

MORPHOLOGY

Morphology allows you to predict crystal morphology from the atomic structure of a crystal.

The bulk shape of crystals is critically important to many industrial processes.

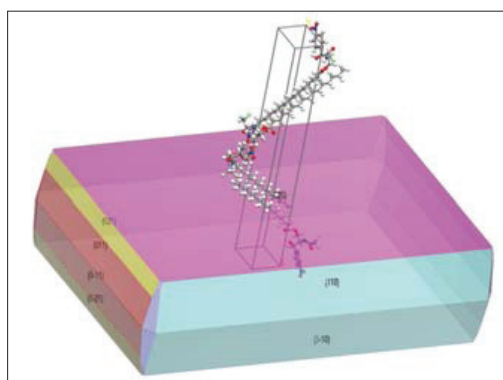
There are numerous examples in the chemical and pharmaceutical industries where crystal shape may affect the following:

- Dissolution rate of chemicals and biological availability of drugs.
- Handling, packaging, and storage of crystalline products.
- Slurry handling, caking, and filtration during processing.
- Milling, grinding, fragmentation, and dusting
- Density and texture optimization.
- Wax and scale formation in petrochemicals.

The relationship between the crystal morphology and the internal arrangement of atoms in the crystal is therefore of great interest to chemists, chemical engineers, and process engineers. Rationalization of this relationship allows the prediction of crystal shape, the development of tailor-made additives, and the control of solvent and impurity effects. Morphology's application areas include pharmaceuticals, agrochemicals, food sciences, petrochemicals, cements, and commodity and specialty chemicals.

WHAT DOES MORPHOLOGY DO?

Morphology has been developed to predict the external morphology of a crystalline material from its internal crystal structure.



The predicted crystal morphology of the most stable polymorph of CAPP (chloramphenicol-3-palmitate).

Three different methods are available to deduce morphology through an easy-to-use interface:

1. Bravais-Friedel Donnay-Harker (BFDH) method^{1,2} uses the crystal lattice and symmetry to generate a list of possible growth faces and their relative growth rates.
2. The growth morphology method^{3,4} assumes that the growth rate of a crystal face is proportional to its attachment energy (the energy released on attachment of a growth slice to a growing crystal surface).
3. The equilibrium morphology⁵ of a crystal is determined by the minimum of the surface energies for all relevant crystal faces at zero Kelvin.

THE MATERIALS STUDIO ADVANTAGE

Morphology is operated within Materials Studio®. The integrated model building and editing tools in Materials Studio enable you to construct, visualize, and manipulate molecular structures in an asymmetric unit or structures of crystallization solids (e.g. drugs, pigments, metal oxides, and zeolites).

A crystal graph describes interactions between molecular fragments in a crystal structure can be overlaid on the crystal structure with Materials Visualizer, or be displayed as tabular data in a grid document. The crystal graph provides a powerful tool for analyzing the crystal morphology and the stability of crystal surfaces in terms of inter-molecular interactions within the bulk crystal.

Growth faces suggested by the Morphology can be analyzed using Materials Studio's new spreadsheet-like table (called a study table) environment. The study table combines an easy association of surface structures with surface properties (e.g. HKL, multiplicity, Dhkl, surface area, center-to-plane distance, energy for each surface, the percentage surface area accounted by certain facets) with powerful sorting and plotting functionality. Polar surfaces can be identified along with their energy contributions. The study table also provides a flexible and convenient way to evaluate additional structural properties for developing quantitative structure-property relationship models.

Crystal morphology and the relationship between the external morphology and its underlying internal crystal structure can be rationalized with Materials Visualizer. Growth faces can be manipulated by simple mouse actions to interactively study the dependence of the morphology on growth rate changes. The most important morphology properties (e.g. interplanar angles, aspect ratio, total volume, and surface area) are stored in a grid document (one or more sets of tabular data) in Materials Studio.

