6. Extraction

A. Background

Extraction is a frequently used technique to selectively transfer a compound of interested from one solvent to another. Extraction is based on solubility characteristics of the organic compound in the solvents being used for the extraction. Let's consider two frequently encountered scenarios when extraction is useful.

1. You have a mixture containing a desired compound in addition to undesired impurities. Depending on the nature of the compound as well as the impurities, you may be able to separate them using extraction. The desired compound could be extracted into one solvent while the impurities may remain in the other solvent.
2. You have just finished a reaction in the laboratory. The reaction was carried out in the solvent THF. Following the reaction, you added water to the reaction flask to quench certain reactive reagents. THF and water are miscible, so a homogeneous solution results. Following the reaction, an extraction can be employed to pull the desired compounds out of the water/THF solution and into another organic solvent. This allows for the selective isolation of organic compounds while water soluble impurities remain in the aqueous solution.

When performing an extraction, two immiscible solvents must be used. See experiment 4 for a solvent miscibility chart. When two immiscible solvents are mixed, the less dense solvent makes up the top layer, while the more dense solvent makes up the bottom layer. Consider mixing either diethyl ether (d = 0.71 g/mL) or dichloromethane (d = 1.33 g/mL) with water (d = 1.00 g/mL) as shown in figure 1. When water is mixed with a less dense immiscible solvent, water forms the bottom layer (figure 1a). When water is mixed with a more dense immiscible solvent, water forms the top later (figure 1b). If two miscible solvents such as dichloromethane and diethyl ether are mixed, a homogeneous solution results, regardless of the densities of the two solvents (figure 1c).

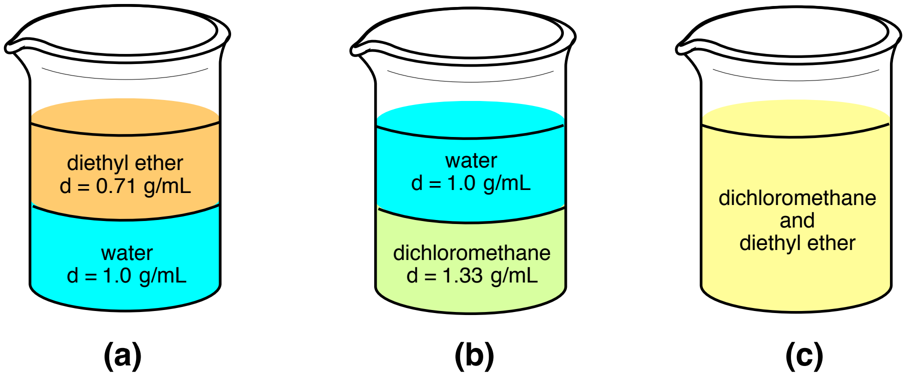


Figure 1. Mixing of Solvents

1. Extraction Theory

Let's consider a compound **X** that is dissolved in water. Compound **X** is water soluble, but is more soluble in diethyl ether. Suppose the solubility of **X** in water is 2.0 g/100 mL, while its solubility in ether is 10.0 g/100 mL. If ether is added to the solution of water containing **X**, compound **X** will partition itself between the ether and the water based on the relative solubility.

$$X_{water} \rightleftharpoons X_{ether}$$

Thus, the partition ratio (*k*) of **X** in ether and water can be described by:

$$k = \frac{X_{ether}}{X_{water}} = \frac{(10.0\text{ g}/100\text{ mL})_{ether}}{(2.0\text{ g}/100\text{ mL})_{water}} = 5$$

Suppose our initial aqueous solution contained 1.5 g of **X** dissolved in the 100 mL of water. If we add 100 mL of ether, compound **X** will partition between the ether and water in such a way to give a partition ratio of 5. Some amount *n* of **X** will go into the ether layer while that same *n* amount of **X** will leave the water layer. This can be described as:

$$k = \frac{X_{ether}}{X_{water}} = \frac{n\text{ g of }\mathbf{X}/100\text{ mL ether}}{1.5 - n\text{ g of }\mathbf{X}/100\text{ mL water}} = 5$$

Now, solving for *n*:

$n = 1.25$ → 1.25 g of **X** in the ether layer

$1.5 – 1.25 = 0.25$ → 0.25 g of **X** remaining in the water layer

Extracting 100 mL of water containing 2.0 g of **X** with 100 mL of ether results in 1.25 g of compound **X** being pulled into the ether layer.

