Recrystallization

Purification of the product is an integral part of any synthesis experiment. The process of recrystallization is often used to obtain the product in pure form. In industry, one of the important steps is obtaining pure chemicals for various purposes where the final purity may depend on the end application of the product.

The current activity aims to acquaint the reader with recrystallization as a learning activity and its process.

During recrystallization, particles of solute deposited from a saturated solution and according to their shapes, fit onto growing crystal lattices. Crystallization from solution canbe thought of as a two-step process. The first step is the phase separation or "birth" of new crystals. The second step is the growth of these crystals to larger sizes. These two processes are known as nucleation and crystal growth, respectively. The solubility of a particular solute in a solvent depends upon its polarities and the interactions with one another and temperature. The difference in solubilities of a solute in a given solvent at different temperatures is the key feature that is used for recrystallization of the solute.

Before starting the activity let us get some idea about the solvents that are generally used for recrystallization (Table I). The information regarding the miscibility of these solvents in one another (Table II) is equally important as often we may have to select a mixed solvent system for recrystallization. This data is available from standard chemical data books such as CRC, etc. This will also give you practice in the handling of data books about chemical compounds.

Table I: General list of solvents used for recrystallization

Solvent	Boiling points (°C)(760 torr)	Dielectric constants	Flammable
Water	100	78.54	No
Ethanol	78	25.30	Yes
Methanol	64	33.00	Yes
Acetone	56	21.01	Yes
Petroleum ether	-	1.90	Yes
Hexane	68	1.89	Yes
Dichloromethane*	41	9.08	No
Toluene	111	2.38	Yes
Chloroform*	61	4.81	Yes
Cyclohexane	81	6.00	Yes
Acetic acid	118	6.15	No
Diethyl ether	35	4.34	Yes
Ethyl acetate	77	6.02	Yes

*-generally use of chlorocarbon solvents is avoided

Reference: CRC Handbook of Chemistry and Physics 83rd Edition, R.Roberts, J.Gilbert, S.Martin: *Experimental Organic Chemistry-a miniscale approach*, Saunders College Publishing, Florida, 1994

Table II: Miscibility of solvents

Solvents	Acetic acid	Acetone	Benzene	Chloroform	Dichloro-methane	Ethanol	Petroleum ether	Hexane	Methanol	Toluene	Water
Acetic acid	-	M	M	M	M	M	M	M	M	M	M
Acetone	M	-	M	M	M	M	M	M	M	M	M
Benzene	M	M	-	M	M	M	M	M	M	M	I
Chloroform	M	M	M	-	M	M	M	M	M	M	I
Dichloromethane	M	M	M	M	-	M	M	M	M	M	I
Ethanol	M	M	M	M	M	-	M	M	M	M	M
Petroleum ether	M	M	M	M	M	M	-	M	M	M	I
Hexane	M	M	M	M	M	M	M	-	I	M	I
Methanol	M	M	M	M	M	M	M	I	-	M	M
Toluene	M	M	M	M	M	M	M	M	M	-	I
Water	M	M	I	I	I	M	I	I	M	I	-

M= miscible, I=immiscible

Reference: Online edition for students of organic chemistry, lab courses at the University of Colorado, Boulder, Dept. of Chemistry and Biochemistry, 2004.

The first essential step of any recrystallization activity is to check the solubility of a givencompound in different solvents. This is done as follows.

- 0.1 g of a solid sample is taken in a small test tube.
- The solvent is then added to the sample in a drop wise manner with constant shaking of the test tube. The addition of the solvent is continued till 1 mL and observations regarding the solubility of the sample are noted.
- If the sample is undissolved at room temperature, the test tube is heated (on the water bath for flammable liquids). Check whether the sample dissolves with gentle heating.
- In case the sample does not dissolve on gentle heating, then 0.5 mL of solvent is added and again checked for solubility (after gentle heating). This is continued in 0.5 mL portions till 3 mL of solvent has been added. If the sample did not dissolve (even on heating) then it is considered to be sparingly soluble in that solvent.
- In case the sample almost dissolves in hot solvent then remove the test tube and cool the solution to check whether recrystallization occurs on the cooling of solution. If recrystallization does not occur rapidly, then scratch the tube with the help of a glass rod (just below the surface of the solution). Fine scratches on glass surfaces and micro-glass pieces both act as nuclei for crystal growth.
- When the sample is sparingly soluble under hot conditions, you have to try another solvent identically.

