# Crystal growth

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A [crystal](https://en.wikipedia.org/wiki/Crystal) is a [solid](https://en.wikipedia.org/wiki/Solid) [material](https://en.wikipedia.org/wiki/Material) whose constituent [atoms](https://en.wikipedia.org/wiki/Atom), [molecules](https://en.wikipedia.org/wiki/Molecule), or [ions](https://en.wikipedia.org/wiki/Ion) are arranged in an orderly repeating pattern extending in all three spatial dimensions. **Crystal growth** is a major stage of a [crystallization process](https://en.wikipedia.org/wiki/Crystallization), and consists of the addition of new atoms, ions, or [polymer](https://en.wikipedia.org/wiki/Polymer) strings into the characteristic arrangement of the crystalline lattice.[[1]](https://en.wikipedia.org/wiki/Crystal_growth%22%20%5Cl%20%22cite_note-1)[[2]](https://en.wikipedia.org/wiki/Crystal_growth%22%20%5Cl%20%22cite_note-2) The growth typically follows an initial stage of either homogeneous or heterogeneous (surface catalyzed) [nucleation](https://en.wikipedia.org/wiki/Nucleation), unless a "seed" crystal, purposely added to start the growth, was already present.

The action of crystal growth yields a crystalline solid whose atoms or molecules are close packed, with fixed positions in [space](https://en.wikipedia.org/wiki/Space) relative to each other. The crystalline [state of matter](https://en.wikipedia.org/wiki/States_of_matter) is characterized by a distinct [structural rigidity](https://en.wikipedia.org/wiki/Structural_rigidity) and very high resistance to [deformation](https://en.wikipedia.org/wiki/Plastic_deformation_in_solids) (i.e. changes of shape and/or volume). Most crystalline solids have high values both of [Young's modulus](https://en.wikipedia.org/wiki/Young%27s_modulus) and of the [shear modulus](https://en.wikipedia.org/wiki/Shear_modulus) of [elasticity](https://en.wikipedia.org/wiki/Elasticity_%28physics%29). This contrasts with most [liquids](https://en.wikipedia.org/wiki/Liquid) or [fluids](https://en.wikipedia.org/wiki/Fluid), which have a low shear modulus, and typically exhibit the capacity for macroscopic [viscous flow](https://en.wikipedia.org/wiki/Viscous_flow).

## Overview

After successful formation of a stable nucleus, a growth stage ensues in which free particles (atoms or molecules) adsorb onto the nucleus and propagate its crystalline structure outwards from the nucleating site. This process is significantly faster than nucleation. The reason for such rapid growth is that real crystals contain [dislocations](https://en.wikipedia.org/wiki/Dislocations%22%20%5Cl%20%22Screw_dislocations) and other defects, which act as a catalyst for the addition of particles to the existing crystalline structure. By contrast, perfect crystals (lacking defects) would grow exceedingly slowly.[[3]](https://en.wikipedia.org/wiki/Crystal_growth%22%20%5Cl%20%22cite_note-frank49-3) On the other hand, **impurities** can act as crystal growth inhibitors and can also modify [crystal habit](https://en.wikipedia.org/wiki/Crystal_habit).[[4]](https://en.wikipedia.org/wiki/Crystal_growth%22%20%5Cl%20%22cite_note-nguyen17-4)

## Nucleation

Main article: [Nucleation](https://en.wikipedia.org/wiki/Nucleation)



Nucleation can be either [homogeneous](https://en.wiktionary.org/wiki/Homogeneous), without the influence of foreign particles, or [heterogeneous](https://en.wikipedia.org/wiki/Mixture%22%20%5Cl%20%22Distinguishing_between_mixture_types), with the influence of foreign particles. Generally, heterogeneous nucleation takes place more quickly since the foreign particles act as a [scaffold](https://en.wikipedia.org/wiki/Scaffold) for the crystal to grow on, thus eliminating the necessity of creating a new surface and the incipient surface energy requirements.

Heterogeneous nucleation can take place by several methods. Some of the most typical are small inclusions, or cuts, in the container the crystal is being grown on. This includes scratches on the sides and bottom of glassware. A common practice in crystal growing is to add a foreign substance, such as a string or a rock, to the solution, thereby providing nucleation sites for facilitating crystal growth and reducing the time to fully crystallize.

