Extraction

A useful technique for purification of mixture

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Separation processes

- Liquid-liquid extraction
- Adsorption
- Filtration
- Solid-liquid extraction (leaching)
- Elution chromatography
- Membrane separation processes
- Distillation
- Affinity separation processes
- Drying and evaporation
- Freeze-drying (lypholyzation)
- Precipitation
- Crystallization
- Electrophoresis
- Centrifugation
- Mechanical sieving
- Dialysis

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Extraction

Extraction is a *purification technique* in which *compounds with different solubilities are separated* using solvents of different polarities. This basic chemical process is often performed in conjunction with reversible acid/base reactions.

Type of Extraction

- **Liquid-Solid Extraction**
- **Liquid-Liquid Extraction**

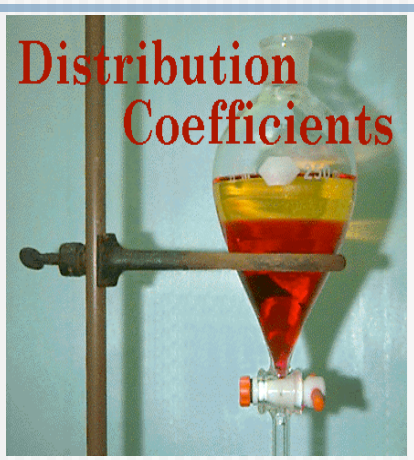
Liquid-Solid Extraction

- Brewing tea
- Percolating coffee
- Spices and herbs

Leaching (Liquid-Solid Extraction)

- Diffusion of the solute out of the solid and into the liquid solvent is mostly the controlling step.
- Principle of separation: preferential solubility
- Created or added phase: liquid
- Separating agent: liquid solvent

Liquid-Liquid Extraction



Liquid-Liquid Extraction

- **Used when distillation is impractical**
  - **The mixture to be separated is heat sensitive.**
  - **Volatility differences are much too small.**
  - **The mixture forms a azeotropic mixture**
  - **Solute concentration is low**

Liquid-Liquid Extraction Principle

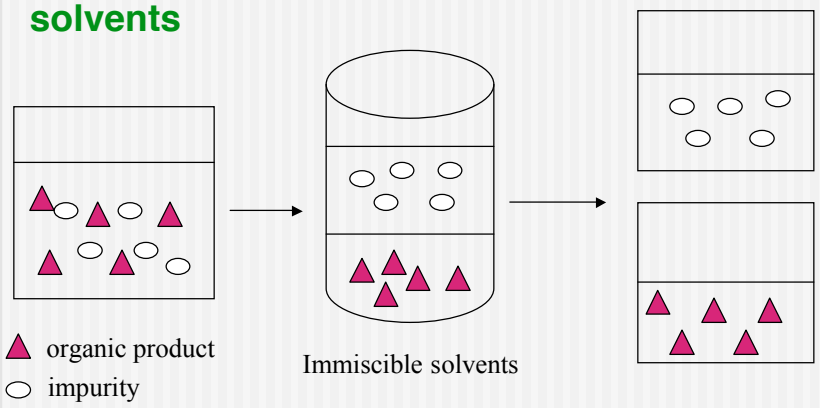
- Different species with different solubilities in the two immiscible liquid phases, i.e., these species have different partition behavior in different phases.

Applications of Liquid-liquid extraction

- Separation of aromatics from aliphatic hydrocarbons
- Purification of antibiotics
- Purification of aromatics such as benzene, xylene and toluene
- Protein purification using aqueous two-phase systems
- Purification of natural products
- Purification of dyes and pigments
- Metallurgical purifications

Theory of Liquid-Liquid Extraction

- **Differential solubility in two immiscible solvents**



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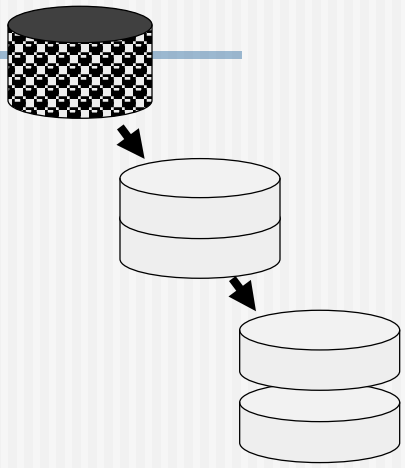
Liquid-liquid extraction: Sequence of events

- **Mixing or contacting**
- **Phase separation**
- **Collection of separate phases**



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Liquid-Liquid Extraction

separatory funnel

➢ Requirements for a liquid-liquid extraction:

✓ **two immiscible liquids with different densities & different refractive indices**

Why ?