Characteristics of a Good Crystallizing Solvent

Choosing the appropriate solvent is the most difficult step of any crystallization. The selectedsolvent for recrystallization will have the following properties:

- The sample is highly soluble at high temperatures (near the boiling point of solvent) and is almost insoluble at room temperature or lower temperatures (i.e. an ice bath, 0°C).
- crystals of the solute are obtained from the solution when it is cool down
- percentage recovery should generally be in the range of 75 - 90%
- Impurities present in the sample should be either completely soluble or completely insoluble at all temperatures.
- The selected solvent preferably should have a relatively low boiling point so that it is easy to remove it from the purified product.
- [% recovery = (mass of recrystallized product /mass of impure sample) * 100]

Mixed solvent system

In case a single solvent is not appropriate for recrystallization, we have to go for a mixed solvent system.
Through solubility test (as described above)

- Identify the solvent in which the sample is soluble at high temperature (and the sample does not come out much while cooling) (solvent A)
- Identify the solvent in which the sample is completely insoluble at high temperature (solvent B)
- Both the selected solvents must be miscible in each other (check against miscibility data)

The following two activities describe the procedures of recrystallization of a sample from a single solvent and then from a mixture of two solvents.

Activity I: Single solvent recrystallization

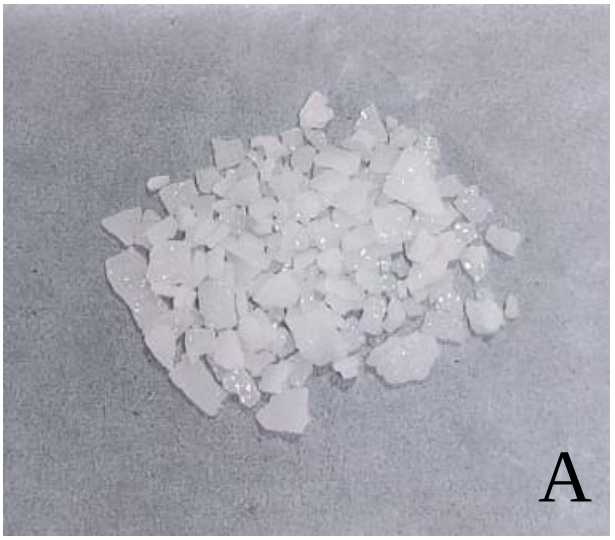
You have given two vials of an unknown compound. Each vial contains 1 g of an unknown sample. Use one vial to carry out the solubility tests and selection of the appropriate solvent for recrystallization. Use another vial for recrystallization after deciding the appropriate solvent. The amount of substance for each solubility test - 0.1 g for each test.
Observation Table for solubility

	Water	Ethanol	acetone	Hexane	Toluene
Solubility at room temperature					
Solubility near boiling point of the solvent					
Recrystallization on cooling					

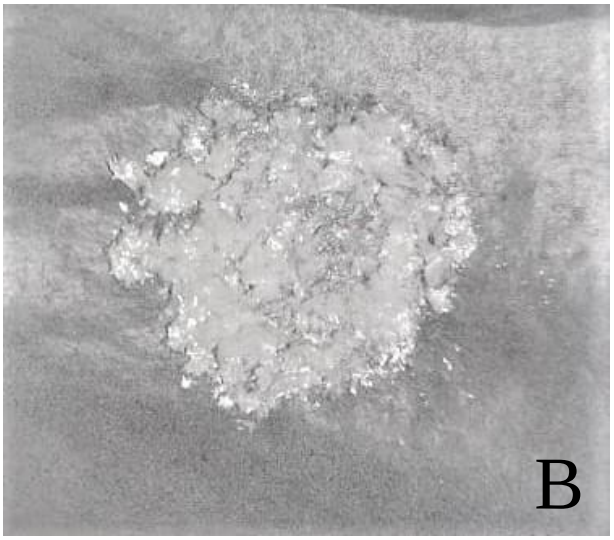
Conclusion: Solvent for recrystallization -_____

