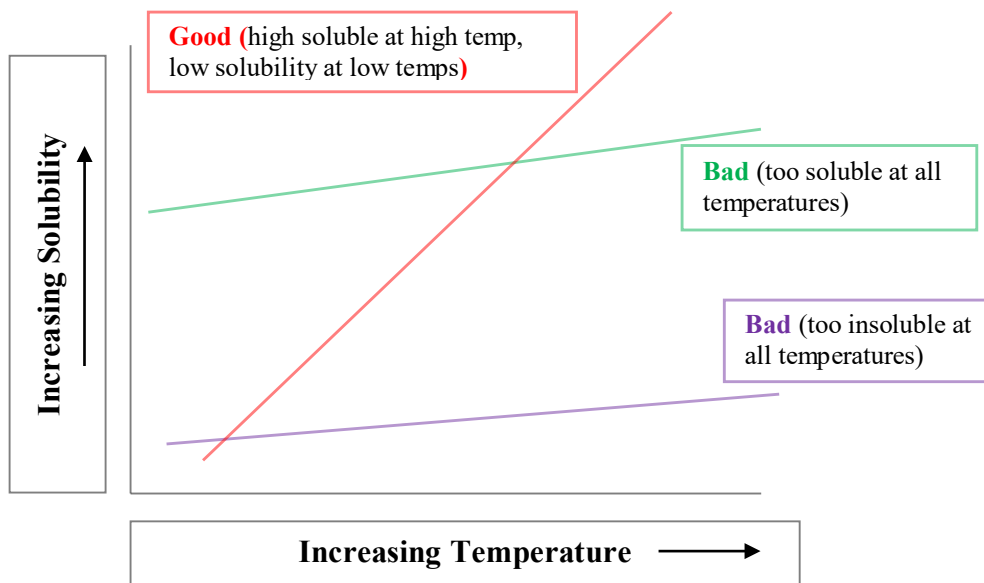


Recrystallization¹

Recrystallization is the most convenient method for purifying organic compounds that are solids at room temperature. Compounds obtained from natural sources, or from reaction mixtures, almost always contain impurities. The impurities may include some combination of insoluble, soluble and colored impurities. To obtain a pure compound these impurities must be removed. Each is removed in a separate step in the recrystallization procedure.

To understand the recrystallization process, solubility behavior must first be considered. It is often stated that "like dissolves like". More correctly, it should be stated that, "compounds having similar structural features will be soluble in one another". Some obvious structural features that may affect solubility include polarity and the ability to hydrogen bond. For example, a compound having just a few carbons and an alcohol functional group (FG) would be expected to be soluble in solvents that have a few carbons and an alcohol FG or in some other polar solvent, and to be less soluble in nonpolar solvents. Conversely an alkane would be expected to show the opposite solubility behavior. In most cases though it is not as simple as this. If for example a compound has lots of carbons and hydrogens (> 6 C's) and just one alcohol group, the solubility will be dominated more by the alkyl part of the molecule than by the alcohol part, and the compound will show a solubility behavior more like that of an alkane. For known compounds it is useful to consider the structure of the compound when choosing a recrystallization solvent. An educated guess can save some time. Usually however, the structure of a compound may not be known so the solvent must be chosen by carrying out solubility tests.

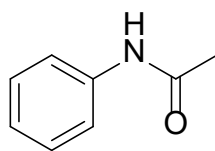
The first part of this experiment involves carrying out solubility tests on known compounds. Later on such solubility tests will be used to find a suitable recrystallization solvent for an unknown compound. A compound usually exhibits one of three general solubility behaviors: (1) the compound has a high solubility in both hot and cold solvent (green), (2) the compound has a low solubility in both hot and cold solvent (purple) and (3) the compound has a high solubility in hot solvent and a low solubility in cold solvent (red). Solvents which exhibit the first two behaviors are not useful for recrystallizing a compound. A solvent showing the third behavior, that is, high solubility at high temperatures, sparingly soluble at room temperature and low solubility (or insoluble) at reduced temperatures, is one that is suitable for use as a recrystallization solvent.



