

Experiment 19

EXTRACTION

Objective

The purpose of this experiment is to separate an organic compound from an organic solvent by forming a water soluble salt using acid-base reaction.

Lab techniques

- Separatory funnel
- Gravity filtration
- Suction filtration
- Rotary evaporator

Introduction

I. Distribution coefficient

Extraction refers to the transfer of a solute from one solvent to another. In a dilute solution, the ratio of concentration of a solute between two immiscible solvents is a constant, which is called the **distribution coefficient**. For instance, under constant temperature, the distribution constant of a solute X between solvents A and B can be represented by K , where $K = C_A/C_B$ (C_A : concentration in g/mL of X in solvent A; C_B : concentration in g/mL of X in solvent B).

In general, solute X cannot be completely extracted to solvent A from solvent B in one single extraction unless the value of K is very large. In order to separate most of the solute X to solvent A, a smaller portion of solvent A can be used with multiple extractions. This is much better than using a large portion of solvent A in one single extraction, as demonstrated below.

Let the concentration of solute X in the original solution be C_{B0} , volume of solvent B be V_B , and volume of solvent A used for extraction be V_A . Thus, the concentration of solute X in solvent B (C_{B1}) after a single extraction can be represented by equation 19-1:

$$C_{B1} = C_{B0} \left(\frac{V_B}{V_B + KV_A} \right) \quad (19-1)$$

However, if V_A' of solvent A is used to extract n times instead of V_A for a single extraction, where $V_A' = V_A/n$, the concentration of solute X in solvent B (C_{Bn}) after n times of extraction can be represented by equation 19-2:

$$C_{Bn} = C_{B0} \left(\frac{V_B}{V_B + KV_A} \right)^n \quad (19-2)$$

Since the value in the bracket is smaller than unity, it can be realized easily that

$$C_{Bn} \text{ (the remnant)} < C_{B1}.$$

This demonstrated the fact that multiple extraction with a specified quantity of solvent for use in extraction is more efficient.

II. Extraction

An ideal solvent for extraction should have several properties: (1) containing selective dissolving ability for a specific organic compound, (2) immiscible with the original solvent, (3) easy to separate from the solute (e.g. low boiling point), (4) not irreversibly reactive with the solute. Moreover, the price of the solvent, the ease of handling, the flammability of the solvent, and its safety should also be taken into consideration.

Commonly used organic extraction solvents include diethyl ether, methylene chloride, ethyl acetate, *n*-hexane, etc. Among them, methylene chloride is denser than water. In addition, ethanol, methanol and acetone, which are miscible with water, are also often used in solid natural product extraction.

In this experiment, using simple acid-base reactions, one can separate acidic (RCOOH), basic (RNH₂), and neutral (R-H) organic compounds. For an acidic substance dissolved in an organic solvent, basic aqueous solution should be used for extraction. A simple acid-base reaction occurs in the separatory funnel and causes the acidic substance to form a water-soluble salt. Then the acidic substance can be regenerated by acidifying the aqueous solution after separation. Afterwards, further purification can be carried out if necessary in order to obtain the pure substance. The same method can be applied for a basic substance, but using acidic aqueous solvent for extraction. Finally, only the neutral compound will be present in the organic solvent. Once this has been achieved, further purification can be carried out. The whole process is demonstrated in Figure 19-1.

