The solubility of organic acids and bases in water can be changed greatly by changing the pH. Except for compounds containing fewer than six carbons, most carboxylic acids, phenols, and amines are insoluble or only slightly soluble in water. However carboxylic acids and phenols dissolve in dilute aqueous sodium hydroxide solution (pH » 7) and amines dissolve in dilute aqueous hydrochloric acid solution (pH « 7) because carboxylic acids and phenols react with bases to form salts,

\[
\text{RCO}_2\text{H} \text{ (l) or (s) + NaOH (aq)} \rightarrow \text{RCO}_2\text{Na (aq)} + \text{H}_2\text{O (l)}
\]

\[
\text{ArOH} \text{ (l) or (s) + NaOH (aq)} \rightarrow \text{ArONa (aq)} + \text{H}_2\text{O (l)}
\]

and amines, like ammonia, react with acids to form salts

\[
\text{RNH}_2 \text{ (l) or (s) + HCl (aq)} \rightarrow \text{RNH}_3\text{Cl (aq)}
\]

The salts are soluble in water because they are ionic.

A mixture containing a water insoluble organic acid, a water insoluble organic base, and a water insoluble neutral compound can be separated by dissolving the mixture in an organic solvent which is not soluble in water, and then extracting the solution first with dilute hydrochloric acid, and then with dilute sodium hydroxide solution as shown in the flow chart below:
The neutral compound can be recovered by evaporation (or, if necessary, fractional distillation) of the solvent. The amine can be recovered from the water solution of its salt by making the acidic solution basic by adding sodium hydroxide solution

\[
\text{RNH}_3\text{Cl (aq)} + \text{NaOH (aq)} \rightarrow \text{RNH}_2\text{(l) or (s)} + \text{NaCl (aq)}
\]

If it is a solid, the amine is collected by filtration. If it is a liquid, it is taken up in the organic solvent (that is, its volume is increased by adding more solvent to reduce mechanical loss), the solution is separated, and the solvent evaporated.

The acid can be recovered from the water solution of its salt by making the basic solution acidic by adding hydrochloric acid solution

\[
\text{RCO}_2\text{Na (aq)} + \text{HCl (aq)} \rightarrow \text{RCO}_2\text{H (l) or (s)} + \text{NaCl (aq)}
\]

and the acid collected by filtration or by taking it up in the solvent, separating, and evaporating.

The extraction of a water insoluble organic acid from solution in an organic solvent by extraction with dilute aqueous sodium hydroxide solution can be understood in terms of the equilibrium between the acid in the water layer and the acid in the organic layer which you studied last semester in Extraction I,

Equilibrium (1): \( \text{RCO}_2\text{H (org)} \rightarrow \text{RCO}_2\text{H (aq)} \)

and the equilibrium between the organic acid and its conjugate base in the water layer

Equilibrium (2): \( \text{RCO}_2\text{H (aq)} + \text{H}_2\text{O (l)} \rightarrow \text{RCOO}^-\text{(aq)} + \text{H}_3\text{O}^+\text{(aq)} \)

Because hydroxide ions react with hydronium ions to form the weak electrolyte water

\[
\text{OH}^-\text{(aq)} + \text{H}_3\text{O}^+\text{(aq)} \rightarrow 2\text{H}_2\text{O (l)}
\]

Equilibrium (2) is shifted to the right by the addition of hydroxide ions. Shifting Equilibrium (2) to the right uses up \( \text{RCO}_2\text{H} \) molecules. Using up \( \text{RCO}_2\text{H} \) molecules in the water layer shifts equilibrium (1) to the right. The acid goes from the organic layer into the water layer.