¹ revised 6/2019

Consider the three different types of impurities that may be present in a sample: soluble, insoluble, and colored. In theory, insoluble impurities can be removed from a compound fairly easily. The compound is dissolved in a solvent, the solution is filtered to remove the insoluble impurities, and the solvent evaporated to produce the solid compound. The insoluble impurities are left behind in the filter paper. Colored impurities can be removed in a similar way but with an additional step. The solid is dissolved in a solvent, activated charcoal is added, the solution is filtered as before, and the solvent is evaporated to produce the solid compound. The charcoal, which has adsorbed the colored impurities, is left behind in the filter paper. The third type of impurity, the soluble impurity, cannot be filtered out because it has solubility characteristics similar to those of the desired compound (hence the name soluble impurity). To remove soluble impurities, first, by doing solubility tests, a suitable solvent is chosen (high solubility in hot solvent, low solubility in cold solvent). The soluble impurities are then removed as follows: the desired compound along with the soluble impurities are dissolved in a MINIMUM of near or at BOILING solvent. The solution is then allowed to cool slowly and without interruption. As the solution cools, the solubility of the compound (and of the soluble impurities) decreases, the solution becomes saturated with the desired compound, and the compound begins to crystallize. Because formation of crystals is a highly selective process that usually excludes foreign molecules, only crystals of the desired compound form. Because the soluble impurities are present in smaller amounts, the solution never becomes saturated with the impurities, so the impurities remain in solution even after the solution has cooled. Removing the solution from the crystals thus removes the solvent and the soluble impurities from the desired crystals. A final rinse with a MINIMUM of ICE-COLD solvent, followed by its removal, cleans off any residual soluble impurities clinging to the surface of the desired crystals. After allowing the solvent to evaporate, pure crystals of desired compound should remain. The mass and the MP of the crystals would be determined, and along with the % recovery, and this data would be included in the report.

In practice, by following a set procedure, the same solvent is used throughout the entire recrystallization process, and the impurities are removed one by one. Note that in any recrystallization some of the desired product is sacrificed and the recovery will be less than 100%. This is because even at the lower temperatures the desired compound has some finite solubility in the recrystallization solvent and is thus lost when solvent and soluble impurities are removed. To illustrate this, look at the solubility of acetanilide in water.



Acetanilide

Solubility in 100 mL water
0.5 g at 10°C; 5 g at 99°C

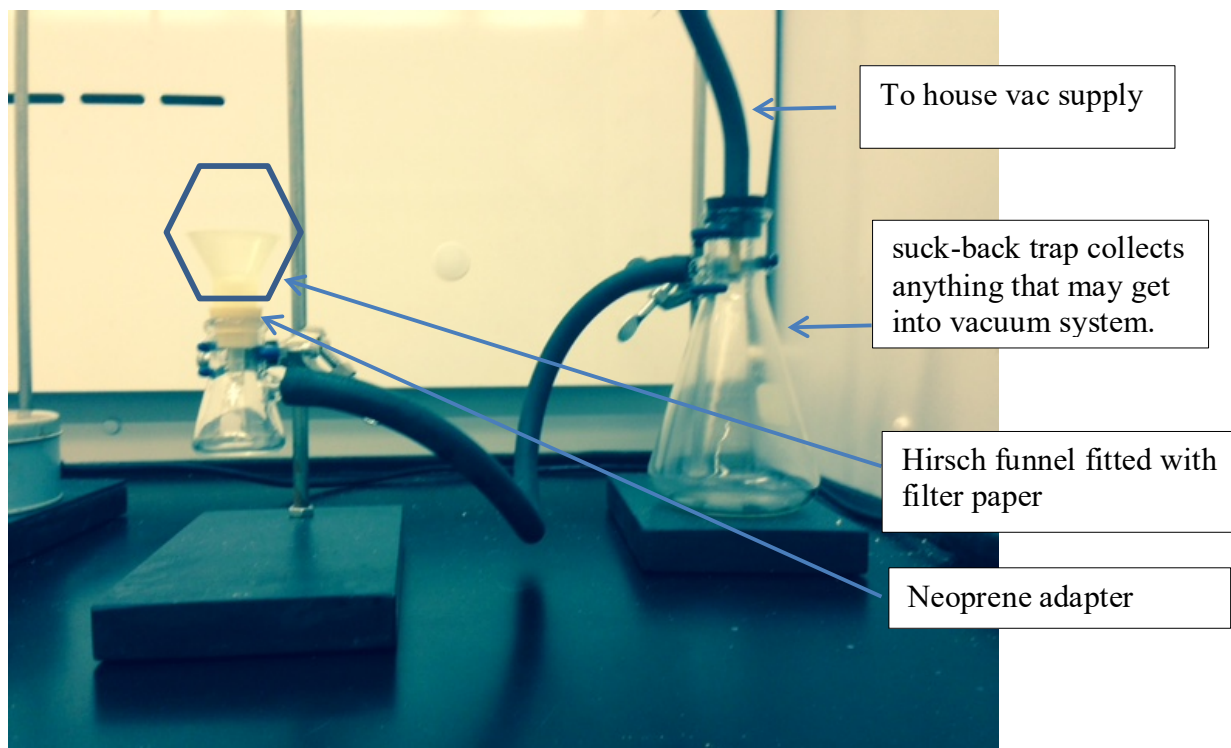
If 5 g were dissolved in 100 mL of water at 99 °C and then allowed to cool to 10 °C, 4.5 g would crystallize out and 0.5 g would remain in solution. The recovery then would be 90%. The 10% remaining in solution would be lost.