Recognize which layer is which (organic vs. aqueous phases) & understand which compounds are dissolved in each phase.

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Liquid-Liquid Extraction

Immiscible → non-mixing (i.e. oil and water)

Immiscible liquids have *significantly different solubilities/polarities* which keep them from dissolving each other (in reality they are not completely non-mixing, there is some carry over). Still they must *physically separate* (density) and be *visibly distinguishable* (n_D).

Associated Terms

hydrophilic	hydrophobic
polar	nonpolar
water layer	organic layer
aqueous phase	organic phase
{aqueous base}	{CH_2Cl_2 layer}

emulsion

Common Immiscible Mixes

oil spill → oil & water
salad dressing → oil & vinegar
ether extraction → EtO_2 & water

An extraction with ethanol and water won't work! Why?

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Extraction Theory

- Separation depends upon the relative solubility of the compound in each of the two immiscible solvents.

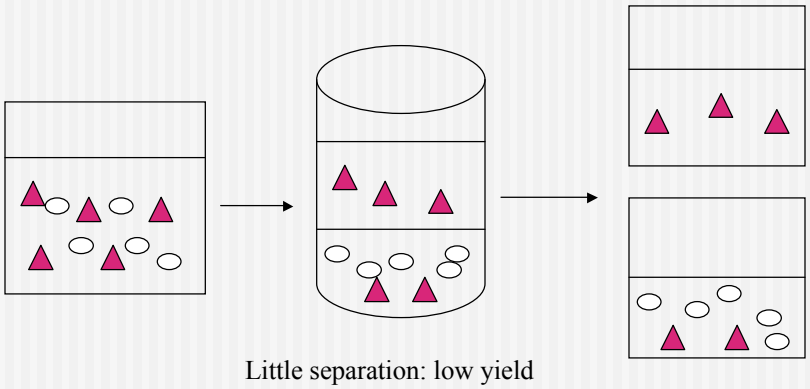
$$K_D = \frac{C_L}{C_H} = \frac{g/mL_{organic}}{g/mL_{water}}$$

(g/mL is the solubility)

- Ideal condition, when K_D >>>> 1 or <<<<<<1

Theory of Extraction

- If K_D ~ 1, don't get good separation.



Little separation: low yield

Solvent miscibility

- **Completely miscible**
  - Unsuitable for extraction
- **Immiscible**
  - Ideally suited for extraction
- **Partially miscible**
  - Composition dependent
  - Various possibilities
  - Could be used for extraction

Properties of Extraction Solvents

- **Solvents used for extraction**
  - immiscible with water (polarity)
  - high solubility for organic compound
  - relatively low boiling point (removal)
  - non-toxic, cheap, available
- **methylene chloride, diethyl ether, hexane, ethyl acetate**
- **densities determine top or bottom**

The Appropriate Solvent

- **Solubility of organic compounds is a function of the polarities of both the solvent and the solute:**
  - "Like Dissolves Like"
  - Polar solvents dissolve polar solutes
  - Nonpolar solvents dissolve nonpolar solutes

Solvent systems

- **Aqueous / non-aqueous systems**
  - Water/Diethyl ether
  - Water/Ethyl Acetate
  - Water/Chloroform
  - Water/Methylene Chloride
- **Aqueous two-phase systems**

  Sodium phosphate/PEG in water

Extraction Technique

- Shaking (to allow dissolved compounds to come in contact with both solvents)
- Venting (to release pressure build-up)
- Separating layers (filter pipet)
  - always remove bottom layer
- Drying
  - drying agents

