Experiment 5 —

Acid-Base Chemistry and Extraction

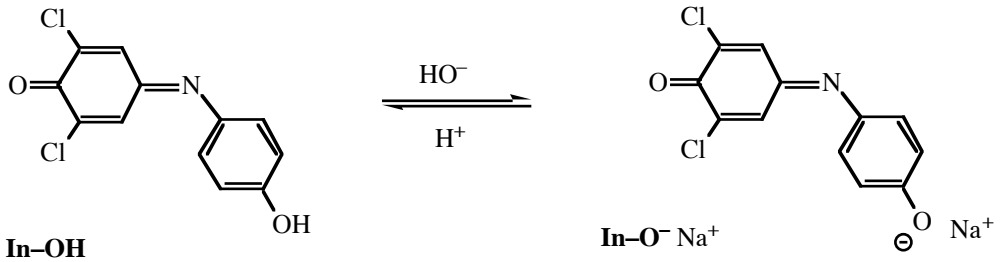
Pre-lab preparation (1) Read the supplemental material on extraction from Fessenden, Fessenden, and Feist on the principles of Extraction. (2) Look up the structures and melting points of the three compounds you will be separating in the second part. The pK_a of benzoic acid is 4.2; the pK_a *of the conjugate acid of* benzocaine is 2.5. You don't need to track down any data on the indicator in part 1 — everything you need is in this handout. (3) Calculate the number of mmol (that's *mili*moles) of benzoic acid, benzocaine, and fluorenone that you will be using in part 2. (4) Look up the densities and boiling points of the organic solvents you will be working with in both parts. You should be able to find these in your notebook, since you looked them up for a previous experiment! (5) Also, review your solubility data from Exp 1, and list your results for the solubility of benzoic acid and of benzocaine (ethyl *p*-aminobenzoate) in water, aqueous HCl, and aqueous NaOH. (Now that you know some relevant acid-base chem, you may know what *should* have happened. That's not the question. Report what you *actually* observed.)

Liquid-liquid extraction is one of the easiest and most common ways in which organic chemists separate reaction products from inorganic byproducts and other organic molecules. The separation is based on differing solubilities of the solutes in two *immiscible* solvents, normally water and a less polar organic solvent. Physically separating the two liquid layers separates the solutes.

Extraction is an especially powerful technique for chemists who have a good command of acid-base properties (and pK_as) and who understand how solubility depends on charge and polarity. Moving compounds between water and an organic solvent by protonation and deprotonation is often a great way to effect a clean separation.

This is a two-part lab. The first part is designed so that you can actually see a compound go from one solvent to the other as it is protonated and deprotonated. In the second part you will separate a mixture of three compounds by extraction.

Experiment 1 — Microscale partitioning of an acid-base indicator between solvents. In this experiment we will use an indicator, 2,6-dichloroindophenol (**In–OH**), to see how protonation and deprotonation can be used to encourage a compound to move between organic and aqueous layers. 2,6-Dichloroindophenol (**In–OH**) itself is *red*, but its conjugate base (**In–O$^-$**) is *blue*. The *color* will tell you if it's protonated or deprotonated.



In–OH
RED
organic-soluble
$pK_a = 5.9$

In–O$^-$ Na^+
BLUE
water-soluble

You will carry out the same sequence of protonation/deprotonation steps twice — once with water and CH_2Cl_2, and again with water and Et_2O. As you go through the procedures, be sure you carefully record and explain all observations *in your notebook*. Explanations should be in terms of structures ("In–OH" or "In–O$^-$".) Please don't rewrite all the questions (below), but do answer them in such a manner that a reader can easily follow what's going on. For example, after recording what you did to get to this point, "(1) the water layer is on top and (2) contains the indicator. (3) The indicator is blue, which means it is in the InO^- form".... etc.

Part a. A deep *blue*, basic solution of **In–O$^-$ Na$^+$** will be provided. (This solution contains of 25 mg of **In–O$^-$ Na$^+$** per 50 ml of 0.02 M NaOH; if it has decomposed and is some color that is not blue, for example *brown*, don't use it! Go to your instructor, and yell "I want my money back!" or "Liar liar!") Add 150 μl (0.15 ml) of this deep blue solution to a mixture of 1 ml H_2O and 1 ml of CH_2Cl_2 in a small test tube. Note which quantities are important and which aren't. You know two ways to measure small volumes like this — the quick and approximate way and the more precise way. (A graduated cylinder is *not* involved in either of them.)

1 Which solvent is on top, and which is on the bottom?

2 Which layer contains the indicator (CH_2Cl_2 or water)?

3 Based on its color, is the indicator in its neutral (In–OH) or anionic ($In–O^-$) form?

Carefully add 100 μl of 0.05 M aq HCl, and note the appearance of the mixture before shaking. Now stopper and shake the tube vigorously. (How do you know how "vigorously"? Shake, look, shake again. If anything changed, then the first shake wasn't vigorous enough. Maybe the second wasn't either. Keep shaking until nothing changes.)

4 Which solvent contains the indicator?

5 Based on its color, what is the form of the indicator?

6 Thinking in terms of structure, polarity, and solvation, briefly explain briefly why the indicator is where it is. In other words, why is it in the one solvent instead of the other?