Recrystallization of the sample using a selected solvent

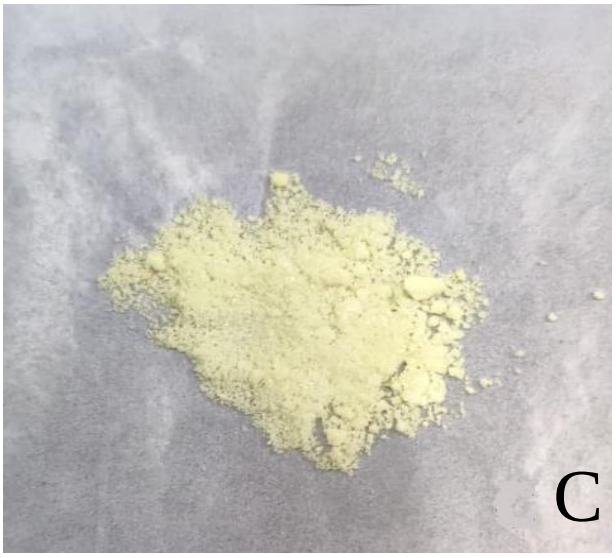
1. Dissolve the entire sample (from vial 2) in a minimum amount of the hot solvent identified by you. (Usually, volatile solvents are heated on a water bath and solvents having melting point greater than 100^0C could be directly heated on a hot plate or burner.)
2. If necessary, an amount of decolorizing carbon (charcoal) is added to the hot mixture. The carbon assists in removing small amounts of colored impurities by absorption (this is an optional step).
3. The hot solution is filtered to remove insoluble material and any carbon by gravity filtration (even if charcoal is not added, sometimes there may be some insoluble impurities. In such cases also the filtration step is carried out).
4. The hot solution is allowed to cool slowly to room temperature and left undisturbed to permit slow crystal development and growth.
5. The solution is allowed to cool to room temperature and then cooled further in an ice-water bath.
6. The crystals from the solution (that is, mother liquor) are collected either by gravity filtration or by vacuum filtration using a Buchner funnel.
7. The crystals are washed with small portions of the ice-cold pure solvent.
8. If the solvent used for the crystallization is fairly volatile, the crystals are air-dried (in fact by using suction, a lot of solvents are already removed). With a solvent such as water, after filtering, the crystals will have to be air-dried overnight or can be placed under an IR heating lamp for 10 - 15 minutes or can be dried in an oven (at an appropriate temperature)
9. After complete drying, weigh the purified product and calculate the percentage recovery.
10. Determine the melting point of the purified product.



A: Benzoic acid before crystallization



B: Benzoic acid after crystallization



C: Benzil before crystallization

D: Benzil after crystallization

Activity II: Recrystallization of the sample with a mixed solvent

1. Dissolve the sample in a minimum amount of the hot solvent A (solvent in which the sample is soluble under hot conditions and does not crystallize much on cooling).
2. If needed, add a small amount of decolorizing charcoal (carbon) to the solution and continue heating (optional step).
3. Filter the hot solution to remove insoluble material and any added charcoal using gravity filtration through filter paper (even if charcoal is not added, sometimes there may be some insoluble impurities. In such cases also the filtration step is carried out).
4. If the filtrate has become cold, then heat it again to the boiling point of solvent A.
5. Now start adding, the hot solvent B (solvent in which sample is almost insoluble under hot condition) in drop wise manner (in case mixture cools down heating ofsample solution is essential)
6. Solvent B is added until the mixture develops slight cloudiness that should disappear on boiling of solution. If the cloudiness persists, add a few drops of solvent A.
7. Follow Steps 4 -10 listed under recrystallization using a single solvent.
   We recommend giving at least 2 compounds in one lab session for practice.

List of organic compounds (single solvent recrystallization)

Sr. No.	Name of the compound	Solvent
1	Benzoic acid	water
2	Salicylic acid	water
3	Naphthalene	ethanol
4	Cinnamic acid	water
5	Resorcinol	water or ethanol

List of organic compounds (mixed solvent recrystallization)

Sr. No.	Name of the compound	Solvent
1	Acetanilide	water/ethanol (7:3)
2	Methyl red	water/methanol (3:7)
3	Benzil	water/ethanol (6:4)
4	Aspirin	ethanol/water(5:5)