

Experiment 20

RECRYSTALLIZATION AND MELTING POINT DETERMINATION

Objective

The purpose of this experiment is to learn the techniques of recrystallization and to determine the melting point, which can further be used to verify the purity and structure of a compound.

Lab techniques

- Gravity filtration
- Suction filtration
- Recrystallization
- Melting point determination

Introduction

I. The melting point

Melting point is the temperature at which solid and liquid coexist in equilibrium. The melting point of a pure crystalline substance is an important physical property of that substance. When a pure crystalline substance melts, the measured melting point range should not exceed 1°C. The amount of a sample required for the determination is normally less than 1 mg.

The determination of the melting point is important. First, it can be used to determine the identity of a known compound. Second, it can help to further define an unknown compound at later times. Third, it can be used to determine the purity of a substance. An impure substance shows a larger melting point range than a pure substance. By applying the technique of recrystallization or sublimation, the purity of a substance can be increased, and its corresponding melting point range will become smaller. For example, if the melting point of a substance is measured to be 120~124°C, it is considered impure. If after recrystallization, the melting point of the substance is improved to be 125~125.5°C, it is then considered pure.

With reference to Figure 20-1, consider a solid mixture consisting of 75% X and 25% Y. When the **eutectic point** temperature is reached, it will start to melt until the temperature reaches point M. However, it is very difficult to observe the true value of the eutectic point temperature experimentally due to the extremely small amount of liquid formed (due to melting) at this point. Hence, the observed value is normally higher than the true value. Only if the composition of X and Y is exactly the same as that of the eutectic point should the mixture have a sharp melting point; however, this

rarely happens in reality. Thus, the melting point of a solid mixture generally covers a range of temperatures.

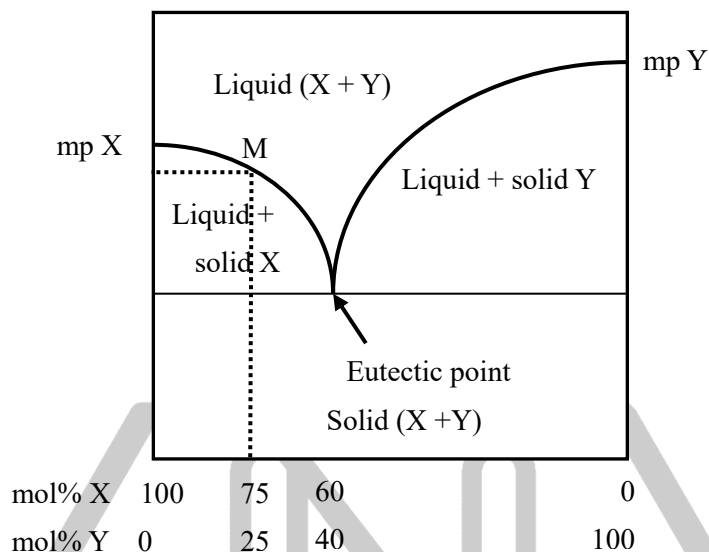


Figure 20-1 Phase diagram for melting of a mixture of X and Y

In fact, it is possible for two different compounds to have the same melting point. For example, the melting points of acetylcholine bromide and 2-aminobenzoic acid are both 146 to 148°C. The mixed melting point technique can be applied in this situation. This technique involves mixing the unknown solid compound with a known compound and then determining the melting point of this mixture. If a melting point depression results, it can be concluded that they are not the same compound. In contrast, if no melting point depression results, then we can conclude that the unknown compound is the same as the known compound. With this approach, the identity of this unknown compound can be revealed.

Figure 20-2 shows the Melt-Temp device currently being used in the laboratory, which is composed of an electro-heating aluminum container that can fit three capillary tubes inside and is capable of heating up to 500°C.

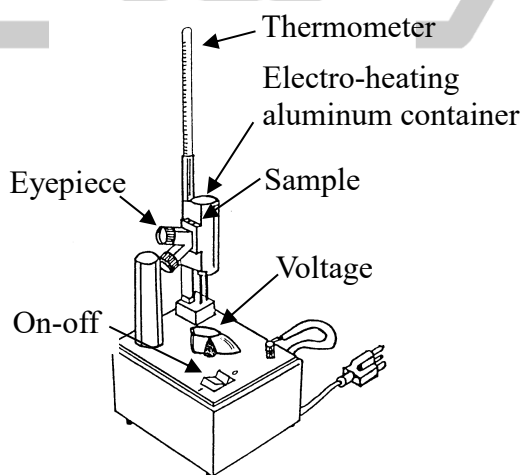


Figure 20-2 Melt-Temp melting point measurement device

To pack a sample in a capillary tube for melting point determination, follow the steps below:

1. Transfer a dry and finely powdered sample onto a piece of weighing paper by using a spatula and stack well.
2. Insert the open end into the powder pile so that the sample is inserted into the tube.
3. Gently knock the closed-end of the capillary tube on the bench top to allow the sample in the open end to drop to the bottom.

