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MAGNETIC PROPERTIES OF IRON BIOMINERALS

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Magnetotactic bacteria provide the simplest example of the use of magnetic iron biominerals by an organism for navigation. Each bacterial cell contains one or more chains of ferrimagnetic magnetite or greigite crystals, which are 20-200 nm in size, have well-defined morphologies, and impart a magnetic moment to the cell that results in its alignment parallel to geomagnetic field lines. The technique of off-axis electron holography in the transmission electron microscope has recently been used to record images of magnetic field lines in bacterial cells at nanometer spatial resolution. Such measurements allow the magnetization, coercivity and magnetic moment of the crystals to be measured directly. Experimentally, magnetite and greigite crystals in bacterial cells are always found to contain single magnetic domains when they are arranged in chains. The magnetization directions of crystals that would normally be multi-domain or superparamagnetic are constrained to lie along the chain axis as a result of magnetic interactions with their neighbors. Surprisingly, the magnetization of greigite is found to be more variable between crystals than that of magnetite, perhaps as a result of the presence of different iron sulfide minerals. It is interesting to compare the magnetic microstructure of biogenic crystals with that of other arrays of magnetic nanoparticles. For example, synthetic iron-nickel crystals that have similar sizes to biogenic crystals are found to have more complicated magnetic domain structures, typically supporting three-dimensional magnetic vortices. The behavior of three-dimensional arrays of magnetite crystals that form naturally in rocks is also more complicated than that in bacteria. In the titanomagnetite system, highly complex interparticle interactions are responsible for the stability of the remanent magnetization of the mineral over geological timescales. Such comparisons serve to highlight the different ways in which the magnetic properties of nanocrystals are optimized in nature.