrum

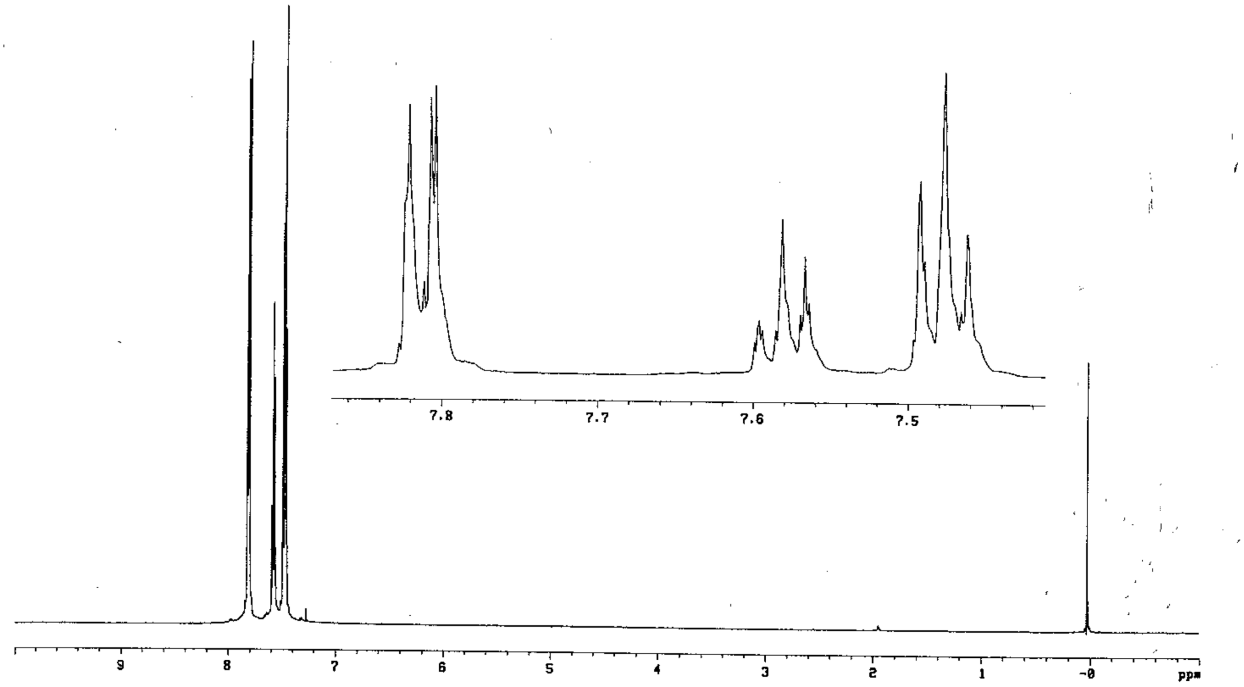


Figure 21.3 500-MHz ^{1}H-NMR spectrum of benzophenone in $CDCl_3$.

Supplemental Reading

Klein, D. "Organic Chemistry, 2nd Edition"; **Mohrig**, J. R.; *et. al*. "Techniques in Organic Chemistry, 4th Edition." See also Exp 3 pre-lab videos on Canvas

Oxidation reactions	Klein 12.10
^{1}H NMR	Klein 15.1-6 or Mohrig Chapter 22.1-22.7
Extraction	Mohrig Chapter 10
TLC	Mohrig Chapter 18

F. Experimental Methods Writing Worksheet – provided in lab ☺

1. Draw the **reaction scheme** by hand (no copy/paste) and list the **name of the product**.
The reaction scheme includes reactant, reagents over arrow, solvent under arrow, and product.

2. What **glassware** and **equipment** was used for this reaction (aside from chemicals)?

3. How much **benzhydrol** was used? Convert **mass** to **mmol (xx g, xx mmol)**. Show your work, including units with every value. *Calculate or look up the molecular weight of benzhydrol (g/mol) = (mg/mmol).*

4. How much bleach (**NaClO**) was used and what was the **concentration (____ M, ____ mL)**? Fill in the blanks and calculate the quantity of **bleach in mmoles.** Show your work. *Recall Molarity = (moles / Liter) … M = (mol / L) = (mmol / mL).*

5. How much *tert*-butylammonium hydrogen sulfate (**Bu_4NHSO_4**) was used (**xx g**)? This is a catalyst – include only mass not mmol.

6. Determine the **limiting reagent** then calculate the **theoretical yield** (mmol and mg). Show your work, including units with every value. *Determine the mole ratio in the reaction (x mol benzyhydrol / x mol benzophenone). Calculate or look up the molecular weight of benzhydrophenone (g/mol) = (mg/mmol).*

F. Experimental Methods Writing Worksheet (cont'd)

7. What **solvent** was used in the oxidation reaction and in what **volume**?

8. What was the **reaction temperature** and **time**? Was the reaction stirred, refluxed, or standing?

9. What **technique** was used to monitor **reaction progress**? What **solvent(s)** were used during this analysis?

10. List the **identity** and **quantities** of the **chemicals (xx mL)** used in the **reaction work-up**. *Note: quantity of drying agent need not be included.*

11. What **additional processes** were involved in the final isolation of product?

12. What is the yield of **benzophenone (_____ g, _____ mmol, _____ % yield)**? Fill in the blanks and show your work below, including units on every value.

(a) Convert **benzophenone mass** (300 mg) to **mmol** using molecular weight (g/mol) = (mg/mmol).

(b) Calculate **percent (%) yield** using 300 mg as the actual yield and the th. yield from #6.

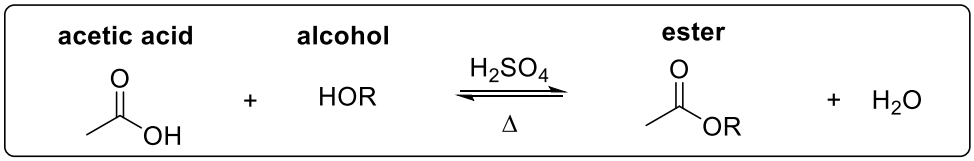
$$\% \text{ yield} = \frac{\text{actual yield (mg)}}{\text{Theoretical yield (mg)}} \times 100\%$$

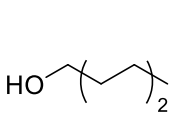
CHEM 8M, Experiment 4 – Synthesis of Fruity Fragrances

Fischer Esterification

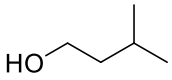
= Reaction of carboxylic acid and alcohol under acidic, refluxing conditions

- "Neat" reaction!