It should be noted, however, that *successive extractions with a smaller volume of solvent is more efficient that one extraction with a large volume of solvent*.

Let's now consider the same 1.5 g of **X** dissolved in 100 mL of water. This time, however, we will do two extractions with 50 mL of ether.

$$\text{1st Extraction:} \qquad k = \frac{X_{ether}}{X_{water}} = \frac{n\text{ g of }\mathbf{X}/50\text{ mL ether}}{1.5 - n\text{ g of }\mathbf{X}/100\text{ mL water}} = 5$$

Solving for *n* shows that $n = 1.07$. Thus, 1.07 g of **X** is pulled into the ether layer while 0.43 g of **X** remains in the aqueous layer (1.5-1.07 = 0.43 g).

Next the ether layer is removed and a second extraction of the aqueous layer containing the remaining 0.43 g of **X** is performed using a second 50 mL portion of ether.

$$\text{2nd Extraction:} \qquad k = \frac{X_{ether}}{X_{water}} = \frac{n\text{ g of }\mathbf{X}/50\text{ mL ether}}{0.43 - n\text{ g of }\mathbf{X}/100\text{ mL water}} = 5$$

Again, solving for *n*, it is found that 0.31 g of **X** is pulled into the ether layer, while 0.12 g of **X** remains in the water layer. When the two 50 mL ether fractions are combined, a total of 1.07 +

0.31 = 1.38 g of **X** was extracted into the ether layer via two successive 50 mL extractions. Compare this with the 1.25 g of **X** that was extracted into the ether layer using a single 100 mL ether extraction. Additional extractions could be performed to pull even more compound out of the water layer.

A series of successive extractions using smaller volumes of solvent is always more efficient than a single extraction with the same total volume of solvent.

2. Acid/Base Extraction

Organic acids and organic bases can be separated from neutral organic compounds via an acid/base extraction. This type of extraction takes advantage of the fact that most organic acids and bases are soluble in organic solvents while their conjugate acid or conjugate base ions are soluble in water.

If you have a mixture of benzoic acid (organic acid), aniline (organic base), and naphthalene (neutral organic molecule), all of these compounds will be soluble in the solvent diethyl ether. Adding an aqueous basic solution will cause an acid base reaction between the aqueous base and the organic acid. The organic base and neutral compound will not be affected. Because the conjugate base of benzoic acid is an ion, it is more soluble in water than ether and thus partitions into the water layer. (Figure 2)

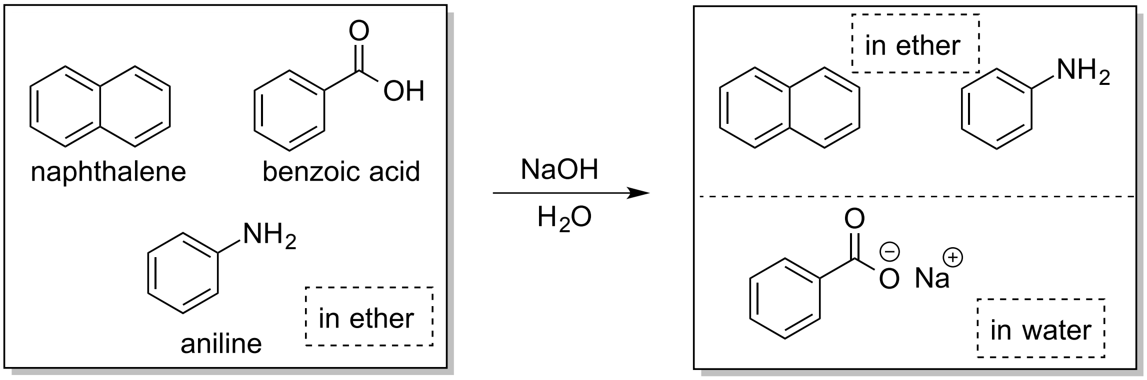


Figure 2. Basic Extraction of an Organic Acid

At this point, you can separate the organic ether layer and the aqueous layer. The aqueous layer can then be acidified and subsequently extracted with ether to obtain benzoic acid, separated from the naphthalene and aniline (figure 3). The ether layer containing benzoic acid can be evaporated off to provide the solid benzoic acid.

