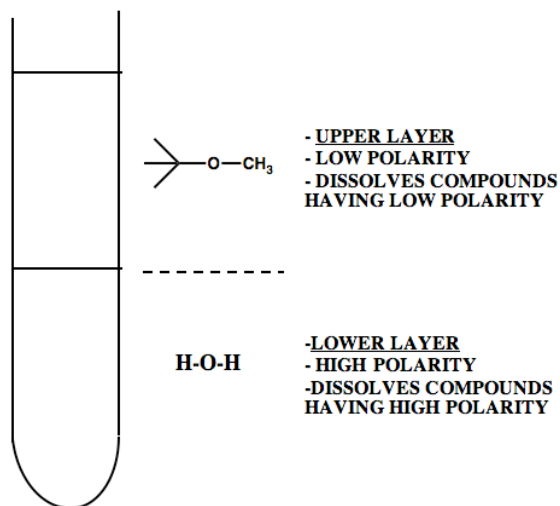


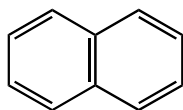
Acid-Base Extraction.

Extraction involves dissolving a compound or compounds either (1) from a solid into a solvent or (2) from a solution into another solvent. A familiar example of the first case is making a cup of tea or coffee - the soluble flavor and odor chemicals and caffeine are extracted from the solid tea leaves or ground coffee beans into hot water (the solvent). Insoluble plant material is left behind in the tea bag or coffee filter. An example of the second case is an experiment that is often done in an introductory organic lab - an organic solvent is used to extract the caffeine from an aqueous tea or coffee solution, leaving the more water-soluble compounds behind in the aqueous solution. This in fact is how decaffeinated tea and coffee are sometimes made.

An acid-base extraction, this week's experiment, is a modification of the second case above; that is, it is a solvent-solvent extraction. Before looking at what makes it an acid-base extraction, first consider solvent-solvent extractions in general. A requirement of a solvent-solvent extraction is that the two solvents be mostly insoluble in one another. That is, a mixture of the two solvents will separate into two layers. It is important to note that the upper layer is that which is less dense. For example, a mixture of *tert*-butyl methyl ether and water will separate into two layers, with the ether layer (density = 0.74) being on top of the water layer (density = 1.0). Note that in almost every case, one of the solvents is water or an aqueous solution. The other solvent is an organic solvent that is mostly insoluble in water. Examples include *tert*-butyl methyl ether, hexane, and dichloromethane. The organic solvent must also be volatile (easily-evaporated) so it can be easily removed by evaporation at the end.

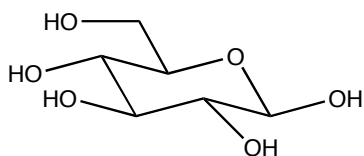


As an example of a separation that could be accomplished by using a solvent-solvent extraction, consider a mixture of two solid compounds, naphthalene and glucose.



Naphthalene

- low polarity
- high ether solubility
- low water solubility

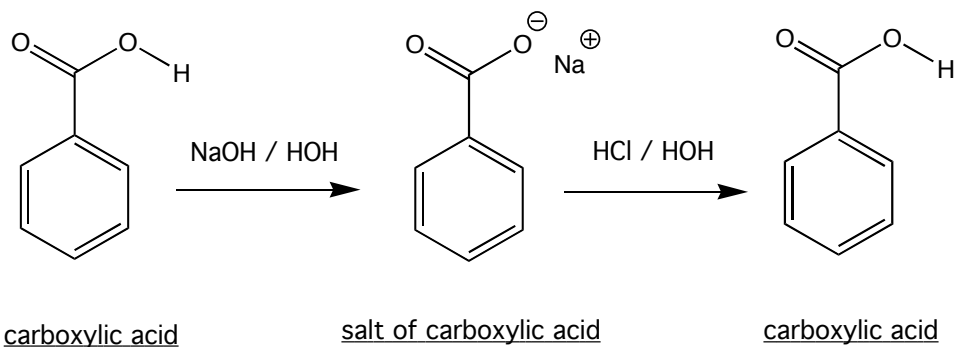


β -D-Glucopyranose

- high polarity/H-bonding
- low ether solubility
- high water solubility

If the mixture of naphthalene and glucose is dissolved in *tert*-butyl methyl ether and mixed well with water, the glucose will mostly dissolve in the lower water phase (phase = layer) and the naphthalene will mostly dissolve in the upper ether phase. The two phases can then be physically separated using a pipet and placed into two separate tubes. The water and ether can then be evaporated to yield the separated solid compounds. This is the gist of an extraction.

