CHEM 3118
Organic Chemistry Laboratory
Supplemental Experiment Package
Semester 2

Southern Methodist University
Chemistry Department
CHEM 3118 – Organic Chemistry Laboratory
Revision 05-1
Identification of Unknown Liquid and Solid
CHEM 3118

Each student will be assigned an unknown organic liquid and an unknown organic solid.

For the unknown liquid, the following parameters must be determined:
- Boiling point
- Refractive index
- Infrared spectrum

Additionally, the following parameters will be provided:
- Mass spectrum
- NMR spectrum

For the unknown solid, the following parameters must be determined:
- Melting range
- Infrared spectrum

Additionally, the following parameters will be provided:
- Mass spectrum
- NMR spectrum

The identity of each unknown compound will be established using these parameters. Literature values and references for each parameter will be recorded. For reference spectra, only a reference is required; photocopies of reference spectra are not required.

The unknowns will be issued in adequate amounts to complete all tests, and additional unknown will not usually be dispensed. However, should an unknown be entirely consumed, due to multiple test repetitions, spillage or loss, an additional aliquot may be issued with an appropriate point deduction from the final laboratory grade.

The following tips and evaluation guidelines are provided by Professor E. R. Biehl. They are compiled from experiences with this experiment, and include many invaluable ‘hints.’

- Tip 1. A strong odor may give hints about compound identify: non-aromatic amines have a fish odor, esters have fruity fragrance
- Tip 2. Refractive index around 1.5 and above are usually aromatic compounds or contain 2 or more halogens (Br, Cl, I).
- Tip 3. All unknowns are listed in Aldrich chemical catalog.
Identification of Unknown Liquid and Solid
CHEM 3118

Evaluating IR spectra - Some tips by ERB

Remember important IR bands for the following families:

- **Alkane/Alkene Stretches** - around 3000 cm\(^{-1}\) (type of CH - slightly greater than 3000 (C=C-H) slightly less (alkyl hydrogens))

- **Aromatic Compounds** - 1600 and 1500 cm\(^{-1}\); substitution patterns on benzene ring are found in the 850-690 region - check Wade for details.

- **Alcohols** - 3500-330 cm\(^{-1}\) C-O stretch around 1050 to 1200 cm\(^{-1}\) (strong)

- **Ketones and Aldehydes** (1725-1715 cm\(^{-1}\)) conjugation lowers frequency about 30 cm\(^{-1}\) (e.g carbonyl attached to a benzene ring). Band is very strong. ALSO aldehydes have carbonyl hydrogen stretch around 2750 cm\(^{-1}\).

- **Esters** - around 1740 cm\(^{-1}\).

- **Alkenes** - remember you just made cyclohexene and should know the pertinent frequencies.

- **Nitriles** - 2250-2225 cm\(^{-1}\)

- **Amine** - two NH stretch frequencies in the 3400-3200 region for NH\(_2\), one for NH (secondary amine) and none for tertiary amines (that is, no NH group).

- **Nitro** - (look up spectra of nitro compounds in Aldrich IR references located in the lab to see if you can figure out where nitro stretching frequencies occur)

- **Amides** - RCONH\(_2\) C=O stretch 1690 cm\(^{-1}\). NH stretch similar to amines listed above.

- **Alkynes** - hydrogen attached to triple bond around 3300 cm\(^{-1}\) (sharp) triple bond around 2100-2200 cm\(^{-1}\). CAREFUL: if symmetrically distributed, the band is quite weak (remember there must be a change in dipole moment during stretch - since triple bond is linear then the symmetrical stretch will have little dipole moment change during vibration.

- **Ethers** - C-O stretch in the 1200-1100 cm\(^{-1}\) region (same as that of alcohols, but alcohols easily distinguished from ethers in that only the former has a OH stretch frequency).
Alkyl halides - no reliable absorption peaks

Carboxylic acids - in the 3500-2700 cm\(^{-1}\) region, a complex broad band is observed that resembles the state of Texas. This is the OH band. Secondly, the carbonyl stretch is around 1720 cm\(^{-1}\); benzoic acids are lower by about 20-30 wavenumbers.

Wade does not have sufficient info on important IR absorption bands for substituted benzene rings. So here are some.

