

CONTENTS

Part I Classical Magnetism

1	MAGNETOSTATIC PHENOMENA	3
1.1	Magnetic moment	3
1.2	Magnetic materials and magnetization	7
1.3	Magnetization of ferromagnetic materials and demagnetizing fields	11
1.4	Magnetic circuit	17
1.5	Magnetostatic energy	22
1.6	Magnetic hysteresis	27
	Problems	31
	References	32
2	MAGNETIC MEASUREMENTS	33
2.1	Production of magnetic fields	33
2.2	Measurement of magnetic fields	39
2.3	Measurement of magnetization	42
	Problems	49
	References	49

Part II Magnetism of Atoms

3	ATOMIC MAGNETIC MOMENTS	53
3.1	Structure of atoms	53
3.2	Vector model	59
3.3	Gyromagnetic effect and ferromagnetic resonance	68
3.4	Crystalline field and quenching of orbital angular momentum	74
	Problems	81
	References	83
4	MICROSCOPIC EXPERIMENTAL TECHNIQUES	84
4.1	Nuclear magnetic moments and related experimental techniques	84
4.2	Neutron diffraction	93
4.3	Muon spin rotation (μ SR)	100
	Problems	104
	References	104

Part III Magnetic Ordering

5	MAGNETIC DISORDER	107
5.1	Diamagnetism	107
5.2	Paramagnetism	110
	Problems	116
	References	117
6	FERROMAGNETISM	118
6.1	Weiss theory of ferromagnetism	118
6.2	Various statistical theories	124
6.3	Exchange interaction	129
	Problems	133
	References	133
7	ANTIFERROMAGNETISM AND FERRIMAGNETISM	134
7.1	Antiferromagnetism	134
7.2	Ferrimagnetism	142
7.3	Helimagnetism	148
7.4	Parasitic ferromagnetism	151
7.5	Mictomagnetism and spin glasses	153
	Problems	158
	References	159

Part IV Magnetic Behavior and Structure of Materials

8	MAGNETISM OF METALS AND ALLOYS	163
8.1	Band structure of metals and their magnetic behavior	163
8.2	Magnetism of 3d transition metals and alloys	173
8.3	Magnetism of rare earth metals	181
8.4	Magnetism of intermetallic compounds	188
	Problems	193
	References	193
9	MAGNETISM OF FERRIMAGNETIC OXIDES	197
9.1	Crystal and magnetic structure of oxides	197
9.2	Magnetism of spinel-type oxides	199
9.3	Magnetism of rare earth iron garnets	207
9.4	Magnetism of hexagonal magnetoplumbite-type oxides	210
9.5	Magnetism of other magnetic oxides	215
	Problems	220
	References	220

10	MAGNETISM OF COMPOUNDS	222
10.1	3 <i>d</i> Transition versus IIIb Group magnetic compounds	223
10.2	3 <i>d</i> -IVb Group magnetic compounds	226
10.3	3 <i>d</i> -Vb Group magnetic compounds	228
10.4	3 <i>d</i> -VIb Group magnetic compounds	232
10.5	3 <i>d</i> -VIIb (halogen) Group magnetic compounds	234
10.6	Rare earth compounds	235
	Problems	236
	References	236
11	MAGNETISM OF AMORPHOUS MATERIALS	239
11.1	Magnetism of 3 <i>d</i> transition metal-base amorphous materials	240
11.2	Magnetism of 3 <i>d</i> transition plus rare earth amorphous alloys	243
	Problem	244
	References	245
 Part V Magnetic Anisotropy and Magnetostriction		
12	MAGNETOCRYSTALLINE ANISOTROPY	249
12.1	Phenomenology of magnetocrystalline anisotropy	249
12.2	Methods for measuring magnetic anisotropy	256
12.3	Mechanism of magnetic anisotropy	266
12.4	Experimental data	274
	Problems	296
	References	296
13	INDUCED MAGNETIC ANISOTROPY	299
13.1	Magnetic annealing effect	299
13.2	Roll magnetic anisotropy	309
13.3	Induced magnetic anisotropy associated with crystallographic transformations	318
13.4	Other induced magnetic anisotropies	329
	Problems	339
	References	339
14	MAGNETOSTRICTION	343
14.1	Phenomenology of magnetostriction	343
14.2	Mechanism of magnetostriction	349
14.3	Measuring technique	357
14.4	Experimental data	359
14.5	Volume magnetostriction and anomalous thermal expansion	363
14.6	Magnetic anisotropy caused by magnetostriction	376

14.7 Elastic anomaly and magnetostriction	379
Problems	381
References	381

Part VI Domain Structures

15 OBSERVATION OF DOMAIN STRUCTURES	387
15.1 History of domain observations and powder-pattern method	387
15.2 Magneto-optical method	393
15.3 Lorentz electron microscopy	394
15.4 Scanning electron microscopy	396
15.5 X-ray topography	401
15.6 Electron holography	402
References	405
16 SPIN DISTRIBUTION AND DOMAIN WALLS	407
16.1 Micromagnetics	407
16.2 Domain walls	411
16.3 180° walls	417
16.4 90° walls	422
16.5 Special-type domain walls	428
Problems	432
References	432
17 MAGNETIC DOMAIN STRUCTURES	433
17.1 Magnetostatic energy of domain structures	433
17.2 Size of magnetic domains	439
17.3 Bubble domains	445
17.4 Stripe domains	450
17.5 Domain structure of fine particles	453
17.6 Domain structures in non-ideal ferromagnets	457
Problems	463
References	464

Part VII Magnetization Processes

18 TECHNICAL MAGNETIZATION	467
18.1 Magnetization curve and domain distribution	467
18.2 Domain wall displacement	480
18.3 Magnetization rotation	491
18.4 Rayleigh loop	498
18.5 Law of approach to saturation	503

18.6	Shape of hysteresis loop	509
	Problems	516
	References	516
19	SPIN PHASE TRANSITION	518
19.1	Metamagnetic magnetization processes	518
19.2	Spin flop in ferrimagnetism	521
19.3	High-field magnetization process	529
19.4	Spin reorientation	533
	Problems	535
	References	536
20	DYNAMIC MAGNETIZATION PROCESSES	537
20.1	Magnetic after-effect	537
20.2	Eddy current loss	551
20.3	High-frequency characteristics of magnetization	556
20.4	Spin dynamics	562
20.5	Ferro-, ferri-, and antiferro-magnetic resonance	567
20.6	Equation of motion for domain walls	574
	Problems	580
	References	581
 Part VIII Associated Phenomena and Engineering Applications		
21	VARIOUS PHENOMENA ASSOCIATED WITH MAGNETIZATION	585
21.1	Magnetothermal effects	585
21.2	Magnetoelectric effects	590
21.3	Magneto-optical phenomena	596
	References	598
22	ENGINEERING APPLICATIONS OF MAGNETIC MATERIALS	600
22.1	Soft magnetic materials	600
22.2	Hard magnetic materials	605
22.3	Magnetic memory and memory materials	608
	References	613
	Solutions to problems	615
	Appendix 1. Symbols used in the text	628

Appendix 2. Conversion of various units of energy	631
Appendix 3. Important physical constants	632
Appendix 4. Periodic table of elements and magnetic elements	633
Appendix 5. Conversion of magnetic quantities – MKSA and CGS systems	638
Appendix 6. Conversion of various units for magnetic field	639
Material index	641
Subject index	649