

Contents

1 The Basis of Nanomagnetism	1
1.1 Introduction: The Importance of Nanomagnetism	1
1.2 The Origin of Nanomagnetic Behavior	2
1.2.1 Sample Dimensions and Characteristic Lengths	4
1.2.2 Broken Translation Symmetry	6
1.2.3 Nanomagnetic Samples and Dynamic Behavior	17
1.3 Dimensionality and Critical Behavior	17
References	22
2 Magnetic Domains	25
2.1 Introduction	25
2.2 Interactions in Magnetic Materials	32
2.2.1 Exchange Interaction	33
2.2.2 Magnetostatic Energy	36
2.2.3 Magnetic Anisotropy	38
2.2.4 Magnetoelastic Energy and Magnetostriction	40
2.3 Elements of Micromagnetism	41
2.3.1 Equation of Motion	46
2.4 Magnetic Domains	48
2.4.1 Domain Wall Width	50
2.4.2 Single-Domain Critical Diameters	56
2.4.3 Domain Wall Motion	58
2.5 Random Anisotropy	65
References	68
3 Magnetism of Small Particles	71
3.1 Introduction	71
3.2 Particle Size and Magnetic Behavior	75
3.3 Superparamagnetism	82
3.3.1 Superparamagnetism: The Langevin Function	90

3.4	Surface Effects	91
3.5	The Stoner–Wohlfarth Model	94
3.5.1	Inhomogeneous Magnetization Reversal	105
3.5.2	Precessional Magnetization Reversal	108
3.5.3	Current-Induced Magnetization Reversal	111
3.6	Interaction Between Particles	112
	References	121
4	Magnetism of Thin Films and Multilayers	125
4.1	Introduction	125
4.1.1	Thin Films: Planar Systems	126
4.1.2	Thin Films: Laterally Structured Systems	130
4.2	Anisotropy in Thin Films	132
4.3	Domain Walls and Magnetization Reversal in Thin Films	135
4.4	Exchange Bias	138
4.5	Interlayer Exchange Coupling	144
	References	148
5	Magnetotransport and Spin Current Effects	151
5.1	Introduction	151
5.2	Spin Dependent Scattering and Giant Magnetoresistance (GMR)	160
5.2.1	Valet–Fert Model for GMR	167
5.3	Tunnel Magnetoresistance (TMR) and Other Magnetoresistance Effects	169
5.3.1	The Anisotropic Magnetoresistance (AMR)	174
5.4	Current-Induced Domain Wall Motion and Spin Transfer Torque (STT)	176
5.5	Spin Current Effects: Spin Hall Effect, Spin Pumping, and Spin Thermal Effects	181
	References	195
6	Magnetism of Nanodisks, Nanorings, Nanowires, and Nanotubes	201
6.1	Introduction	201
6.2	Nanodisks	202
6.3	Nanorings	210
6.4	Nanowires and Nanotubes	214
	References	226
7	Magnetic Recording	231
7.1	Introduction	231
7.2	Principles of Magnetic Recording	232

7.3 Novel Magnetic Recording Systems 237

 7.3.1 Nanodisk and Nanoring Memories 240

 7.3.2 Domain Wall and Skyrmion Memories 244

References. 246

Solutions to the Exercises 249

Appendix A: The Hall Effect 257

Appendix B: Elements of Thermoelectricity 261

Appendix C: Units in Magnetism. 265

Appendix D: Physical Constants 269

Glossary 271

Bibliography 277

Material Index. 297

Symbol Index 309

Author Index. 313

Subject Index. 319

energy dependence of the dynamic response of the constituent material and over which the exchange length and the magnetic domain wall width are some of the characteristic lengths that are more relevant in the magnetic properties. The shape of the energy of excitation curves is also dependent on the dimensionality of the sample.

1.1 Introduction: The Importance of Nanomagnetism

The objects of study of this science are the phenomena involving objects of finite size, usually in the range from 1 nm (1 nm = 10^{-9} m) to 100 nm. This is the range of size of many molecules and viruses and is also the characteristic length scale of many physical processes. The lateral dimensions of the present-day integrated circuit components, as well as the dimensions of viruses in biological systems, fall within this size range.

In recent years, by the onset of research in Physics that deals with the magnetic properties of objects that have at least one dimension in the nanoscopic range, Nanomagnetism includes in its scope the study of properties and applications of the magnetic behavior of isolated nanoparticles, nanowires, nanorings, thin films and multilayers, and the nano-scale samples that contain nanoscale particles. Materials that contain particles, filars, and other structures in the nanoscale are often described as nanostructured materials.