The number of nucleating sites can also be controlled in this manner. If a brand-new piece of glassware or a plastic container is used, crystals may not form because the container surface is too smooth to allow heterogeneous nucleation. On the other hand, a badly scratched container will result in many lines of small crystals. To achieve a moderate number of medium-sized crystals, a container which has a few scratches works best. Likewise, adding small previously made crystals, or seed crystals, to a crystal growing project will provide nucleating sites to the solution. The addition of only one seed crystal should result in a larger single crystal.

## Mechanisms of growth

[cubic crystals](https://en.wikipedia.org/wiki/Cubic_crystal) typical of the [rock-salt structure](https://en.wikipedia.org/wiki/Crystal_growth%22%20%5Cl%20%22Rock-salt_structure). Duration: 4 seconds.0:04[Time-lapse](https://en.wikipedia.org/wiki/Time-lapse) of growth of a [citric acid](https://en.wikipedia.org/wiki/Citric_acid) [crystal](https://en.wikipedia.org/wiki/Crystal). The video covers an area of 2.0 by 1.5 mm and was captured over 7.2 [min](https://en.wikipedia.org/wiki/Minute).

The interface between a crystal and its vapor can be molecularly sharp at temperatures well below the melting point. An ideal crystalline surface grows by the spreading of single layers, or equivalently, by the lateral advance of the growth steps bounding the layers. For perceptible growth rates, this mechanism requires a finite driving force (or degree of supercooling) in order to lower the nucleation barrier sufficiently for nucleation to occur by means of thermal fluctuations.[[5]](https://en.wikipedia.org/wiki/Crystal_growth%22%20%5Cl%20%22cite_note-5) In the theory of crystal growth from the melt, Burton and Cabrera have distinguished between two major mechanisms:[[6]](https://en.wikipedia.org/wiki/Crystal_growth%22%20%5Cl%20%22cite_note-6)[[7]](https://en.wikipedia.org/wiki/Crystal_growth%22%20%5Cl%20%22cite_note-7)[[8]](https://en.wikipedia.org/wiki/Crystal_growth%22%20%5Cl%20%22cite_note-8)

### Non-uniform lateral growth

The surface advances by the lateral motion of steps which are one interplanar spacing in height (or some integral multiple thereof). An element of surface undergoes no change and does not advance normal to itself except during the passage of a step, and then it advances by the step height. It is useful to consider the step as the transition between two adjacent regions of a surface which are parallel to each other and thus identical in configuration—displaced from each other by an integral number of lattice planes. Note here the distinct possibility of a step in a diffuse surface, even though the step height would be much smaller than the thickness of the diffuse surface.

### Uniform normal growth

The surface advances normal to itself without the necessity of a stepwise growth mechanism. This means that in the presence of a sufficient thermodynamic driving force, every element of surface is capable of a continuous change contributing to the advancement of the interface. For a sharp or discontinuous surface, this continuous change may be more or less uniform over large areas for each successive new layer. For a more diffuse surface, a continuous growth mechanism may require changes over several successive layers simultaneously.

Non-uniform lateral growth is a geometrical motion of steps—as opposed to motion of the entire surface normal to itself. Alternatively, uniform normal growth is based on the time sequence of an element of surface. In this mode, there is no motion or change except when a step passes via a continual change. The prediction of which mechanism will be operative under any set of given conditions is fundamental to the understanding of crystal growth. Two criteria have been used to make this prediction:

Whether or not the surface is *diffuse*: a diffuse surface is one in which the change from one phase to another is continuous, occurring over several atomic planes. This is in contrast to a sharp surface for which the major change in property (e.g. density or composition) is discontinuous, and is generally confined to a depth of one interplanar distance.[[9]](https://en.wikipedia.org/wiki/Crystal_growth%22%20%5Cl%20%22cite_note-9)[[10]](https://en.wikipedia.org/wiki/Crystal_growth%22%20%5Cl%20%22cite_note-10)

Whether or not the surface is *singular*: a singular surface is one in which the surface tension as a function of orientation has a pointed minimum. Growth of singular surfaces is known to requires steps, whereas it is generally held that non-singular surfaces can continuously advance normal to themselves.[[11]](https://en.wikipedia.org/wiki/Crystal_growth%22%20%5Cl%20%22cite_note-11)