An acid-base extraction operates on the same principle, but can provide a further level of fine-tuning. If one or more of the compounds in the mixture to be separated is acidic or basic, the solubilities of these acidic and basic components can be manipulated to our advantage by applying simple acid-base reactions. Using such a manipulation, an acidic or basic compound that may be ether soluble and water insoluble can be changed to be ether insoluble and water soluble by carrying out an acid-base reaction. The solubilities of acidic and basic compounds can thus be changed at will. Once the layers are separated as before, the neutral acid or base can be regenerated by yet another acid-base reaction. An example of such a manipulation of solubilities is shown below for a carboxylic acid.



- high solubility in ether
- low solubility in water

- low solubility in ether
- high solubility in water

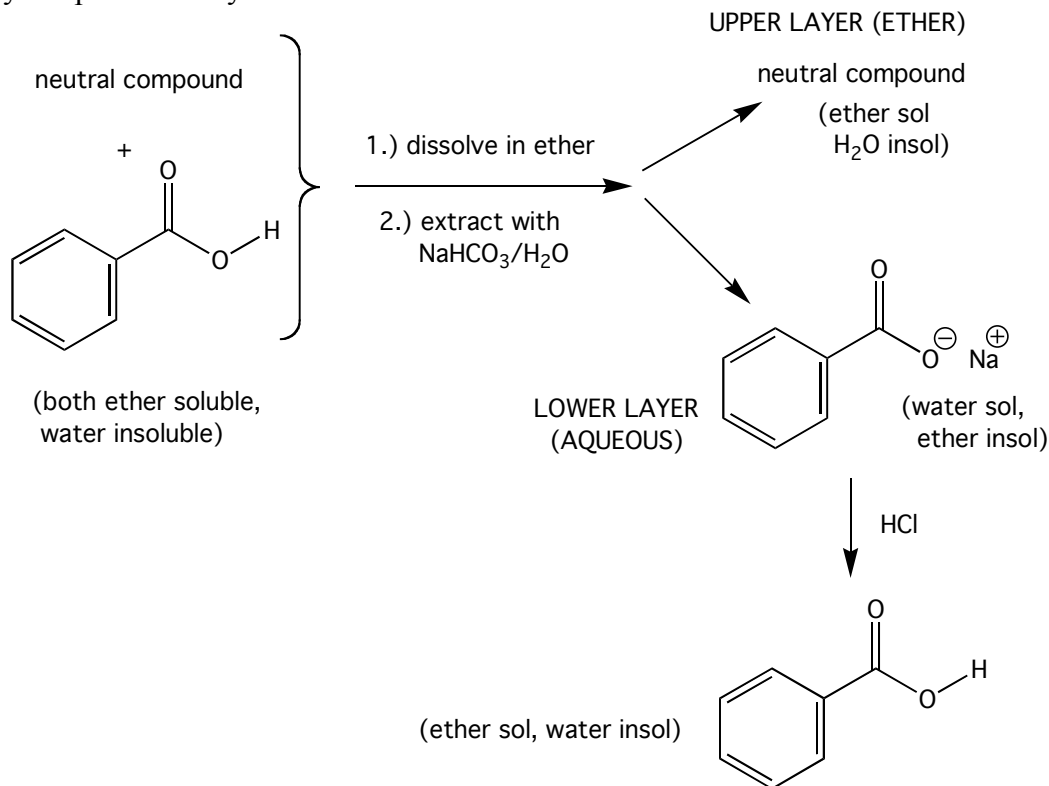
- high solubility in ether
- low solubility in water

In the experiment done in this lab, a mixture of a carboxylic acid and a neutral compound will be separated by an acid-base extraction. The separate compounds will be purified by recrystallization and identified by melting points. A general scheme for the separation is given below. Note that instead of using sodium hydroxide as the base, sodium bicarbonate is used. A strong base such as sodium hydroxide is not necessary in this particular case.