Surface chemistry can be further explored using molecular mechanics tools (Discover®, Forcite, and COMPASS) or quantum mechanics tools (DMol³ or CASTEP). Results can be easily shared with colleagues and copied to standard word processors, spreadsheet, and presentation packages.

HOW DOES MORPHOLOGY WORK?

The BFDH method combines the Donnay-Harker² rules to isolate the likely growth planes, and then the Bravais-Friedel rules¹ to deduce their relative growth rates. The method is an approximation and does not account for the energetics of the system. The stronger the bonding effects in the crystal, the less accurate the method becomes. In many cases, however, you can get good approximations, and the method is always useful for identifying important faces in the growth process.

The growth morphology method assumes that the growth rate of the crystal face is proportional to its attachment energy; that is, faces with the lowest attachment energies are the slowest growing and, therefore, have the most morphological importance. The attachment energy is calculated for a series of suitable slices (hkl) that are chosen either by performing a Donnay-Harker prediction² or by entering your own data. From the energy calculation and, hence, the growth rate, a center-to-plane distance is assigned to each face. This information is used to deduce the morphology using a Wulff plot⁶.

The equilibrium morphology method calculates the surface energy using a predefined finite and fixed slab thickness at a temperature of 0 K. The surface energy is an average between the surfaces with Miller indices $\{hkl\}$ and $\{-h-k-l\}$. The latter restriction is important for crystal structures that do not have a center of inversion.

Instead of performing an energy calculation as part of the Morphology calculation, the Crystal Graph functionality can be used to create interactions between molecular fragments in a crystal. The bond energies for all these interactions are then calculated, and used as input for Growth morphology or Equilibrium morphology to determine the habit of a crystal.

HOW MORPHOLOGY BENEFITS YOU?

Morphology allows researchers both to study particle shape and to consider the effects of altering the growth rate of particular faces on crystal morphology. This may help to estimate to the effect of tailor-made additives in modifying growth. Knowledge of shape and aspect ratio is essential to understanding packing, flow problems, clogging of filters, and other problems. Morphology can also provide insight into other properties, such as the texture of powders and polymorphism.

WITH MORPHOLOGY, YOU ARE ABLE TO:

- Understand structural reasons for morphology as you predict crystal habit from crystal structure and analyze relevant growth faces.
- Relate predicted morphology to experiment, enabling indexing of experimental data.
- Consider the effects of tailor-made additives and solvents by identifying important interactions at key growth faces.
- Predict the morphological effects of modifying the growth rates of particular faces.
- Take an essential step towards preferential crystallization of metastable polymorphs.

Morphology provides researchers with a fast pathway for the application of computational techniques to solve real crystallization problems.

FEATURES**Setup**

- The initial crystal structure can easily be imported from other sources or created using the Crystal

Builder within Materials Visualizer.

- A variety of force fields, as well as quantum mechanics techniques, are available for calculating atomic charges and crystal geometries providing flexibility in geometry optimization.
- Crystals with more than one molecule in the asymmetric unit can be considered.
- Multiple default settings allow for simple operations, or advanced users can adjust individual simulation parameters as necessary.

Calculation Features

- Create crystal graph for organic crystals from the atomic crystal structures.
- Create crystal graph for inorganic systems without infinite network of bonded atoms.
- Crystal graph interaction energies may be edited manually to explore quickly the effect of interaction changes on crystal morphology.
- Predict morphology of organic^{7,8} crystals from the atomic crystal structures.
- Predict morphology of inorganic systems⁹ without infinite network of bonded atoms using the growth morphology or equilibrium morphology method. The BFDH method, on the other hand, can be applied to all inorganic crystal systems.
- Bravais-Friedel Donnay-Harker geometrical rules are used to determine the likely growth faces.
- Attachment energy calculations are performed to estimate the relative growth rate of each face, resulting in the growth shape of a crystal.
- Surface energy calculations predict the morphology that minimizes the total surface energy of a crystal, i.e., the equilibrium morphology.
- Fully implemented Forcite engine including two dimensional Ewald summation for more accurate energy calculations.
- Predict growth morphology or equilibrium morphology of a crystal based on its crystal graph.
- Calculate attributes of a crystal graph (atomic compositions of molecule pairs involved in an interaction, their symmetry multiplicity, center-to-center lengths, and bond energies).
- Calculate attributes of a crystal morphology (interplanar angles, aspect ratios, surface area, volume)
- Calculate attributes of a crystal surface (multiplicity, Dhkl, surface area, energy, polarity, effective surface charge, center-to-plane distance)
- Automatic cleaving functionality for all crystal surfaces or stable surfaces only. Atomistic surface models of arbitrary substrate thickness can be generated.

