Contents

Introdu	ction d	and Survey	1
	I.1	Maxwell Equations in Vacuum, Fields, and Sources 2	
	I.2	Inverse Square Law, or the Mass of the Photon 5	
	I.3	Linear Superposition 9	
	I.4	Maxwell Equations in Macroscopic Media 13	
	I.5	Boundary Conditions at Interfaces Between Different Media 16	
	I.6	Some Remarks on Idealizations in Electromagnetism 19 References and Suggested Reading 22	
Chapter	1 / In	troduction to Electrostatics	24
	1.1	Coulomb's Law 24	
	1.2	Electric Field 24	
	1.3	Gauss's Law 27	
	1.4	Differential Form of Gauss's Law 28	
	1.5	Another Equation of Electrostatics and the Scalar Potential 29	
	1.6	Surface Distributions of Charges and Dipoles and Discontinuities	
		in the Electric Field and Potential 31	
	1.7	Poisson and Laplace Equations 34	
	1.8	Green's Theorem 35	
	1.9	Uniqueness of the Solution with Dirichlet or Neumann Boundary Conditions 37	
	1.10	Formal Solution of Electrostatic Boundary-Value Problem with Green Function 38	
	1.11		40
	1.12	Variational Approach to the Solution of the Laplace and Poisson	,,
		Equations 43	
	1.13	Relaxation Method for Two-Dimensional Electrostatic Problems References and Suggested Reading 50 Problems 50	47
Chapter	2 / Be	oundary-Value Problems in Electrostatics: I	57
	2.1	Method of Images 57	
	2.2	Point Charge in the Presence of a Grounded Conducting Sphere	58
	2.3	Point Charge in the Presence of a Charged, Insulated, Conducting Sphere 60	
	2.4	Point Charge Near a Conducting Sphere at Fixed Potential 61	
	2.5	Conducting Sphere in a Uniform Electric Field by Method	
		of Images 62	
	2.6	Green Function for the Sphere; General Solution	
		for the Potential 64	
	2.7	Conducting Sphere with Hemispheres at Different Potentials 65	

	2.8	Orthogonal Functions and Expansions 67	
	2.9	Separation of Variables; Laplace Equation in Rectangular	
		Coordinates 70	
	2.10	A Two-Dimensional Potential Problem; Summation	
		of Fourier Series 72	
	2.11	Fields and Charge Densities in Two-Dimensional Corners	
		and Along Edges 75	
	2.12	Introduction to Finite Element Analysis for Electrostatics 79	
		References and Suggested Reading 84	
		Problems 85	
Chantar	1 / D	oundam Valua Problems in Flastrostation II	95
Chapter	SID	oundary-Value Problems in Electrostatics: II	93
	3.1	Laplace Equation in Spherical Coordinates 95	
	3.2	Legendre Equation and Legendre Polynomials 96	
	3.3	Boundary-Value Problems with Azimuthal Symmetry 101	
	3.4	Behavior of Fields in a Conical Hole or Near a Sharp Point 104	
	3.5	Associated Legendre Functions and the Spherical Harmonics	
		$Y_{lm}(\theta, \phi)$ 107	
	3.6	Addition Theorem for Spherical Harmonics 110	
	3.7		11
	3.8	Boundary-Value Problems in Cylindrical Coordinates 117	
	3.9	Expansion of Green Functions in Spherical Coordinates 119	
	3.10	Solution of Potential Problems with the Spherical Green Function	
		Expansion 112	
	3.11	Expansion of Green Functions in Cylindrical Coordinates 125	
	3.12	Eigenfunction Expansions for Green Functions 127	
	3.13	Mixed Boundary Conditions, Conducting Plane with a Circular	
		Hole 129	
		References and Suggested Reading 135	
		Problems 135	
Chapter	4 / M	Iultipoles, Electrostatics of Macroscopic Media,	
Dielectr			145
	4.1	Modern P. Communication	
	4.1	Multipole Expansion 145	
	4.2	Multipole Expansion of the Energy of a Charge Distribution	
	4.2	in an External Field 150	1.51
	4.3		151
	4.4	Boundary-Value Problems with Dielectrics 154	
	4.5	Molecular Polarizability and Electric Susceptibility 159	
	4.6	Models for Electric Polarizability 162	
	4.7	Electrostatic Energy in Dielectric Media 165	
		References and Suggested Reading 169	
		Problems 169	
Chapter	5 / M	lagnetostatics, Faraday's Law, Quasi-Static Fields	174
		Introduction and Definitions 174	
	5.1 5.2	Biot and Savart Law 175	
	J.L	DIUL MIG JUTALL LAW 1/J	