Liquid-liquid contacting

- Shaking the extraction device
- Using an stirred tank
- Counter-current liquid flow
- Agitated counter-current liquid flow
- Contacting across a porous structure
- Ultrasonic vibration

Distribution Coefficient

- The extraction of a compound from one phase to another is based on the difference in solubilities of the compound in each phase.

$$K_D = \frac{C_L}{C_H}$$

where C_L & C_H are the solute concentrations in the light and heavy phases, respectively. Normally water is the heavy phase and the solvent is the light phase

Separation of phases

- Coalescence and phase separation due to density difference
- Coalescence and phase separation by centrifugal assistance
- Assisted coagulation of dispersed phase
- Separation by membrane

The Extractant

- **Ideally, the extractant should possess the following properties:**
  - non toxic;
  - selective;
  - inexpensive;
  - high distribution coefficient for the product.

Calculations

- **Determine K_D for extraction of solid in the two solvents**

$$K_D = \frac{unk(g)/solvent(mL)}{unk(g)/water(mL)}$$

Multiple Extraction

- If same amount of organic solvent is used for extraction of one molecule, the extraction in several portions is much more efficient than single extraction using the whole amount of solvent.
- Say, an organic molecule with distribution coefficient (or partition coefficient) of 10 between ether and water, and 150 mL of ether will be used to extract 5.0 g of such organic molecule from 100 mL of water.

Single Extraction

- Assuming x gram of molecule is left in aqueous phase after the equilibrium is reached, then 5-x gram of organic will enter the ether layer. Thus, we have:

$$K_D = 10 = \frac{\frac{5.0 - x}{150}\ \frac{g}{mL_{ether}}}{\frac{x}{100}\ \frac{g}{mL_{water}}} \longrightarrow 10 = \frac{(5.0 \quad x)(100)}{150x}$$

$$1500x = 500 \quad 100x$$

Single Extraction

- After single extraction, only 0.31 g of organic left in water, and 4.69 g is separated from water.
- The extraction efficiency is 4.69/5.0 = 93.8%.

$$1600x = 500$$
$$x = 0.31g$$
$$5.0 - x = 5.0 - 0.31 = 4.69g$$

Multiple Extraction

- Same amount of ether (150 mL) is used to extract the same organic from 100 mL water but in three portions, each with 50 mL of ether.
- Similar calculation can be applied for each cycle of extraction, as follows:
  - First cycle of extraction

$$K_D = 10 = \frac{\frac{5.0 \quad x}{50 \quad mL_{ether}}}{\frac{x}{100} \; \frac{g}{mL_{water}}}; \qquad 10 = \frac{(5.0 \quad x)(100)}{50x}$$

$$500x = 500 \quad 100x$$

$$600x = 500$$

$$x = 0.83$$

- **0.83 g of organic remains in aqueous phase**
- **4.17 g of organic stays in ether**
- **Extraction efficiency is 4.17/5.0 = 83.4%**

2nd Cycle of Extraction

- **After 2nd cycle of extraction, only 0.14 g of organic is left in aqueous phase, 0.69 g of organic stay in 50 mL of ether.**
- **4.86 g of organic is extracted into 100 mL of ether, the extraction efficiency is 4.86/5.0 = 97.2%, already greater than the single extraction (93.8%).**

$$K_D = 10 = \frac{\frac{0.83 - x \quad g}{50 \quad mL_{ether}}}{\frac{x}{100} \; \frac{g}{mL_{water}}}; \qquad 10 = \frac{(0.83 - x)(100)}{50x}$$

$$500x = 83 - 100x$$

$$600x = 83$$

$$x = 0.14$$

3rd Cycle of Extraction

- **After 3rd cycle of extraction, only 0.02 g of organic remains in aqueous phase, and 4.98 g of organic in total is extracted into 150 mL of ether.**
- **The extraction efficiency is 4.98/5 = 99.6%.**

$$K_D = 10 = \frac{\frac{0.14 - x}{50}\frac{g}{mL_{ether}}}{\frac{x}{100}\frac{g}{mL_{water}}}; \qquad 10 = \frac{(0.14 - x)(100)}{50x}$$