The mixture is dissolved in ether and mixed thoroughly with aqueous sodium bicarbonate. The layers are allowed to separate and each is worked up separately. Dissolved water is removed from

the ether solution using a drying procedure and the ether is evaporated to yield the solid neutral compound. This can then be recrystallized to yield pure solid neutral compound.

The basic aqueous solution is neutralized with concentrated HCl to yield the carboxylic acid, which, because of its water insolubility, precipitates out. This can be collected, recrystallized and allowed to dry to yield pure carboxylic acid.



Neutralization of the carboxylic acid salt and excess sodium bicarbonate with concentrated hydrochloric acid. It is critical to add an amount of HCl necessary to completely neutralize the base, otherwise the yield of carboxylic acid will suffer. To be certain that neutralization is complete, a slight excess of HCl is added. The amount of HCl needed is calculated as follows: 1.15 mL of saturated aqueous sodium bicarbonate is used in the extraction. This determines the amount of HCl needed. A saturated aqueous solution of sodium bicarbonate is 1 M (1 mole/liter). Concentrated HCl is 12 M. Because HCl reacts with sodium bicarbonate in a 1:1 molar ratio, it follows that 1 mL of saturated aqueous sodium bicarbonate would be neutralized with 1/12 mL of concentrated HCl. If 1.15 mL of sat'd aq sodium bicarbonate has to be neutralized, how much HCl is needed? First, how many moles of sodium bicarbonate is present in 1.15 mL of a sat'd aq solution?

$$1 \text{ mol/L} \times 0.00115 \text{ L} = 0.00115 \text{ mol (1.15 mmol) sodium bicarbonate}$$

Therefore, 0.00115 mol of HCl is needed for neutralization. How many mL of HCl then is needed?

$0.00115 \text{ mol} / 12 \text{ mol/L} = 0.000096 \text{ L} = 0.096 \text{ mL}$ or, rounded off, about 0.1 mL. Thus 1.15 mL of sat'd aq sodium bicarbonate is neutralized by about 0.1 mL of conc HCl. With our pipets, there are about 30 drops in one mL of conc HCl. This translates into about 3 drops of HCl, a very small amount indeed.

Drying the organic solvent. The organic solvent containing the neutral compound contains some dissolved water. If the solvent were evaporated at this point, the resulting solid neutral compound would be wet with water and would consequently be a gooey mess and would take a long time to dry. A drying procedure is therefore necessary to remove all traces of water before the solvent is evaporated. This procedure consists of two steps: (1) thoroughly mixing the solution with saturated aqueous sodium chloride (saturated salt solution) and discarding the aqueous layer (this is a preliminary drying step that removes most of the water) and (2), adding a solid inorganic drying agent (this strongly binds to the remaining traces of water dissolved in the organic solvent), allowing it to remain in contact with the solution for several minutes, then separating the solution from the solid drying agent. The solvent can then be removed by evaporation, leaving behind the solid neutral compound.

Very often in the synthesis of a compound or in the isolation of a compound from a natural source, acid-base extractions are used to either directly isolate a desired acidic or basic compound or to remove acidic or basic impurities. Extraction, along with recrystallization and distillation, is one of the most important separation and purification techniques in organic chemistry.

The Experiment.

This experiment combines techniques learned in previous experiments (recrystallization, MP) with a new technique, extraction. The separation is based on the acid/base properties of the substances in the mixture. To understand the principles behind the separation, it is essential that you understand the acid/base chemistry involved and why each chemical species is soluble or insoluble in each layer. To help you with this, draw a stepwise diagram using structures, clearly showing each step in the process and showing the chemical species present in each layer at each step. Include this as part of your prelab outline. The flow diagram above can be used as a template, but more detail, such as the drying steps and recrystallizations should be included. This flow sheet should provide a clear outline of all the steps in the process and should therefore enable you to follow the experiment more easily.

Mixing the layers. In extractions, it is important to mix the two solvents well. On the micro scale, this can be accomplished by drawing a portion of the lower layer up into a pipet and expelling it forcefully but carefully back into the tube, through the upper layer, and doing this repeatedly for about three minutes. The mixture is then allowed to separate into two layers. Normally, in separating the layers in a microscale extraction, the lower layer is carefully removed from the upper layer with a pipet, and transferred to another tube. Normally the upper layer is not removed from the lower layer because it is very difficult to get a clean and complete separation in this way. (One exception to this rule is in drawing off the upper layer of backwash in the procedure below.)

