Contents

		page
	Table of Applications	xv
	Preface	xix
1	**Mathematical Preliminaries**	1
1.1	Introduction	1
1.2	Vectors	1
1.3	Derivatives	7
1.4	Integrals	9
1.5	Generalized Functions	11
1.6	Fourier Analysis	15
1.7	Orthogonal Transformations	18
1.8	Cartesian Tensors	20
1.9	The Helmholtz Theorem	22
1.10	Lagrange Multipliers	24
	Sources, References, and Additional Reading	24
	Problems	25
2	**The Maxwell Equations**	29
2.1	Introduction	29
2.2	The Maxwell Equations in Vacuum	33
2.3	Microscopic vs. Macroscopic	38
2.4	The Maxwell Equations in Matter	43
2.5	Quantum Limits and New Physics	46
2.6	SI Units	50
2.7	A Heuristic Derivation	51
	Sources, References, and Additional Reading	53
	Problems	55
3	**Electrostatics**	58
3.1	Introduction	58
3.2	Coulomb's Law	59
3.3	The Scalar Potential	60
3.4	Gauss' Law and Solid Angle	68
3.5	Electrostatic Potential Energy	74
3.6	Electrostatic Total Energy	76
3.7	The Electric Stress Tensor	81
	Sources, References, and Additional Reading	84
	Problems	85

4 Electric Multipoles 90

4.1 Introduction 90
4.2 The Electric Dipole 92
4.3 Electric Dipole Layers 98
4.4 The Electric Quadrupole 102
4.5 Spherical Mathematics 106
4.6 Spherical and Azimuthal Multipoles 109
4.7 Primitive and Traceless Multipole Moments 116
Sources, References, and Additional Reading 119
Problems 121

5 Conducting Matter 126

5.1 Introduction 126
5.2 Electrostatic Induction 126
5.3 Screening and Shielding 133
5.4 Capacitance 134
5.5 The Energy of a System of Conductors 142
5.6 Forces on Conductors 143
5.7 Real Conductors 149
Sources, References, and Additional Reading 151
Problems 152

6 Dielectric Matter 158

6.1 Introduction 158
6.2 Polarization 158
6.3 The Field Produced by Polarized Matter 162
6.4 The Total Electric Field 165
6.5 Simple Dielectric Matter 167
6.6 The Physics of the Dielectric Constant 175
6.7 The Energy of Dielectric Matter 178
6.8 Forces on Dielectric Matter 184
Sources, References, and Additional Reading 191
Problems 193

7 Laplace's Equation 197

7.1 Introduction 197
7.2 Potential Theory 198
7.3 Uniqueness 199
7.4 Separation of Variables 201
7.5 Cartesian Symmetry 203
7.6 Azimuthal Symmetry 209
7.7 Spherical Symmetry 212
7.8 Cylindrical Symmetry 215
7.9 Polar Coordinates 218
7.10 The Complex Potential 221
7.11 A Variational Principle 226
Sources, References, and Additional Reading 228
Problems 229

8 Poisson's Equation 236

8.1 Introduction 236
8.2 The Key Idea: Superposition 236
8.3 The Method of Images 237
8.4 The Green Function Method 250
8.5 The Dirichlet Green Function 252
8.6 The Complex Logarithm Potential 260
8.7 The Poisson-Boltzmann Equation 262
Sources, References, and Additional Reading 264
Problems 265

9 Steady Current 272

9.1 Introduction 272
9.2 Current in Vacuum 273
9.3 Current in Matter 275
9.4 Potential Theory for Ohmic Matter 276
9.5 Electrical Resistance 277
9.6 Joule Heating 280
9.7 Electromotive Force 282
9.8 Current Sources 287
9.9 Diffusion Current: Fick's Law 291
Sources, References, and Additional Reading 293
Problems 294

10 Magnetostatics 301

10.1 Introduction 301
10.2 The Law of Biot and Savart 304
10.3 Ampère's Law 307
10.4 The Magnetic Scalar Potential 312
10.5 The Vector Potential 320
10.6 The Topology of Magnetic Field Lines 325
Sources, References, and Additional Reading 328
Problems 329

11 Magnetic Multipoles 336

11.1 Introduction 336
11.2 The Magnetic Dipole 337
11.3 Magnetic Dipole Layers 345
11.4 Exterior Multipoles 346
11.5 Interior Multipoles 353
11.6 Axially Symmetric Magnetic Fields 357
Sources, References, and Additional Reading 359
Problems 361

12 Magnetic Force and Energy 365

12.1 Introduction 365
12.2 Charged Particle Motion 366

12.3 The Force between Steady Currents 368
12.4 The Magnetic Dipole 372
12.5 The Magnetic Stress Tensor 381
12.6 Magnetostatic Total Energy 384
12.7 Magnetostatic Potential Energy 389
12.8 Inductance 394
Sources, References, and Additional Reading 399
Problems 401

13 Magnetic Matter 407
13.1 Introduction 407
13.2 Magnetization 407
13.3 The Field Produced by Magnetized Matter 412
13.4 Fictitious Magnetic Charge 415
13.5 The Total Magnetic Field 419
13.6 Simple Magnetic Matter 421
13.7 The Energy of Magnetic Matter 433
13.8 Forces on Magnetic Matter 435
13.9 Permanent Magnetic Matter 443
Sources, References, and Additional Reading 447
Problems 448