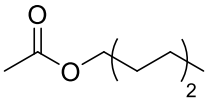




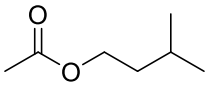
***n*-hexanol**



isoamyl alcohol

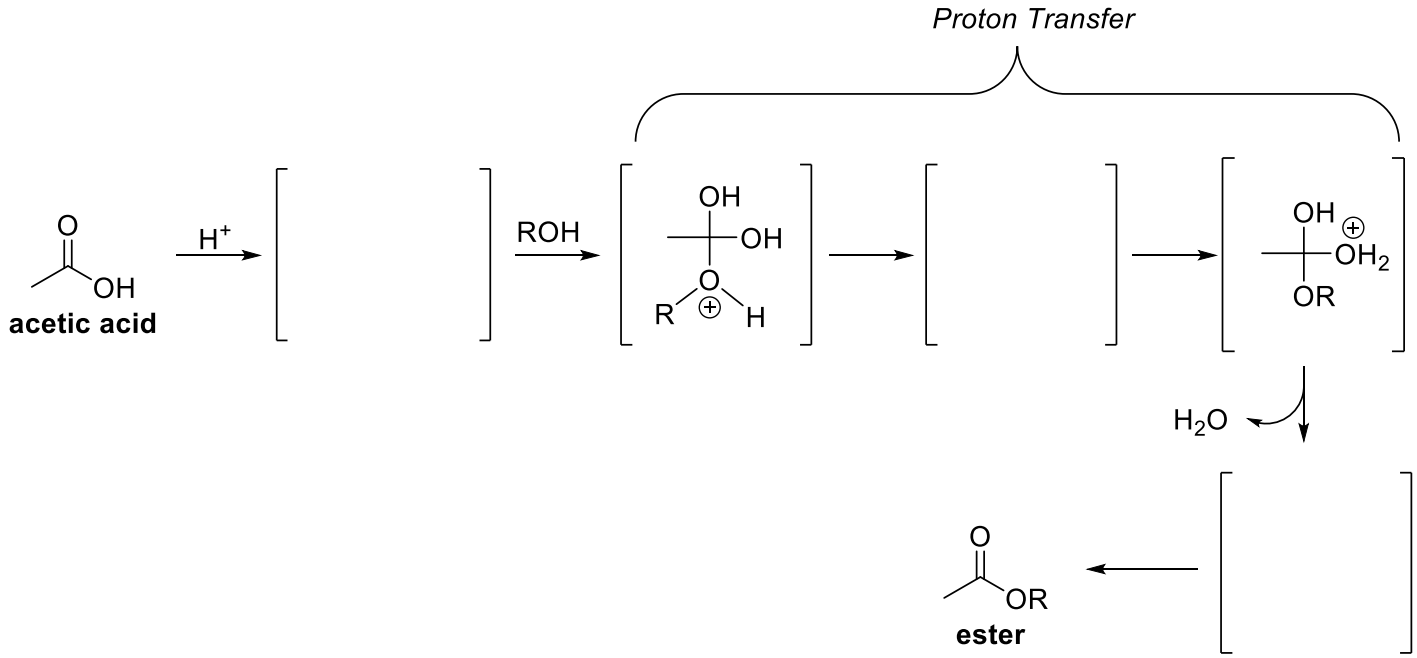


***n*-hexyl acetate (sour apple)**



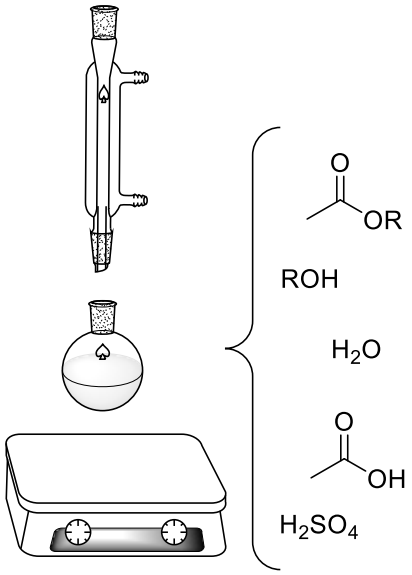
isoamyl acetate (banana oil)

Reaction Mechanism



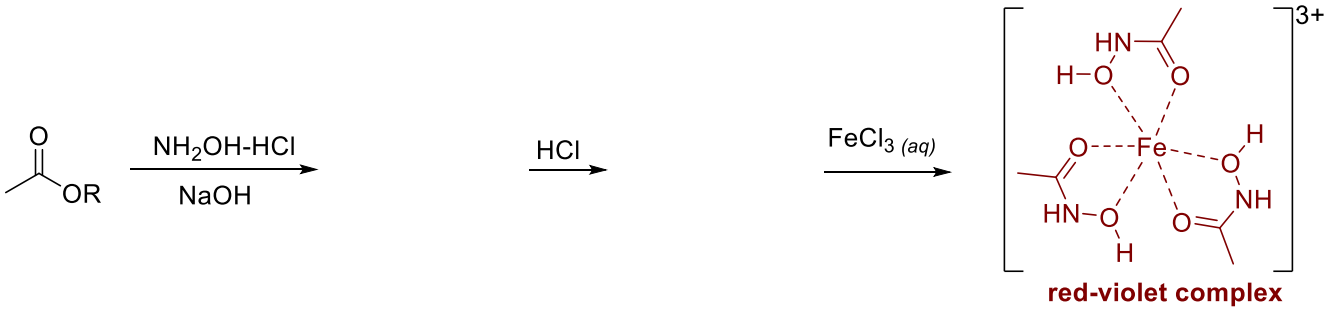
Le Chatelier's Principle – brainstorm!

Reaction Setup & Reflux



Reaction Workup

Hydroxamic Acid Test for Esters



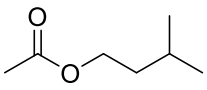
red-violet complex

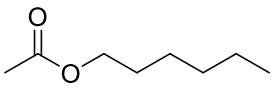
What to Test?

___ alcohol acetic acid EtOAc your product

^{1}H NMR Banana Oil & Apple Oil

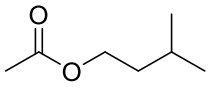
- *How many different types of protons (signals) do you see?*
- *What's the splitting pattern for each signal?*

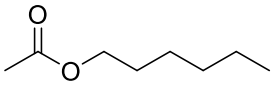




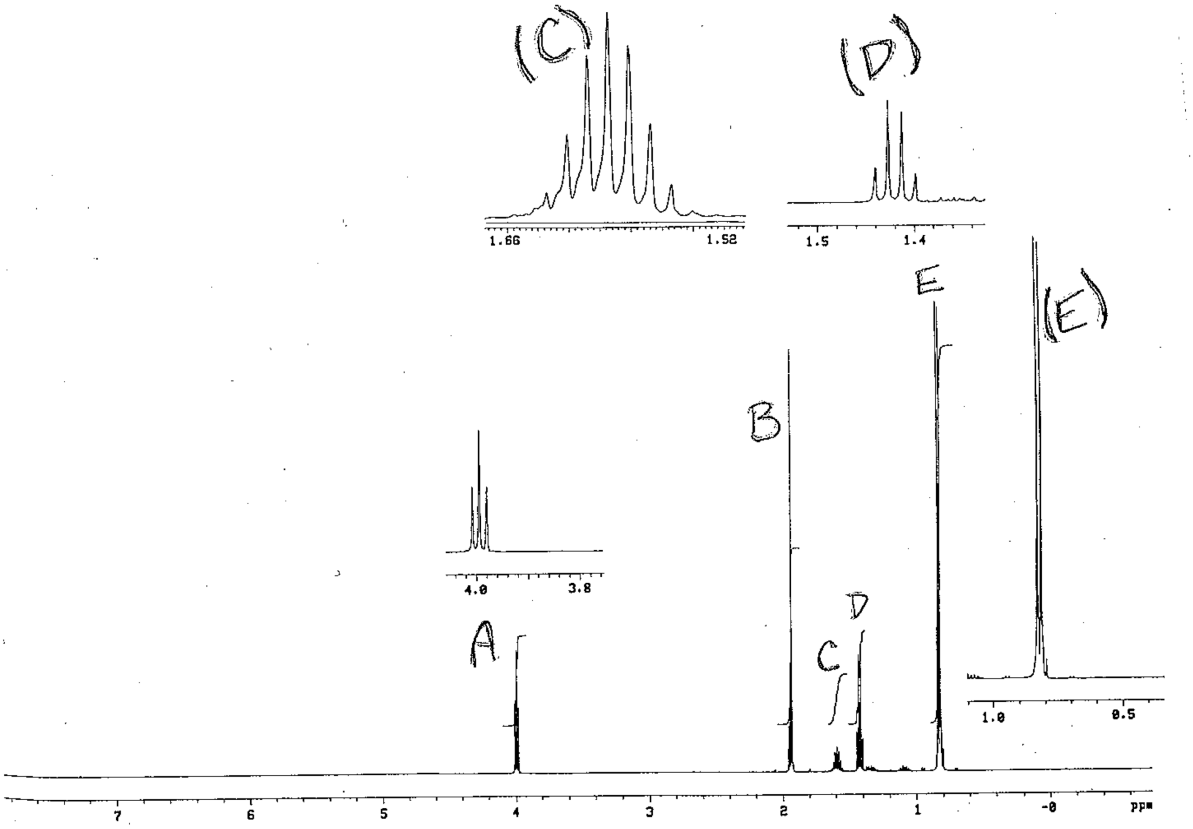
Predicting Relative Chemical Shifts

- *What is the expected chemical shift range & calculated value for each set of H's?*
- Deshielding increases chemical shifts
    - Electron withdrawing groups (EWGs) or electronegative (EN) atoms
    - Proximity effects