Recrystallization summary. For our recrystallizations you may assume that only soluble impurities are present. The six steps used here to recrystallize a compound are, (1) carry out solubility tests to determine a suitable solvent; (2) dissolve the solute in a minimum of near- or at boiling solvent; (3) allow the solution to cool slowly and undisturbed to room temperature (rt) then possibly to ice temperature; (4) collect the crystals by filtration; (5) rinse the crystals with a minimum amount of **ice-cold solvent**; and (6) allow the crystals to dry.

What can go wrong in a recrystallization? Care must be taken at each step to obtain good results, which can be measured by % recovery and purity of the desired compound. Fortunately, for most of the recrystallizations

done in this course, for various reasons, colored impurities and insoluble impurities will not be present. Removing soluble impurities will thus be the focus of most recrystallizations done here. Recrystallizations require careful technique and practice. Some loss, resulting from transferring solids from one container to another and leaving a little material behind, cannot be avoided. Such losses should however be minimized as much as possible by using careful technique. Also, because of the finite solubility of the solid in the recrystallization solvent, even at low temperatures, any unnecessary prolonged contact with recrystallization solvent, especially if the solvent is not ice-cold will result in loss of product. For that reason, the following problems commonly occur: if too much solvent is added in the recrystallization, a poor or no yield of crystals will result. If the solid is dissolved below the boiling point of the solution, too much solvent will be needed, resulting in a poor yield. If too much rinse solvent or rinse solvent that is not chilled to ice temperature is used, some of the product will be redissolved and lost. In summary, to obtain optimal results, a MINIMUM of near-BOILING solvent should be used for the recrystallization, and a MINIMUM of ICE-COLD solvent should be used for the rinse. Occasionally crystals will not form, even though the saturation point has been reached. If a recrystallization solution has been allowed to cool and crystals have not formed, it may be due to a condition known as supersaturation. If this happens, you may induce crystallization by scratching the inside of the glass tube just below the surface of liquid using a glass stirring rod. The tiny scratch provides a rough surface on which the crystallization may begin. The same result could be obtained by adding a small “seed” crystal of that substance, assuming a small amount of solid had been saved.

Suction filtration: Isolation of the solid. There are many filtration methods to isolate a solid from a liquid: pipet (used later in a different experiment), gravity and best of all, suction. We will utilize suction filtration, so it is the only one described. In this method, the number of transfers from one container to another is kept to a minimum, thereby minimizing loss of material. An advantage of suction filtration is that the solution is completely separated from the solid, and can be allowed to dry with briskly passing air, so drying time is often shorter. The photo below shows the set-up:



The procedure for setting up a suction filtration is described below.