$$500x = 14 - 100x$$

$$600x = 14$$

$$x = 0.02$$

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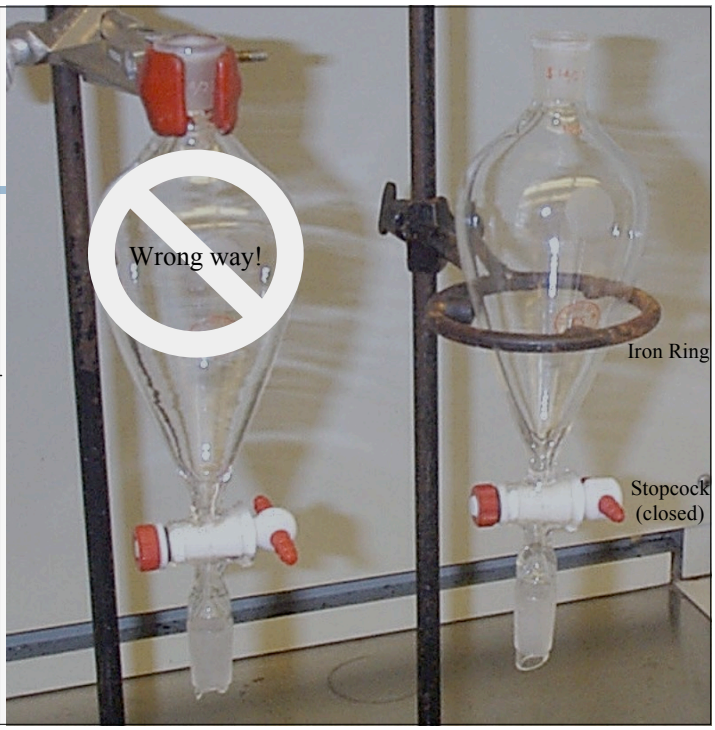
Proper Use of the Separatory Funnel

1. Use an iron ring to hold separatory funnel upright.
2. Stopper, invert, shake, and vent to mix contents.



Weak Acid and Weak Base Products

- Compounds that are not ionised are soluble in the organic phase.
- pH conditions are selected so that the extracted compound is neutral and soluble in the organic phase.
  - weak bases are extracted at high pHs
  - weak acids are extracted at low pHs

Partially Ionised Solutes

- At intermediate pH values and when compounds are partially ionised, the analysis becomes more complex.
- The extraction of ionised compounds (weak acids or weak bases) is termed dissociation extraction.

General Acid/Base Extraction

Acid/Base/Neutral Categories of Organic Functional Groups

Category	Functionality	Extracted with	Acid/base reaction
Strong organic acid	carboxylic acid	weak base (5% $NaHCO_3$)	$RCO_2H \rightarrow RCO_2^- Na^+$
Weak organic acid	phenol	strong base (5% NaOH)	$ArOH \rightarrow ArO^- Na^+$
Organic base	amine	strong acid (5% HCl)	$RNH_2 \rightarrow RNH_3^+ Cl^-$
Neutrals	[everything else]	[not acid/base extractable]	Nothing happens!