Assigning Banana Oil's Spectrum
Signals **A-E** represent sets of protons in the product

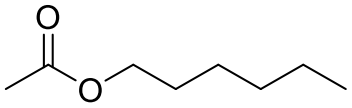


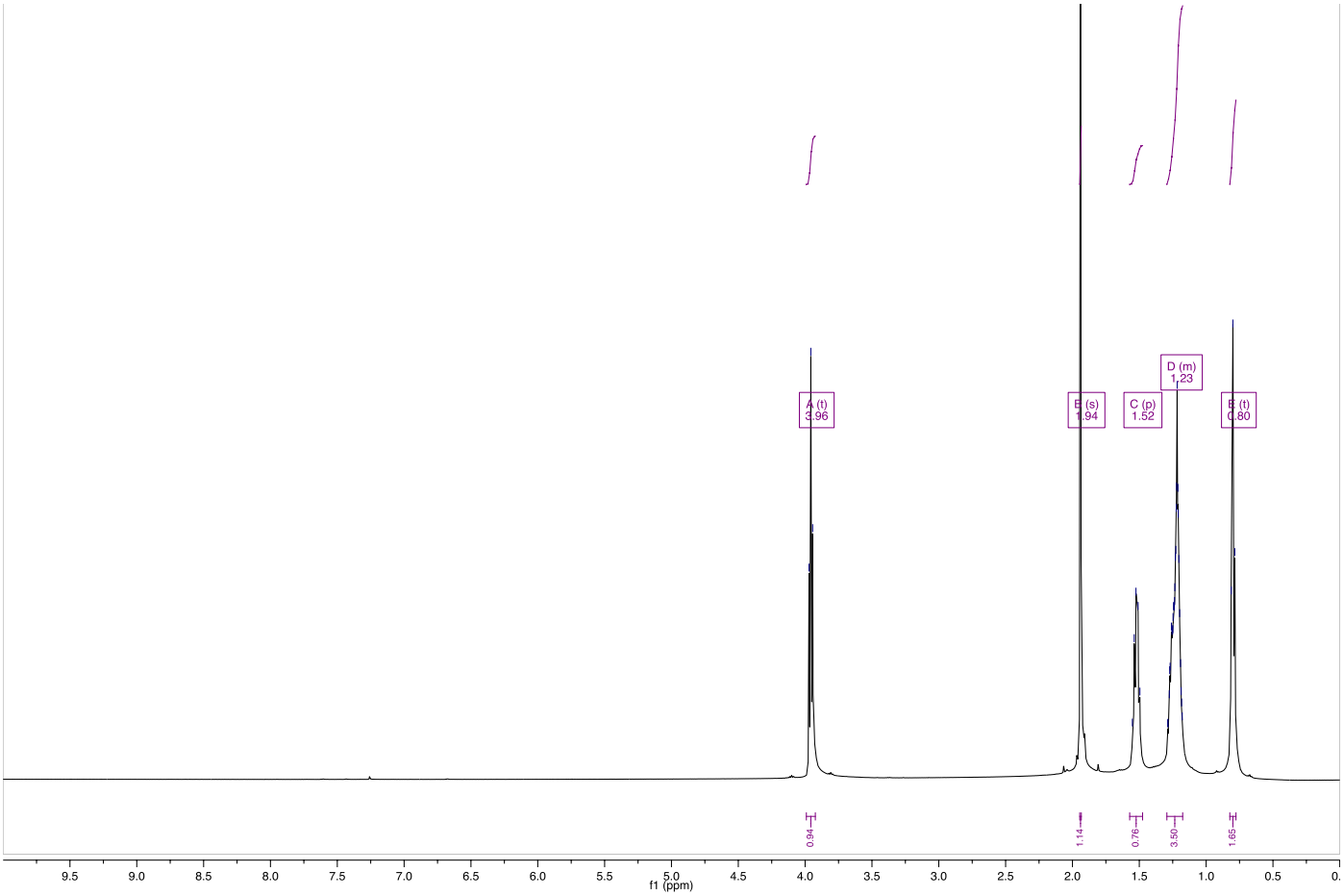
500-MHz ^{1}H-NMR spectrum of isoamyl acetate in $CDCl_3$.

Signal	Integration (# of H's)	Expected Chemical Shift (ppm)	Observed Chemical Shift (ppm)	# of 3-bond Neighbors (n)	Multiplicity/ Splitting (m = n+1) ex. Singlet, doublet, etc.
A			4.0		
B			2.0		
C			1.6		
D			1.4		
E			0.9		

^{1}H NMR Analysis of Hexyl Acetate (Apple Oil)

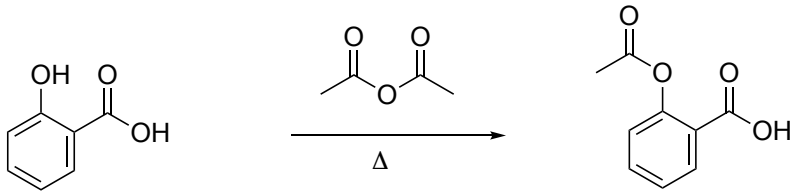
Signal	Integration (# of H's)	Expected Chemical Shift (ppm)	Observed Chemical Shift (ppm)	# of 3-bond Neighbors (n)	Multiplicity/ Splitting (m = n+1)
A	2H		4.0		triplet
B	3H		2.0		singlet
C	2H		1.5		pentet
D	6H		1.2	(Many)	multiplet
E	3H		0.8		triplet





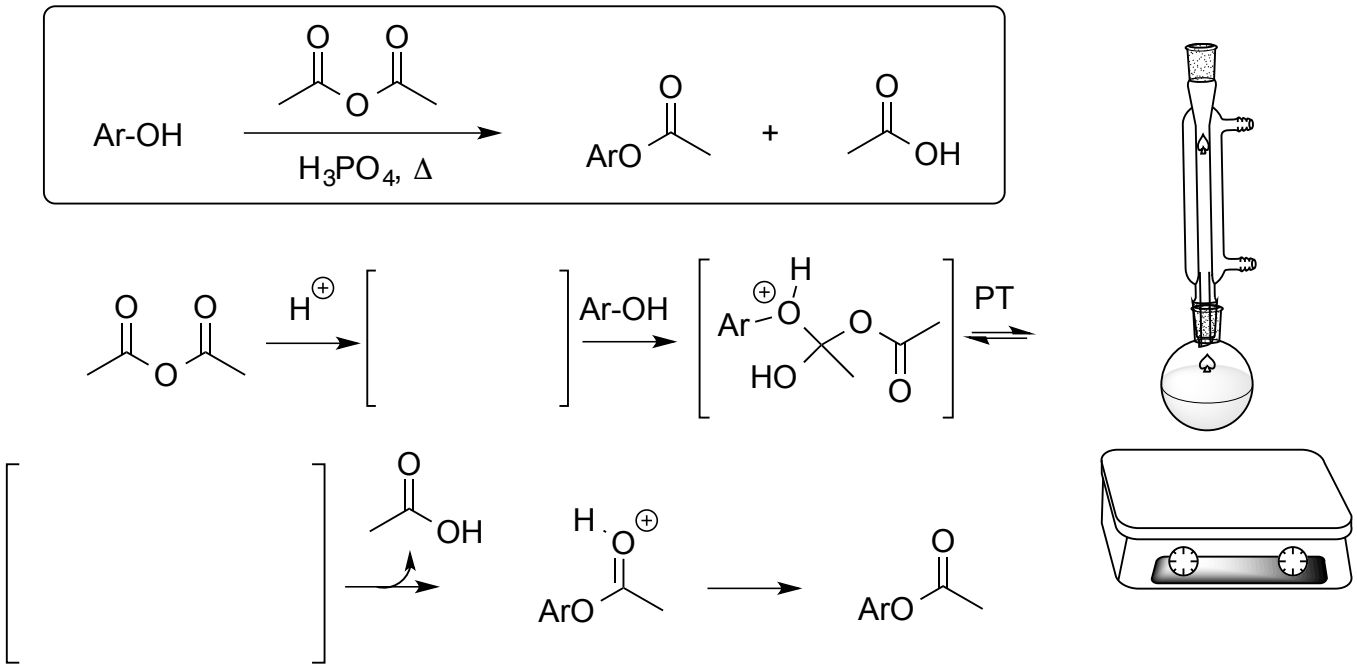
CHEM 8M, Experiment 5 – Synthesis of Aspirin