The extraction of a water insoluble amine from solution in an organic solvent by extraction with dilute aqueous hydrochloric acid can be understood similarly in terms of the equilibrium between the amine in the water layer and the amine in the organic layer,

\[
\text{RNH}_2\text{(org)} \rightarrow \text{RNH}_2\text{(aq)}
\]

and the equilibrium between the amine and its conjugate acid in the water layer

Before beginning the experimental work, you should study examples (3), (4), and (5) and be able to do Problem 6 in the Review of Concentration, pp. 14-16. You should also be able to answer the following questions:

1. Define: take up, wash with water, drying agent, absorb, mother liquor
2. Why must the organic compounds to be separated by extraction be insoluble in water?
3. What is the purpose of washing with water after extraction with a reaction solvent?
What is the purpose of using a fared test tube?
Why is the aspirator used to evaporate the dichloromethane?
What is the purpose of using a porous plate?
Why should a piece of weighing paper be put under the porous plate?
Why should you not touch the crystals with your fingers?

**MICROSCALE PROCEDURE FOR EXTRACTION II**

In this procedure, the scale of the experiment is reduced to one tenth the scale of the macroscale procedure that is usually found in organic laboratory manuals. Experiments in natural product chemistry, in pharmaceutical chemistry, in biochemistry, and in many other fields of modern research are often carried out on a very small scale. Operations on a microscale require less material, generate less waste, take less time, and are safer than macroscale operations. This experiment, the final experiment of organic chemistry lab, will introduce you to some microtechniques.

**EXPERIMENTAL**

**WARNING:** Amines can be absorbed through the skin. Although the amines used in the unknown have been chosen for their low toxicity based on existing information, try not to get any of the unknown on your skin or clothing. If you do, wash immediately with lots of soap and water. If you find a basic compound in your unknown, follow the directions for disposing of it carefully.

An analytical balance and glossy balance paper must be used to determine small masses accurately. Instructions for using an analytical balance and glossy balance paper are in the balance room. Use 1-mL graduated pipets to measure the volumes of liquids.

**PART A: SEPARATION OF MIXTURE.**

Determine the mass of your unknown, which should be about 0.1 g, transfer the sample to a small test tube, and dissolve it in 1.0 mL of dichloromethane.

Extract the dichloromethane solution with 0.50 mL of 5% hydrochloric acid by adding the hydrochloric acid to the sample in the small test tube, corking firmly, and shaking vigorously for at least two minutes. Let the test tube stand until the layers have separated and then open carefully. Note that on a microscale, emulsions can often be broken by centrifugation. If you have to centrifuge, don't forget to balance the test tube that contains the sample with another test tube that contains the same volume of water. Use a Pasteur pipet to separate the layers. Place the aqueous layer in a small test tube labeled, "HCl extract".

Extract the dichloromethane layer with another 0.50-mL portion of 5% hydrochloric acid combining the second HCl extract with the original. Mix the combined HCl extracts and test with litmus paper to be sure that they are acidic. (If they are not, continue extracting the dichloromethane layer with 0.50-mL portions of 5% HCl until they are.) Then wash (extract) the dichloromethane layer with 0.50 mL of water. Add the water wash to the HCl extract and set the HCl extract aside for Part B.

Extract the dichloromethane solution twice with 0.50-mL portions of 5% NaOH. Collect the NaOH extracts in a third small test tube labeled, "NaOH extract". Mix the combined NaOH extracts and test with litmus paper to be sure that they are basic. (If they are not, continue extracting the dichloromethane layer with 0.50-ml portions of 5% NaOH until they are.) Then wash the dichloromethane layer with 0.50 mL of water, add the water wash to the NaOH extract, and set the NaOH extract aside for Part B.
If the volume of the dichloromethane solution is less than 1.0 mL, add enough dichloromethane to make the volume equal to 1.0 mL. Then add enough anhydrous granular sodium sulfate to fill the rounded bottom of the test tube, cork firmly, and shake. If the Na₂SO₄ clumps together, separate the solution from the Na₂SO₄, wash the Na₂SO₄ twice with dichloromethane, and add more Na₂SO₄. The second portion of Na₂SO₄ should fall freely through the solution; if the Na₂SO₄ still clumps, repeat until the Na₂SO₄ does not clump or stick to the bottom of the test tube. Then let stand about five minutes to complete the drying process.