1. Clamp the 25-mL filter flask (Erlenmeyer flask with a tapered side-arm) to the ringstand as shown above.
2. Add the neoprene adapter (tapered neck piece) and plastic Hirsch funnel with a piece of filter paper.
3. Make sure vacuum is working by turning on the knob; place a finger over the black tubing. You will know if it is working.
4. Connect the thick-walled vacuum tubing from the suck-back trap to side arm of flask.
 - a. the trap prevents anything from mistakenly entering the vacuum system.
5. Turn on vacuum 'full blast', until knob stops.
6. Actual filtration described in the experimental procedure.

Prelab: You may either print out your prelab and bring it with you to lab, or bring your computer. Your TA will grade it on the spot before you begin the experiment. For the in lab observations, you may use scratch paper and record later in your ELN, or bring your computer and record directly in your ELN.

Postlab Report: Make sure to use the non-formal postlab report template on the course website!

The Experiment.

Because we will utilize recrystallizations throughout this course, it is vital that you understand the principles behind it and learn to do it correctly from the start. In later experiments, you are not be given detailed instructions for recrystallizations. You will simply be told to recrystallize a compound. A good recrystallization solvent is one in which the solid has a very high solubility at high temperatures and a very low solubility at low temperatures. Refer to the flow chart shown on the last page of this handout. Note the distinction between melting and dissolving. Melting is the process that converts a solid to a liquid by supplying heat. Dissolving is the process that homogeneously disperses a solid into a solvent by interfering with the intermolecular forces that allow a compound to be in its solid state.

Include in your prelab outline, the separate recrystallization steps noted above, along with the purpose of each.

(1) Solvent determination of your unknown. *Your TA will assign the unknown to you.* Remember: hot plates take time to heat up so whenever a procedure calls for the use of a hot plate, the first thing to do upon entering the lab is to turn the controller on to a setting suggested by your TA. Always turn the heater off before you leave for the day. You will determine the recrystallization solvent of your unknown using an optimal solvent (water, methanol, pure ethanol, 70% ethanol in water, hexanes or toluene) at different temperatures (hexanes is a mixture of hydrocarbons mainly composed of isomeric hexanes). You must use all solvents available and determine which is best after you have analyzed data. You will use this information in part three of this lab, so ***look for a solvent that produces the highest recovery and the most well-formed crystals.***

Use about 10 mg of unknown for each test. It is not necessary to use a balance to measure out the solids accurately. Samples of about 10 mg of solid in a reaction tube will be on display on the reagent bench. To avoid spilling the solid, use the scoopula and the plastic funnel from the kit to help transfer the solid to the tube. The solvent does not have to be measured exactly either. Use a disposable pipet to add solvent and the calibrations on the reaction tube to measure the amount. This level of accuracy is enough for qualitative tests such as these and will be done often in certain microscale experiments, where accuracy is not essential. To heat solutions in a reaction tube, use the hot plate as the heat source and a boiling stick to promote smooth boiling (**handle tube with your test-tube tongs**). Failure to use a boiling stick will result in superheating of

the solution followed by bumping of the solution out of the tube. In heating a tube with a hot plate, the temperature of the tube is controlled by adjusting the depth to which it is immersed in the block. Use care in heating low-boiling solvents such as hexanes. Such solvents evaporate easily. Note that hexanes and toluene are flammable. Never point the heating tube at yourself or at anyone else because the tube contents may become overheated and shoot out of the tube. Always work in the hood and **DO NOT PUT YOUR HEAD IN THE HOOD!!**