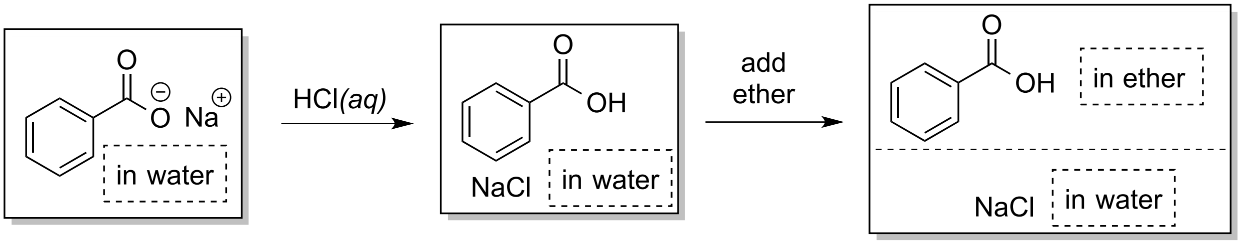


Figure 3. Acidification of the Basic Solution

From here, if you want to separate the naphthalene (neutral organic molecule) and aniline (organic base) that remain in the original solution, you can employ an acidic extraction of the organic base. To the ether solution containing naphthalene and aniline, aqueous acid is added. This acid reacts with the amine to form an ammonium salt. The ammonium salt is water-soluble and goes into the aqueous layer. (Figure 4)

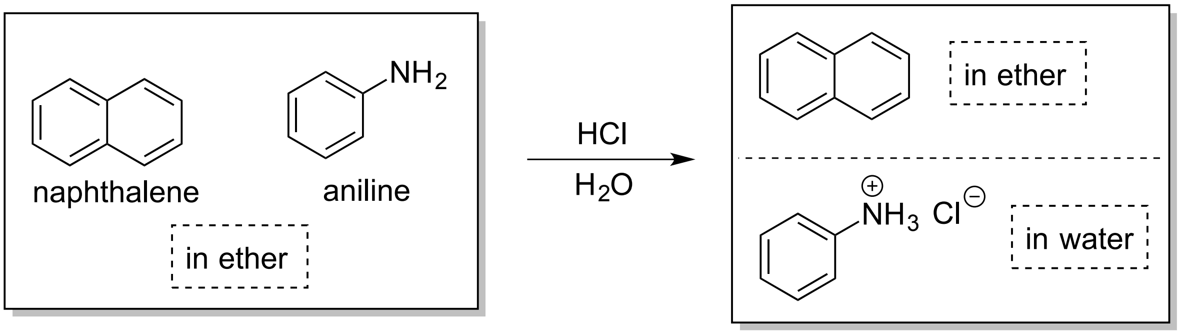


Figure 4. Acid Extraction of an Organic Base

The organic and aqueous layers can then be separated. The organic layer contains pure naphthalene while the aqueous layer contains the ammonium ion of aniline. To isolate aniline, the acidic solution can be basified followed by the addition of ether to extract the neutral aniline into the organic solvent as shown in figure 5.

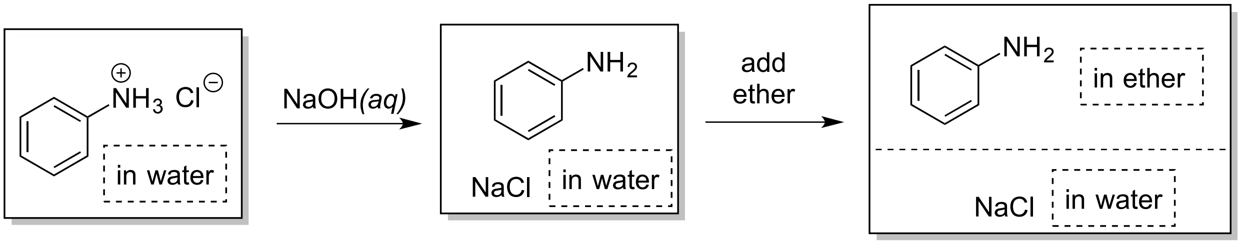


Figure 5. Basification of the Acidic Solution

Figure 6 details a full acid/base extraction flow chart that describes the separation of a mixture of an organic acid (HA), organic base (B:) and a neutral organic molecule (N).