The region from about 690 to 850 cm\(^{-1}\) gives info on type of substitution in aromatic compounds.
- monosubstituted bands are 690 and 730-760 cm\(^{-1}\)
- ortho (1,2) appear at 700 and 760 cm\(^{-1}\)
- meta at 710 and 790 cm\(^{-1}\)
- para at 820-850 cm\(^{-1}\)
- unsymmetrically trisubstituted 700 cm\(^{-1}\) and 830-870 cm\(^{-1}\)

For some of you it will be important to know that conjugation lowers C=O frequency about 30 cm\(^{-1}\) for unsaturated unit attach to it. For example, if two units are attached to C=O the observed C=O stretch is observed a ca. 60 cm\(^{-1}\) from absorption frequency of the non-conjugated parent. These are 1740 cm\(^{-1}\) for esters, 1725-1710 cm\(^{-1}\) for aldehydes and ketones, 1690 cm\(^{-1}\) for amides.
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CHEM 3118

Evaluating mass spectra - Some tips by ERB

1. Parent peak (P) - actual molecular mass of your unknown. Odd Nitrogen rule may be of help: Compounds containing an odd number of nitrogen atoms have an odd molecular mass (the corollary is a molecule containing zero or an even number of nitrogen atoms having an even molecular mass. Some compounds have very weak molecular ions and fragment to more stable ions. Ones to watch out for are: tertiary alcohols - lose water very easily, 1,4-dichloro- or 1,4-dibrombutanes - lose HCl or HBr. (The parent peak is not observed - the resulting P minus HX peak (X = Cl or Br) appears to be parent peak, but it isn't.

2. Isotope peaks - (P+1, P+2, etc) arise when one of more of the elements exist in nature in two or more isotopic forms. H, C and O exist mainly as \(^1\)H, \(^{12}\)C, and \(^{16}\)O. Thus the P+1 and P+2 isotopics peaks are small. However Bromine exist in nature as \(^{79}\)Br and \(^{81}\)Br: the relative abundance of each isotope is 50% each. - 79 and 81. Therefore we have equal chances of \(^{79}\)Br and \(^{81}\)Br being in a bromine containing compound.

Consider CH\(_3\)Br. Half will have a molecular mass of \(12(\text{C}) + 3(\text{H}) + 79\) or 94 molecular mass and \(12(\text{C}) + 3(\text{H}) + 81\) or 96. This gives rise to a P peak (94) and a P+2 peak (96) and they appear with equal intensity. By similar reasoning, Cl, which exists as \(^{35}\)Cl and \(^{37}\)Cl in a ratio of 3:1, respectively, leads to any chlorine containing compound having P and P+2 peaks in a ratio of 3:1 respectively.

What if we have two bromines in a compound? We can use the binomial theorem to calculate the number of isotope peaks and the relative intensities (much like the N+1 rule in NMR) - using only the coefficients the solution. In general \((A + B)^n\) where n = the number of similar elements and A and B represents each isotope.

For two bromines we have \((^{79}\text{Br} + ^{81}\text{Br})(^{79}\text{Br} + ^{81}\text{Br}) = ^{79}\text{Br}^{79}\text{Br} + 2^{79}\text{Br}^{81}\text{Br} + ^{81}\text{Br}^{81}\text{Br}. This gives rise to a P, P+2 and a P+4 with relative intensities of 1:2:1. Consider chlorine and bromine: \((^{79}\text{Br} + ^{81}\text{Br})(^{35}\text{Cl} + ^{37}\text{Cl})\). Show that this leads to P, P+2 and P+4 peaks in ratio of 3:4:1. Two chlorine atoms is 9:6:1.

3. Most of the spectroscopic data packages include only the parent peak, isotope peaks, base peak (the largest peak), and the relative abundances of each. This is because mass spectra can now be “looked up on the internet.” In some cases, the abundances or base peaks were omitted, so that the compound cannot be identified without interpreting the spectra. For that reason, little or no fragmentation data is available.
Isotope Patterns of Various Combinations of Cl and Br

Note: The signals are separated by 2 mass units.
For exact abundances see p. M105, M110.
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**CHEM 3118**

Evaluating NMR spectra - Some tips by ERB

Remember where different types of hydrogens appear in spectrum- (1-2 ppm - alkyl groups away from electronegative atoms; around 2 ppm - hydrogen attached to carbon adjacent to carbonyl group, 3-4 = hydrogen attached to carbon adjacent to electronegative atom such as oxygen (CH-O) bromine or chlorine. 5-6 = alkenic hydrogens; 7-8 aromatic hydrogens, 9.5 = aldehydic CH, greater than 10 = CO$_2$H) alcohol OH variable between 2.5 to 5.0.