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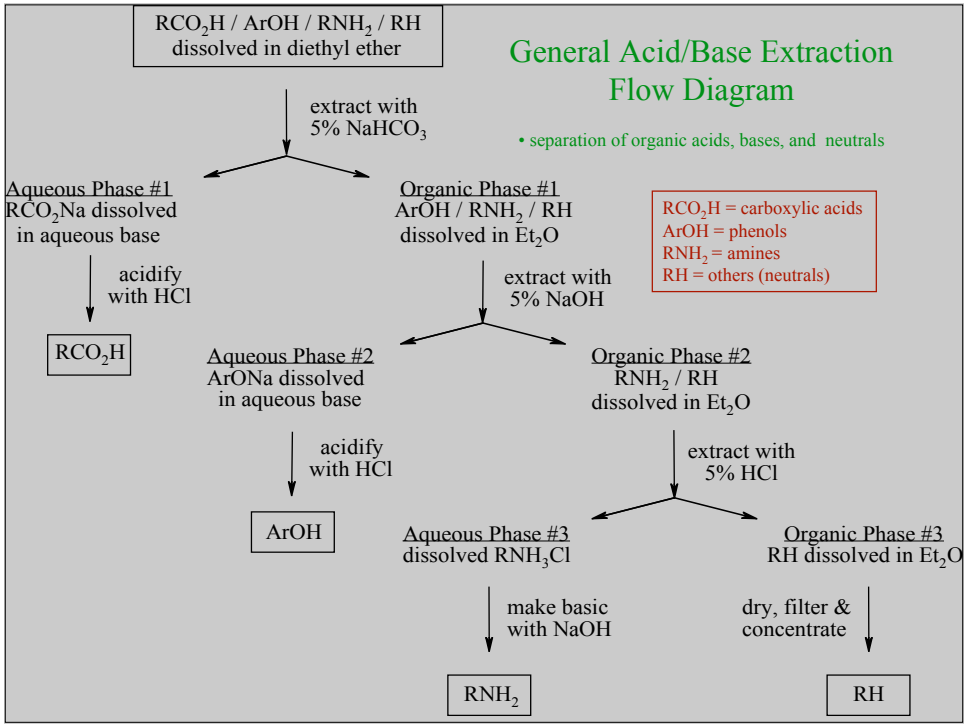
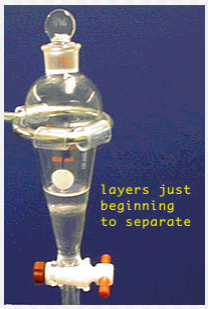


Extractors



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Aqueous 2-phase Extraction

- **The extraction of soluble components (eg. proteins) between two aqueous phases containing incompatible polymers, eg. polyethylene glycol (PEG) and dextran.**
- **Typical aqueous phases used for this purpose include:**
  - PEG-water/dextran-water
  - PEG-water/K phosphate-water

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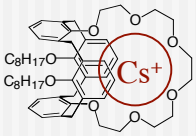
Isolation of Metallic Ions

- ^{137}Cs comprises a significant portion of radioactivity in nuclear waste
- Calix[4]arene crowns have been shown to selectively extract cesium through liquid/liquid extraction
  - This selectivity is due to the matching of size between the calixarene cavity and the cesium as well as π-bonding interactions with the arene groups, and structural preorganization of the molecule



- Calix[4]arenes containing aza-crowns have been proposed so as to functionalize the crown and increase potential anion selectivity

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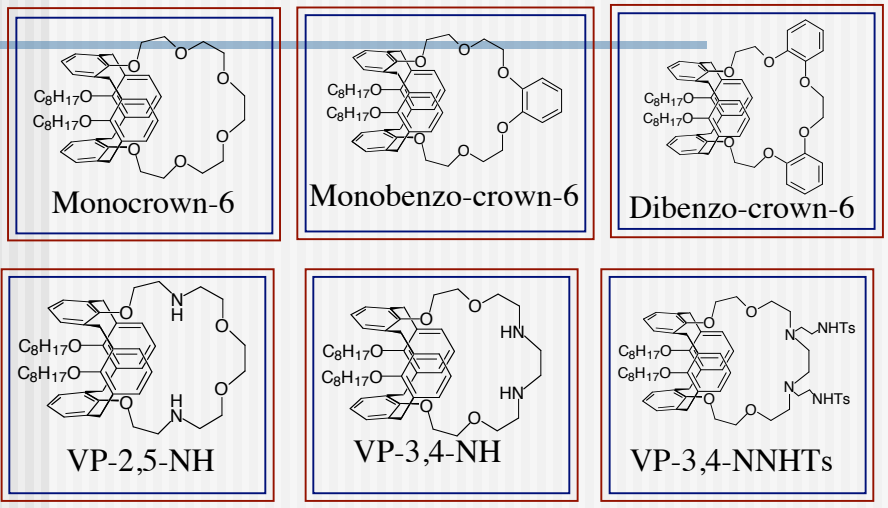
Ligands



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