	5.3	Differential Equations of Magnetostatics and Ampère's Law 178
	5.4	Vector Potential 180
	5.5	Vector Potential and Magnetic Induction for a Circular Current Loop 181
	5.6	Magnetic Fields of a Localized Current Distribution, Magnetic Moment 184
	5.7	Force and Torque on and Energy of a Localized Current Distribution in an External Magnetic Induction 188
	5.8	Macroscopic Equations, Boundary Conditions on B and H 191
	5.9	Methods of Solving Boundary-Value Problems in Magnetostatics 194
	5.10	Uniformly Magnetized Sphere 198
	5.11	Magnetized Sphere in an External Field; Permanent Magnets 199
	5.12	Magnetic Shielding, Spherical Shell of Permeable Material in a Uniform Field 201
	5.13	Effect of a Circular Hole in a Perfectly Conducting Plane with an Asymptotically Uniform Tangential Magnetic Field on One Side 203
	5.14	Numerical Methods for Two-Dimensional Magnetic Fields 206
	5.15	Faraday's Law of Induction 208
	5.16	Energy in the Magnetic Field 212
	5.17	Energy and Self- and Mutual Inductances 215
	5.18	Quasi-Static Magnetic Fields in Conductors; Eddy Currents; Magnetic
		Diffusion 218
		References and Suggested Reading 223
		Problems 225
~		
-		axwell Equations, Macroscopic Electromagnetism,
Conserve	ation .	Laws 237
	6.1	Maxwell's Displacement Current; Maxwell Equations 237
	6.2	Vector and Scalar Potentials 239
	6.3	Gauge Transformations, Lorenz Gauge, Coulomb Gauge 240
	6.4	Green Functions for the Wave Equation 243
	6.5	Retarded Solutions for the Fields: Jefimenko's Generalizations
		of the Coulomb and Biot-Savart Laws; Heaviside-Feynman
		Expressions for Fields of Point Charge 246
	6.6	Derivation of the Equations of Macroscopic Electromagnetism 248
	6.7	Poynting's Theorem and Conservation of Energy and Momentum
		for a System of Charged Particles and Electromagnetic Fields 258
	6.8	Poynting's Theorem in Linear Dissipative Media with Losses 262
	6.9	Poynting's Theorem for Harmonic Fields; Field Definitions
		of Impedance and Admittance 264
	6.10	Transformation Properties of Electromagnetic Fields and Sources
		Under Rotations, Spatial Reflections, and Time Reversal 267
	6.11	On the Question of Magnetic Monopoles 273
	6.12	Discussion of the Dirac Quantization Condition 275
	6.13	Polarization Potentials (Hertz Vectors) 280
		References and Suggested Reading 282
		Problems 283