Determine the best solvent as follows: First see if 10 mg of your unknown is soluble in 0.25 mL of the solvent at room temperature (rt). After adding solvent always flick the tube with a finger to swirl the contents and to help ensure complete mixing, and give it 30 seconds (s) to dissolve. If the solid completely dissolves, it is considered to be very soluble at rt, in which case nothing more has to be done with that unknown/solvent combination. If the compound is insoluble at rt, heat the tube to the BP of the solution. If the compound is still insoluble at the BP (give it 30s or so), it is considered to have a very low solubility at all temperatures, in which case nothing more has to be done with that unknown/solvent combination. If it seems that some of it has dissolved in 0.25 mL of boiling solvent, add another 0.25 mL and reheat it to see if it will all dissolve. If the compound has dissolved in boiling solvent (either 0.25 mL or 0.5 mL), cool the tube in ice-cold water to see if crystallization occurs. Scratching the reaction tube with a glass stirring rod at the air-liquid interface may be necessary to induce crystallization. If crystals form, redissolve the solid by heating and allow the tube to cool more slowly, without cooling in cold water. Slow cooling may allow larger crystals to form. If the crystals are large enough, record the crystal form (e.g., needles, plates, prisms). The relative amount of the crystals, compared to the starting amount, should be noted.

Table 1. Solubility using 0.25 mL solvent.

Solvent	Cold	Hot	Observations
Water	Insoluble	Soluble	Needles on Cooling
PhCH ₃	Insoluble	Slightly Soluble	Precipitates on cooling

Table 2. Solubility using 0.50 mL solvent.

Solvent	Cold	Hot	Observations
Water	Insoluble	Insoluble	N/A
PhCH ₃	Insoluble	Soluble	Precipitates on cooling

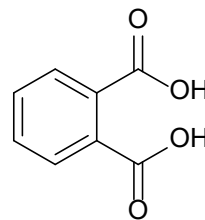
Note that your table will have additional entries for the other solvents not listed in these tables. Also note that you may not have an entry for the 0.5 mL table for a solvent that didn't require additional solvent added.

Dispose of all solutions in the ORGANIC LIQUID WASTE container in the hood. Place used boiling sticks into the "boiling stick" waste container in the hood, NOT into the trash. Being environmentally responsible: Minimize the number of Pasteur pipets being used. It is usually not necessary to dispose of a pipet after each use. For example, if you have just transferred an aqueous solution with a pipet and you are going to transfer another aqueous solution, simply rinse the pipet with water, if necessary, and use it again.

In the next part, you will recrystallize phthalic acid from water.

(2) Macroscale Recrystallization of Phthalic Acid.

- a) Make sure the hot plate was turned on.
- b) Weigh out 325 +/- 10 mg of phthalic acid. Place into a 10 mL Erlenmeyer flask.
 - a. Make sure to record the actual amount that you used.
- c) Add 5-6 mL of DI H₂O (about half-full) to a clean and dry test tube. Add a boiling stick.
- d) Clamp test tube with a three-pronged clamp attached to the ring stand at edge of hot plate and allow water to boil.
 - a. water may, at times, boil vigorously. If this happens, do not panic. Simply raise the test tube by securing it with the test tube clamp and raise until just the lower portion is just touching the hot surface, or hovering just above..
- e) Carefully add the boiling (or near boiling) water *dropwise* via a Pasteur pipet to the flask containing phthalic acid and keep the flask warm by allowing it to rest at the hot plate/block surface. Simply let it set on top of the hot plate
- f) Keep adding water dropwise while the flask sets on the hot plate.
 - a. Swirl flask very gently on the hot plate (keep flask in contact with the top) using the test tube holder.
 - b. Solvent will inevitably evaporate due to keeping it warm. Be patient...
- g) Add more solvent if needed; maybe this time down the inside edge of the flask to remove the phthalic acid that adheres itself to the glass.
- h) By now, complete dissolution should take place. If you see solid form while it is still being kept warm, too much has evaporated. Add a few drops more, gently swirl and remove (test tube holder) and let cool, unaided, to room temperature (rt). Don't bother it! Place it on a book, inside a beaker stuffed with a paper towel insulator, or something other than the hood surface (it's cold and may induce precipitation, which is NOT what you want).
 - a. If procedure is performed correctly, crystallization should start almost immediately.
- i) While waiting for the solution to cool . . .
 - a. set up a suction filtration apparatus as described above. *Do not turn on vac just yet.*
 - b. add DI H₂O (~ 6-7 mL) to your other 10 mL Erlenmeyer flask and get cooling in an ice bath.
- j) Once cooled to rt, place solution into another ice bath to induce further crystallization. Let cool for 5-10 minutes.
- k) Gently stir crystals with a micro-spatula
- l) Wet filter paper with 2-3 drops of ice-cold solvent. and turn on house vac knob 'full blast.'
 - a. Wetting the filter paper prevents it from rising when your solution is poured over it.
- m) Pour solution onto filter paper.
- n) To aid in transfer of crystals, simultaneously rinse with ~ 1 mL (pipet about a third full) of ice-cold solvent and pour onto filter paper. This is known as *quantitative transfer*.
 - a. It may be helpful to rinse flask with it at almost the angle you would pour it out!
 - b. Rinsing may be done 1-2 additional times without significant loss of product. You should be able to get all crystals out within 1-2 rinses/washes.
- o) There is no need to perform additional washes after rinsing as above.
- p) Let dry under suction 5 - 10 minutes.
- q) Add your crystals to a **tared piece of filter paper** and place directly into your drawer. Dry at least overnight.



