Extraction

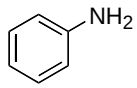
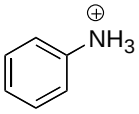
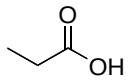
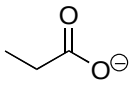
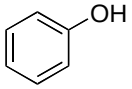
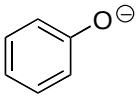
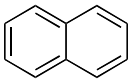
Background

Extraction is a technique that separates compounds (usually solids) based on solubility. Depending on the phases involved, extractions are either liquid-solid or liquid-liquid. If you have ever brewed a cup of tea or boiled bones for soup, you have performed a liquid-solid extraction. Compounds that are soluble in hot water (the liquid) are extracted from tea leaves or bones (the solid). Flavoring extracts are also made by liquid-solid extraction; vanilla extract is made by soaking vanilla beans in alcohol.

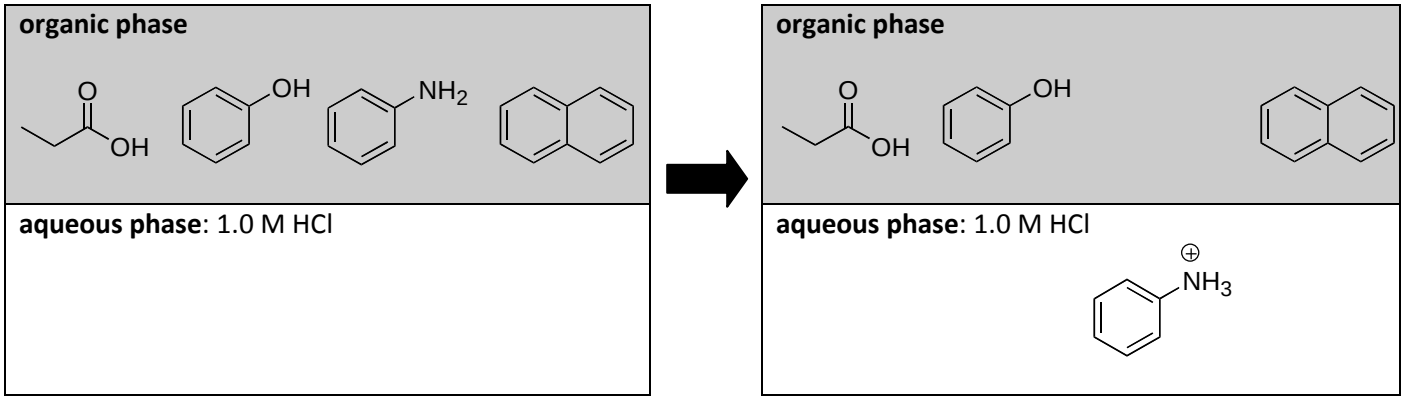
In organic laboratory, liquid-liquid extraction is most commonly used. Liquid-liquid extraction requires two immiscible liquids known as the organic phase and the aqueous phase. The aqueous phase is water-based and can be an acidic, basic, neutral, or a saturated salt solution. The organic phase is an organic solvent, usually diethyl ether or dichloromethane, which has minimal solubility in water. For instance, ethanol would be a poor extraction solvent because it forms a solution with water. Organic extraction solvents do not mix with water, they form distinct layers, much like oil and water. The denser liquid is the bottom layer. Compounds can be separated based on which liquid they are more soluble in.

Extraction works based on solubility and solubility is based on the principle of "like dissolves like". Neutral organic compounds will dissolve in the relatively non-polar organic phase; highly polar and ionic compounds will dissolve in the aqueous phase. Certain neutral organic compounds can be converted to ions with acid-base chemistry, which changes them from organic soluble to water-soluble. Acid-base extraction takes advantage of this change in solubility to separate compounds.

