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Nanoscale magnetic properties of iron minerals in bacteria

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We have used a combination of advanced transmission electron microscopy techniques to study the physical and chemical properties of intracellular ferrimagnetic magnetite (Fe_3O_4) and greigite (Fe_3S_4) nanocrystals inside magnetotactic bacteria that were collected from lakes and streams. The relative orientations and the morphologies of magnetic nanocrystals in magnetosome chains were identified using electron diffraction, high-resolution electron microscopy and high-angle annular dark field electron tomography. Whereas magnetite chains were found to be analogous to beads on a string, in which biological control set the [111] magnetocrystalline easy axes of the crystals parallel to each chain axis, greigite crystals had more random orientations. Within each bacterial strain, magnetite magnetosomes were observed to have distinct and well-controlled morphologies. In contrast, greigite crystals appeared to have more irregular shapes. We used off-axis electron holography to record magnetic induction maps from the magnetosome chains. The magnetic signal was dominated by inter-particle interactions and by the shapes of the individual crystals. Magnetite nanocrystals were found to be uniformly magnetized, parallel to the magnetosome chain axes. In contrast, the disordered three-dimensional arrangement of multiple chains of greigite crystals resulted in the magnetic field following a meandering path between adjacent crystals. Over a three-year period, with the sample stored in air, each greigite crystal developed an amorphous iron oxide shell and its magnetic moment decreased. Our results are useful for obtaining an insight into biomineralization processes, and for studying the fundamental effects that influence the magnetic properties of closely-spaced nanoscale magnets.

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Biomineralization and self-assembled nanostructures - structure determination and material properties

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Biomineralization is a common strategy in Nature to produce hard parts for protection, grasping food etc. Many biomineralized tissues are also nanostructured materials and the study of their formation and growth has inspired the synthesis of self-assembled nanostructures in the laboratory. It has been shown that material properties are strongly linked to the structure on the nanometer scale. Many of these materials, in particular those of biological origin, pose a challenge to the researcher due to their complex hierarchical structure.
Here, a combination of synchrotron microfocus techniques, microscopy and mechanical testing is used to study hierarchical nanostructured materials. Two examples are presented in more detail: first a natural biomineralized tissue, the copper containing jaws of marine worms. It was shown that 50-80 nm thick, polycrystalline fibers of a rare copper mineral locally reinforce the material. Secondly, a hierarchical material made in the laboratory is investigated. Mesostructured monoliths were shaped into macroscopic, cellular structures with sacrificial 3-D molds built from a resin formula soluble in alkali. Synchrotron radiation techniques and mechanical tests were combined to learn more about structure and properties.