- Reaction Set Up, Work Up, Chemical Tests, IR,
- ^{1}H NMR Analysis and intro to ^{13}C NMR



Salicylic Acid **Acetylsalicylic Acid (Aspirin)**

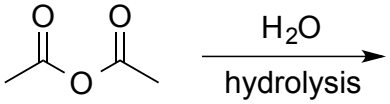
Reaction Mechanism & Set Up



Reaction Work Up

1. Cool for ~1 min

2. Add water to quench in warm water bath, 5 min



3. Crystallize

(a) Cool to RT, transfer to beaker

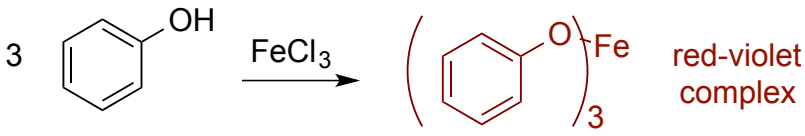
(b) Cool in ice bath, then scratch inside bottom of beaker, then wait!

(c) No crystals after ~5 min? Add seed crystal

- Wait at least 5 min *after* adding seed crystal to filter

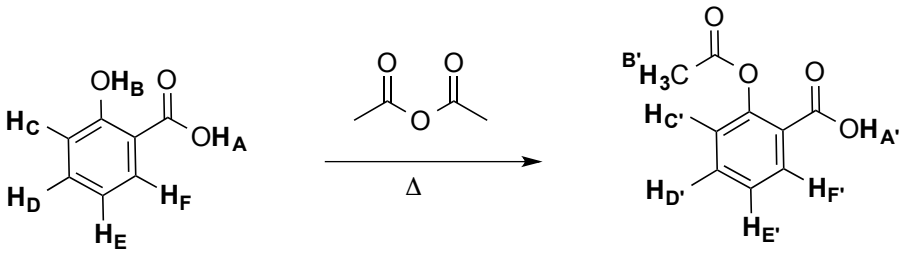
4. Vacuum Filtration

Ferric Chloride Test for Phenols



3 test tubes: (1) Salicylic Acid (2) Product (3) H_2O

IR Spectra of Salicylic Acid & Aspirin



Salicylic Acid

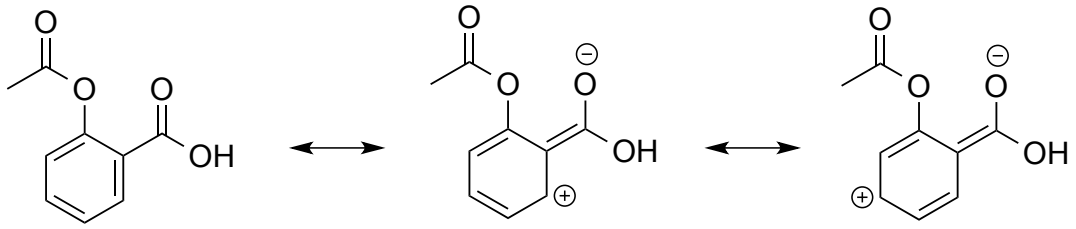
Acetylsalicylic Acid (Aspirin)

^{1}H NMR Analysis

Resonance effects in aromatic rings: *Predicting relative chemical shifts without calculations*

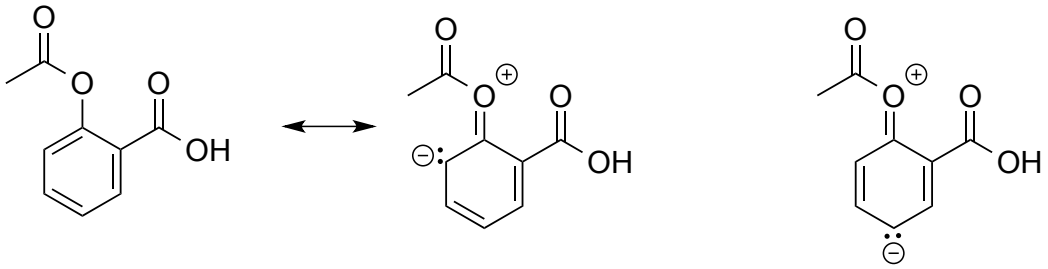
- Deshielding increases chemical shifts

EWG deshields the *ortho* & *para* H's

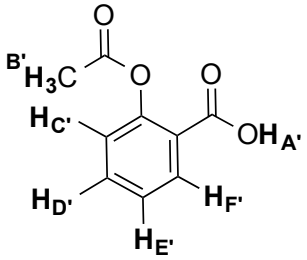


- Shielding decreases chemical shifts

EDG shields the *ortho* & *para* H's



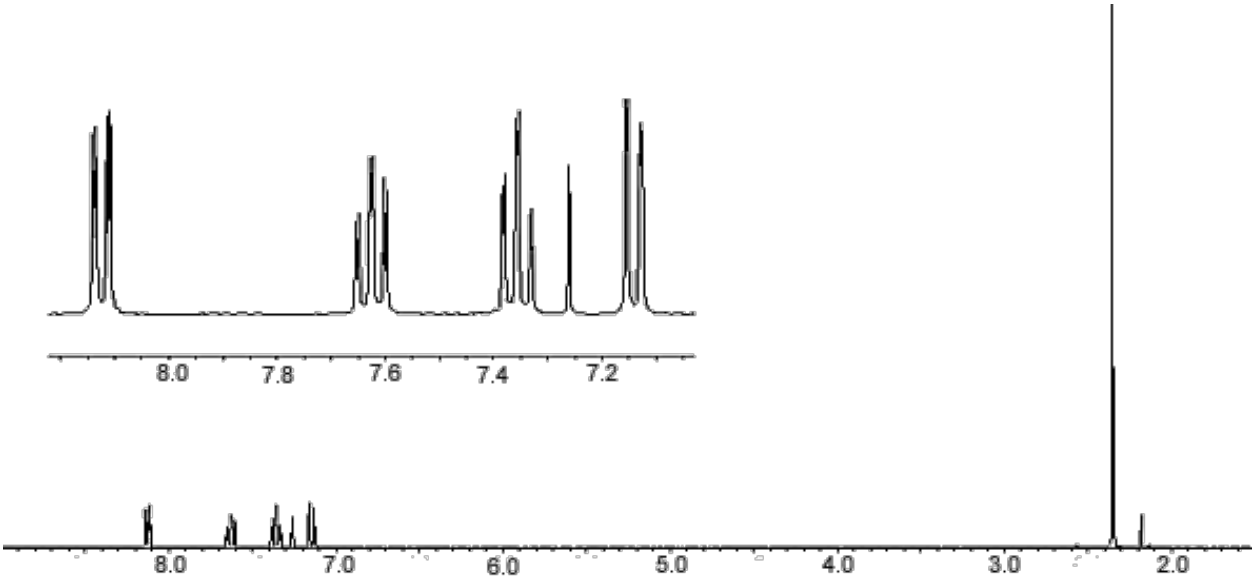
SUMMARIZE ^{1}H NMR of ASPIRIN



Acetylsalicylic Acid (Aspirin)

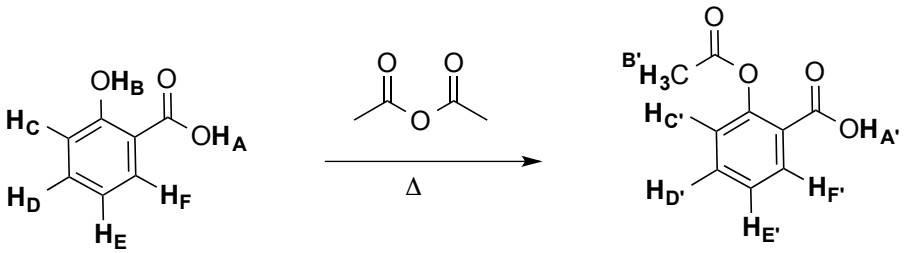
Most deshielded Ar-H (highest chem shift)

Most shielded Ar-H (lowest chem shift)



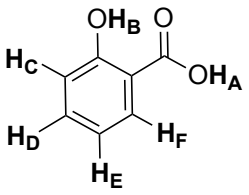
***11.5 ppm broad singlet** expected by not observed in this particular spectrum

What differences are expected / observed in the ^{1}H NMR of aspirin & its precursor?

