Edited by Sergey P. Gubin

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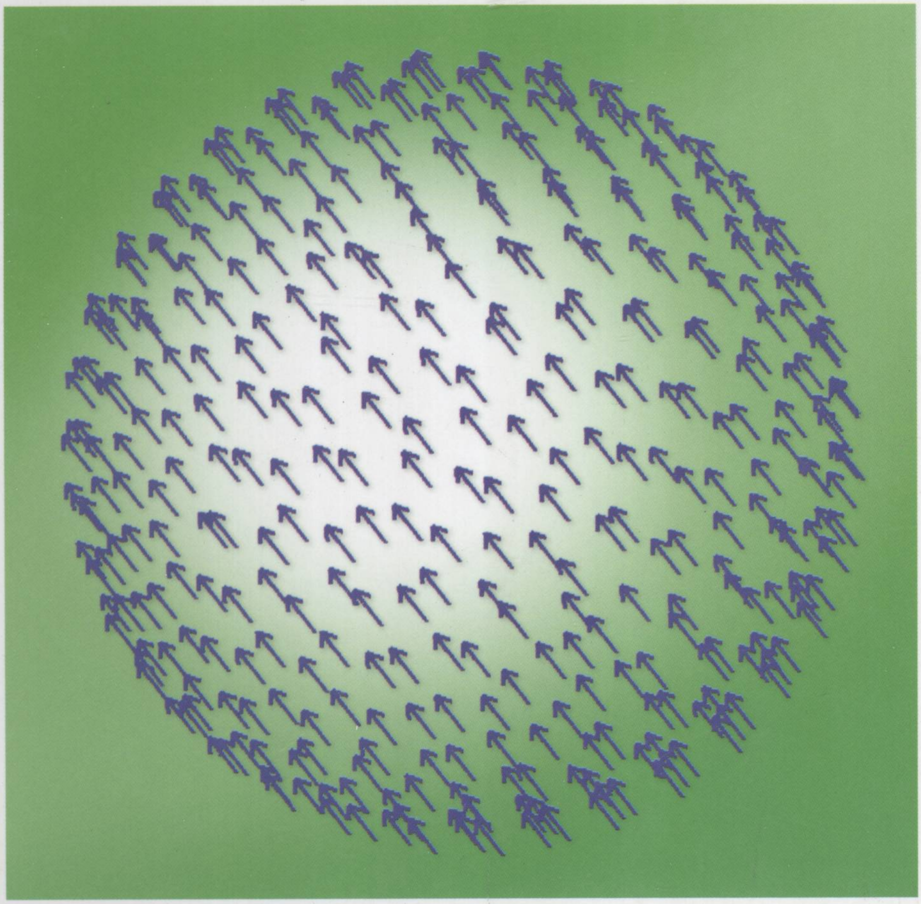

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Preface

Nanoparticles are essential part of our natural environment, modern science, and high technology. Magnetic nanoparticles are most common and very promising for applications. Although the magnetism of fine particles has been studied for almost 60 years, there is the rich variety of phenomena which remain to be understood. However, the meaningful progress in this field, including theory and in particular – practice, is rather recent and particularly remarkable for the last two decades. The major significance of magnetic nanoparticles is attributed to the uniformity in magnetic properties of individual particles in the real dispersion system, which allows us to directly correlate the magnetic properties of a whole material with those of each particle and facilitates theoretical approaches.

One of my main aims in preparing this book is to build bridge between theory of nanomagnetism and the study of synthetic materials with isolated magnetic nanoparticles. This book is not a comprehensive review of the many studies concerned with magnetic nanoparticles; instead, we concentrate our attention on giving a broad overview and key examples and attempt to motivate a deeper than usual examination of forefront fundamental developments in this field.

This book provides a forum for critical reviews on many aspects of nanoparticle magnetism, which are at the forefront of nanoscience today. The chapters do not cover the whole spectrum of nanomagnetism, which would be limitless, but present highlights especially in the domains of interest of the authors and editor.

I hope that this book, probably the first book dealing with general aspects of magnetic nanoparticles, will serve as a guide to the magnetic nanotechnology for wide audience: from senior- and graduate-level students up to advanced specialists in both academic and industrial centers.

The editor gratefully acknowledges the contributing authors of these chapters, who are world renowned experts in this burgeoning field of nanoscience. I thank all the colleagues who spend considerable time and effort in writing these high-level contributions.

Moscow, Russia
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S.P. Gubin

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Contents

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1 Introduction

Sergey P. Gubin

1.1 Some Words about Nanoparticles

First of all, it is necessary to consider the general concepts related to the nanosized objects. A nanoobject is a physical object differing appreciably in properties from the corresponding bulk material and having at least 1 nm dimension (not more than 100 nm). When dealing with nanoparticles, magnetic properties (and other physical ones) are size dependent to a large extent. Therefore, particles whose sizes are comparable with (or lesser than) the sizes of magnetic domains in the corresponding bulk materials are the most interesting from a magnetism scientist viewpoint.

Nanotechnology is the technology dealing with both single nanoobjects and materials, and devices based on them, and with processes that take place in the nanometer range. Nanomaterials are those materials whose key physical characteristics are dictated by the nanoobjects they contain. Nanomaterials are classified into compact materials and nanodispersions. The first type includes so-called nanostructured materials [1], i.e., materials isotropic in the macroscopic composition and consisting of contacting nanometer-sized units as repeating structural elements [2]. Unlike nanostructured materials, nanodispersions include a homogeneous dispersion medium (vacuum, gas, liquid, or solid) and nanosized inclusions dispersed in this medium and isolated from each other. The distance between the nanoobjects in these dispersions can vary over broad limits from tens of nanometers to fractions of a nanometer. In the latter case, we are dealing with nanopowders whose grains are separated by thin (often monoatomic) layers of light atoms, which prevent them from agglomeration. Materials containing magnetic nanoparticles, isolated in nonmagnetic matrices at the distances longer than their diameters, are most interesting for magnetic investigations.