Esters (RCO$_2$R') have interesting NMR spectra. Consider methyl acetate, CH$_3$CO$_2$CH$_3$. The methyl group attached to oxygen appears around 3.7 ppm, whereas the methyl group attached to the carbonyl appears around 2.0 ppm.

Integration especially of the aromatic hydrogens will tell you the nature of substitution on the benzene ring. For example, if there are 4 aromatic hydrogens, then you have a disubstituted benzene ring. Possibilities are 1,2 (ortho), 1,3 (meta) or 1,4 (para). If the groups are the same, then the hydrogens in the 1,4-case appear as a singlet (all equivalent) if they are different (e.g. 4-chloronitrobenzene) then they appears as a doublet of doublets. *meta* and *ortho* are a little more complicated, but you can get ideas of what they look like from Aldrich FT-NMR library located in the laboratory. Mono substituted benzenes will appear as a broad singlet if the group attached is alkyl, but will become more complication if an electronegative group is attached (e.g. nitro, halogen, OH, OCH$_3$, etc).

It goes without saying that you should remember characteristic splitting patterns of simple alkyl groups. ALSO, if your unknown has a carbon chain containing roughly 4 or more carbons then virtual coupling is observed. The region between 1-2 is very complicated but you can usually determine the number of hydrogens in the band spread and if the chain is attached to an alcohol or amine, one can usually see a band associated with the CH attached to electronegative atom. Again, you might want to look in the Aldrich library for spectrum of say pentyl amine or 1-hexanol.

ALSO I noticed that some NMR spectra contain impurity signals. You should check with an instructor or teaching assistant if there are questions. NOTE ALSO THAT THE LARGE SIGNAL AT ZERO PPM IS TMS!!
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CHEM 3118

Elements of the Final Report

Unknown reports must include the following:

1) your name

2) unknown sample numbers

3) must write a separate report for each unknown

4) unknown liguids - must report boiling point, refractive index, (density is optional) along with literature values (e.g. bp = 60 °C; lit.[Aldrich Chemical Catalog, p. XXX, 1999] = 61 °C]).

5) Unknown solids - must report melting range along with literature value.

6) IR, NMR and MS for both liquids and solids - must report reference for IR and NMR (page number and spectrum number if appropriate.)

7) the name and structure determined for the unknown compound.

8) IR spectra must have pertinent absorptions indicated.

9) NMR spectra - equivalent sets of hydrogens must be indicated on the spectra. Where possible, coupling constants should be indicated. You will not be penalized if coupling constant calculations are not possible.

10) Mass spectral data - I have indicated all major isotope peaks along with parent peak on your spectra. You should determine molecular weight, isotope information, and any other elucidation obtainable from the data.

11) You should write a concise story of how the spectrum and physical properties aided you in your unknown determination. Remember you can correctly identify your unknown, but lose many points for poor use of spectral data. For example, to not identity a peak around 3500-3300 cm⁻¹ in, say, an unknown alcohol is unforgivable.
Preparation of Aspirin and Phenacetin

Aspirin and phenacetin are two commonly used analgesics. They usually are synthesized by treating salicylic acid and \( p \)-phenetidine, respectively, in refluxing acetic anhydride. In today’s experiment, the analgesics will be prepared using microwave radiation. Microwaves have been used extensively in a variety of applications, including rapid synthesis of organic compounds. In today’s experiment you will be able to synthesize each compound using an irradiation time of a minute or less.

The reactions of the day are shown below:

\[
\text{H}_3\text{PO}_4 \text{ cat. microwave 30% power 75 seconds} \quad \text{salicylic acid} \quad \text{acetic anhydride} \quad \text{acetylsalicylic acid} \quad \text{“aspirin”}
\]

Both reactions proceed via a mechanism involving nucleophilic attack of N or O onto one of the carbonyl groups of the acetic anhydride reactant. In your report you will need to write the detailed mechanism for both reaction with the arrows pointing in the right directions. Check Chapter 21, ‘Carboxylic Acid Derivatives’ in Wade for details.
Experimental Procedure

**Synthesis of Aspirin.** Using a centrifuge tube, cool 10 mL dionized water in an ice bath. In a 100 mL beaker, combine 0.005 mol (0.70 g) of salicylic acid, 0.015 mol (1.4 mL) of acetic anhydride and one drop of phosphoric acid. Cover the mixture with a watch glass (concave side up!) and place the assembly in a microwave oven. Heat the assembly for 75 seconds using a power level of 3 (30%). Remove the assembly and allow the beaker to cool to room temperature. Place the beaker in the ice bath to aid in the precipitation of aspirin from solution.

