

AC 2007-3120: NANOSCALE HETERO-COAGULATION AND ABSORPTION PHENOMENA: MAGNETIC BONE MINERAL

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Dr. Otto C. Wilson, Jr. received his Ph.D. in Ceramic Science and Engineering from Rutgers University in 1995. Otto conducted post doctoral studies in bioceramics at the University of Maryland (UM) and Johns Hopkins University and taught at UM from 1997-2003. In September, 2003 he joined the Biomedical Engineering Faculty at Catholic University where he focuses on research and teaching in biomimetics, biomaterials, biomineralization, bone, and tissue engineering in the Biomimetics, Orthopedics, and Nanomaterials Education/Composite Research for Advanced Biomaterials (BONE/CRAB Lab). Otto is also very involved in K-12 educational outreach. He was recently awarded a NSF CAREER Award for his proposal entitled "Bone Inspiration in Research and Education. When not working, he enjoys spending time with his beautiful wife Debra and their wonderful sons, Otto III (7) and Daniel 18 months).

Nanoscale Hetero-coagulation and Adsorption Phenomena: Magnetic Bone Mineral

Abstract

The Magnetic Bone Mineral demonstration was developed to provide students with a simple way to visualize nanoscale hetero-coagulation and adsorption phenomena. In this demonstration, aqueous suspensions of hydroxyapatite and magnetic nanoparticles are mixed together in a small clear container. The resulting suspension takes on a tan color intermediate between the initial magnetic nanoparticle and hydroxyapatite suspension. The most unique aspect of the hetero-coagulated nanoparticles is that the magnetic nanoparticle modified hydroxyapatite can be translated in solution under the influence of a magnetic field. This demonstration is suitable for all age groups from K-12 through college level and can be tailored to fit a number of curriculums due to the wide range of topics that can be incorporated into the demonstration (biomaterials, interaction potentials, colloid stability, magnetic phenomena, etc.).

Introduction

The unique properties and unusual behaviors of nanoscale materials provide a driving force for a wide range of technologies. However, it is often very difficult to prepare effective educational demonstrations that illustrate nanoscale phenomena with a limited budget. The Magnetic Bone Mineral demonstration was developed to provide students with a simple way to visualize nanoscale hetero-coagulation and adsorption phenomena. Adsorption is a very fundamental nanoscale phenomena that plays a very important role in natural phenomena and science and engineering technologies. It is utilized in biological processes, catalysis, detergent applications, microelectronics, coatings and a wide variety of other processes. Hetero-coagulation is a term that describes particle/particle adsorption interactions involving two or more types of particles^{1, 2}. These interactions are typically driven by electrostatic (opposite charges attract), chemical affinity effects, or size effects. In size based hetero-coagulation, nanoparticles seek to lower their surface energy by adsorbing onto larger particles. In this demonstration, magnetic nanoparticles are mixed with hydroxyapatite particles in suspension to allow visual observation of nanoscale heterocoagulation and adsorption interactions with the use of a strong magnet.

Procedure

Synthesis of magnetic nanoparticles

A solution containing a 1:2 molar ratio of Fe^{2+} to Fe^{3+} (typically 0.5 M FeCl_3 and 0.25 M FeCl_2 , 50-100 ml) in de-ionized water was prepared and then slowly added to an ammonium hydroxide alkaline solution. The magnetic nanoparticle suspension was allowed to stir for 1 hour, washed via gravity sedimentation in the presence of a strong magnet or centrifugation to remove excess ammonium hydroxide, and stored in polypropylene bottles at room temperature.

Synthesis of Nanophase Hydroxyapatite

In a typical reaction, equal masses of 1.00 molal (m) PO_4^{3-} solution and the 1.67 m Ca^{2+} solution (500 grams each) were measured and the pH of each solution was adjusted to 10 by the addition of NH_4OH . Five ml aliquots of the Ca^{2+} solution were sequentially added to the mechanically stirred PO_4^{3-} solution. The pH of the precipitated hydroxyapatite slurry was maintained at 10 by the addition of NH_4OH as needed. Precipitation reactions were performed in 1000 ml polypropylene bottles. The precipitate slurry was stirred for 1–3 hr after mixing

and subsequently aged in a Teflon lined hydrothermal reaction vessel (Model 4524, 2 L stirred reaction vessel, Parr Instrument Company, Moline, IL) at 130 °C for 3 – 6 hr. After aging, the particles were washed with deionized water via centrifugation using a Beckman Avanti J-25I Centrifuge (Fullerton, CA). Nanophase hydroxyapatite was stored in water.