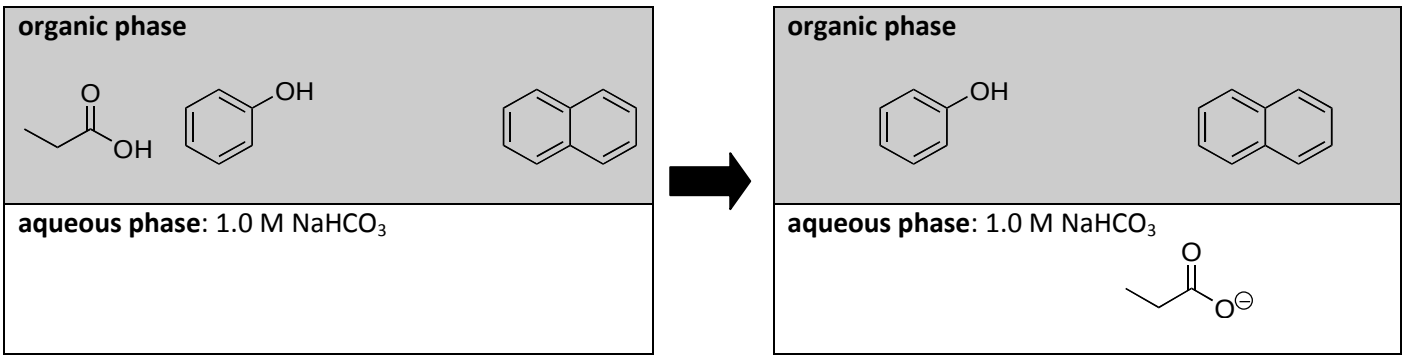
To demonstrate the principles of extraction we will consider the separation of four compounds: aniline, propanoic acid, phenol, and naphthalene. Aniline, acetic acid and phenol can be converted to ions under relatively mild conditions therefore they can be extracted into the aqueous phase. Naphthalene cannot be converted to an ion so it will always remain in the organic phase. By a sequence of extractions the four compounds can be separated.

 Aniline	+ acid → 	weak base	pK_a = 4.63 (of ammonium ion)
 Propanoic acid	+ base → 	weak acid	pK_a = 4.8
 Phenol	+ base → 	weaker acid	pK_a = 9.9
 Naphthalene		not acidic or basic	pK_a = 43

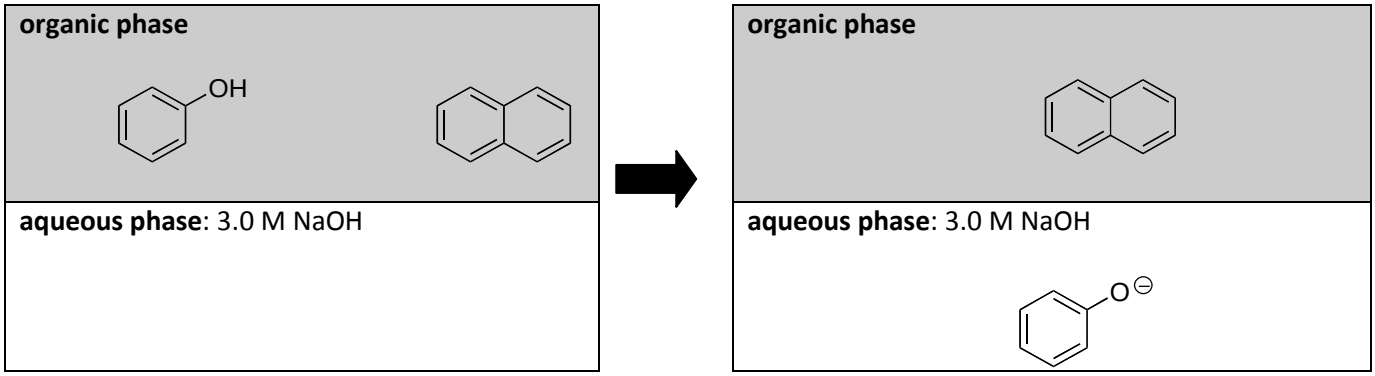
We will begin by dissolving a mixture of these four compounds in an organic solvent then bring them in contact with an aqueous phase. To protonate aniline and make it water soluble, it must come in contact with an acid that is stronger than its conjugate acid, that is, an acid with a pK_a at least 1 unit lower than 4.63. HCl (pK_a = -7), is acidic enough to protonate aniline and draw it into the aqueous phase. After the two phases are brought in contact, the aqueous layer that contains the protonated aniline can be drawn off, thus separating it from the rest of the compounds.



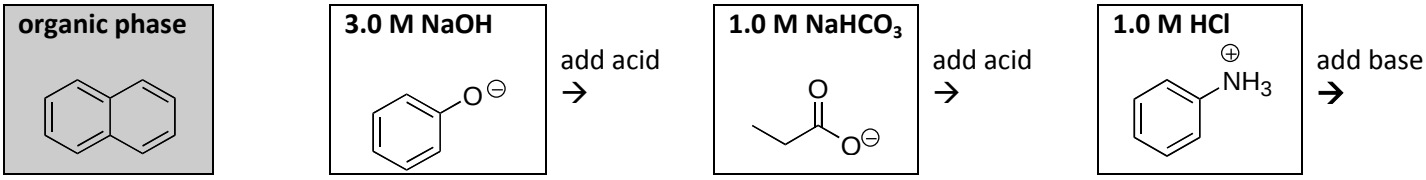
Next, we will bring the organic layer in contact with 1.0 M $NaHCO_3$ (H_2CO_3 pK_a = 6.35). Note that propionic acid is a stronger acid than H_2CO_3 (the conjugate acid of $NaHCO_3$) but phenol is not. This means that $NaHCO_3$ is strong enough to deprotonate propionic acid but not phenol therefore only propionic acid will be ionized and drawn into the aqueous phase. The aqueous phase is separated, leaving phenol and naphthalene in the organic phase.