Photos of the extraction technique are shown on the course website.

In an extraction such as this one it is important to keep track of the many different solutions at each step. There will be two main solutions throughout this extraction procedure - an aqueous layer and an ether layer. Label all tubes carefully and know exactly what chemical species is in each tube. Know which layer is which. Think carefully about each step and don't rush. This will help you to better understand what you are doing and why, and will help to decrease the possibility of error. What physical property of the solvents determines which will be the top or bottom layer? A careful

chemist does not throw anything away until he or she is certain of its identity, so save each layer in a separate tube until the final products have clearly been obtained.

In this experiment an acid-base extraction will be used to separate a mixture containing about equal parts of an unknown carboxylic acid and an unknown neutral compound. The unknown compounds will be identified by MP. The possible compounds are shown at the end of this handout.

Experimental Procedure. Your TA will assign an unknown mixture to you. Dissolve about 0.12 g (± 0.01 g, but weigh it exactly) of the mixture in 2 mL of *tert*-butyl methyl ether in a reaction tube. Add 1 mL of saturated aqueous sodium bicarbonate. The amounts of solutions in this experiment do not have to be exact. The graduations on the side of the tube can be used to measure the amounts. Mix the two layers thoroughly as described above. After the layers separate, transfer the lower layer into another reaction tube (well labeled), being sure to make a clean separation. Is this the aqueous or organic (ether) layer? What is the structure of the species dissolved in it? Extract the ether layer with an additional 0.15 mL of saturated aqueous sodium bicarbonate and combine this with the first aqueous extract. Extract the combined aqueous extracts with about 0.2 mL *tert*-butyl methyl ether. This is called backwashing and is used to remove any small amount of neutral compound that may contaminate the aqueous layer. Normally, the lower layer is removed from the mixture because it is easier to make a clean separation this way. With the backwash, however, you may directly remove the small amount of upper ether layer. Try to get most of it into a pipet, then examine the contents of the pipet. If a small amount of aqueous layer exists in the pipet along with the ether backwash, this may be carefully squeezed out back into the main aqueous layer in the tube. Because this ether backwash contains only minute amounts of neutral compound it can be discarded (Organic Liquid Waste container in the waste hood).

Extract the original ether layer with about 1 mL of saturated aqueous sodium chloride solution and discard the aqueous layer (Organic Liquid Waste container in the hood). This removes most of the water dissolved in the ether. With a clean dry pipet, carefully transfer the ether solution to a clean dry vial, leaving behind any water clinging to the side of the tube. Use a few drops of fresh ether to do a transfer rinse. Drying is completed by adding anhydrous calcium chloride pellets in small numbers, with swirling, until the pellets no longer clump together. This vial should be capped and set aside.

Using the amount of concentrated HCl that is required to neutralize 1.15 mL of saturated aqueous sodium bicarbonate, neutralize the aqueous extract. This must be done carefully, as carbon dioxide will be generated and frothing will occur. If care is not taken, product will bubble out the top of the tube and be lost. Add the HCl one drop at a time, with stirring between each addition. When the last amount of HCl has been added, stir the solution well and check to see that the solution is acidic using indicator paper. If the solution is still basic, carefully add another drop of conc HCl, stir well and check the pH again. To obtain the maximum yield, the solution must be acidic. A small excess of HCl is therefore desirable. (If no solid is present it is likely that you have not added enough HCl or have not mixed the solution well.) Heat the tube to boiling (boiling stick) to dissolve most of the solid and allow the tube to cool slowly to room temperature (RT), then in an ice-water bath for several minutes. Remove the solvent from the crystals using the pipet method and discard it (“Organic Liquid Waste”). This is an initial crude recrystallization. Recrystallize the solid again from water (minimal amount of water, slow cooling) and collect it by suction filtration (rinse with minimal amount of ice-cold HOH). Use no more than about 1 mL of water in the recrystallization,

but the exact amount should be determined as in any recrystallization. The solid should be dried to constant weight (overnight), weighed, and its MP determined.