Phthalic Acid

Solubility per
1 mL of water:
5.4 mg at 14 °C (cold);
180 mg at 99 °C

r) Record final weight and % recovery. Place your purified phthalic acid into the container provided by your TA. Do not put in solid waste. It is recycled. *Go Green!*

(3) Purification of an Unknown. You will now recrystallize your unknown (obtain a small amount for a **melting point of impure unknown** for comparison). Using the best solvent determined in part one, recrystallize 250 mg +/- 10 mg of your unknown exactly as you did in part 2 with phthalic acid. **Record the exact mass used.** Remember, a sample recrystallized from water must be allowed to dry at least overnight. Once the recrystallized sample has dried to constant weight, obtain a mass, per cent recovery and determine the MP. (CAUTION: always turn off the melting point apparatus and the digital thermometer (if applicable) after use).

While you are waiting for your sample to dry on the funnel, obtain a melting point of the impure unknown for comparison to your purified sample.

Using the MP of the purified sample, identify your unknown by checking the list of possible compounds shown below. Note that if the crystals are not completely dry a MP depression may be observed. It may be useful to confirm your identification by considering other physical properties such as solubility behavior and color (consult structure-property relationships handout on course website). Chemfinder.com or a web search may be helpful for physical properties of compounds. As part of the report, draw the structure of your unknown and comment on its structural features and how they might affect solubility (consult aforementioned handout).

Report the % recovery (mass recovered/mass used), MP of your purified sample and the MP of the impure unknown for comparison. You should discuss all these aspects in the results and discussion section of your report.

BEFORE YOU LEAVE THE LAB: turn off the hot plate, turn off the air if used, put away your equipment and lock your drawer, clean up your work areas, close the fume hood sash completely and ask your TA for their signature. In general, please try to keep the lab in as good of a condition as you found it. If you see caps off of bottles, replace the caps. If you see spilled chemicals, clean them up or at least report it to your TA.

A note on morning hours. Sometimes before a sample can be accurately weighed, it must be left overnight to dry. So that you may finish and write up an experiment before the next lab period, the lab will be open at certain hours during the morning for simple things such as weighings and melting point determinations. Schedules and rules for use of the morning hours are posted on the web site and are posted at the entrance to the lab. Be sure that you know the schedules and the rules. Use of morning hours is a CONVENIENCE, NOT a REQUIREMENT. Many students have schedules that do not allow them to attend any morning hours. In such cases, these students will do the weighings/MPs during their next lab period and submit the report the next day (Monday for Friday section students). Most people, however, make use of the **morning hours**, which will **make things less stressful for the student** during the next lab period. The few of those who cannot will have no problem finishing up at the next lab period, you just don't have a lot of time to turn in your report.