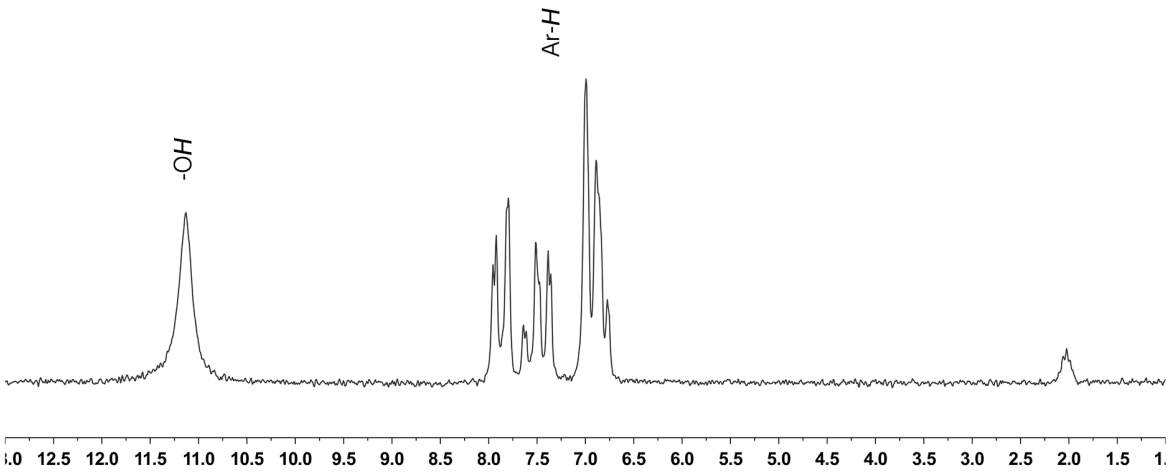


Salicylic Acid

Acetylsalicylic Acid (Aspirin)



Salicylic Acid



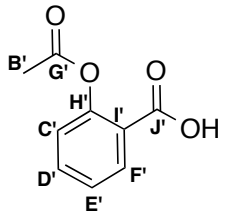
1H NMR Spectrum of Salicylic Acid

^{13}C NMR

- Exploring carbon nuclei of ^{13}C isotopes (< 1.1% abundance)
  - longer experiment, requires more sample

- ^{13}C nuclei resonate at higher chemical shifts (10-220ppm) than ^{1}H nuclei (0-12ppm)

- Similar deshielding effects to ^{1}H NMR



Acetylsalicylic Acid (Aspirin)

Deshielded **Shielded**

160 - 180 ppm	110 - 160	55 - 80	20 - 35
Carboxylic Acids, Esters O-**C**=O	Aromatic **Ar**	Alcohols, Esters O-**C**	Carboxylic Acids, Esters O=C-**C**

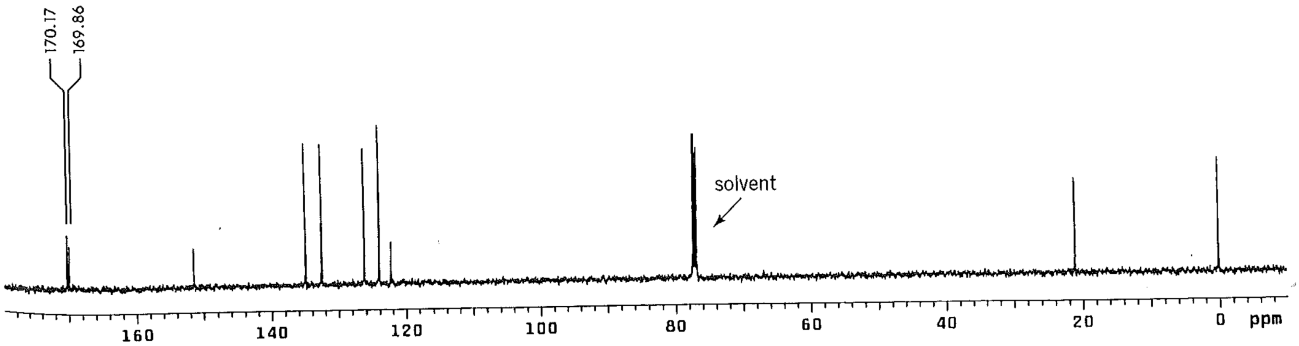
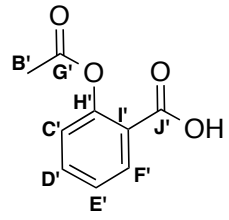


Figure 14.13 125.7-MHz ^{13}C-NMR spectrum of aspirin in $CDCl_3$.

 **Acetylsalicylic Acid (Aspirin)**	**Chemical Shift (Observed ppm)**	**Assignment(s) (A' – J')**	**Expected Chemical Shift Range (ppm)**
	169 & 170		
	152		
	125 – 135 (4 peaks)		
	122		
	20		

CHEM 8M, Experiment 6 – Colorful Chemistry

Synthesis & Application of Azo Dyes

- Nature of color - Dye to Fabric Interactions - Diazonium Coupling

Outcomes: Observe effects of dye structure, fibers, and metals (mordants) on appearance

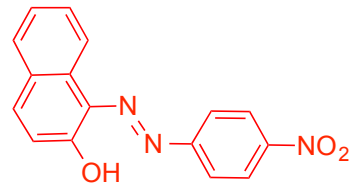
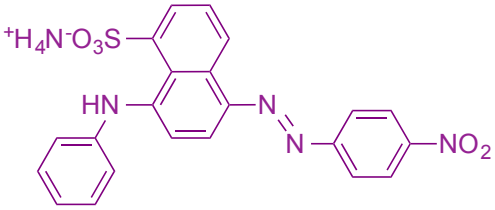
---

UV-Visible Spectrum

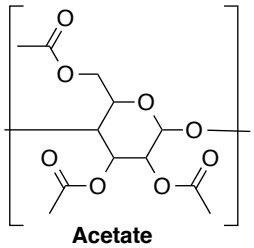
Purple	Blue	Green	Yellow	Orange	Red
400	450	500	550	500	650 700

λ(nm)

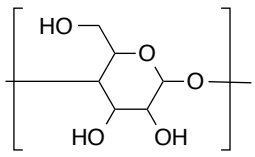
What is it about the structure of the dye that causes it to appear (emit) a specific color?