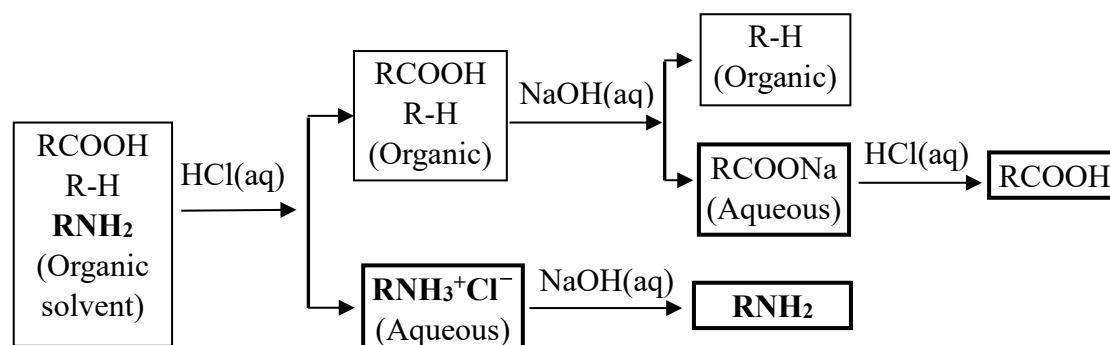


Figure 19-1 Flow chart of extraction using acid-base reactions

III. Salting out and salting in

The solubility of an organic compound is always affected by the concentration of inorganic solutes within the solvent. For example, ethanol is completely miscible with water, but is only slightly miscible with sodium chloride, potassium carbonate, or other inorganic aqueous solutions. This phenomenon of lowered solubility of organic compound in an aqueous salt solution is called salting out, which always occurs with salts with small radii and high charges. In contrast, the phenomenon of increasing solubility of an organic compound in an aqueous salt solution is called salting in, which always occurs with salts with large radii and low charges. For example, the solubility of benzene in 1 *M* tetramethylammonium bromide ($\text{Me}_4\text{N}^+\text{Br}^-$) solution is 1.4 times higher than that in pure water.

IV. Drying agents

In general, extraction makes use of organic solvents immiscible with water. However, there is always some unobservable water within the organic layer (particularly when it is turbid). Therefore, the organic layer should be dried with drying agents before concentration. Some commonly used drying agents and their properties are listed in Table 19-1⁽³⁾.

The ideal drying agent has strong water absorption capacity, fast speed, and does not adsorb any solvent or solute. It should not interact with solvents or solutes, and is cheap. Here is a brief introduction to several commonly used drying agents.

1. Anhydrous magnesium sulfate (MgSO_4): It is the most commonly used drying agent by organic chemists because of its strong water absorption capacity (can absorb twice its own weight of water) and absorbs water quickly. Compatible with most organic compounds. The only disadvantage is that the magnesium sulfate used for drying is in powder form and needs to be separated by filtration. When using magnesium sulfate, add a small spoonful of the powder first and swirl the Erlenmeyer flask a few times. If one can see the powdery magnesium sulfate suspended in the solution, the amount is enough.
2. Anhydrous sodium sulfate (Na_2SO_4): Suitable for all organic compounds, very cheap, and often used. However, its water absorption capacity is weaker than magnesium sulfate, and its water absorption speed is also slightly slower. The advantage of sodium sulfate is that the particles are larger and heavier and can be separated by decantation (sodium sulfate will remain at the bottom of the bottle).
3. Anhydrous calcium chloride (CaCl_2): It has a strong water absorption capacity and slow rate. Therefore, it requires a longer time to achieve a good drying effect. It should be noted that alcohols will interact with calcium chloride. At the same time, it is best not to use it for drying acidic compounds, because industrial grade calcium chloride often contains alkaline salts.

4. Anhydrous calcium sulfate (CaSO_4): The commercial product is called Drierite, which absorbs water very quickly, but can only absorb 6.6% of its weight in water.

V. The separatory funnel

The extraction of liquid solutions is often performed using a separatory funnel, as shown in Figure 19-2. If the control stopcock has a ground glass joint, it should be lubricated with Vaseline to avoid leakage. However, organic extraction solvents often dissolve Vaseline used and cause contamination. Therefore, stopcocks made of more expansive Teflon are often used. The tightness is better, and there is no need to apply Vaseline. The stopper of the opening can be moistened with water to achieve a tight seal.

The operation of the separatory funnel during extraction is an art. It is best learned by observing the operation of instructor. First, support the separatory funnel using an iron ring attached to an iron stand. Close the stopcock, transfer the sample solution and the extraction solvent to the separatory funnel through an ordinary funnel, then stopper it. Second, tilt the funnel as shown in Figure 19-2, with one hand holding the stopper and the other hand operating the stopcock. Shake the funnel vigorously several times to mix the solution thoroughly and then quickly release the pressure by opening the stopcock. Repeat the shaking and pressure releasing processes several times, until there is no obvious release of pressure. Then allow the funnel to stand on a ring as shown in Figure 19-3, and remove the stopper. Wait till the two layers become visible. Collect the lower layer by flowing out from the bottom and the upper layer by pouring out from the top opening.