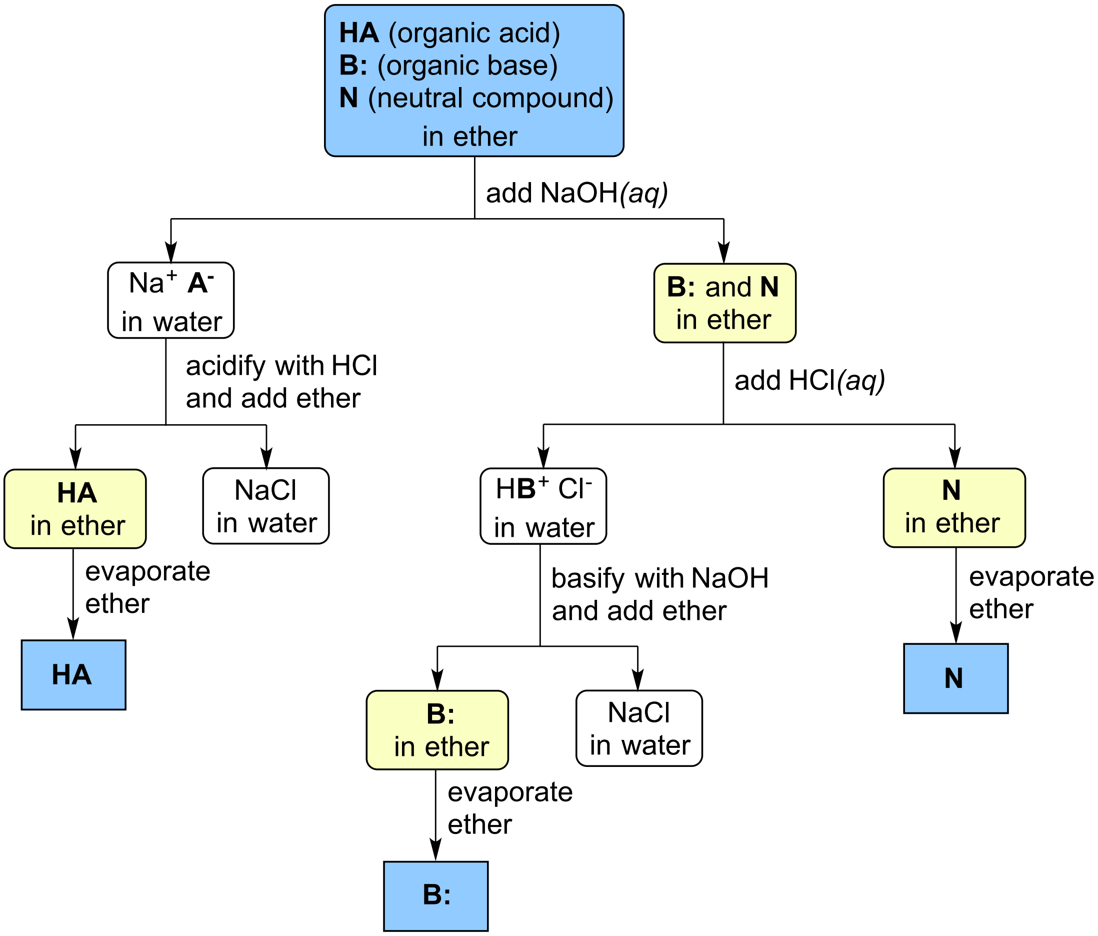


Figure 6. Extraction Flow Chart

B. Experimental Procedure

1. Microscale Extraction

Weigh out 200 mg of your unknown (contains an organic acid **HA** and a neutral compound **N**) and place it along with a spin-vane into a 5 mL conical reaction vial. Add 2 mL of diethylether (ether) and stir to dissolve the solid. Next, add 1 mL of 5% aqueous sodium hydroxide. Stir the mixture rapidly for 1-2 min to affect the acid/base reaction and subsequent extraction of **A**$^-$ into the aqueous layer. Stop stirring and allow the two layers to separate. Use a pipet to carefully draw off the lower aqueous layer. Eject this solution from the pipet into a small beaker. Be careful not to remove any of the upper ether layer. *It is okay if you leave a small bit of aqeous layer behind.* Next, add a second 1 mL portion of 5% aqueous sodium hydroxide to the conical vial and repeat the extraction process. After the extraction, again pipet out the lower aqueous layer and combine it with the aqueous extracts in the beaker. (Figure 7)