It should be noted that the height of the sample inside the capillary tube should not exceed 1~2 mm. A few final points need to be noted in this experiment. First, the accuracy of the thermometer will definitely affect the measurement of the melting point. Therefore, it is recommended that the thermometer be calibrated before use.

Second, and most importantly, it should be noted that the rate of heating should not exceed 1°C per minute. The reason is that time is required for heat transfer to the sample and the bulb of the thermometer and reach temperature equilibrium; otherwise, errors will exist. Generally, a crude melting point measurement will be carried out in a faster heating mode just to get an idea of what the approximate melting point is. In a second run, well before reaching the melting point, the rate of heating can be as fast as about 3~4°C/min until a point 4~6°C below the melting point. Then the heating rate should be slowed to about 2°C/min until the temperature is 2~4°C below the melting point. Afterwards, the heating rate should be further slowed to 1°C/min or lower.

Third, as some compounds may decompose before melting, the true value of their melting points may not be determined. Therefore, the decomposition temperature is usually reported and marked as [decomposition], in brackets as shown here. Moreover, for compounds which sublime easily, both ends of the capillary tube should be sealed.

II. Recrystallization

Recrystallization is the most important technique for purifying solid substances, but at the same time, it is also the most difficult one. Although crystals can be formed by cooling from a molten state, impurities will also be included in the crystal lattice. Therefore, the recrystallization method in the laboratory consists of dissolving the solid substance in a minimal amount of a suitable hot solvent. Cooling the solution causes the formation of a supersaturated solution, and the pure solid will be crystallized out. In addition, ideally, the concentration of the impurity will not reach the saturation level; hence, it will not be crystallized out. Under this crystallization condition, the sample adheres to the lattice in an orderly manner, without any impurities included. Thus, successful purification can be obtained.

The crystals formed can then be collected by filtration, followed by washing

with a cold fresh solvent (the same solvent used in recrystallization), which removes any residual liquid adhering to the surface of the crystals. The crystals are then set to dry. This purification method is very quick and convenient.

If a saturated solution is cooled without forming any crystals, the cooled solution is called a supersaturated solution. When a solution is supersaturated, then a seed crystal, a speck of dust, or even a scratch on the wall of the container can all be used for adhesion and starting the process of nucleation. In order to form a large crystal, a seed crystal is usually used with a slow cooling rate. If the cooling rate is too fast, then the rate of crystal formation will be too fast. This may cause some impurities to be trapped in the crystal lattice during the process. Furthermore, stirring during the process of crystallization will further divide the crystals into smaller ones, which can be used as nucleation sites. As a result, the overall rate of crystallization will increase and the purity of the crystals will also be affected.

The procedures of recrystallization can be divided into 7 steps: (I) choosing the solvent, (II) dissolution, (III) removing the color, (IV) filtration, (V) nucleation, (VI) collection, and (VII) washing and drying. The details are as followings:

(I) Choosing solvent

An ideal solvent for crystallization is a solvent in which the sample is highly soluble when it is hot, but slightly soluble or insoluble when it is cold. At the same time, it should also be a solvent in which the impurities are either insoluble or highly soluble at room temperature. Moreover, the solvent should not react with the sample. An ideal solvent should be nonflammable, nontoxic, cheap, and highly volatile. Some commonly used solvents are listed in Table 20-1.

To choose a solvent, a small quantity of impure sample can be placed in a test tube with the addition of a drop of the solvent. If the sample dissolves immediately under room temperature, it can be considered unsuitable for recrystallization. On the contrary, if the sample dissolves when heated in a hot water bath and then crystallizes out again after cooling, it is considered a usable solvent.