Chapte	er 7 / <i>P</i>	lane Electromagnetic Waves and Wave Propagation 295
	7.1	Plane Waves in a Nonconducting Medium 295
	7.2	Linear and Circular Polarization; Stokes Parameters 299
	7.3	Reflection and Refraction of Electromagnetic Waves at a Plane
		Interface Between Two Dielectrics 302
	7.4	Polarization by Reflection, Total Internal Reflection; Goos-Hänchen Effect 306
	7.5	Frequency Dispersion Characteristics of Dielectrics, Conductors, and Plasmas 309
	7.6	Simplified Model of Propagation in the Ionosphere and Magnetosphere 316
	7.7	Magnetohydrodynamic Waves 319
	7.8	Superposition of Waves in One Dimension; Group Velocity 322
	7.9	Illustration of the Spreading of a Pulse As It Propagates in a Dispersive Medium 326
	7.10	Causality in the Connection Between D and E ; Kramers-Kronig Relations 330
	7.11	Arrival of a Signal After Propagation Through a Dispersive Medium 335
		References and Suggested Reading 339
		Problems 340
Chapt		Vaveguides, Resonant Cavities, and Optical Fibers 352
	8.1	Fields at the Surface of and Within a Conductor 352
	8.2	Cylindrical Cavities and Waveguides 356
	8.3 8.4	Waveguides 359
	8.5	Modes in a Rectangular Waveguide 361
	8.6	Energy Flow and Attenuation in Waveguides 363 Perturbation of Boundary Conditions 366
	8.7	Perturbation of Boundary Conditions 366 Resonant Cavities 368
	8.8	Power Losses in a Cavity; Q of a Cavity 371
	8.9	Earth and Ionosphere as a Resonant Cavity: Schumann Resonances 374
	8.10	Multimode Propagation in Optical Fibers 378
	8.11	Modes in Dielectric Waveguides 385
	8.12	Expansion in Normal Modes; Fields Generated by a Localized
		Source in a Hollow Metallic Guide 389
		References and Suggested Reading 395
		Problems 396
Chapt	er 9 / <i>R</i>	adiating Systems, Multipole Fields and Radiation 407
	9.1	Fields and Radiation of a Localized Oscillating Source 407
	9.2	Electric Dipole Fields and Radiation 410
	9.3	Magnetic Dipole and Electric Quadrupole Fields 413
	9.4	Center-Fed Linear Antenna 416
	9.5	Multipole Expansion for Localized Source or Aperture in Waveguide 419

	9.6 9.7 9.8 9.9 9.10 9.11 9.12	Multipole Expansion of the Electromagnetic Fields 429 Properties of Multipole Fields, Energy and Angular Momentum of Multipole Radiation 432 Angular Distribution of Multipole Radiation 437 Sources of Multipole Radiation; Multipole Moments 439 Multipole Radiation in Atoms and Nuclei 442 Multipole Radiation from a Linear, Center-Fed Antenna 444 References and Suggested Reading 448 Problems 449	
Chapter	10 / 5	Scattering and Diffraction	456
	10.1 10.2	Scattering at Long Wavelengths 456 Perturbation Theory of Scattering, Rayleigh's Explanation of the Blue Sky, Scattering by Gases and Liquids, Attenuation in Optical Fibers 462	
	10.3 10.4	Spherical Wave Expansion of a Vector Plane Wave 471	
	10.4	Scattering of Electromagnetic Waves by a Sphere 473 Scalar Diffraction Theory 478	
	10.6	Vector Equivalents of the Kirchhoff Integral 482	
	10.7	Vectorial Diffraction Theory 485	
	10.8	Babinet's Principle of Complementary Screens 488	
	10.9	Diffraction by a Circular Aperture; Remarks on Small Apertures 490	
	10.10 10.11	Scattering in the Short-Wavelength Limit 495 Optical Theorem and Related Matters 500 References and Suggested Reading 506 Problems 507	
Chapter	11 / S	pecial Theory of Relativity	514
	11.1	The Situation Before 1900, Einstein's Two Postulates 515	
	11.2 11.3	Some Recent Experiments 518 Lorentz Transformations and Basic Kinematic Results of Special Relativity 524	
	11.4	Addition of Velocities; 4-Velocity 530	
	11.5	Relativistic Momentum and Energy of a Particle 533	
	11.6	Mathematical Properties of the Space-Time of Special Relativity 539	
	11.7	Matrix Representation of Lorentz Transformations, Infinitesimal Generators 543	
	11.8	Thomas Precession 548	
	11.9		53
		Transformation of Electromagnetic Fields 558 Relativistic Equation of Motion for Spin in Uniform or Slowly Vary External Fields 561	ing
	11.12	Note on Notation and Units in Relativistic Kinematics 565 References and Suggested Reading 566 Problems 568	