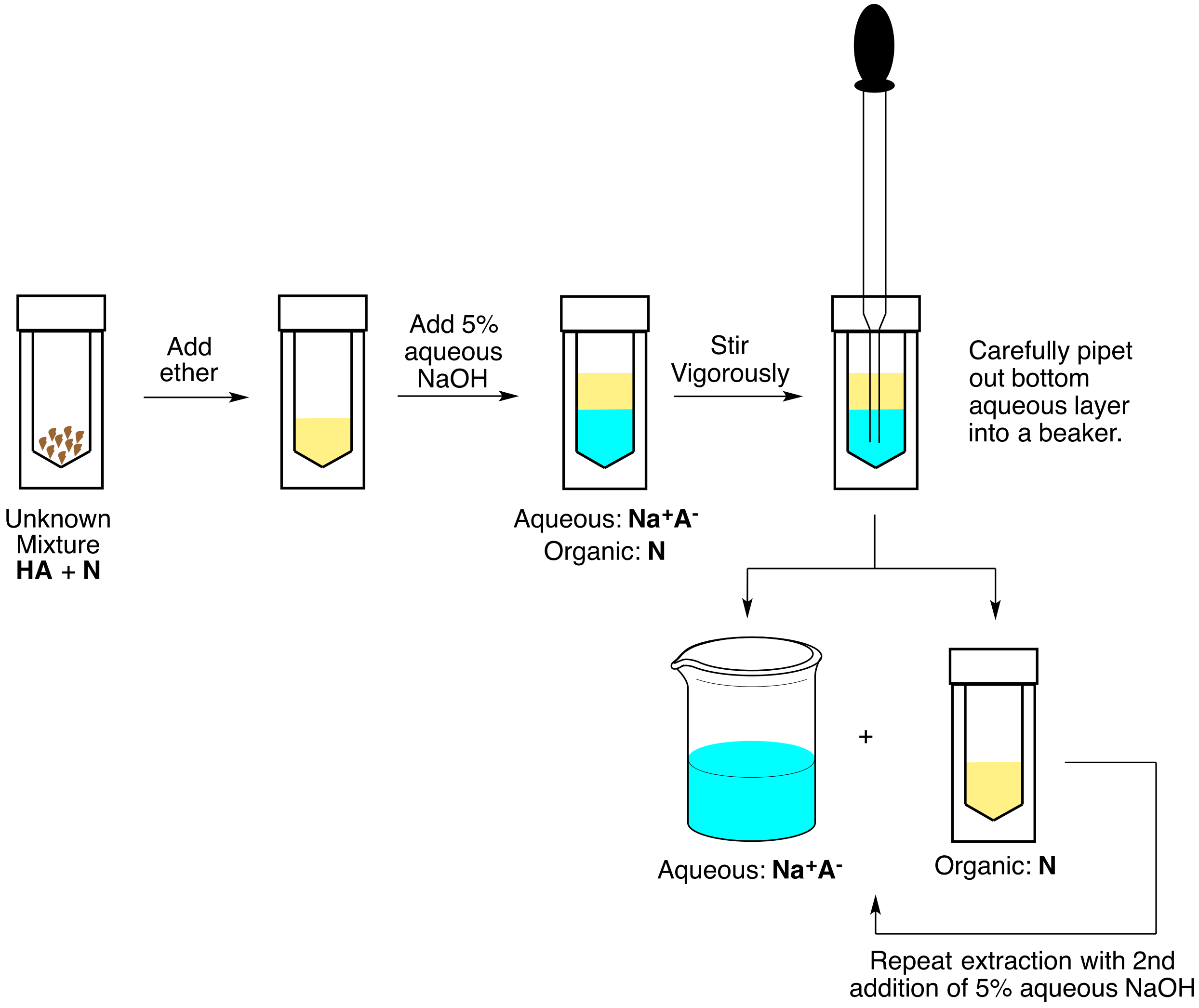


Figure 7. Microscale Extraction

Now that the two components from the original mixture are separated, they need to be isolated. Different isolation protocols are required for the neutral compound and the organic acid.