In fact, it is not easy to find a single solvent that is suitable for recrystallization. Furthermore, it is a time-consuming process. Therefore, a solvent obtained by mixing two different solvents is usually used; in such a mixture, one of them (solvent A) can completely dissolve the sample, while the other has a very low solubility (solvent B) for the sample. In this method, the sample is first dissolved in solvent A and heated till boiling, followed by the addition of solvent B drop-by-drop with gentle swirling until the mist that forms in the solution persists for 5 seconds of stirring. Then, the clear solution is allowed to stand for cooling. If too much solvent B is added, the solid may start to precipitate out right at the beginning, with the result that a saturated solution cannot be obtained. In this situation, a small amount of solvent A can be added with

heating to redissolve the solids, followed by cooling.

Moreover, it should be noted that the boiling point of the solvent should not exceed the melting point of the sample. The reason is that crystallization requires the sample to dissolve in the solvent at its boiling point. If a supersaturated solution is formed with a temperature higher than the melting point of the sample, the sample will be oiled out, rather than crystallized out. Hence, not only will crystals not be formed, but impurities will also be extracted into the liquid sample. Apart from choosing a solvent with a boiling point lower than the melting point of the sample, excess solvent can also be added to decrease the concentration of the solute so that the crystallization can occur at a lower temperature.

(II) Dissolution

In terms of container selection, if the amount of sample is small, round-bottomed flask is often used in research laboratories. The advantage of this is that if it fails, you can immediately use a rotary evaporator to remove the solvent and do it again. For large scale, one can use an Erlenmeyer flask which has a small opening. When heated, the vapor can be condensed on the wall forming reflux without too much leakage. Another tip is to immerse only the part of the solution in hot water when heating, rather than immersing the entire flask. Beaker has a wide mouth, and the solvent can easily escape, making it unsuitable for recrystallization. During the dissolution process, since there are still undissolved solids, sudden boiling may occur, causing bumping and overflowing. Thus stirring is very important. However, if a magnetic stirrer is added, it will need to be removed after complete dissolution, which is more troublesome. The best way is to swirl the Erlenmeyer flask while heating, so that it is not prone to sudden boiling. The temperature of the heating source should not be too different from the boiling point of the solvent.

It is important to note that most organic solvents are flammable and should never be heated directly with a flame. A safer method is to heat them with a hot water bath or steam bath. At the same time, when the solid dissolves, it may not be very fast; therefore, you must be patient and do not keep adding solvent. If too much solvent is added, the solution will not be supersaturated when cooling, and the crystals will of course not precipitate.

(III) Removing color

Some colored by-products may be produced in a reaction. These colored materials can be removed by charcoal. The surface area of charcoal is very large; hence, a very small amount of it can adsorb a large amount of impurities. Normally, less than 5% of it is used, as the desired product may also be adsorbed if too much is used. Usually, when the color of the solution is very dark or the colored impurities cannot be completely removed by recrystallization, charcoal should be used.

The principle of using charcoal is based on the adsorption property of colored impurities on charcoal. As adsorption is an exothermic process, it is suggested that the process be carried out at lower temperature for a better result. However, the decoloring process is usually performed at higher temperature because the saturated solution needs to be filtered to remove the charcoal while still hot. If it is necessary to carry out this process under room temperature, excess solvent can be added, followed by concentration after the decoloring process. The resulting residue is then subjected to the normal recrystallization procedure.

(IV) Filtration

If the solution contains some insoluble substances, filtration should be carried out to remove them; otherwise, they will become nucleation sites, which may increase the rate of crystallization and hence decrease the purity of the desired product. However, it is not necessary to carry out this step if the solution contains no insoluble substances.

Filtration is not easy to operate, as the minimum amount of solvent should be used to dissolve the crystals under the boiling point of the solvent. Thus, if the temperature of the glassware is too low, then once the hot filtrate touches the cold surface of the funnel and the collecting container, the crystals will precipitate out immediately. Thus, the apparatus for filtration should be preheated.

Another problem to deal with is the evaporation of the solution during the filtration process, which will increase the concentration of the solution and cause the crystals to precipitate out. Therefore, gravity filtration is used for the removal of solid impurities in a hot saturated solution. A stemless funnel can be used in order to prevent crystal formation within the stem of the funnel during filtration, which would cause clogging. Suction filtration should not be used in this step because the reduced pressure will quickly withdraw a large amount of the solvent vapor.

