MAGNETIC CHARACTERISTICS OF MAGNETITE NANOCRYSTALS FORMED BY ESTUARY MAGNETOTACTIC BACTERIA FROM COLOMBIA

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Magnetotactic bacteria contain chains of magnetite nanocrystals that comprise a permanent magnetic dipole in each cell (Frankel et al. 2006; Fischer et al., 2008). These nanocrystals fall within the stable single domain magnetic size range of between 30 and 120 nm, and are permanently magnetic. Smaller sizes crystals do not show persistent magnetization. In crystals larger than 120 nm, multiple magnetic domains of opposite magnetic orientation can be formed, which reduces the total magnetic remanence of the crystal (Lang and Shüler, 2006; Pósfai et al. 2006; Shuler, 2008). This means that magnetite nanocrystals of magnetotactic bacteria show superior magnetic properties (Arakaki et al. 2008; Frankel et al. 2006; Fischer et al., 2008). In order to study the morphology, crystal size and elemental analysis of nanocrystals of magnetotactic bacteria, the cells were magnetically harvested and deposited on Cu TEM grids (Lins et al. 2003). The grids were analyzed using a TECNAI G2 20 D345 (FEI) transmission electron microscope operating at 200 kV, equipped with an EDX analysis system. For magnetic measurements, concentrated samples of bacteria were packed into paraffin blocks. Magnetic hysteresis loops were measured using a Quantum Design Vibrating Sample Magnetometer (VSM) in a magnetic field of 1 Tesla. The saturation magnetization ($M_s$), remanent magnetization after saturation ($M_r$), coercivity ($H_c$) and remanence coercivity ($H_{cr}$) were determined at room temperature (300 K) and lower temperatures (150 K and 80 K).

TEM images of magnetotactic bacteria showed that the nanocrystals are arranged in two pairs of parallel chains in each cell (Figure 1A). Each chain, containing about 6 to 8 elongated prismatic nanocrystals (Figures 1B and 1C), showed a size range between 30 and 110 nm, with the maximum of the size distribution at 80 – 110 nm (Figure 1D). These crystals were elongated (width/length ratio of 0.8) along [111] their axes. These particles fall within the single magnetic domain (SD) range. EDX analyses showed that the nanocrystals consist of magnetite (Figure 1E). Saturation magnetization, $M_s$, remanent magnetization after saturation, $M_r$, coercive force, $H_c$ and coercivity of remanence, $H_{cr}$, and their ratios ($M_r/M_s$ and $H_{cr}/H_c$) serve to define domain states. For single domain crystals of magnetite, the theoretical values of the remanence ratio and the coercivity ratio are $M_r/M_s \sim 0.5$ and $H_{cr}/H_c \sim 1.5$, respectively and these ratios are essentially temperature invariant (Davila, 2005). The hysteresis loops of magnetotactic bacteria at all temperatures showed a coercive force ($H_c$) ranging from 0.375 to 0.416 mT, and a coercivity of remanence ($H_{cr}$) ranging of 0.125 to 0.917. The remanence ratio ($M_r/M_s$) was 0.44 (300 K), 0.38 (150 K) and 0.4 (80 K), while the coercivity ratio $H_{cr}/H_c$ was 0.5 (300 k), 0.58 (150 K) and 2.2 (80 K) (Figure 2). The samples were saturated at 100 mT, showed the presence of ferromagnetic minerals such as magnetite (Han et al. 2007). These results demonstrate that the nanocrystals of estuary magnetotactic bacteria consist of single domain magnetite. In a Day plot (remanence ratio, $M_r/M_s$ versus coercivity ratio $B_{cr}/B_c$) the ratios of the hysteresis parameters $M_r$, $M_s$, $B_c$ and $B_e$ are sensitive to the domain state of the particles (Davila, 2005). As can be seen, the Day plot parameters for the magnetotactic bacteria sample fall well within the single domain range ($M_r/M_s \sim 0.5$, $H_{cr}/H_c \sim 1.5$) (Figure 2D). The magnetite nanocrystals of magnetotactic bacteria are good candidates for the potential applications as single-domain nanomagnets in fields such as biomedical, electronics, catalysis, and magnetic recording.

References

Figure 1. A. TEM Image of intact magnetotactic bacteria with two pairs of chains of magnetite nanocrystals. B and C. The pairs of chains of magnetite nanocrystals with elongated prismatic crystals. D. Crystal size distribution of intracellular magnetite nanocrystals of magnetotactic bacteria (120 crystals were measured). E. EDX spectrum of a nanocrystal showing mainly iron and oxygen peaks. Small Mg, P, S, and Cl peaks are derived from the cytoplasm and membranes surrounding the magnetosome. Cu peaks were derived from the supporting grid.

Figure 2. A. Hysteresis loops measured at 300 K. B. Hysteresis loops measured at 150 K. C. Hysteresis loops measured at 80 K. D. Comparison of the Day plot for the nanocrystals from estuary magnetotactic bacteria sample. (remanence ratio, $M_{rs}/M_r$) and coercivity ratio ($B_{cr}/B_c$). Single domain (SD), Pseudo-single domain (PSD) and Multi-domain (MD).