Dye Structure	Pi System
 **American Flag Red** Emission ~700 nm	
 **Easter Purple** Emission ~400 nm	

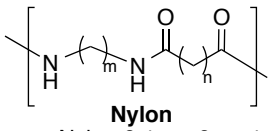
Fabric Fibers – Polymers with repeating units of…



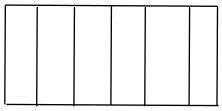
Acetate



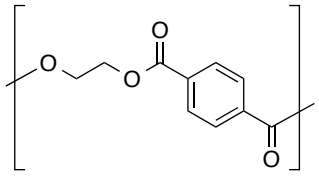
Cotton



Nylon
ex. Nylon 6.4, m=6, n=4

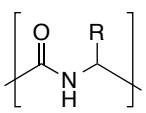


fabric swatch



Polyester

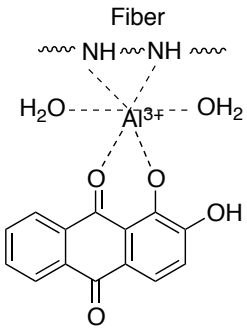
Acrylic



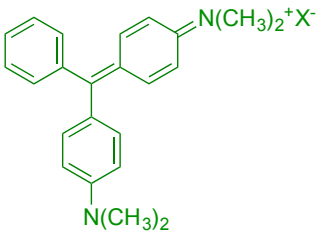
Wool

Mordant Dyeing

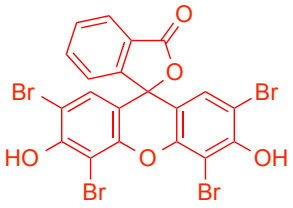
- Fabric strip is pre-treated with coordinating metal: Cu^{2+}, Al^{3+}, or Fe^{2+}
- Pre-made swatches with copper (II) sulfate, aluminum potassium sulfate, or iron (II) sulfate
- Use same ingrain dye procedure above with 'mordant fabrics'
- *How does this effect dye – fiber interactions?*



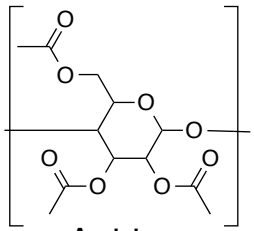
Direct Dyeing



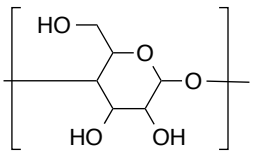
Malachite Green



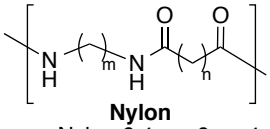
Eosin Y



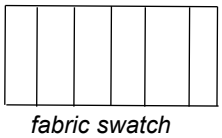
Acetate



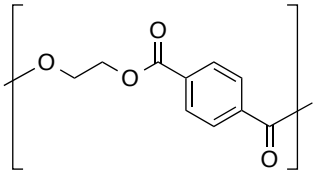
Cotton



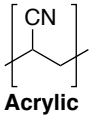
Nylon
ex. Nylon 6.4, m=6, n=4



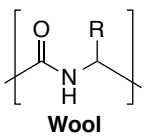
fabric swatch



Polyester



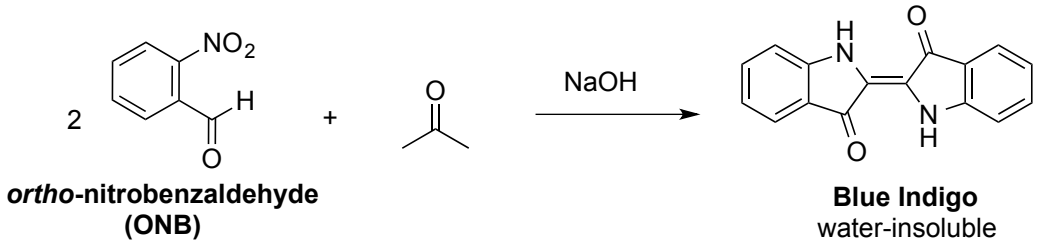
Acrylic



Wool

INDIGO SYNTHESIS & VAT DYEING

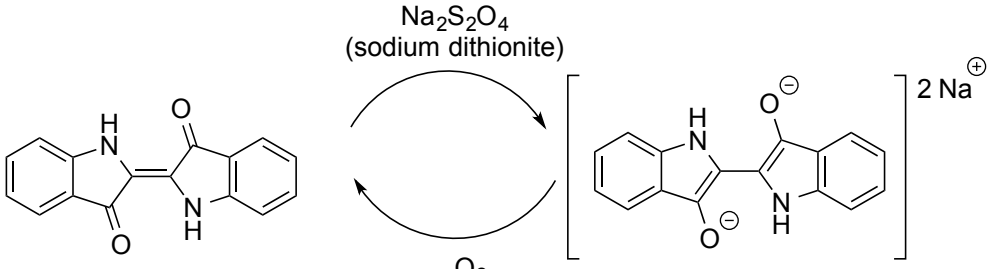
Part D.1. Synthesis



***ortho*-nitrobenzaldehyde (ONB)**

Blue Indigo
water-insoluble

Part D.2. Vat Dyeing with Indigo



Blue Indigo
water-insoluble

White-indigo
water-soluble

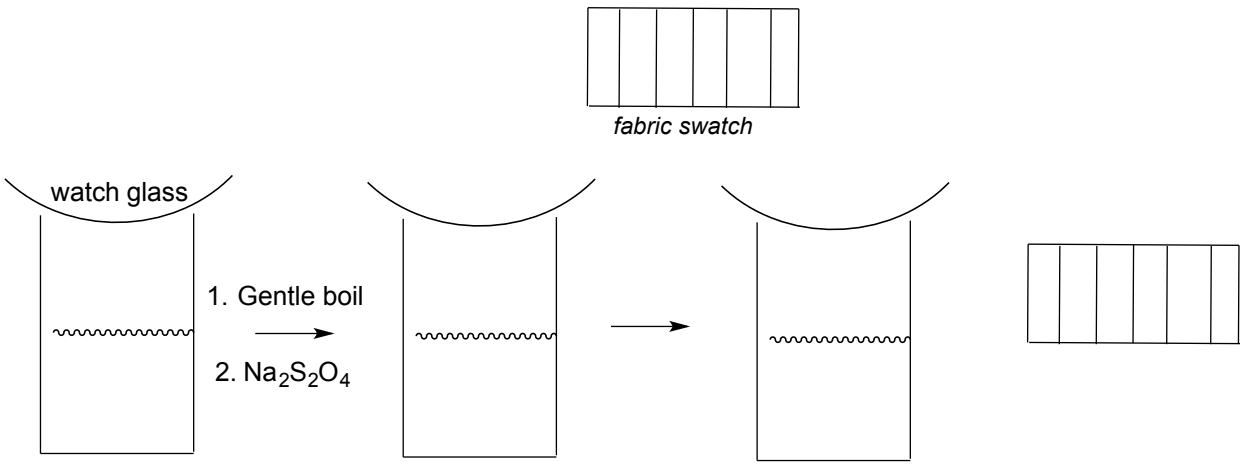


Table 1. Characteristic IR Absorption Peaks of Functional Groups*

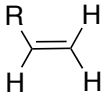
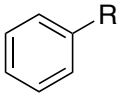
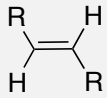
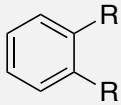
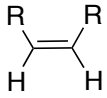
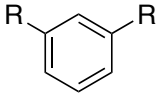
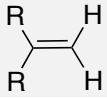
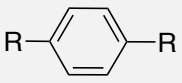
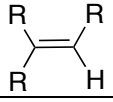
Vibration	Position (cm^{-1})	Intensity*	Notes
Alkanes			
C-H stretch	2990 – 2850	m to s	
Alkenes			
=C-H stretch	3100 – 3000	m	
C=C stretch	1680 – 1620 (sat.) 1650 – 1600 (conj.)	w to m	
=C-H bend	995 – 685	s	See Table 2 for detail
Alkynes			
≡C-H stretch	3310 – 3200	s	
C≡C stretch	2250 – 2100	m to w	
Aromatic Compounds			
C-H stretch	3100 – 3000	m to w	
C=C stretch	1625 – 1440	m to w	Hidden in fingerprint region
C-H bend	900 – 680	s	See Table 2 for detail
Alcohols**			
O-H stretch	3550 – 3200	br, s	Hydrogen bonded (typical)
Amines			
N-H stretch	3550 – 3250	br, m	Primary (two bands) Secondary (one band)
Nitriles			
C≡N stretch	2280 – 2200	s	
Aldehydes			
C-H stretch	2900 – 2800 & 2800 – 2700	s	H-C=O Fermi doublet
C=O stretch	1740 – 1720 (sat.) 1715 – 1680 (conj.)	s	
Ketones			
C=O stretch	1750 – 1705 (sat.) 1700 – 1665 (conj.)	s	
Esters**			
C=O stretch	1765 – 1735 (sat.) 1730 – 1715 (conj.)	s	
Carboxylic Acids**			
O-H stretch	3200 – 2500	br, m to w	
C=O stretch	1725 – 1700 (sat.) 1715 – 1680 (conj.)	s	
Amides			
N-H stretch	3500 – 3150	m	Primary (two bands) Secondary (one band)
C=O stretch	1700 – 1630	s	