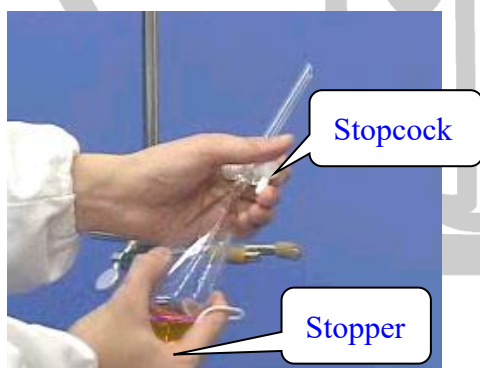


Figure 19-2 Holding a separatory funnel



Figure 19-3 Support the funnel using an iron ring

Apparatus






Separatory funnel, iron ring, funnel, Erlenmeyer flasks (50 mL, 2), round bottom flask (100 mL), dropper, glass rod, Büchner funnel, rubber stopper, vacuum filter flask, three prong clamp, filter paper, aluminum foil, test tubes (2).

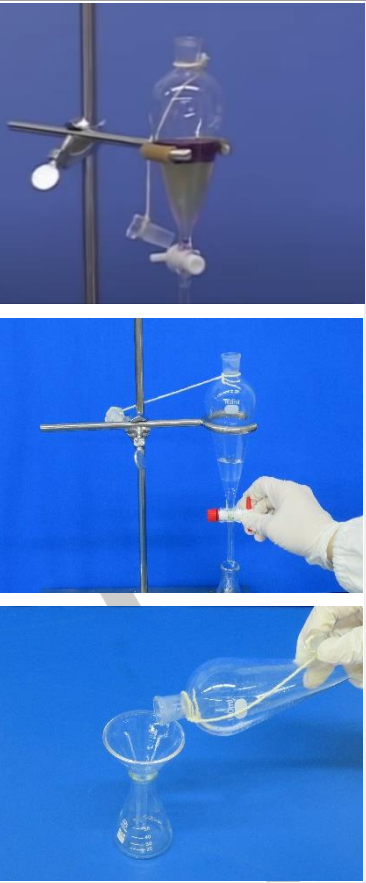


Shared: Scissor, suction pump, electronic balance, and rotary evaporator.



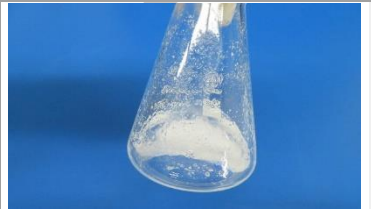


Chemicals


Benzoic acid ($\text{C}_6\text{H}_5\text{COOH}$), acetanilide ($\text{C}_6\text{H}_5\text{NHCOCH}_3$), 5% sodium hydroxide (NaOH), ethyl acetate ($\text{CH}_3\text{COOC}_2\text{H}_5$), 6 M hydrochloric acid (HCl), anhydrous magnesium sulfate (MgSO_4), universal paper.

Procedure

Procedure		Illustration
I. Acid-base extraction		
1.	Weigh and record the exact mass of 0.5 g benzoic acid and 0.5 g acetanilide (1:1 by mass), then transfer to a 50 mL Erlenmeyer flask. Dissolve the mixture with 10 mL of ethyl acetate (EA).	
2.	(1) Support a clean separatory funnel using an iron ring and make sure the stopcock is tight and shut off. Put an empty Erlenmeyer flask underneath the separatory funnel as a leak prevention measure. (2) Transfer the previous solution through a funnel into the separatory funnel. Rinse the flask with 2 mL of EA twice and pour into the separatory funnel.	 
3.	Pour 5 mL of 5% NaOH solution to the separatory funnel to carry out the extraction. (1) Release pressure: Stopper the separatory funnel and pick it up from iron ring with two hands. Carefully invert the separatory funnel and open the stopcock to vent into fume hood. (2) Extraction: Close the stopcock. Mix two solutions by shaking vigorously. Keep on shaking and venting several times until the “whoosh” is no longer audible. Note: Operate extraction and venting in fume hood for safety.	 