Running Jobs

- The crystal graph is generated synchronously on local Materials Studio clients.
- All Morphology jobs are run in the background freeing up the Materials Studio client for other research.
- All Morphology jobs can be submitted to local or remote compute servers.

Results

- Crystal graph and its corresponding atomic crystal structures are stored in a single 3D structure files.
- Crystal graph attributes are stored in a grid document.
- Crystal morphology and its corresponding atomic crystal structure are stored in a single 3D structure file.
- Surface attributes including atomistic surface models are stored in a study table.
- Morphology attributes are stored in a grid document.
- Parameter settings are automatically saved for each simulation.

Analysis

- Display 3D graphic image of a crystal graph.
- A crystal graph can be displayed overlaid on the crystal structure.
- The display style, transparency, and color of the molecules in a crystal graph can be controlled.
- The display style and color of the molecular interactions in a crystal graph can be manipulated.
- Molecules in a crystal graph can be label with properties such as cell formula and molecular center, whereas molecular interactions can be labeled with potential energy, electrostatic energy, hydrogen-bond energy, length, midpoint.
- Molecular interactions in a crystal graph can be filtered by energy cutoffs.
- Display 3D graphic image of a crystal morphology.
- The atomistic structure can be displayed with its external morphology.

- The transparency and color of the crystal faces can be controlled.
- The relative growth rate of each face can be changed interactively to analyze the effects of solvents, additives, and impurities on particle shape.
- Crystal faces can be labeled with properties like Miller indices and relative surface area.
- Analysis of surface structures and their properties is carried out with the help of a spreadsheet-like table, called the study table.
- Each surface structure is embedded in the study table, which can be viewed independently and displayed along with various properties.
- Surface structures in a study table can be sorted according to one or more properties, e.g. center-toplane distance, attachment energy, or surface energy.
- A user specified subset can be filtered out from a study table into a new table.
- Flexible graph plotting enables plotting properties against each other, and plotting to a selected subset.
- All or part of a study table or a grid document can be copied and pasted into Microsoft Excel® and Microsoft Word®.
- An interactive, dynamic link is enabled between any growth face or habit facet of a predicted morphology in a crystal habit document and its corresponding study table document providing detailed tabular views of properties for each growth face or habit facet.
- Structures, crystal graphs, and morphologies can be exported to bitmap files, and also be printed on grayscale or color PostScript printers.

Typical Applications

- Explore the effect of the intermolecular interaction strength on the crystal morphology.
- Provide knowledge of shape and aspect ratio, which are essential for understanding packing, flow problems, clogging of filters, and other problems in processing, handling, and formulation.
- Analyze surface chemistry and consider the effects of tailor-made additives, impurities, and solvents.
- Provide insight into many other problems such as the texture of powders and dense packing.
- Examine why certain crystal faces are more stable than others.

SYSTEM DETAILS

Operated through the Materials Studio user interface on Windows® 2000 and XP, Morphology calculations can be executed on Windows® 2000, 2003, XP, SGI IRIX, Red Hat Linux (Intel IA32, EM64T, and compatibles), and SuSe Linux (Intel IA32, EM64T, and compatibles) operating systems.

To learn more about Materials Studio, go to accelrys.com/materials-studio

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