Table 1 cont'd

Vibration	Position (cm^{-1})	Intensity	Notes
Anhydrides**			
C=O stretch	1850 – 1800 & 1790 – 1740	s	
Acid Chlorides			
C=O stretch	1815 – 1770	s	
Nitro Compounds			
NO_2 stretch	1570 – 1490 & 1390 – 1300	s	
Thiols†			
R-S-H stretch	2550 – 2600		
Alkyl & Aryl Halides†			
C-F stretch	1000 – 1400		Hidden in fingerprint region
C-Cl stretch	< 600 – 840		
C-Br stretch	< 700		
C-I stretch	< 600		

* Abbreviations: s = strong; m = medium; w = weak; br = broad; sat. = saturated; conj. = conjugated
** Alcohols, Esters, Carboxylic Acids, and Anhydrides also absorb in the fingerprint region due to the C-O stretch (1300 – 1000, s).

Table 2. Out-of-Plane C-H Bending Vibrations in Alkenes and Aromatics

Alkene Structure	Position (cm^{-1})	Phenyl Structure	Position (cm^{-1})
Mono-substituted 	997 – 985 & 915 – 905	Mono-substituted 	770 – 730 & 720 – 680
Disubstituted, *trans* 	980 – 960	Disubstituted, *ortho* 	770 – 735
Disubstituted, *cis* 	730 – 665	Disubstituted, *meta* 	810 – 750 & 725 – 680
Disubstituted, symm. 	895 – 885	Disubstituted, *para* 	860 – 800
Trisubstituted 	840 – 790		

* Adapted from…Mohrig, J. R.; Hammond, C. N.; Schatz, P. F. "Infrared Spectroscopy" in *Techniques in Organic Chemistry*. Freeman: New York, 2006.
† Palleros, D. R. "Infrared Spectroscopy" in *Experimental Organic Chemistry*. Wiley: New York, 2000. p. 688.

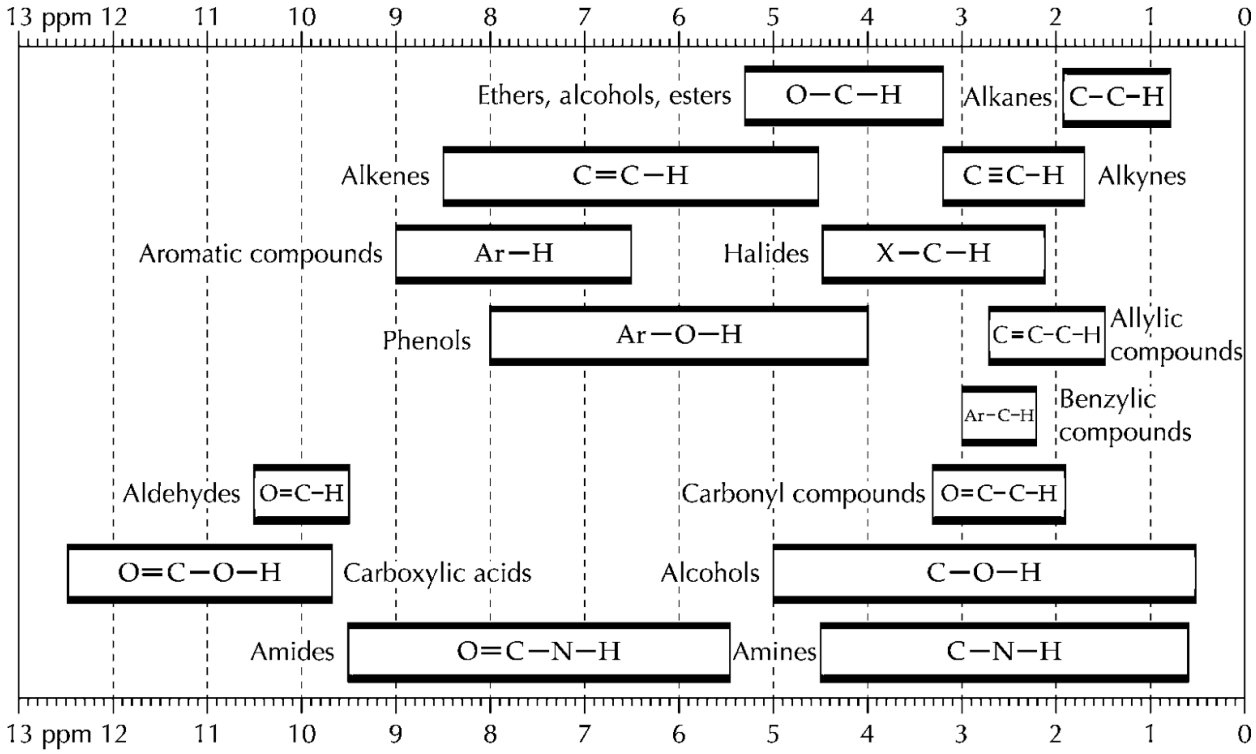


FIGURE 22.13 Approximate regions of chemical shifts for different types of protons in organic compounds.

TABLE 22.2 Characteristic ^{1}H NMR chemical shifts in $CDCl_3$

Compound	Chemical shift (δ, ppm)
TMS	0.0
Alkanes (C–C–**H**)	0.8–1.9
Amines (C–N–**H**)	0.6–4.5
Alcohols (C–O–**H**)	0.5–5.0
Alkenes[a] (C=C–C–**H**)	1.5–2.6
Alkynes (C≡C–**H**)	1.7–3.1
Carbonyl compounds (O=C–C–**H**)	1.9–3.3
Halides (X–C–**H**)	2.1–4.5
Aromatic compounds[b] (Ar–C–**H**)	2.2–3.0
Alcohols, esters, ethers (O–C–**H**)	3.2–5.3
Alkenes (C=C–**H**)	4.5–8.5
Phenols (Ar–O–**H**)	4.0–8.0
Amides (O=C–N–**H**)	5.5–9.5
Aromatic compounds (Ar–**H**)	6.5–9.0
Aldehydes (O=C–**H**)	9.5–10.5
Carboxylic acids (O=C–O–**H**)	9.7–12.5

a. Allylic protons.
b. Benzylic protons.

TABLE 22.4 Additive parameters for predicting NMR chemical shifts of aromatic protons in $CDCl_3$

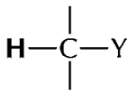
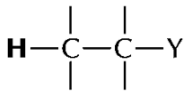
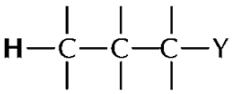
	Base value	7.36 ppm[a]	
Group	***ortho***	***meta***	***para***
—CH_3	–0.18	–0.11	–0.21
—$CH(CH_3)_2$	–0.14	–0.08	–0.20
—CH_2Cl	0.02	–0.01	–0.04
—$CH{=}CH_2$	0.04	–0.04	–0.12
—CH=CHAr	0.14	–0.02	–0.11
—$CH{=}CHCO_2H$	0.19	0.04	0.05
—CH=CH(C=O)Ar	0.28	0.06	0.05
Group	***ortho***	***meta***	***para***
—Ar	0.23	0.07	–0.02
—(C=O)H	0.53	0.18	0.28
—(C=O)R	0.60	0.10	0.20
—(C=O)Ar	0.45	0.12	0.23
—(C=O)CH=CHAr	0.67	0.14	0.21
—$(C{=}O)OCH_3$	0.68	0.08	0.19
—$(C{=}O)OCH_2CH_3$	0.69	0.06	0.17
—(C=O)OH	0.77	0.11	0.25
—(C=O)Cl	0.76	0.16	0.33
—$(C{=}O)NH_2$	0.46	0.09	0.17
—C≡N	0.29	0.12	0.25
—F	–0.32	–0.05	–0.25
—Cl	–0.02	–0.07	–0.13
—Br	0.13	–0.13	–0.08
—OH	–0.53	–0.14	–0.43
—OR	–0.45	–0.07	–0.41
—OAr	–0.36	–0.04	–0.28
—O(C=O)R	–0.27	0.02	–0.13
—O(C=O)Ar	–0.14	0.07	–0.09
—NH_2	–0.71	–0.22	–0.62
—$N(CH_3)_2$	–0.68	–0.15	–0.73
—NH(C=O)R	0.14	–0.07	–0.27
—NO_2	0.87	0.20	0.35

a. Base value is the measured chemical shift of benzene in $CDCl_3$ (1% solution).