A nanoparticle is a quasi-zero-dimensional (0D) nanoobject in which all characteristic linear dimensions are of the same order of magnitude (not more than 100 nm). Nanoparticles can basically differ in their properties from larger

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particles, for example, from long- and well-known ultradispersed powders with a grain size above 0.5 μm. As a rule, nanoparticles are shaped like spheroids. Nanoparticles with a clearly ordered arrangement of atoms (or ions) are called nanocrystallites. Nanoparticles with a clear-cut discrete electronic energy levels are often referred to as "quantum dots" or "artificial atoms"; most often, they have compositions of typical semiconductor materials, but not always. Many magnetic nanoparticles have the same set of electronic levels.

Nanoparticles are of great scientific interest because they represent a bridge between bulk materials and molecules and structures at an atomic level. The term "cluster," which has been widely used in the chemical literature in previous years, is currently used to designate small nanoparticles with sizes less than 1 nm. Magnetic polynuclear coordination compounds (magnetic molecular clusters) belong to the special type of magnetic materials often with unique magnetic characteristics. Unlike nanoparticles, which always have the distributions in sizes, molecular magnetic clusters are the fully identical small magnetic nanoparticles. Their magnetism is usually described in terms of exchange-modified paramagnetism.

Nanorods and nanowires, as shown in Figure 1.1, are quasi-one-dimensional (ID) nanoobjects. In these systems, one dimension exceeds by an order of magnitude the other two dimensions, which are in the nanorange.

The group of two-dimensional objects (2D) includes planar structures – nanodisks, thin-film magnetic structures, magnetic nanoparticle layers, etc., in which two dimensions are an order of magnitude greater than the third one, which is in the nanometer range. The nanoparticles are considered by many authors as giant pseudomolecules having a core and a shell and often also external functional groups. The unique magnetic properties are usually

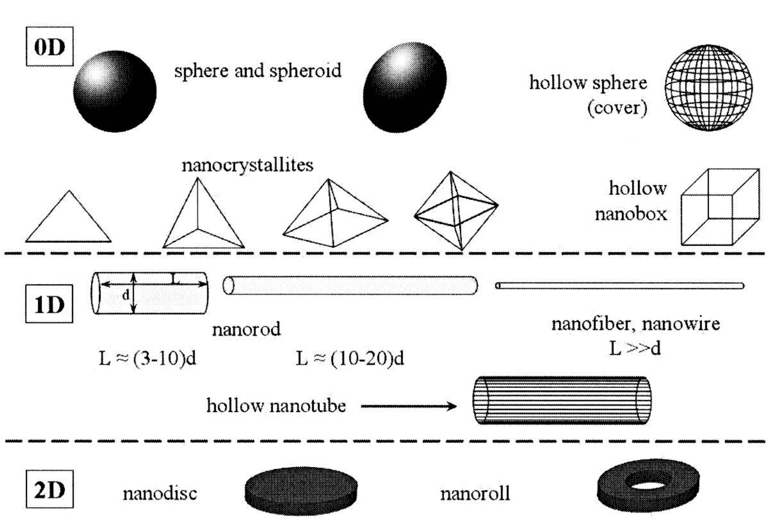

Figure 1.1 The classification of metal containing nanoparticles by the shape.

inherent in the particles with a core size of 2–30 nm. For magnetic nanoparticles, this value coincides (or less) with the size of a magnetic domain in most bulk magnetic materials. Methods of synthesis and properties of nanoparticles were considered in the books and reports [3].

1.2 Scope

Among many of known nanomaterials, the special position belong to those, in which isolated magnetic nanoparticles (magnetic molecular clusters) are divided by dielectric nonmagnetic medium. These nanoparticles present giant magnetic pseudoatoms with the huge overall magnetic moment and "collective spin." In this regard nanoparticles fundamentally differ from the classic magnetic materials with their domain structure. As a result of recent investigations, the new physics of magnetic phenomena – nanomagnetism – was developed. Nanomagnetism advances include superparamagnetism, ultrahigh magnetic anisotropy and coercive force, and giant magnetic resistance. The fundamental achievement of the last time became the development of the solution preparation of the objects with advanced magnetic parameters.

Currently, unique physical properties of nanoparticles are under intensive research [4]. A special place belongs to the magnetic properties in which the difference between a massive (bulk) material and a nanomaterial is especially pronounced. In particular, it was shown that magnetization (per atom) and the magnetic anisotropy of nanoparticles could be much greater than those of a bulk specimen, while differences in the Curie or Néel temperatures between nanoparticle and the corresponding microscopic phases reach hundreds of degrees. The magnetic properties of nanoparticles are determined by many factors, the key of these including the chemical composition, the type and the degree of defectiveness of the crystal lattice, the particle size and shape, the morphology (for structurally inhomogeneous particles), the interaction of the particle with the surrounding matrix and the neighboring particles. By changing the nanoparticle size, shape, composition, and structure, one can control to an extent the magnetic characteristics of the material based on them. However, these factors cannot always be controlled during the synthesis of nanoparticles nearly equal in size and chemical composition; therefore, the properties of nanomaterials of the same type can be markedly different.

In addition, magnetic nanomaterials were found to possess a number of unusual properties – giant magnetoresistance, abnormally high magnetocaloric effect, and so on.

Nanomagnetism usually considers so-called single-domain particles; typical values for the single-domain size range from 15 to 150 nm. However, recently the researchers focused their attention on the particles, whose sizes are smaller than the domain size range; a single particle of size comparable to the minimum domain size would not break up into domains; there is a reason to