2. Isolation of the Neutral Product

The conical vial contains your neutral compound dissolved in ether. There may be, however, some residual aqueous NaOH solution that needs to be removed. To accomplish this, the organic solution must be "washed" with brine (saturated aqueous NaCl solution). Additionally, brine helps to remove any traces of water that is dissolved in an organic solvent.

To the vial containing the neutral compound, add approximately 1 mL of brine and stir the solution. Next, stop the stirring and allow the layers to separate. Using a pipet, carefully remove and discard the lower aqueous layer. (Figure 8)

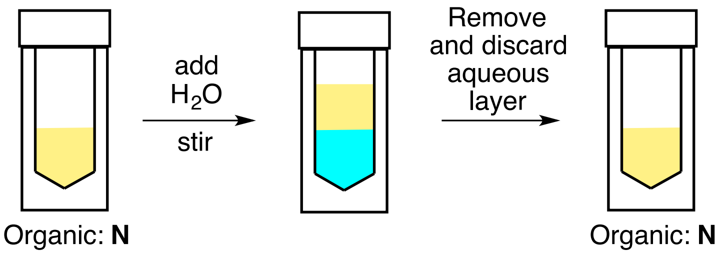


Figure 8. Washing the Organic Layer With Water

The last thing you want is to concentrate your organic solution only to find that residual water remains. To ensure all water is removed, the organic solutions should be dried. Drying involves letting an organic solution stand over a drying agent (usually an inorganic salt). On a microscale level, it is easiest to pass the organic solution through a drying column. A drying column consists of a pipet plugged with a small wad of cotton. Approximately 0.5 cm of sand is added to the pipet followed by 5 cm of anhydrous sodium sulfate, Na_2SO_4 (the drying agent). This column can be clamped directly above the collection vessel. The organic solution is then passed through this drying column and collected in a clean dry vessel such as a conical vial. Once all of your solution has passed through, you should pass an additional 1 mL of solvent (ether) through the column to flush out any residual product. (Figure 9)

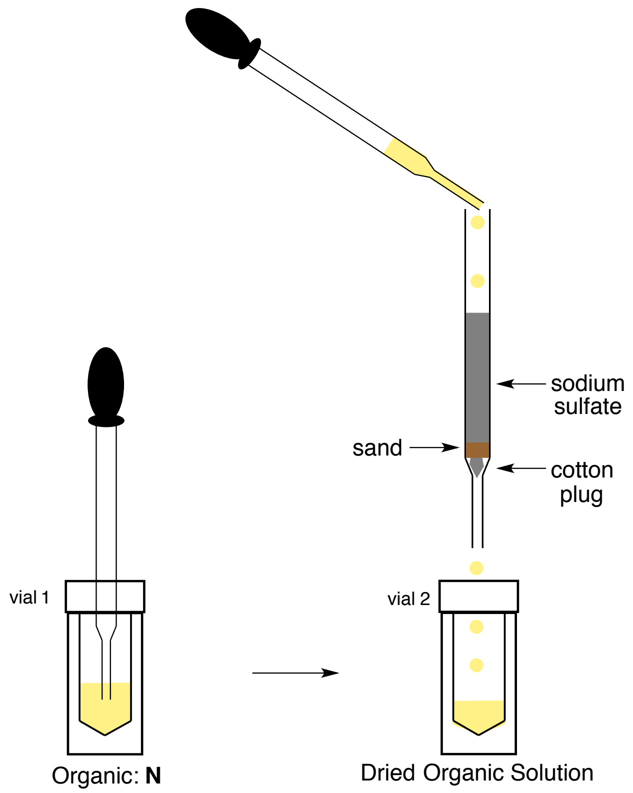


Figure 9. Drying an Organic Solution

The solvent can then be evaporated from the neutral compound by gently blowing a stream of nitrogen over the solution (figure 10). Gentle heating will aid in evaporation of the solvent. The crystals can be scraped out onto a weighed watch glass. Once the crystals have dried completely, determine the melting point and percent recovery.