Preparation of Magnetic Bone Mineral

Hetero-coagulation interactions between hydroxyapatite and magnetic nanoparticles can be observed by mixing a few drops of the hydroxyapatite suspension into a small cuvette containing deionized water. Add a few drops of the magnetic nanoparticles suspension to the hydroxyapatite suspension and mix by stirring with the pipette. The mixed suspension should turn tan in color as the dark magnetic nanoparticles suspension mixes with the light hydroxyapatite suspension. In solution, the smaller magnetic nanoparticles (approximately 20 nm in diameter) adhere to the larger hydroxyapatite particles (approximately 50-150 nm) via a hetero-coagulation mechanism (Figure 2). This becomes evident when a strong magnet is placed next to the side of the cuvette. The hetero-coagulated particles are attracted to the magnet and quickly adhere onto the side of the cuvette next to the magnet.

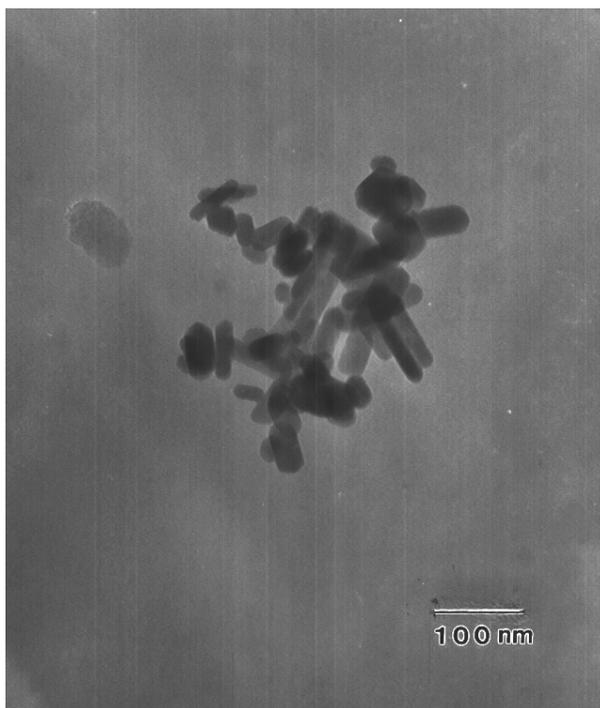


Figure 1 Transmission electron microscope picture of nanophase hydroxyapatite (from ref 3)

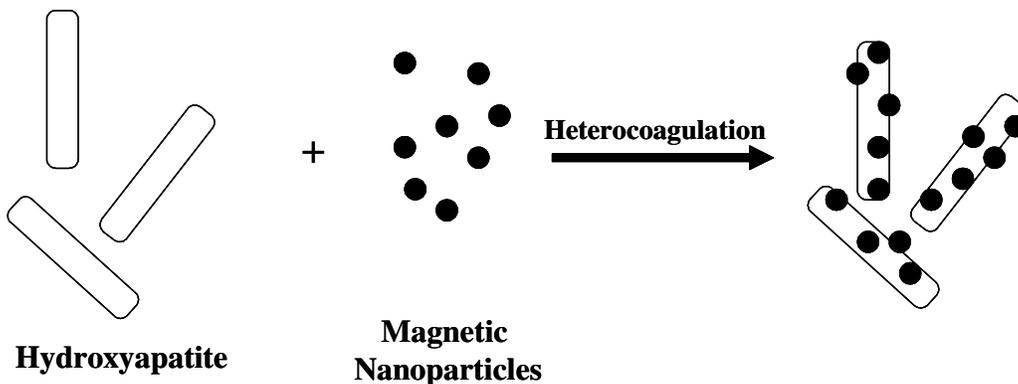


Figure 2 Schematic showing heterocoagulation interactions between hydroxyapatite and magnetic nanoparticles.

Comments

This demonstration can be tailored in a number of different ways to inspire student interest at various academic levels. A few of the ideas that we have tried include

- 1.) Varying the relative amount of hydroxyapatite and magnetic nanoparticles. This influences the color of the suspension and the relative strength of the magnetic field interactions.
- 2.) Students can synthesize the nanoparticles as part of the demonstration
- 3.) Surfactant and colloid stability effects can be incorporated into this demonstration by using PEI and/or gum Arabic. Figure 3 shows a picture of a well dispersed hydroxyapatite suspension that contains gum Arabic (left hand bottle) and an unstable hydroxyapatite suspension with no additive (on the right).
- 4.) This demonstration can be performed using a Petri dish or glass microscope slide and projected onto a screen with an overhead projector for large audiences.



Figure 3 Influence of gum Arabic surfactant on the colloid stability of hydroxyapatite. The bottle on the left contains hydroxyapatite and gum Arabic and the bottle on the right contains only hydroxyapatite.

Bibliography

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