Place a small Boileezer in a dry small test tube labeled, "Neutral fraction". Tare the test tube and Boileezer and transfer the dry dichloromethane solution to it. Complete the transfer by washing the sodium sulfate with two more portions of dichloromethane. Use just enough dichloromethane to cover the sodium sulfate and stir by swirling. Combine the washes with the dichloromethane solution in the fared test tube.

**PART B: RECOVERY OF COMPONENTS OF MIXTURE FROM SOLUTION.**

**1) BASIC FRACTION FROM HCl EXTRACTION.**

Cool the "HCl extract" in an ice bath. Pour a little 10% sodium hydroxide solution into a small beaker and transfer to a small test tube. Add the 10% sodium hydroxide solution to the "HCl extract" drop wise with stirring and continued cooling until the solution is basic to litmus. About ten drops will be required. If you have sodium hydroxide solution left, wash it down the drain with water. Do NOT return it to the bottle or put your dropper in the bottle. If the solute separates as an oil, scratch with the stirring rod until the oil solidifies. Separate the liquid from the solid with a Pasteur pipet or by suction filtration. Wash the solid twice with ice water. Use just enough ice water to cover the solid and stir by swirling. Scrape the solid out of the test tube with a clean spatula and dry it on a piece of porous plate.

**2) ACIDIC FRACTION FROM NaOH EXTRACTION.**

Cool the "NaOH extract" in an ice bath. Pour out a little concentrated HCl into a small beaker and transfer to a small test tube. Add the concentrated HCl to the "NaOH extract" dropwise with stirring and continued cooling until the solution is acidic to litmus. If you have concentrated HCl leftover, wash it down the drain with lots of water. Do NOT return it to the bottle or put your dropper in the bottle.

Separate the liquid from the solid with a Pasteur pipet or by suction filtration. Wash the solid twice with ice water. Use just enough ice water to cover the solid and stir by swirling. Scrape the solid out of the test tube with a clean dry spatula and dry it on a piece of porous plate.

**3) NEUTRAL FRACTION.**

In a hood, evaporate the dichloromethane by warming the test tube in a water bath at 50°C. Remove the last traces of dichloromethane by placing the warm test tube in your filter flask, stoppering tightly with a rubber stopper, and evacuating with an aspirator. Use copper wire to make a handle for the test tube so that it stands upright in the filter flask and can easily be removed from the filter flask. Determine the mass of test tube, Boileezer, and neutral fraction. Then scrape the solid out of the test tube with a clean dry spatula and dry it on a piece of porous plate.

Make a flow chart of the separation of the mixture and the recovery of the acidic, basic, and neutral fractions. Enter the mass of the neutral fraction in the flow chart.
Determine the masses of the acidic and basic fractions and the melting points of all three fractions and enter in the flow chart. Put the porous plate from the basic fraction and any sample leftover from the basic fraction in the labeled container provided. Porous plate and leftover sample from the acidic and neutral fractions can be put in the crock.

Which fraction was least pure? On what evidence do you base your conclusion?

After you have finished this experiment you should be able to:

1. Determine mass with an analytical balance.
2. Carry out extraction and recovery of a nonvolatile solute from solution in a volatile solvent on a microscale.
3. Answer the following questions:
   a) What properties are desirable in a solvent for extraction?
   b) Carboxylic acids are soluble in both sodium hydroxide and sodium hydrogen carbonate solution. Phenols are weaker acids than carboxylic acids; although they are soluble in sodium hydroxide solution, they are not soluble in sodium hydrogen carbonate solution, which is less basic. With a flow chart, show how a mixture of benzoic acid and the phenol 2-naphthol, could be separated and the benzoic acid and 2-naphthol recovered. The structure of 2-naphthol is

![Structure of 2-naphthol](image)

**Examples**

**Example (1)** (a) How many grams of \( \text{Pb(C}_2\text{H}_3\text{O}_2\text{)}_2 \) are needed to prepare 750 grams of 1.25% lead acetate solution? (b) How many grams of water are needed? (c) How would you measure the water?