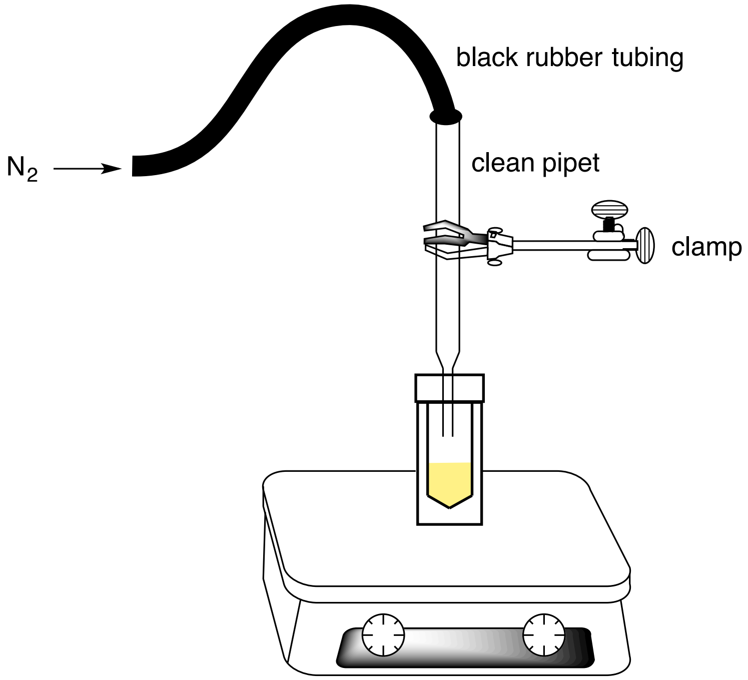
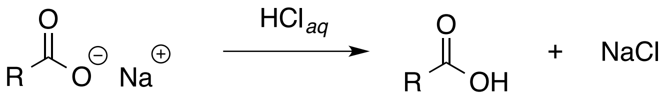


Figure 10. Evaporation Setup

3. Isolation of the Organic Acid Product

The aqueous layer containing the conjugate base salt of the acid should be transferred from the beaker into a clean conical vial. This solution should first be washed with 1 mL of ether to remove any remaining organic impurities. The organic wash can be removed and discarded. *Remember, the organic layer is the top layer since you are using ether*. Next, acidify the solution by adding 6 M HCl dropwise until the solution is strongly acidic as measured by pH paper. Collect the precipitate via filtration using a Hirsch funnel (don't forget the filter paper). Wash the solid with 1 mL of ice water. Scrape the product onto a weighed watch glass and allow it to dry open to the air. Determine the percent recovery and obtain a melting point of the pure crystals.

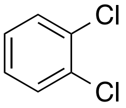


Based on melting point data, you should be able to determine the identity of both the organic acid and the neutral compound present in the unknown. Your TA will provide you with a list of potential unknowns along with their corresponding melting points.

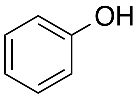
Dispose of all chemical waste in the properly labeled waste containers.

C. Pre-Lab Questions

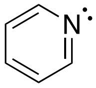
1. Draw a diagram similar to that in figure 6 detailing the separation of 1,2-dichlorobenzene, phenol (pKa = 10), and pyridine by an extraction protocol.



1,2-dichlorobenzene



phenol



pyridine

2. Sodium bicarbonate ($NaHCO_3$) can be used as a base to extract carboxylic acids into the aqueous layer, but it cannot be used to extract most alcohols. Explain. *Hint: the pKa of* H_2CO_3 *is approximately 6*.

3. Explain the difference between extraction and washing.

4. Look up the densities and miscibility of hexane and water. *See the miscibility chart from experiment 2.* Would these two solvents work well together in an extraction procedure? Explain.

D. Post-Lab Questions

1. In this procedure your organic acid was isolated by precipitation and subsequent filtration. If the resulting organic acid had been soluble in the aqueous solution, how could it have been isolated?

2. You are given a two-phase system containing an aqueous layer and an organic layer, but you don't know which is which, nor do you know the identity of the organic solvent. How could you determine which layer is the water layer?

3. In this experiment, could you have used methanol in place of diethylether?

4. What is the identity of the two components present in your unknown?