

Only good crystals will give a good structure determination.  
A good crystal is clear, has no cracks or inclusions, is not  
twinned and has a suitable size

For further information see:

J. Hulliger, Angew. Chem.,106(1994),151

And

W. Massa, Kristallstrukturbestimmung, Stuttgart:Teubner, 1994, page 87

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## Crystal Growth, Selection and Mounting

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## Crystal Growth

Dr. Paul Boyle's Crystal Growing Recipes--an excellent resource.

### Introduction

Crystallization is the process of arranging atoms or molecules that are in a fluid or solution state into an ordered solid state. This process occurs in two steps--nucleation and growth. Nucleation may occur at a seed crystal, but in the absence of seed crystals usually occurs at some particle of dust or at some imperfection in the surrounding vessel. Crystals grow by the ordered deposition of material from the fluid or solution state to a surface of the crystal. In general, the faces of the crystal which grow most rapidly are those to which the crystallizing particles are bound most securely. These rapidly growing faces are usually the smaller, less well developed faces. The larger faces are usually associated with directions in the crystal where there are only weak intermolecular interactions.

There is a large variety of methods available for growing crystals. The choice of method depends greatly upon the physical and chemical properties

of the sample. Solution methods of crystallization are probably the simplest. For these and other methods the solubility of the sample in various solvent systems is one of the first chemical properties to be explored. If heating methods are selected for growing crystals, the thermal stability and melting point of the sample should be determined.

There are a few general points that apply to all crystallization methods. First, It is important that the sample be as pure as possible. When crystallization attempts consistently yield oils, the sample is probably not pure. Second, the solvents or cocrystallizing materials should be as pure as possible. Contaminants may often break down the desired sample. Third, it is important for most solution methods that the glassware be thoroughly clean and "old" or "used." New glassware is so smooth that there are no nucleation sites available on the exposed surfaces. Also, new glassware from the manufacturer usually has a variety of dusty contaminants. A final point about the crystallization process is that if a sample only yields small crystals, the method should be altered so as to slow down the growth step. Slowing down the growth step often requires changing the method used to grow the crystals.

### **Evaporation**

Evaporation is by far one of the easiest methods for crystallizing organic and organometallic small molecule compounds. The choice of solvent is very important because it can greatly influence the mechanism of crystal growth and because the solvent may be incorporated into the crystalline lattice. It is customary to screen a large number of solvents or solvent mixtures to find the best conditions for crystal growth. The rate of crystal growth can be slowed either by reducing the rate of evaporation of the solvent or by cooling the solution. Formation of rosette-shaped masses is an indication of an insufficient number of nucleation sites. The number of nucleation sites may be increased either by seeding the solution or by scratching the exposed surfaces of the glass vessel.

### **Vapor and Liquid Diffusion**

Liquid and vapor diffusion methods are often tried when evaporation methods do not immediately succeed. Both methods require finding two solvents or solvent mixtures in which the compound is soluble in one system but insoluble in the other. The two solvent systems should be immiscible or nearly immiscible for liquid diffusion and should be miscible for vapor diffusion. Crystal growth may be slowed somewhat by cooling the apparatus.

Liquid diffusion usually requires that the less dense solvent system be carefully layered on top of the more dense system. The sample can be dissolved in either solvent system. Crystals grow at the interface between the solutions. When compounds precipitate immediately upon being formed, it is possible to slow down the reaction and thus grow larger crystals by putting the reactants in different liquid layers which are separated by a third solvent layer which is not miscible with either of the layers with reactants.

Vapor diffusion is carried out by dissolving a small amount of the sample in one vial, then sealing this inner vial inside a larger vial that contains a small volume of another solvent system. Vapor from the solvent of the outer vial then diffuses into the solution in the inner vial, causing the compound to precipitate. The vertical surfaces of the inner vial should not touch the outer vial to keep the outer solution from rising by capillary action and entering the inner vial.

### **Thermal Gradient**

Thermal gradient methods usually produce very high quality crystals. Such methods include slow cooling of sealed, saturated solutions, refluxing of saturated solutions, sublimation, and zonal heating. Zonal heating is used primarily for crystallizing solid solutions or mixtures. Small crystals may sometimes be grown larger by zonally refluxing a supersaturated. Sublimation

may be carried out in a variety of tubes or vessels. Sealed vessels offer an advantage for sublimation in that the chamber may be evacuated or a partial pressure of some inert gas may be introduced before sealing the sample in the apparatus. Sublimation methods consistently produce very high quality crystals. Larger crystals may be grown either by decreasing the thermal

gradient or by cyclic heating and cooling of the sample.