**Solution:** (a) Substituting the numbers given in the example in the definition of percent

\[
1.25\% = \left( \frac{g \text{Pb(C}_2\text{H}_3\text{O}_2\text{)}_2}{750 \text{ g}} \right) \times 100
\]

and solving for grams of lead acetate gives

\[
(1.25 \times 750 \text{ g}) / 100 = g \text{Pb(C}_2\text{H}_3\text{O}_2\text{)}_2 = 9.4
\]

(b) Because the total mass of the solution equals the sum of the masses of the solute and solvent

\[
750 - 9 \text{ g} = 741 \text{ g} \text{ of water are needed}
\]

(c) Since it is quicker and easier to measure the volume of a liquid with a graduated cylinder than it is to find the mass of the liquid, 741 ml of water should be measured out in a 1-liter graduated cylinder (the density of water is 1.00 g/ml at room temperature).

Because, all ions are hydrated (surrounded by water molecules) in aqueous solution, and many substances solidify with loosely bound water in the crystal, many substances are bought and sold in the form of hydrates. For example, the lead acetate on the stockroom shelf is \( \text{Pb(C}_2\text{H}_3\text{O}_2\text{)}_2 \cdot 3 \text{ H}_2\text{O} \) not \( \text{Pb(C}_2\text{H}_3\text{O}_2\text{)}_2 \). \( \text{Pb(C}_2\text{H}_3\text{O}_2\text{)}_2 \cdot 3 \text{ H}_2\text{O} \) is called lead (II) acetate trihydrate. The water of crystallization must be taken into account in calculating how much solute to use.

**Example (2)** (a) How many grams of \( \text{Pb(C}_2\text{H}_3\text{O}_2\text{)}_2 \cdot 3 \text{ H}_2\text{O} \) are needed to prepare 750 grams of 1.25% lead acetate solution? (b) How much water would you use to dissolve the lead (II) acetate trihydrate.
Solution (a) In Example (3)(a) you found that you needed 9.4 g Pb(C₂H₃O₂)₂ to prepare 750 g of 1.25% lead acetate solution. A conversion factor for converting grams Pb(C₂H₃O₂)₂ to grams Pb(C₂H₃O₂)₂ • 3 H₂O is needed. This is obtained from the formula masses of Pb(C₂H₃O₂)₂ and Pb(C₂H₃O₂)₂ • 3 H₂O which are 325.2 and 379.2 amu, respectively.

\[9.4 \text{ g Pb(C₂H₃O₂)₂} \times \left(\frac{379.2 \text{ g Pb(C₂H₃O₂)₂} \cdot 3 \text{ H₂O}}{325.2 \text{ Pb(C₂H₃O₂)₂}}\right) = 11.0 \text{ g Pb(C₂H₃O₂)₂} \cdot 3 \text{ H₂O}\]

(b) 750 g - 11 g = 739 g or 739 ml of water

Concentrations expressed in percent can be converted to concentrations expressed in molarity if the density of the solution is known and this is given on the labels of the bottles of concentrated reagents which the university buys.

Example (3) Concentrated HCl is 36.7% HCl by mass. The density is 1.18 g/ml. What is the molarity?

