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Role of laterally shifted dipoles in 3d microstructure formation of Janus magnetic colloids: insights from Brownian dynamics simulations

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The three-dimensional microstructures of a dilute suspension of magnetic Janus colloids with a magnetic dipole laterally displaced from their center were studied using Brownian dynamics simulations. The microstructure and aggregation properties were obtained from the temporal evolution of the positions and orientations of the colloidal particles. The mean average cluster size, the nucleation and growth process, the cluster size distribution, the orientational distribution, and the effective radius of the clusters were evaluated for different values of Janus balance, i.e., the lateral dipolar shift (s)—dimensionless with the particle radius and taking values in the range of $0 \leq s \leq 1$. At small dipolar shifts ($s \longrightarrow 0$), chain- and ring shaped structures are formed that are typically observed in particles with a centered dipole ($s = 0$). However, at intermediate dipolar shifts ($0.2 \leq s \leq 0.4$), structures mainly form vesicles that in some cases coexist with rings and spherical micelles. Finally, for $s > 0.4$, spherical micelles are observed that progressively decrease in size as s increases until clusters of 2 or 3 particles are reached. For intermediate and high dipolar shifts, the typical power-law aggregation is broken down, and the system saturates to a few particles per cluster. Therefore, the observed structural behavior provides a basis for the rational design of drug delivery encapsulation materials and highly stable suspensions. The results demonstrate that novel magnetic fluids can be engineered by tuning the dipolar displacement of their constituent particles, enabling precise control over microstructure and, consequently, macroscopic properties.

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