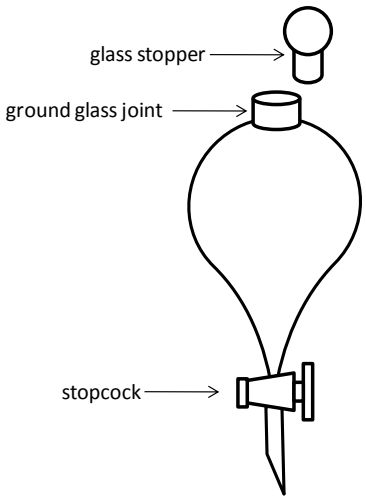
Finally, we will bring the organic layer in contact with 3.0 M NaOH (H_2O pK_a = 15.74), a base that is strong enough to deprotonate phenol. This brings phenol into the aqueous layer leaving only naphthalene in the organic phase.



Once the layers are separated, all four compounds will have been isolated. Addition of acid or base will bring the aqueous ionic species back to their original neutral form.



Practical Aspects of Extraction



Separatory Funnel

The Separatory Funnel

Separating two the two liquid layers in an extraction requires a specialized piece of equipment called a separatory funnel. A separatory funnel (often shortened to "sep funnel"), seen in the drawing on the right, has a ground glass joint with a fitted stopper on the top and a stopcock on the bottom which leads to a narrow spout. The stopper is never greased. The stopcock, which is made of Teflon, should be stored loose and tightened before using – it should feel snug but still turn easily. When the stopcock is horizontal, the valve is closed, when vertical it is open. When the liquids are ready to be separated, the sep funnel is placed in a ring support (not a clamp), the glass stopper is removed, the stopcock is opened and the bottom layer drains into a clean flask. If the flow stops soon after you begin, you have probably forgotten to remove the stopper and the pressure difference is preventing flow. When the interface between the two liquids gets to the top of the stopcock, the stopcock is closed leaving the top layer in the sep funnel and the bottom layer in a flask thus separating the two liquids.

Making Contact Between the Layers

In order for the extraction to take place, the two phases must come in contact with one another. Vigorous shaking is the best way to get contact. During extraction, the funnel is inverted and vigorously shaken. This allows the solids being separated to migrate into the layer they are most soluble in. During the shaking process it is important to securely hold the glass stopper in with your hand as pressure can build up inside the sep funnel; heat transferred from your hands or from an exothermic heat of dissolution will vaporize some of the low boiling organic solvent and produce pressure. It is a good idea to pause from shaking a few times, point the spout into the hood (not at someone's face!) and open the stopcock to release pressure. This is especially important when your extraction liquids produce gas. (For instance, shaking acids with sodium bicarbonate, $NaHCO_3$, will produce carbon dioxide gas.)

Getting the Most out of an Extraction

The dissolving process is often not an all-or-nothing proposition. For example, 90% of a solid might be extracted into the aqueous layer while 10% remains in the organic layer. Since not everything can be extracted in one go, extraction solvents are always added two or three times. Chemists will shake with an extraction solvent, separate the layers, then shake with a fresh portion of extraction solvent, separate the layers and combine the two common solvents. If 90% of a solid is dissolved each time, two extraction cycles should extract 99% of the material.

Dealing with Emulsions

Ideally, as soon as you stop shaking, the liquids will separate into two clearly defined layers. In practice, shaking can lead to an emulsion – a stable or semi-stable mixture of immiscible liquids. If you do not see two layers or if the interface of the two liquids is fuzzy, you have an emulsion. Sometimes emulsions will settle out given time, other times, they may need help. One remedy is to add a few milliliters of saturated NaCl solution to the funnel and swirl (never shake again if you have an emulsion) – NaCl makes the aqueous layer more polar, making an emulsion with an organic layer less favorable. If an emulsion does not go away on its own within a few minutes, consult your instructor.

Another situation where students only get one layer is when they accidentally add two aqueous layers to the funnel, rather than having an aqueous and an organic layer. Label beakers to keep track of which beaker contains what and don't throw out any washes until the end of the lab when you are sure you have what you need!

