Self-assembly of colloids with magnetic caps

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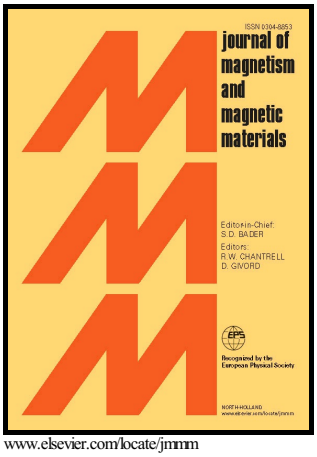

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Self-assembly of colloids with magnetic caps

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Abstract

In our earlier work [1] we investigated a homogeneous system of magnetically capped colloidal particles that self-assembled via two structural patterns of different symmetry. The particles could form a compact, equilateral triangle with a three-fold rotational symmetry and zero dipole moment and a staggered chain with mirror symmetry with a net magnetisation perpendicular to the chain. The system exhibited a bistability already in clusters of three particles. Based on observations of a real magnetic particles system, analytical calculations and molecular dynamics simulations, it has been shown that the bistability is a result of an anisotropic magnetisation distribution with rotational symmetry inside the particles. The present study is a logical extension of the above research and forms a preparatory stage for the study of a self-assembly of such magnetic particles under the influence of an external magnetic field. Since the magnetic field is only an additive contribution to the total ground state energy, we can study the interparticle interaction energies of candidate ground state structures based on the field-free terms.

Keywords: magnetic capped colloids, self-assembly, theoretical study, staggered chain, three-fold rotationally symmetric chain

1. Introduction

Application of soft magnetic materials is based on the ability to control the microstructure of these systems via the concentration and magnetic particle sizes and viscous properties of the carrier liquid, followed by obtaining desired macroproperties of systems. These opportunities are used extensively in medicine and industry [2, 3, 4, 5, 6, 7, 8]. Nowadays, the experimental technology reached an even higher level - scientists can control individual particles, their internal structure, shape, topology at the level of synthesis. In magnetic materials innovative complex methods led to the creation, for example, of Janus magnetic particles. Micron-sized Janus particles, named after the two-faced god in Roman mythology, are composed of two hemispheres that have fundamentally different properties [9, 10]. These particles can form various types of clusters under the influence of an external magnetic field, and without it. Another example of particles with magnetic anisotropy are non-magnetic cores with a thin magnetic coating surface coating. All the above-mentioned materials, being very promising, were synthesised during the last five years and require detailed theoretical study to optimise their properties. Thus, few years ago, in Germany, our colleagues synthesised silica particles hemispherically covered with a ferromagnetic thin film, in the following denoted as cap [11]. There are examples of Janus particles, with two hemispheres, where cap had a magnetic anisotropy that points perpendicular to the particle surface. In solution, the colloidal particles sediment and form quasi-2D assemblies due to their magnetostatic potential. Via video microscopy, it is possible to access the information on spatial and magnetic configurations of assembled clusters. In the article of Steinbach et al. [1], we presented our joint study of a homogeneous system of magnetic colloidal particles that self-assembled via two structural patterns of different symmetry. The particles could form a compact, equilateral triangle with a three-fold rotational symmetry and a staggered chain with mirror symmetry. The system exhibited a bistability already in clusters of three particles. We found two stable states with distinct topologies: one cluster type was compact and had zero net magnetic moment, whereas the other one had the shape of a staggered chain, with a net magnetisation perpendicular to the chain. The self-assembly of two particles always resulted in a dumbbell structure, characterised by the antiparallel alignment of caps, that was previously seen in [1]. This admirable magnetic feature of staggered antiparallel orientation has been presented before [12]. In order to explain this configuration, a model of so-called shifted-dipole particles has been introduced in Ref. [13], where every particle contains a dipole that is shifted radially away from its centre. Therefore, at first we tried to describe the observed bistability using this model, however, only three-fold rotationally symmetric rings were observed. This meant that we incorrectly approximate magnetic caps by a single shifted dipole. Consequently, we introduced additional anisotropy by assigning each particle three point dipoles, which were radially shifted outwards due to the form of the magnetisation distribution of the cap.

In the present study we extend the above research and prepare the basis for the investigation of a self-assembly of such a magnetic particle systems under the influence of an external magnetic field. Since the magnetic field coupling enters the interaction potentials as an additive contribution, here, we focused on a comprehensive study of the interparticle energies of

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