TABLE 22.3 Additive parameters for predicting NMR chemical shifts of alkyl protons in $CDCl_3$[a]

Base values

Methyl	0.9 ppm
Methylene	1.2 ppm
Methine	1.5 ppm

Group (Y)	Alpha (α) substituent 	Beta (β) substituent 	Gamma (γ) substituent 
—R	0.0	0.0	0.0
—C=C	0.8	0.2	0.1
—C=C–Ar[b]	0.9	0.1	0.0
—C=C(C=O)OR	1.0	0.3	0.1
—C≡C–R	0.9	0.3	0.1
—C≡C–Ar	1.2	0.4	0.2
—Ar	1.4	0.4	0.1
—(C=O)OH	1.1	0.3	0.1
—(C=O)OR	1.1	0.3	0.1
—(C=O)H	1.1	0.4	0.1
—(C=O)R	1.2	0.3	0.0
—(C=O)Ar	1.7	0.3	0.1
—(C=O)NH_2	1.0	0.3	0.1
—(C=O)Cl	1.8	0.4	0.1
—C≡N	1.1	0.4	0.2
—Br	2.1	0.7	0.2
—Cl	2.2	0.5	0.2
—OH	2.3	0.3	0.1
—OR	2.1	0.3	0.1
—OAr	2.8	0.5	0.3
—O(C=O)R	2.8	0.5	0.1
—O(C=O)Ar	3.1	0.5	0.2
—NH_2	1.5	0.2	0.1
—NH(C=O)R	2.1	0.3	0.1
—NH(C=O)Ar	2.3	0.4	0.1

a. There may be differences of 0.1–0.5 ppm in the chemical shift values calculated from this table and those measured from individual spectra.
b. Ar = aromatic group.

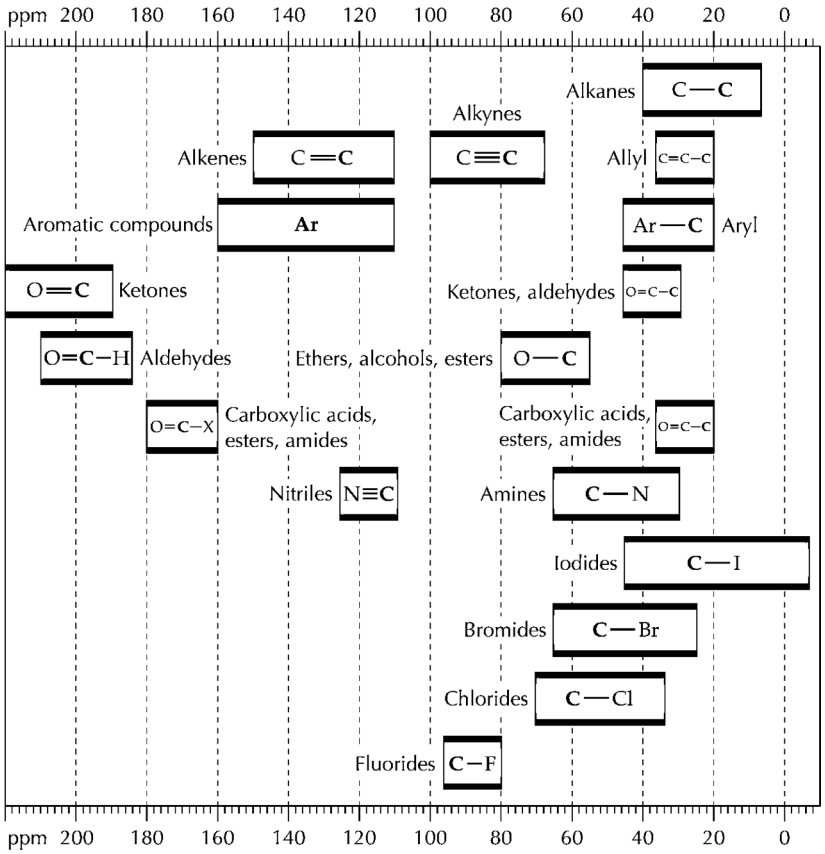
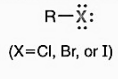
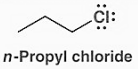
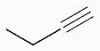
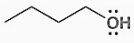
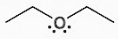
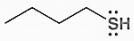
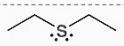


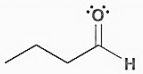
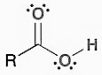
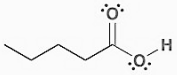
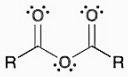
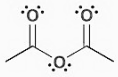
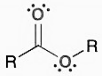
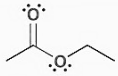
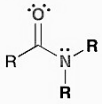
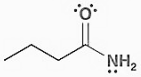
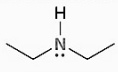
FIGURE 23.4 Approximate regions of ^{13}C chemical shifts for different types of carbon atoms in organic compounds.

TABLE 23.1 Characteristic ^{13}C NMR chemical shifts in $CDCl_3$

Compound	Chemical shift (ppm)
TMS	0.0
CDCl_3 (t)	77
Alkane (C–**C**H_3)	7–30
Alkane (C–**C**H_2)	15–40
Alkane (C–**C**H) and (C–**C**)	15–40
Carboxylic acids, esters, and amides (**C**–C=O)	20–35
Allyl (**C**–C=C)	20–35
Arene (**C**–Ar)	20–45
Ketones, aldehydes (**C**–C=O)	30–45
Amines (**C**–N)	30–65
Iodides (**C**–I)	–5–45
Bromides (**C**–Br)	25–65
Chlorides (**C**–Cl)	35–70
Fluorides (**C**–F)	80–95
Alcohols (**C**–OH), ethers (**C**–OR), esters (**C**–O[C=O]R)	55–80
Alkyne (**C**≡C)	70–100
Alkene (**C**=C)	110–150
Aromatic	110–160
Nitriles (**C**≡N)	110–125
Carboxylic acids, esters, and amides (**C**=O)	160–180
Aldehydes (**C**=O)	185–210
Ketones (**C**–O)	190–220

TABLE 2.1 EXAMPLES OF COMMON FUNCTIONAL GROUPS

FUNCTIONAL GROUP*	CLASSIFICATION	EXAMPLE	CHAPTER
 (X=Cl, Br, or I)	Alkyl halide	 *n*-Propyl chloride	7
	Alkene	 1-Butene	7, 8
	Alkyne	 1-Butyne	9
	Alcohol	 1-Butanol	12
	Ether	 Diethyl ether	13
	Thiol	 1-Butanethiol	13
	Sulfide	 Diethyl sulfide	13
	Aromatic (or arene)	 Methylbenzene	17, 18

FUNCTIONAL GROUP*	CLASSIFICATION	EXAMPLE	CHAPTER
	Ketone	 2-Butanone	19
	Aldehyde	 Butanal	19
	Carboxylic acid	 Pentanoic acid	20
	Acyl halide	 Acetyl chloride	20
	Anhydride	 Acetic anhydride	20
	Ester	 Ethyl acetate	20
	Amide	 Butanamide	20
	Amine	 Diethylamine	22

* The "R" refers to the remainder of the compound, usually carbon and hydrogen atoms.

Klein, D. (2019) Organic Chemistry, 3rd edition.