Drying to constant weight. To be certain that a solid is dry, it must be weighed, left to dry for some period of time, then weighed again. If the sample does not lose weight, it can be considered to be dry. Because water evaporates very slowly, solids recrystallized from water must be left at least overnight to dry. Solids recrystallized from most common organic solvents dry more quickly and are often dry within an hour. Note that solvent remaining in the solid will affect not only the weight of the solid but its MP range as well.

Being environmentally responsible: Minimizing waste - cleaning reaction tubes: once the contents of a tube are disposed of in the correct waste container in the hood, the tube should be washed using soap, water, and a

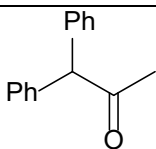
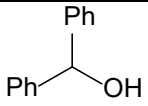
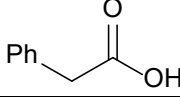
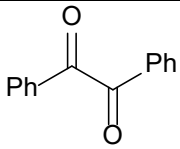
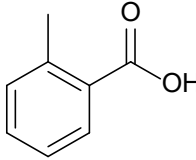
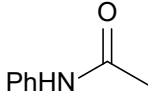
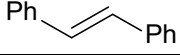
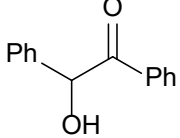
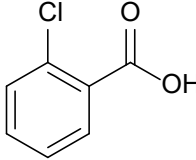
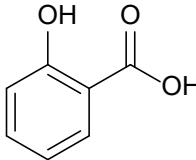
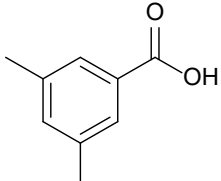
brush. If the tube must be used immediately, and if it must be free of water, rinse it with a SMALL amount of acetone (several drops a few separate times), drain the acetone into the ORGANIC LIQUID WASTE container in the hood, and turn the tube upside down to drip dry. DO NOT FILL the tubes with acetone - this creates excessive waste and is unnecessary- use just a little to rinse the tube. If the glassware must be dried quickly, use the compressed air in the hoods. (Use a gentle airflow only.). Remember to always minimize the chemical waste generated in the lab.

Conserve pipets. Do not throw away a pipet after each use unless it cannot be easily cleaned. If a pipet is used to measure a volatile (low-boiling) solvent, let the pipet dry after use and use it again. If an aqueous solution is measured, rinse with water and allow it to dry for future use. Minimize waste. The yellow pipet bulbs can be used until corroded, at which point they general become "crunchy."

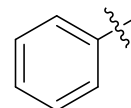
Postlab Questions

- 1.) Draw a solubility (y) vs temperature (x) plot showing the three common solubility behaviors and indicate which one is that of a good recrystallization solvent.
- 2.) Briefly describe how soluble impurities are separated from the desired compound, at the molecular level.
- 3.) Using the information given in this handout, how many mL of boiling water are required to dissolve 4.2 g of phthalic acid?
- 4.) If the resulting solution in question 3 were cooled to 14° C, how many grams of phthalic acid would crystallize out? What would be the percent recovery?
- 5.) What structural property of sodium 4-amino-1-naphthalenesulfonate makes it very soluble in water? You will have to look up the structure of this compound and comment on why it is water-soluble. Simply stating that it's polar will get no credit.

Possible Unknowns

Compound	Structure	MP (°C)
1,1-diphenylacetone		61
benzhydrol		69
phenylacetic acid		77
α -methyladipic acid	$\text{CO}_2\text{HCH}_2\text{CH}(\text{CH}_3)(\text{CH}_2)_2\text{CO}_2\text{H}$	85
benzil		95-96
o-toluic acid		105
acetanilide		115-116
<i>trans</i> -stilbene		124-125
benzoin		133-134
2-chlorobenzoic acid		142
adipic acid	$\text{CO}_2\text{H}(\text{CH}_2)_4\text{CO}_2\text{H}$	152
salicylic acid		159
3,5-dimethylbenzoic acid		166

Note: 'Ph' =



Values here may differ slightly from those on the Melting Point list because you have purified the compounds. Melting point values here are from the CRC Handbook, 54th edition.