Recover the aspirin by vacuum filtration, rinsing with two 5 mL portions of chilled water, and then allow it to dry in a heated oven for ten minutes. Weigh the dried aspirin, determine its melting range, and calculate its percent yield. Determine the purity of the product by IR spectroscopy (KBr pellet.)

**Synthesis of Phenacetin.** Using a centrifuge tube, cool 10 mL dionized water in an ice bath. In a 100 mL beaker, combine 0.005 mol (0.65 mL) of \( p \)-phenetidine, 5 mL of water and 0.015 mol (1.4 mL) of acetic anhydride. Cover the mixture with a watch glass (concave side up!) and place the assembly in a microwave oven. Heat the assembly for 30 seconds using a power level of 3 (30%). Remove the assembly and allow the beaker to cool to room temperature. Place the beaker in the ice bath to aid in the precipitation of phenacetin from solution.

Recover the phenacetin by vacuum filtration, rinsing with two 5 mL portions of chilled water, and then allow it to dry in a heated oven for ten minutes. Weigh the dried product, determine its melting range, and calculate its percent yield. Determine the purity of the phenacetin sample by thin-layer chromatography using 6:4 pentane-ethyl acetate as the mobile phase. Run the chromatogram of your product along with known samples of \( p \)-phenetidine (starting material) and phenacetin (product.) Report Rf values for your product and the known samples.

Post Laboratory Questions:

1. a) What are the by-products of the aspirin synthesis?
   b) What are the by-products of the phenacetin synthesis?
2. Sketch the reaction mechanism for each preparation (include the role of \( \text{H}_3\text{PO}_4 \) in the aspirin preparation).
3. Why do you think the aspirin synthesis requires a catalytic amount of acid while the phenacetin synthesis does not?
4. Compare the melting ranges obtained for each product to their literature values. What do these results tell you about the identity and purity of your products?
Preparation of Aspirin and Phenacetin

Pre-Laboratory Questions:

1. What is the structure of aspirin? Of phenacetin?

2. What is the non-microwave preparation of aspirin and phenacetin?

3. What is an analgesic?

4. How long will you irradiate the aspirin reaction? The phenacetin reaction?
Synthesis of Terephthaloyl Nylon

Read sections 26.1 and 26-7A in Organic Chemistry by Wade.

Nylon is made industrially by condensing a diacid with a diamine. The most common reaction is the condensation of adipic acid and hexamethylene diamine to produce Nylon 66. This reaction requires somewhat exotic equipment and elevated temperatures. A room temperature reaction can be achieved by substituting adipoyl chloride, which is much more reactive than the corresponding acid. In today’s experiment you will make a slightly different polymer, which we will call Terephthaloyl Nylon, by treating terephthaloyl chloride with hexamethylene diamine in a rather mundane 100 mL beaker. When you mix the acid chloride (dissolved in diethyl ether) with the diamine (dissolved in water), a two layer liquid results (water at the bottom and ether at the top.) The reaction will occur (a film immediately forms) at the interface of the two liquid phases.

Reagents and Properties

<table>
<thead>
<tr>
<th>substance</th>
<th>conc’n</th>
<th>quantity (mL)</th>
<th>mol mass (g/mol)</th>
<th>density</th>
</tr>
</thead>
<tbody>
<tr>
<td>terephthaloyl chloride</td>
<td>0.28M in ether</td>
<td>10</td>
<td>203.02</td>
<td></td>
</tr>
<tr>
<td>hexamethylene diamine</td>
<td>70% in H₂O</td>
<td>0.6</td>
<td>116.20</td>
<td>0.89</td>
</tr>
</tbody>
</table>

Reaction of the Day

\[
\text{terephthaloyl chloride} + \text{hexamethylene} \rightarrow \text{“living” polymer chain} + 2 \text{HCl}
\]
Experimental Procedure:

In a 100 mL beaker, dissolve 0.6 mL of 70% hexamethylene diamine (Caution! Caustic!) in 10 mL of water. Add 0.3 g sodium hydroxide. In a separate beaker, obtain 10 mL of 0.28 M terephthaloyl chloride dissolved in diethyl ether.