Now back to the ether layer that has been drying over calcium chloride: use a pipet to separate the ether from the drying agent and transfer the ether to a clean dry tared reaction tube. Do a transfer rinse a couple of times with a small amount of fresh ether to ensure a complete transfer of neutral compound from the drying agent and drying container to the new container. Evaporate the ether by passing a stream of air GENTLY over the solution (sol'n) in the hood while warming the tube with your hand. Caution: if the stream of air is too fast or if you get the air tube too close to the sol'n, you may blow the sol'n out of the tube and lose product. Weigh the crude product then recrystallize it from hexanes (a mixture mainly made up of isomeric hexanes. This mixture is sometimes called ligroin). (What is the correct amount of solvent to use in a recrystallization and what will result if too much is added?). Collect the solid by suction filtration and allow it to dry to constant weight (hexanes evaporate fairly quickly so within about 30 min the solid should be dry – it may also be left to dry overnight). Weigh the dry neutral compound and determine its MP.

Report the % recovery of each compound (assume a 1:1 original mixture) and identify each, based on its MP (MPs at end of handout). Store the products in vials and save them until your TA has checked them.

Things to watch out for: (1) mix layers well – if not, complete separation will not occur and products will be contaminated; (2) acidification of the aqueous layer – not enough acid, low or no yield – not mixed well after adding acid – low or no yield; (3) recrystallization – too much solvent, low or no yield – add solvent at the BP in small portions until solid dissolves – allow time between additions; (4) it's easy to mix tubes up – be sure to label them well.

WASTE DISPOSAL: Combine all liquid wastes, including washes and filtrates, and put them into the Organic Liquid Waste container in the waste hood. Put the calcium chloride drying agent into the labeled evaporating dish in the waste hood. When finished with the products, place them into the Solid Waste container in the hood.

BEFORE YOU LEAVE THE LAB: turn off the sand bath, Mel-Temp, vacuum, and air, put away your equipment and lock your drawer, clean up your work areas, close the fume hood sash completely and ask your TA for her or his signature. 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.

Postlab Questions

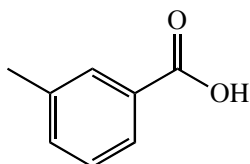
- 1.) In this experiment, if the carboxylic acid is benzoic acid, how many moles of benzoic acid are present? How many moles of sodium bicarbonate are contained in 1 mL of a saturated aqueous sodium bicarbonate. Is the amount of sodium bicarbonate sufficient to react with all of the benzoic acid?
- 2.) To isolate the benzoic acid from the bicarbonate solution, the bicarbonate solution is acidified with concentrated HCl. What volume of acid is required to neutralize the bicarbonate?
- 3.) The ether solution is extracted with saturated aqueous sodium chloride. What is the purpose of this?

4.) A mixture of benzoic acid and a neutral nonpolar compound is dissolved in ether and mixed thoroughly with aqueous sodium bicarbonate. What is the organic chemical species that is present in the ether layer? In the aqueous layer?

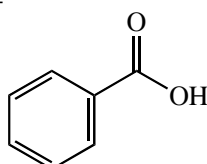
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Acid-Base Extraction

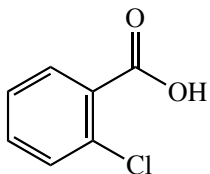
Possible Carboxylic Acids



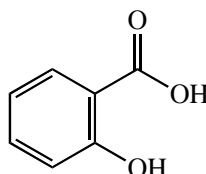
3-toluic acid (mp 112°)



benzoic acid (mp 122°)

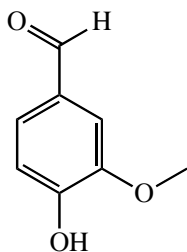


2-chlorobenzoic acid (mp 142°)

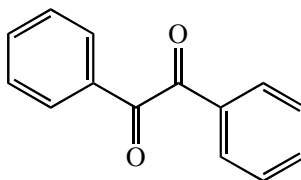


salicylic acid (mp 159°)

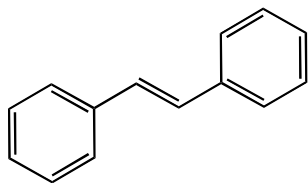
Possible Neutral Compounds



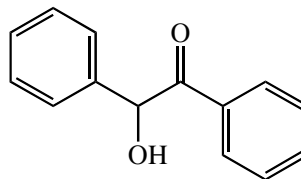
vanillin (mp 81°)



benzil (mp 96°)



trans-stilbene (mp 125°)



benzoin (mp 133°)