### **Gel Diffusion**

Some compounds, that precipitate as very small crystals immediately upon synthesis, are extremely insoluble. Suitable crystals of these compounds can often be prepared by greatly decreasing the rate at which the reactants combine by making the reactants diffuse through a gel barrier. This is often carried out by forming a gel in a U-tube, then introducing the reactants in the two separate ends of the tube. Such methods usually take weeks to months to produce crystals, depending on the rate of diffusion of reactants through the gel.

### **Cocrystals and Clathrates**

The crystal structure of some compounds can only be determined by coordinating the compound with another material or by incorporating the compounds into a lattice of another material. Crystals which are mixtures of different compounds are called cocrystals. Some crystal mixtures are simply formed by the incorporation of one or more solvent molecules into the lattice of the compounds of interest. Other cocrystal mixtures are formed when the compound of interest is bonded to a large molecule such as triphenylphosphine oxide usually through a hydrogen bond. A final group of cocrystals can be thought of as being formed by incorporating the compound of interest or "guest" molecule into the small vacant regions in the lattice around large, rigid "host" molecules. This lattice of host molecules is called a clathrate. Structures of porphyrin-based clathrates are very common. It should be noted that for highest precision geometry in the guest molecule, the host should not contain any heavy atoms; in particular, the porphyrins should not be bound to a metal.

### **Choice of Solvents and Counter Ions**

There are a number of solvents and counter ions which are commonly found to be disordered in crystal structures and thus should be avoided if possible. The solvents giving the most trouble are pet ether, mixed hydrocarbons like

"hexanes," toluene, and halogenated hydrocarbons such as methylene chloride

and chloroform. Often these solvents occupy sites in a crystal structure that are larger than the solvent molecule. The halogenated solvents are particularly troublesome because the disorder includes heavier atoms. Better choices of solvents are benzene, xylene, primary and secondary alcohols, and

tetrahydrofuran. The counter ions most likely to be disordered are  $\text{Et}_4\text{N}^+$ ,  $\text{ClO}_4^-$ ,  $\text{BF}_4^-$ , and  $\text{PF}_6^-$ . Some alternative counter ions that are usually ordered are triflate,  $\text{B}(\text{C}_6\text{H}_5)_4^-$ ,  $((\text{C}_6\text{H}_5)_3\text{P})_2\text{N}^+$ , and  $(\text{C}_6\text{H}_5)_4\text{As}^+$ .

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## **Crystal Selection**

Ideal crystals for diffraction studies are well-ordered single crystals of suitable size. Crystals should be examined under low power (10X to 40X) magnification to determine their overall quality, size and, if possible, point group symmetry. Good crystals usually have smooth flat faces, sharp edges, no inclusions, no striations and no obvious dislocations. Careful notes should be made if the bulk sample is not visibly homogeneous. The selected crystal should show no obvious external twinning. Transparent crystals should be checked with a polarizing microscope to verify that the crystals are single. The typical morphology and point group symmetry should be noted.

The crystal chosen for analysis needs to be large enough to produce an adequate diffraction pattern and, at the same time, as small as possible to minimize absorption problems. The calculation of structure factor amplitudes assumes that the crystal is being completely bathed in a uniform beam of X-rays. Since the uniform region of the X-ray beam is about 0.5 mm in diameter, this is taken as the maximum dimension of any crystal. For most samples, a minimum dimension of 0.1 mm is needed to produce adequate X-ray scattering. Compounds with few atoms or very heavy atoms can have all three dimensions toward the small end of this 0.1 to 0.5 mm range. The best crystals for compounds with many light atoms should have all three

dimensions toward the large end (0.5 mm) of this range. Crystals that are too large can be cut with a razor blade, scalpel, or solvent saw.

If the crystals are strongly absorbing (contain heavy atoms), it is worthwhile to reshape the crystal to make it as nearly spherical as possible. This reshaping may be done by cutting, grinding or dipping the crystal in solvent.