Recovering Solids

When the extraction process is over, the chemicals need to be recovered from the solvents. The aqueous solutions contain ionic forms of the compounds. Neutralizing the solution with acid or base will convert the ions back to neutral organic compounds. Once neutralized, the compounds will no longer be soluble in water and will precipitate. In this lab you will extract with weak base ($NaHCO_3$) and strong base (NaOH). Both solutions should be chilled then neutralized with 6.0M HCl. The resulting precipitates can be isolated with vacuum filtration.

During extraction organic solvents pick up trace amounts of water that need to be removed before recovering the solid. To "dry" the solvent (remove traces of water) a drying agent is used, in our case, anhydrous $MgSO_4$. Add a small spatula tip (the volume of a pea) of $MgSO_4$ to the Erlenmeyer that holds the diethyl ether solution and swirl gently. When $MgSO_4$ absorbs water it clumps together and looks sticky. Continue adding magnesium sulfate in small portions and swirling until the solid no longer sticks to itself or the sides of the flask. When the recently added magnesium sulfate is loose and sandy when swirled, it indicates that there is no more water to react with and you can stop adding. Do not over-add drying agents – product will stick to its surface and may decrease your yield. Ask the instructor if you are unsure how much to add.

Once dry, you will cold gravity filter your diethyl ether solution into a pre-weighed round bottom flask to remove the drying agent. Hot filtration and vacuum filtration are never used with low boiling organic solvents. The solvent will be removed with a rotary evaporator (known as a "rotovap") – an instrument which quickly performs simple distillations under reduced pressure.

Extracting verses Washing

The terminology used in extractions differs based on our purpose. If we are shaking an organic layer with bicarbonate to remove trace acid impurities, we say that we are "washing" the organic layer with bicarbonate. If we are shaking with bicarbonate to dissolve a desired carboxylic acid product in the aqueous layer, we say we are "extracting" with bicarbonate. We say we washed with a solvent if we will later discard it. We say we extracted with a solvent if we will use its contents.

Procedure

In this laboratory exercise, you will separate up to three solids using acid-base extraction. Your unknown will contain two or three of the compounds below. Use the knowledge of their structures and the example given in this handout to make sense of the procedure below. It is helpful to draw a flow chart of the procedure in your notebook. Figure out which compounds will be in each layer at each stage of the extraction. Determine which acid-base reactions will take place based on the pK_a data below.

Benzoic Acid	pK_a = 4.2
2-Naphthol	pK_a = 9.5
Biphenyl	pK_a = 42

Extraction

You will be given a vial that contains either 2 or 3 of the chemicals listed above. Dissolve about 0.8 g of the unknown in 30 mL of diethyl ether in an Erlenmeyer flask. Once dissolved, pour the solution into the separatory funnel. If the unknown doesn't dissolve completely, continue anyway.

Extract the organic layer with 7 mL of 1.1 M $NaHCO_3$. Drain and reserve the $NaHCO_3$ layer. Extract the organic layer a second time with a fresh 7 mL of $NaHCO_3$. Combine the two bicarbonate extracts and set aside.

Extract the organic layer 7 mL of 3.0 M NaOH. Drain and reserve the NaOH layer. Extract the organic layer a second time with a fresh 7 mL of NaOH. Combine the two extracts and set aside. Pour the organic layer into a separate Erlenmeyer flask.

Recovery of solids

Remove any traces of water from the diethyl ether layer by adding small portions of anhydrous $MgSO_4$ until it no longer sticks to itself. Cold gravity filter the solution into a wide beaker. Heat the beaker on a hot plate to dryness.

Reclaim benzoic acid and 2-naphthol by cooling the $NaHCO_3$ and NaOH extracts in an ice bath then acidifying each extraction with 6M HCl. Neutralizing $NaHCO_3$ will produce large amounts of carbon dioxide. Calculate the approximate volume of 6M HCl needed to neutralize each solution before lab. Add this amount and enough extra to complete precipitation. The pH may be checked by seeing if it turns blue litmus paper red. Cool the mixtures in an ice-water bath, vacuum filter each separately.

Characterization

Determine which solids were in your unknown. Record the weight of any solids recovered and take their melting point. Solids recovered from aqueous solvents must dry until the next lab period before their meting point is measured.

Chemicals: diethyl ether, 1.1 M sodium bicarbonate, 3.0 M sodium hydroxide, 6M HCl, benzoic acid, 2-naphthol, biphenyl, magnesium sulfate.

Waste

- Filtered aqueous layers go in the labeled waste jug for this lab.
- Solids go in the disposal jar for this lab.

Common Mistakes

- Trying to drain the funnel without removing the stopper. If you notice no liquid flowing, this is the problem
- Greasing the stopper
- Allowing pressure to build up by not venting
- Venting in someone else's face rather than in the hood
- Mixing up layers or prematurely discarding layers
- Adding liquid to a sep funnel when the stopcock is open