Furthermore, in order to increase the filtration rate to prevent evaporation and cooling of the solvent, the filter paper can be folded into a fluted shape in order to fully utilize its surface area. The size of the filter paper should also be considered. It should not extend beyond the top of the filter funnel. Alternatively, adding more solvent to the solution during filtration, followed by partial concentration of it by heating to remove the volatile solvent through evaporation, can also solve the problem of precipitation during the process. It should also be noted that suction filtration is better for use with highly hygroscopic or highly volatile solvents.

(V) Nucleation

Recrystallization is performed by cooling a saturated solution slowly. In general, it is more difficult to crystallize out a solid with poor crystallinity or a low melting point. However, once crystallization begins, the process will continue without stopping. Therefore, a seed crystal can be added to the solution to help provide a site for

nucleation. Scratching the wall of the container at the surface level of the solution with a glass rod can also help increase the rate of nucleation. Once the process of nucleation starts, the solution should be allowed to stand still to allow slow cooling. Crystals formed under this condition will not only be large, but also of high purity. Since the surface area of the large crystals is smaller, the amount of impurities adhered to the surface due to the unremoved residual mother liquor will be smaller.

(VI) Collecting, cleaning, and drying

Suction filtration is usually used for collecting the desired crystals. The filter paper used for filtration should be of a diameter smaller than that of the filter funnel, while completely covering all the holes on it at the same time. The reason is that if the filter paper is too large, the edge will fold up and form gaps. The filtrate obtained is called mother liquor.

The crystals collected should be rinsed with a small amount of the cold recrystallization solvent to remove the residual mother liquor attached on the surface of the crystals. Finally, the crystals may possess a small amount of solvent on the surface. The crystals can then be air dried or vacuum dried to remove the volatile solvent. If the solvent is water, which is nonvolatile, the crystal can be dried in a 120°C oven if it will not melt or decompose under this temperature. The concentrated mother liquor can further be used to carry out a second or even a third recrystallization if necessary.

It should be noted that during suction filtration, the pressure-releasing device should be opened and the rubber tube should be removed from the suction flask before the motor is switched off. Otherwise, back flow of the water will occur, which may destroy the mother liquor.

Apparatus

Thermometer, capillary tube and tube stand, long glass tube (7 mm × 40 cm), Erlenmeyer flask (50 mL), glass rod, Büchner funnel, vacuum filter flask, rubber stopper, filter paper, dropper.

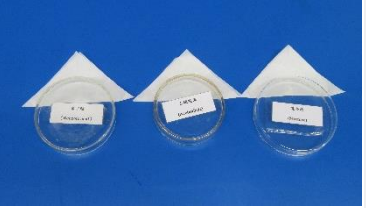

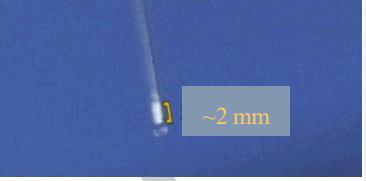
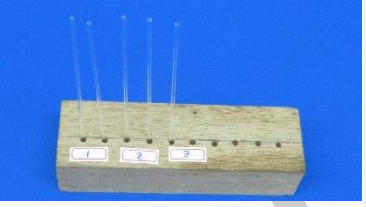



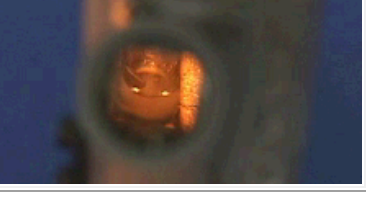
Shared: Melt-Temp device, suction pump (water-flow type), electronic balance.






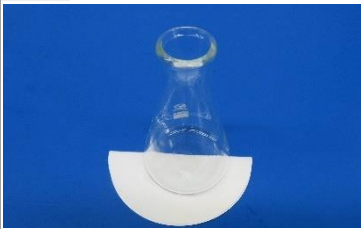
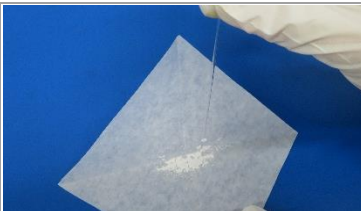
Chemicals


Acetanilide ($\text{C}_6\text{H}_5\text{NHCOCH}_3$), benzoic acid ($\text{C}_6\text{H}_5\text{COOH}$), benzoic acid/acetanilide (1:1, w/w).

