

## Interactions between bacteria and silver nanoparticles with biodegradable coatings

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The interactions between nanomaterials and living organisms are key to elucidating their environmental impact. Many engineered nanomaterials consist of a core material (*e.g.* CdSe, Ag, TiO<sub>2</sub>) and a surface coating (*e.g.* a polymer or molecular moiety). Both can influence the biological behavior of a given nanomaterial; in particular, a systematic understanding of the effects of different coatings is lacking.

We address this issue by investigating the effects of silver nanoparticles with different biodegradable coatings upon *Pseudomonas aeruginosa*, an environmentally-common bacterial species. Silver nanoparticles are increasingly being used in a variety of consumer products. Their antimicrobial properties, while commercially useful, may also be of concern when they are released into the environment.

Twenty-eight nm (average diameter) silver nanoparticles were synthesized with polyvinylpyrrolidone (PVP) coatings of varying chain lengths. *P. aeruginosa* was cultured with solutions of PVP polymer and found to metabolize the PVP to varying degrees, depending upon chain length. Subsequently, the bacteria were exposed to the PVP-coated silver nanoparticles in a minimal growth medium. To better understand whether the silver nanoparticle toxicity is caused by ionic silver as opposed to mechanisms specific to the actual nanoparticles, silver nanoparticle suspensions were analyzed for total and ionic silver concentrations, respectively. Equivalent concentrations of ionic silver, added as silver nitrate, were also tested in bacterial cultures. Minimal inhibitory concentrations and growth curves were determined. Mixtures of bacterial cells and nanoparticles were analyzed via transmission electron microscopy to examine their interactions. The physical state of the nanoparticles in the media was also characterized with dynamic light scattering and absorption spectroscopy.

The effect of varied PVP coatings upon silver nanoparticle-bacteria interactions will be discussed, as well as possible environmental implications.

## Unification of growth and dissolution models: A carbonate example

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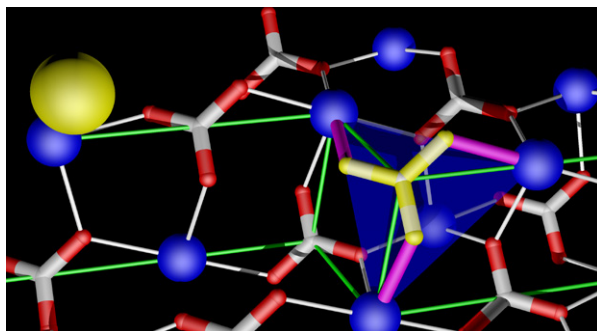


Figure 1. Exit of calcium ion from calcite (1014) kink site.

Classical crystal models introduced by Kossel and Stranski [1, 2] recognized the kink site in terms of its central role in crystal growth. The generation of these sites, and their concentration and distribution with respect to chemical equilibrium has been extensively developed in several key papers [3, 4, 5]; however, the sequence of events involved in the destruction or formation of individual bonds has not been considered in detail. In our computer simulations of crystal dissolution [6], we also assumed molecular attachment and detachment processes at kink sites to be mechanistically equivalent, differing only in outcome.

Using a new conceptual model, we examine the sequence of events involved in both dissolution and growth of a simple calcite solid. This model is completely consistent with long-observed relationships between dissolution and growth rates in those crystals for which the surface integration step is energetically expensive, but yields significant insight into the relationship between these rates, as well as aspects of impurity incorporation and growth of ordered phases at low temperatures, and the justification for free energy as a 'driving force' for reaction rate equations.

[1] Stranski (1928) *Z. Phys. Chem.* **36**, 259. [2] Kossel (1927) *Nachr. Akad. Wiss. Göttingen, Math.-Phys. Kl. 2A, Math. Phys. Chem. Abt.* **1**, 135. [3] Frenkel (1945) *J. Phys. (USSR)* **9**, 392. [4] Burton, Cabrera & Frank (1951) *Phil. Trans. R. Soc. Lond. Ser. A* **243**, 299. [5] Zhang & Nancollas (1998) *J. Coll. Interf. Sci.* **200**, 131. [6] Lasaga & Luttge (2001) *Science* **291**, 2400.