4.	<p>(1) Layer separation: Support the separatory funnel using the iron ring and the top stopper is immediately removed. Let it stand till the solution be separated into two distinct layers. The solution with higher density (aqueous layer) will situate at the lower layer, the other solution (EA) will be on the top.</p> <p>(2) Drain the lower aqueous layer from the bottom of the separatory funnel to a 50 mL Erlenmeyer flask (Label it as A).</p> <p>(3) Wash and extract the upper layer (EA) remaining in the separatory funnel with 5 mL DI water (as procedure 3). Drain the denser lower layer to flask A to combine with the previous solution.</p> <p>(4) Pour out the upper layer (EA) from the top of separatory funnel to another dry 50 mL Erlenmeyer flask (Label it as B).</p>	
II. Separation of benzoic acid		
5.	<p>Put flask A in ice-water bath and then add 6 M hydrochloric acid drop by drop with swirling until the formation of a large amount of precipitate. The solution part should be acidic, with a pH less than 3, when tested with universal paper.</p> <p>Note: Use a glass rod to spot the solution on a piece of universal paper to test.</p>	
6.	<p>Collect the crystals by suction filtration and wash the crystals with small portions of cold DI water. Suction dry the crystals for 10 min.</p> <p>Note: Fix the vacuum filter flask with a clamp. Then use a rubber stopper to join the Büchner funnel and the filtering flask. Moisten the paper with small portions of solvent. Close the two-way valve of the safety flask, then start and test the suction. Start filtering when the filter paper is tightly stuck on the funnel. At the end, remember releasing the pressure before turning off the water pump.</p>	

7.	Use a spatula to scrape and collect the crystals on another piece of filter paper, then press the crystals between the folded paper and air dry for 15 minutes.	
8.	<p>(1) Weigh the mass of an empty large test tube. Place the crystals in it and weigh it again to calculate the percent yield.</p> <p>(2) Use a piece of aluminum foil to seal the test tube (poke small holes to allow further drying). The dried crystals will be used in the next experiment.</p>	
III. Separation of acetanilide		
9.	Add magnesium sulfate (ca. 2 g) to flask B and swirl until the solution is clear.	
10.	<p>(1) Wash and dry a 100 mL round bottom flask. Cool and weigh the mass of the flask.</p> <p>(2) Filter the EA solution in flask B to remove magnesium sulfate by gravity filtration, and receive the filtrate in previously weighed round bottom flask. Rinse the flask B with ca. 2 mL EA, then continue the process and combine the filtrate into the round bottom flask.</p>	
11.	<p>(1) Use rotary evaporator to evaporate the organic solvent (Set water bath temperature at 40°C). Weigh the mass of the solvent free compound and calculate the percent yield.</p> <p>(2) Store the extracted benzoic acid and acetanilide in a small test tube for the next experiment to determine the melting points and purify by recrystallization.</p>	

12.	Dispose the liquid waste into the designated container.	
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Reference

1. National Taiwan University, Department of Chemistry; *Experiments of Organic Chemistry*, 8th ed.; NTU Press: Taipei, 2006.
2. Pasto, D. J.; Johnson, C. R.; Miller, M. J. *Experiments and Techniques in Organic Chemistry*; Englewood Cliffs: N.J., 1992.
3. Pavia, D. L. *Introduction to Organic Laboratory Techniques: A Microscale Approach*, 1st ed.; Saunders College Pub.: Philadelphia, 1990.

Table 19-1 Common drying agents and their properties

Drying agent (anhydrous)	pH	Hydrated compound	*Drying ability	Rate	Applicability
Magnesium sulfate	Neutral	$\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$	High	Fast	General purpose
Sodium sulfate	Neutral	$\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$	High	Medium	General purpose
Calcium chloride	Neutral	$\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$	Low	Fast	Applicable on hydrocarbons and halogenated compounds
Calcium sulfate	Neutral	$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$	Low	Fast	General purpose
Potassium carbonate	Basic	$\text{K}_2\text{CO}_3 \cdot 2\text{H}_2\text{O}$	Medium	Medium	Applicable on amines, lipids, bases and ketones
Molecular sieve	Neutral	—	High	—	General purpose

* Drying ability refers to the amount of water absorbed by the drying agents per unit mass