Procedures

Procedure	Illustration
I. Melting point determination of known compounds	

1.	<p>Prepare two capillary tubes for each sample: (1) pure benzoic acid, (2) pure acetanilide, and (3) the mixture of benzoic acid and acetanilide (1:1 by weight).</p> <ol style="list-style-type: none"> (1) Transfer a few finely powdered samples on a weighing paper. (2) Use the open-end of the capillary tubes to collect the samples. (3) After the sample is inserted into the capillary tube, wipe the tube with tissue, and knock the bottom gently on the bench top a few times (or drop it into a long glass tube which is sitting vertically on the bench top) to tightly pack the sample to about 2 mm in height. If the sample sublimes easily, both ends of the capillary tube should be sealed. (4) Wipe clean the outer wall of each tubes and label properly. Place the capillary tube on the tube stand for later use. 	   
2.	<p>Operate the Melt-Temp device to determine the melting points.</p> <ol style="list-style-type: none"> (1) Clean up the sample container and set the voltage to zero before turn on the power. (2) Carry out a crude melting point measurement in a faster heating mode just to get an idea of the approximate melting point range. (3) Cool the Melt-Temp device to about 20°C lower than the crude melting point. (4) Replace the capillary tubes and slowly heat the samples at a rate of 2°C/min to determine the melting points. (5) Record the melting point range of the sample, which means the temperature range from starting to melt to completely melted. (If the true melting point of the compound is known, the sample can be heated directly to 20°C below that value first.) 	   

II. Recrystallization		
3.	Prepare two capillary tubes of crude benzoic acid sample from previous experiment; then transfer the remaining sample to a 50 mL Erlenmeyer flask after weighing.	
4.	Add appropriate amount of hot water to the flask, heat and swirl the solution gently to dissolve the solid.	
5.	Allow the solution to cool slowly at room temperature for 15~20 min to let crystals grow. <i>Note: If crystals do not precipitate out easily, a tiny crystal of the desired product can be added to serve as seed crystals. Scratching the container wall at the solution surface level with a clean glass rod can also help the crystallization process.</i>	
6.	Cool the solution in an ice-water bath to decrease the temperature and increase the yield.	
7.	Carry out suction filtration to collect the crystals and wash the crystals with a small portion of cooled DI water. Let the crystals suction dry for 10 min.	
8.	(1) Use a spatula to scrape and collect the crystals on a filter paper. Dry the crystals by pressing them between the folded filter paper or 2 pieces of filter paper. (2) Dry in the air for 10 min. Weigh the dried crystals and determine the yield.	
9.	Determine the melting points of (1) crude and (2) recrystallized benzoic acid; (3) crude acetanilide from previous experiment, separately.	

10.	Recycle the benzoic acid and discard the capillary tubes in the assigned waste bin.	
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References

1. Atkins, P. W. *Physical Chemistry*, 4th ed.; Oxford University Press: Oxford, 1990; pp197-198.
2. Mosely, C. G. *J. Chem. Educ.* **1989**, 66, 1063.
3. Adams, R.; Johnson, J. R.; Wilcox, C. F. *Laboratory Experiments in Organic Chemistry*, 6th ed.; Macmillan: New York, 1970.
4. Williamson, K. L. *Macroscopic and Microscale Organic Experiments*; D.C. Heath: Lexington, Mass, 1989.

Table 20-1 Common solvents for recrystallization

Solvent	Melting point (°C)	Boiling point(°C)	Dielectric constant	Properties and usage
Petroleum ether Petroleum ether Ligroin <i>n</i> -Hexane	< 0 < 0 < 0 < 0	40 - 60 60 - 80 80 - 110 69	~2	Useful for numerous compounds; can form solvent pairs with polar solvent; flammable.
Diethyl ether	< 0	35	4.2	Good solvent but with low boiling point; used to precipitate solute dissolved in alcohol; flammable.
Acetone	< 0	56	20.7	Usage is limited when used alone; more useful when used with alcohol; flammable.
Methanol	< 0	64	32.7	Toxic, must be used with care; usually used with water; flammable.
Ethyl acetate	< 0	78	6	Usually used with alcohol; flammable.
Ethanol (95%)	< 0	78	24.6	Non-toxic; usage same as that of methanol; flammable.
Water	0	100	78	Limited usage due to its low solubility towards organic compounds, but more useful when used with alcohol, acetone, etc.
Toluene	< 0	111	2.4	Good solvent for aromatic compounds; can be used with hexane or petroleum ether; flammable.
Acetic acid	17	118	6.2	Irritating vapor; flammable.