14 Dynamic and Quasistatic Fields 455
14.1 Introduction 455
14.2 The Ampère-Maxwell Law 456
14.3 Faraday's Law 460
14.4 Electromagnetic Induction 462
14.5 Slowly Time-Varying Charge in Vacuum 467
14.6 Slowly Time-Varying Current in Vacuum 470
14.7 Quasistatic Fields in Matter 472
14.8 Poor Conductors: Quasi-Electrostatics 473
14.9 Good Conductors: Quasi-Magnetostatics 475
14.10 The Skin Effect 477
14.11 Magnetic Diffusion 481
14.12 Eddy-Current Phenomena 483
14.13 AC Circuit Theory 486
Sources, References, and Additional Reading 493
Problems 494

15 General Electromagnetic Fields 501
15.1 Introduction 501
15.2 Symmetry 501
15.3 Electromagnetic Potentials 503
15.4 Conservation of Energy 507
15.5 Conservation of Linear Momentum 511
15.6 Conservation of Angular Momentum 516
15.7 The Center of Energy 519
15.8 Conservation Laws in Matter 522

15.9 The Force on Isolated Matter 526
Sources, References, and Additional Reading 529
Problems 531

16 Waves in Vacuum 536
16.1 Introduction 536
16.2 The Wave Equation 537
16.3 Plane Waves 539
16.4 Polarization 545
16.5 Wave Packets 552
16.6 The Helmholtz Equation 557
16.7 Beam-Like Waves 558
16.8 Spherical Waves 565
16.9 Hertz Vectors 569
16.10 Forces on Particles in Free Fields 571
Sources, References, and Additional Reading 575
Problems 577

17 Waves in Simple Matter 584
17.1 Introduction 584
17.2 Plane Waves 584
17.3 Reflection and Refraction 588
17.4 Radiation Pressure 599
17.5 Layered Matter 602
17.6 Simple Conducting Matter 607
17.7 Anisotropic Matter 613
Sources, References, and Additional Reading 616
Problems 617

18 Waves in Dispersive Matter 624
18.1 Introduction 624
18.2 Frequency Dispersion 624
18.3 Energy in Dispersive Matter 627
18.4 Transverse and Longitudinal Waves 629
18.5 Classical Models for Frequency Dispersion 630
18.6 Wave Packets in Dispersive Matter 641
18.7 The Consequences of Causality 649
18.8 Spatial Dispersion 656
Sources, References, and Additional Reading 657
Problems 659

19 Guided and Confined Waves 666
19.1 Introduction 666
19.2 Transmission Lines 667
19.3 Planar Conductors 672
19.4 Conducting Tubes 675
19.5 Dielectric Waveguides 687
19.6 Conducting Cavities 693

19.7 Dielectric Resonators 704
Sources, References, and Additional Reading 706
Problems 707

20 Retardation and Radiation 714

20.1 Introduction 714
20.2 Inhomogeneous Wave Equations 715
20.3 Retardation 719
20.4 The Time-Dependent Electric Dipole 727
20.5 Radiation 730
20.6 Thin-Wire Antennas 737
20.7 Cartesian Multipole Radiation 743
20.8 Spherical Multipole Radiation 755
20.9 Radiation in Matter 762
Sources, References, and Additional Reading 765
Problems 767

21 Scattering and Diffraction 775

21.1 Introduction 775
21.2 The Scattering Cross Section 776
21.3 Thomson Scattering 777
21.4 Rayleigh Scattering 782
21.5 Two Exactly Solvable Problems 783
21.6 Two Approximation Schemes 790
21.7 The Total Cross Section 793
21.8 Diffraction by a Planar Aperture 797
21.9 Generalized Optical Principles 807
Sources, References, and Additional Reading 812
Problems 814

22 Special Relativity 822

22.1 Introduction 822
22.2 Galileo's Relativity 823
22.3 Einstein's Relativity 825
22.4 The Lorentz Transformation 826
22.5 Four-Vectors 834
22.6 Electromagnetic Quantities 839
22.7 Covariant Electrodynamics 848
22.8 Matter in Uniform Motion 858
Sources, References, and Additional Reading 863
Problems 865

23 Fields from Moving Charges 870

23.1 Introduction 870
23.2 The Liénard-Wiechert Problem 870
23.3 Radiation in the Time Domain 880
23.4 Radiation in the Frequency Domain 886
23.5 Synchrotron Radiation 891

23.6 Radiation Reaction 899
23.7 Cherenkov Radiation 906
Sources, References, and Additional Reading 910
Problems 912

24 Lagrangian and Hamiltonian Methods 916

24.1 Introduction 916
24.2 Hamilton's Principle 916
24.3 Lagrangian Description 918
24.4 Invariance and Conservation Laws 927
24.5 Hamiltonian Description 931
Sources, References, and Additional Reading 940
Problems 941

Appendix A List of Important Symbols 945
Appendix B Gaussian Units 949
Appendix C Special Functions 953
Appendix D Managing Minus Signs in Special Relativity 959

Index 964