14.4

14.5

Charge

Motion

Chapter 12 /	Dynamics of Relativistic Particles
and Electron	agnetic Fields 579
12.1	Lagrangian and Hamiltonian for a Relativistic Charged Particle
	in External Electromagnetic Fields 579
12.2	Motion in a Uniform, Static Magnetic Field 585
12.3	Motion in Combined, Uniform, Static Electric and Magnetic Fields 586
12.4	Particle Drifts in Nonuniform, Static Magnetic Fields 588
12.5	Adiabatic Invariance of Flux Through Orbit of Particle 592
12.6	Lowest Order Relativistic Corrections to the Lagrangian for Interacting
	Charged Particles: The Darwin Lagrangian 596
12.7	Lagrangian for the Electromagnetic Field 598
12.8	Proca Lagrangian; Photon Mass Effects 600
12.9	Effective "Photon" Mass in Superconductivity; London Penetration
10.10	Depth 603
	Canonical and Symmetric Stress Tensors; Conservation Laws 605
12.11	Solution of the Wave Equation in Covariant Form; Invariant Green
	Functions 612
	References and Suggested Reading 615 Problems 617
	Froblems 017
Chapter 12 /	Collisions Emorgy Loss and Scattering of Channel Bantislan
	Collisions, Energy Loss, and Scattering of Charged Particles, and Transition Radiation 624
	··· = · ··· · · · · · · · · · · · · · ·
13.1	Energy Transfer in Coulomb Collision Between Heavy Incident Particle
	and Free Electron; Energy Loss in Hard Collisions 625
13.2	Energy Loss from Soft Collisions; Total Energy Loss 627
13.3	Density Effect in Collisional Energy Loss 631
13.4	Cherenkov Radiation 637
13.5	Elastic Scattering of Fast Charged Particles by Atoms 640
13.6	Mean Square Angle of Scattering; Angular Distribution of Multiple Scattering 643
13.7	Transition Radiation 646
	References and Suggested Reading 654
	Problems 655
Chapter 14 /	Radiation by Moving Charges 661
14.1	Liénard-Wiechert Potentials and Fields for a Point Charge 661
14.2	Total Power Radiated by an Accelerated Charge: Larmor's Formula and Its Relativistic Generalization 665
14.3	Angular Distribution of Radiation Emitted by an Accelerated

Radiation Emitted by a Charge in Arbitrary, Extremely Relativistic

673

Distribution in Frequency and Angle of Energy Radiated

by Accelerated Charges: Basic Results

	14.7 14.8	Particle in Instantaneously Circular Motion 676 Undulators and Wigglers for Synchrotron Light Sources Thomson Scattering of Radiation 694 References and Suggested Reading 697 Problems 698	683	
		Bremsstrahlung, Method of Virtual Quanta, a Processes		708
	15.1 15.2 15.3 15.4 15.5 15.6 15.7	Radiation Emitted During Collisions 709 Bremsstrahlung in Coulomb Collisions 714 Screening Effects; Relativistic Radiative Energy Loss Weizsäcker-Williams Method of Virtual Quanta 724 Bremsstrahlung as the Scattering of Virtual Quanta 72 Radiation Emitted During Beta Decay 730 Radiation Emitted During Orbital Electron Capture: Disa of Charge and Magnetic Moment 732 References and Suggested Reading 737 Problems 737		
Chapter of Charg		Radiation Damping, Classical Models articles		745
	16.1 16.2	Introductory Considerations 745 Radiative Reaction Force from Conservation of Energy	747	
	16.3	Abraham-Lorentz Evaluation of the Self-Force 750		
	16.4 16.5	Relativistic Covariance; Stability and Poincaré Stresses Covariant Definitions of Electromagnetic Energy and Momentum 757	755	
	16.6	Covariant Stable Charged Particle 759		
	16.7 16.8	Level Breadth and Level Shift of a Radiating Oscillator Scattering and Absorption of Radiation by an Oscillator References and Suggested Reading 768 Problems 769	763 766	
A <i>ppend</i> i.	x on l	Units and Dimensions		775
	1 2 3 4	Units and Dimensions, Basic Units and Derived Units Electromagnetic Units and Equations 777 Various Systems of Electromagnetic Units 779 Conversion of Equations and Amounts Between SI Units and Gaussian Units 782	775	
	Biblio	graphy 785		
	Index	791		

14.6 Frequency Spectrum of Radiation Emitted by a Relativistic Charged