7 Did shaking the vial cause a change in the appearance of the mixture? If so, explain what happened in terms of structure.

Now carefully add 100 μl of 0.1 M aq NaOH, then shake.

8 Which solvent contains the indicator?

9 Based on its color, what is the form of the indicator?

10 Explain in terms of structure, polarity, and solvation, why the indicator is where it is.

Part b. *Repeat the entire sequence using Et_2O (diethyl ether) in place of CH_2Cl_2.*

Be sure to record the results in your notebook — think and write in terms of *structures*. Remember, your macroscopic observations are just a *consequence* of what's happening on a molecular level.

Experiment 2 — Macroscale separation of three compounds. Over the summer, an accident in the stockroom caused the **benzoic acid**, **benzocaine** (ethyl *p*-aminobenzoate), and **fluorenone** to get mixed together. Your mission is to separate them. This will be done on a larger scale than the previous experiment, so you'll need to use a small separatory funnel ("sep funnel").

First, however, we need to be sure we understand the solubilities. Benzoic acid and benzocaine are both nearly insoluble in water. But one of these should dissolve in aqueous acid, and the other in aqueous base. If this is *not* what you found in your first Chem 21 lab, please repeat these two solubility tests on each of these compounds — 20 mg of compound in about ½ ml of 1 M aq HCl, and in ½ ml of 1 M aq NaOH. Shake, look, shake some more; add a little more solvent if necessary. This is important. Be sure you understand what's happening.

In collaboration with your partner, **write a flow chart for the separation and isolation** of the three pure solids. Include structures of the compounds at every step. Your solvents are Et_2O and water. In addition, 1 M aqueous HCl and 1 M aqueous NaOH will be available. The tips below will help you develop the procedure. Have your lab instructor or TA check your flow chart before you attempt the actual separation.

(a) You will start by dissolving 1.0g of the stock 1:1:1 (by mass) mixture of the three compounds in about 30 ml of Et_2O.

(b) If you want to extract with aqueous acid or base, use two 10-ml portions of the stock 1 M aq HCl or NaOH. Do you agree that this should be more than enough based on the amount of each solid? (1 M = 1 mol/liter = **1 mmol/ml**, so 10 ml contains how much H^+ or OH^-?)

(c) You will end up with two of the compounds in acidic or basic aqueous solutions (ca. 1 M HCl or 1 M NaOH). The best way to recover pure (neutral) compound is to neutralize this solution by *slow, careful* addition of 6 M HCl or 6 M NaOH. Some acid-base reactions are quite exothermic. Have ice ready just in case things get out of hand. Actually, we're going to go a bit past neutral. Add HCl to the basic soln until it's acidic; add NaOH to the acidic soln until it's basic. Use pH paper. Transfer a drop to the pH paper; don't dip the paper into the soln.

(d) Cooling your final aqueous solution in ice will encourage all the solid to precipitate; isolate this by suction filtration on your Büchner funnel, rinse with a few ml of cold water, and put it on a watch glass to dry. Leave it in your drawer until the next lab period.

(e) Now what do we do if we end up with a compound in the Et_2O that can't be moved into water by acid-base chemistry? To isolate this, we need to dry the solution, and then remove the solvent. Still in the sep funnel, wash the Et_2O solution with 5 ml of saturated NaCl ("brine"), then dry it with anhydrous $CaCl_2$, and filter by gravity (short-stemmed funnel and filter paper) into a 24/40 round-bottom flask. We're going to remove the solvent with a *rotary evaporator*.

Here are some general technical hints: (1) Diethyl ether is quite volatile, so all operations with Et_2O need to be done in a fume hood. If too much ether evaporates during the procedure, you may need to add a little more to keep the volume from getting too low.

(2) Shake, vent, shake, vent, shake, vent... make sure you don't point the sep funnel at anyone — *including yourself* — when you vent it. Shake means really shake it vigorously. Your goal is to get good contact between the liquid phases so that the solute molecules have a chance to sample both solvents and decide which one they prefer.

(3) You'll need to remove one layer or another in each step of the extraction — *don't throw anything away until you're done!* You may think you have a solution that contains nothing of value, but you could be mistaken. Chemists more experienced than you have accidentally tossed valuable — *really* valuable — compounds into the waste. Save all the solutions, then if something goes awry you should still be able to locate and rescue the goodies.

(4) Drain the lower layer out the bottom of the sep funnel, then *pour* what's left (upper layer) out the top. This minimizes cross-contamination.

(5) Keep an Erlenmeyer flask under the sep funnel as you fill it in case the stopcock leaks or your partner (not you!) forgets to close it.

(6) Be sure that all your flasks are labelled so you don't lose track of what's what. In the interest of keeping the lab neat and organized, the instructor and TA will be prowling around the lab and will immediately discard the contents of any unlabelled flask that we find. No need to thank us; it's our job.

(7) Turn in the copies of your notebook pages and you're done.

Indicator extraction adapted from TR Kelly, KR Williams *J Chem Educ*, **1993**, *70*, 848-9. Three-component separation adapted from DW Mayo, RM Pike, PK Trumper *Microscale Organic Laboratory*, 3rd ed, pp 151-4.