Carefully pour the less dense of these two solutions (water or diethyl ether? If in doubt, check density in the Aldrich Chemical catalog) down the inside of the beaker containing the other solution with as little stirring as possible. A film forms at once at the interface.

Push the film away from the wall of the beaker and pull out the mass that forms with a tweezer to raise it as a strand of continuously forming polymer. This can be wound on a rod or pencil to yield several feet of fiber. Place the resultant polymer on sheets of paper on the benchtop. DO NOT PERMIT THE LIVING POLYMER TO TOUCH THE BENCHTOP. (The impervious-looking benchtops are ‘epoxy resin’ hard plastic. Your polymer will react with the benchtop, and fuse with it.) Measure and record the length of the longest strand.

Gather all of the polymer generated and blot the strands dry with paper towels. Measure and record the total mass of polymer formed.

Post Laboratory Questions:

1) Describe briefly how you drew your strand, and whether this was an effective technique. Discuss what factors need to be considered to draw a good strand.

2) For this laboratory scale experiment, terephthaloyl chloride was used, rather than the less reactive terephthalic acid. Why is the acid chloride more reactive?

3) What was the purpose of the sodium hydroxide added to the original reaction mixture?

4) How do the fibers produced compare with commercially produced nylon, which is used (for example) in sports clothing?

Calculating theoretical and actual yields for polymers is impossible to do conventionally, because there is no absolute molecular weight for the product. The length of the polymer molecules is difficult to determine, and usually the molecules are of varying length. The mathematical solution to this difficulty is to base yield calculations on the “repeating unit” of the polymer, and use that as the molecular weight of the polymer. That is, determine a structure for which the polymer can be represented as:

In this case, the molecular weight of the repeating unit, C₁₄H₁₈O₂N₂, gives a molecular weight of 246g/mol. Note that other repeating units may be selected, but all will lead to the same formula and molecular weight.
Calculating Retention Factors (Rf) for Thin Layer Chromatography

Upon the development and viewing of a TLC plate, the starting point and solvent front (the level the solvent reached when the plate was removed from the developing tank) are marked and all spots observed on the plate are circled in lead pencil. The location of each spot on the plate is then represented numerically by calculating a Retention Factor (Rf). This is accomplished by making the following measurements and calculations:

Retention factors are numbers between zero and one, representing the position of the spot on the TLC plate. Hence:

\[ R_f \approx 0 \]

\[ R_f \approx 0.5 \]

\[ R_f \approx 1.0 \]

If the number obtained is not between zero and one, a mathematical error occurred. Note that this number is dimensionless, and the distances may be measured in centimeters, inches or barleycorns.

Chemistry 3117/3118
Southern Methodist University
How to get maximum efficiency from your Meltemp apparatus

The Meltemp apparatus is the small piece of equipment you have been using to determine melting and boiling points. We have two models in the lab - one has a black body and the other has a gray body. They both work in essentially the same manner.

Now that you will be doing more careful work with melting points, it would be a good idea to pick up some pointers concerning the Meltemp apparatus, particularly the correct power settings to use. Check out the graph below:

![Graph showing power settings for desired heating rate at anticipated melting point](image)

The y-axis corresponds to the expected melting temperature of whatever it is you are measuring. The x-axis corresponds to the power setting on the black-bodied Meltemp apparatus (the black-bodied apparatus has a power scale from 0 to 10 whereas the gray-bodied apparatus has a scale from 0 to 120. Obviously then, a setting of 5.0 on the black-bodied apparatus corresponds to a setting of 60 on the gray-bodied one). Normally, you want the apparatus to be heating at a rate of 2°C/min at the expected melting point of your compound. So for example, if you have a compound that should melt at 150°C, you find 150 on the y-axis and move over on the graph to the line that says “2°/min”. That corresponds to a power setting of approximately 3.7. If you go ahead and set the apparatus to 3.7, you can feel safe that the heating rate will be 2°C/min at 150°C.

If you do not know the melting point of your compound, determine what we call a “ballistic” or “estimation” melting point, i.e. crank the heat to a setting of 6 to 8 and see what the approximate melting point is. Then use this approximate melting point value with the graph above to set the correct power level (after letting the apparatus cool). This method will save you a tremendous amount of time compared to slowly heating the apparatus over the whole temperature range (imagine if your unknown compound had a melting point >200°C).