Solution We must find the number of moles of HCl in one liter of the concentrated acid. We know from the density that 1.00 ml has a mass of 1.18 grams or 1 liter (1000 ml) has a mass of 1180 grams. But only 36.7% of this mass is HCl. Use the definition of percent to calculate the mass of HCl in 1180 grams:

\[36.7\% = \left(\frac{\text{g HCl}}{1180 \text{ g}}\right) \times 100; \quad \text{g HCl} = \left(\frac{36.7 \times 1180 \text{ g}}{100}\right) = 433.1 \text{ g}\]

The formula mass of HCl is 36.5 amu; therefore 433.1 g HCl equals

\[433.1 \text{ g HCl} \times \left(\frac{1 \text{ mole HCl}}{36.5 \text{ g HCl}}\right) = 11.87 \text{ mole HCl}\]

and the molarity is

\[\left(\frac{11.87 \text{ mole}}{1 \text{ L}}\right) = 11.9 \text{ M HCl}\]

Sometimes, instead of giving the concentration of a solution in percent or molarity, procedures call for a saturated solution. There are two ways of preparing saturated solutions. One is to mix a volume of solvent with a mass of solute greater than will dissolve rapidly at room temperature, and let the mixture stand for several days or a week shaking from time to time so that equilibrium is reached. The other is to mix a volume of solvent with a mass of solute greater than will dissolve at room temperature, heat to boiling stirring by swirling, and then cool to room temperature. In this way equilibrium is reached rapidly, but more energy (both fuel and the chemist's) is used. A saturated solution should always have undissolved solid in the bottom.

You should be able to do problems like the following:

1. How many ml is 0.374 l? (b) How many l is 25.2 ml?
2. A solution is made by dissolving 0.610 g of benzoic acid, C₆H₅COOH, in water and diluting to 250 ml. What is the molarity? The formula mass of benzoic acid is 122.12 amu.
3. Write out instructions for preparing:
   a) 50 ml of 0.25 M CuSO₄
      i. from anhydrous (not containing any water of crystallization) CuSO₄. The formula mass of CuSO₄ is 159.60 amu.
      ii. CuSO₄ • 5H₂O. The formula mass of CuSO₄ • 5H₂O is 249.68 amu.
   b) 500 ml of dilute (6.0 M) HCl from glacial (17.0 M) HCl.
4. If 23.47 and 23.37 ml of KOH solution are required to neutralize 2 - 25.00 ml portions of 0.467 M acetic acid, what is the molarity of the potassium hydroxide solution? (The formula for acetic acid is CH₃COOH; it is a monoprotic acid.)
5. In an experiment to determine the partition ratio of a monoprotic organic acid between water and ether, a 50.0 ml sample of 0.750 M acid was extracted with ml of ether. The water layer was titrated with 0.314 M NaOH; 25.76 ml were required to neutralize it. What is the value of the partition ratio?

6. Write out instructions for preparing:

   a) 1.25 kg of 10.0% aqueous potassium carbonate solution starting with $K_2CO_3$ (s).
   b) 500 g of 5.0% aqueous FeCl$_3$ solution from FeCl$_3$ • 6 H$_2$O (s).
   c) 250 ml of 2.00 M HNO$_3$ from concentrated HNO$_3$ which is 70.0% HNO$_3$ and has a density of 1.42 g/ml.

**Answer to problems:**

1. (a) 374 (b) 0.0252
2. 0.01998
3. (a) (i) 2.0 g CuSO$_4$ (ii) 3.1 g CuSO$_4$•5H$_2$O (b) 176 ml glacial acetic acid. Measure in 250 ml graduated cylinder, dissolve in about 300 ml of deionized water in 500 ml volumetric flask, mix thoroughly, cool to room temperature, and dilute to mark. Again mix thoroughly.
4. 0.499
5. 7.27
6. (a) Measure 125 g K$_2$CO$_3$ (s) on a balance and dissolve in 1125 ml water measured in 2-l graduated cylinder, (b) 42 g FeCl$_3$ • 6 H$_2$O and 458 ml of water in 500-ml cylinder (c) 31.6 ml conc. HNO$_3$ measured in 50-ml graduated cylinder. Add concentrated acid to water in 250 ml volumetric flask (usual procedure).