

Contents

<i>Table of Applications</i>	<i>page</i> xv
<i>Preface</i>	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
<i>Sources, References, and Additional Reading</i>	24
<i>Problems</i>	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
<i>Sources, References, and Additional Reading</i>	53
<i>Problems</i>	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
<i>Sources, References, and Additional Reading</i>	84
<i>Problems</i>	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
	<i>Sources, References, and Additional Reading</i>	119
	<i>Problems</i>	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
	<i>Sources, References, and Additional Reading</i>	151
	<i>Problems</i>	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
	<i>Sources, References, and Additional Reading</i>	191
	<i>Problems</i>	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
	<i>Sources, References, and Additional Reading</i>	228
	<i>Problems</i>	229

CONTENTS

ix

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
	<i>Sources, References, and Additional Reading</i>	264
	<i>Problems</i>	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
	<i>Sources, References, and Additional Reading</i>	293
	<i>Problems</i>	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
	<i>Sources, References, and Additional Reading</i>	328
	<i>Problems</i>	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
	<i>Sources, References, and Additional Reading</i>	359
	<i>Problems</i>	361
12	Magnetic Force and Energy	365
12.1	Introduction	365
12.2	Charged Particle Motion	366

x	CONTENTS	
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
	<i>Sources, References, and Additional Reading</i>	399
	<i>Problems</i>	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
	<i>Sources, References, and Additional Reading</i>	447
	<i>Problems</i>	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
	<i>Sources, References, and Additional Reading</i>	493
	<i>Problems</i>	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

CONTENTS	xi
15.9 The Force on Isolated Matter	526
<i>Sources, References, and Additional Reading</i>	529
<i>Problems</i>	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
<i>Sources, References, and Additional Reading</i>	575
<i>Problems</i>	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
<i>Sources, References, and Additional Reading</i>	616
<i>Problems</i>	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
<i>Sources, References, and Additional Reading</i>	657
<i>Problems</i>	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

xii	CONTENTS	
19.7	Dielectric Resonators	704
	<i>Sources, References, and Additional Reading</i>	706
	<i>Problems</i>	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
	<i>Sources, References, and Additional Reading</i>	765
	<i>Problems</i>	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
	<i>Sources, References, and Additional Reading</i>	812
	<i>Problems</i>	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
	<i>Sources, References, and Additional Reading</i>	863
	<i>Problems</i>	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

CONTENTS	xiii
23.6 Radiation Reaction	899
23.7 Cherenkov Radiation	906
<i>Sources, References, and Additional Reading</i>	910
<i>Problems</i>	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
<i>Sources, References, and Additional Reading</i>	940
<i>Problems</i>	941
<i>Appendix A List of Important Symbols</i>	945
<i>Appendix B Gaussian Units</i>	949
<i>Appendix C Special Functions</i>	953
<i>Appendix D Managing Minus Signs in Special Relativity</i>	959
<i>Index</i>	964