## CONTENTS

Chapter 1. The Electrostatic Field in Vacuum ..... 1
1-1 Vector fields ..... 1
1-2 The electric field ..... 7
1-3 Coulomb's law ..... 8
1-4 The electrostatic potential ..... 10
1-5 The potential in terms of charge distribution ..... 11
1-6 Field singularities ..... 13
1-7 Clusters of point charges ..... 13
-8 Dipole interactions ..... 19
1-9 Surface singularities ..... 20
-10 Volume distributions of dipole moment ..... 23
Chapter 2. Boundary Conditions and Relation of Microscopic to Macroscopic Fields ..... 28
2-1 The displacement vector ..... 28
2-2 Boundary conditions ..... 31
2-3 The electric field in a material medium ..... 33
2-4 Polarizability ..... 38
Chapter 3. General Methods for the Solution of Potential Problems ..... 42
3-1 Uniqueness theorem ..... 42
3-2 Green's reciprocation theorem ..... 43
3-3 Solution by Green's function ..... 44
3-4 Solution by inversion ..... 47
3-5 Solution by electrical images ..... 49
3-6 Solution of Laplace's equation by the separation of variables ..... 53
Chapter 4. Two-dimensional Potential Problems ..... 61
4-1 Conjugate complex functions ..... 61
4-2 Capacity and field strength ..... 63
4-3 The potential of a uniform field ..... 64
4-4 The potential of a line charge ..... 64
-5 Complex transformations ..... 66
4-6 General Schwarz transformation ..... 67
4-7 Single-angle transformations ..... 70
4-8 Multiple-angle transformations71
4-9 Direct solution of Laplace's equation by the method of harmonics ..... 73
4-10 Illustration: Line charge and dielectric cylinder ..... 74
-11 Line charge in an angle between two conductors ..... 77
Chapter 5. Three-dimensional Potential Problem ..... 81
5-1 The solution of Laplace's equation in spherical coordinates81
82
83
5-2 The potential of a point charge
5-3 The potential of a dielectric sphere and a point charge ..... 83
5-4 The potential of a dielectric sphere in a uniform field ..... 84
5-5 The potential of an arbitrary axially-symmetric spherical potential distribution ..... 86
5-6 The potential of a charged ring ..... 87
5-7 Problems not having axial symmetry ..... 88
5-8 The solution of Laplace's equation in cylindrical coordinates ..... 88
5-9 Application of cylindrical solutions to potential problems ..... 91
Chapter 6. Energy Relations and Forces in the Electro- static Field ..... 95
6-1 Field energy in free space ..... 95
6-2 Energy density within a dielectric ..... 98
6-3 Thermodynamic interpretation of $U$ ..... 100
6-4 Thomson's theorem
101
101
-5 Maxwell stress tensor ..... 103
6-6 Volume forces in the electrostatic field in the presence of dielectrics ..... 107
6-7 The behavior of dielectric liquids in an electrostatic field ..... 111
Chapter 7. Steady Currents and Their Interaction ..... 118
7-1 Ohm's law ..... 118
7-2 Electromotive force ..... 119
7-3 The solution of stationary current problems ..... 120
7-4 Time of relaxation in a homogeneous medium ..... 122
-5 The magnetic interaction of steady line currents ..... 123
$7-6$ The magnetic induction field ..... 125
7-7 The magnetic scalar potential ..... 125
7-8 The magnetic vector potential ..... 127
7-9 Types of currents ..... 129
7-10 Polarization currents ..... 129
7-11 Magnetic moments ..... 130
7-12 Magnetization and magnetization currents ..... 13
7-13 Vacuum displacement current ..... 135
Chapter 8. Magnetic Materials and Boundary Value Problems ..... 139
8-1 Magnetic field intensity
139
139
8-2 Magnetic sources ..... 140
8-3 Permeable media: magnetic susceptibility and boundary conditions ..... 144
8-4 Magnetic circuits ..... 145
8-5 Solution of boundary value problems by magnetic scalar potentials. ..... 146
8-6 Uniqueness theorem for the vector potential ..... 147
8-7 The use of the vector potential in the solution of problems ..... 148
8-8 The vector potential in two dimensions ..... 151
8-9 The vector potential in cylindrical coordinates ..... 153
Chapter 9. Maxwell's Equations ..... 158
9-1 Faraday's law of induction ..... 158
9-2 Maxwell's equations for stationary media ..... 159
9-3 Faraday's law for moving media ..... 160
9-4 Maxwell's equations for moving media ..... 163
9-5 Motion of a conductor in a magnetic field ..... 165
Chapter 10. Energy, Force, and Momentum Relations in the Electromagnetic Field ..... 170
10-1 Energy relations in quasi-stationary current systems ..... 170
10-2 Forces on current systems ..... 172
10-3 Inductance ..... 174
10-4 Magnetic volume force ..... 177
10-5 General expressions for electromagnetic energy ..... 178
10-6 Momentum balance ..... 181
Chapter 11. The Wave Equation and Plane Waves ..... 185
11-1 The wave equation ..... 185
11-2 Plane waves ..... 187
11-3 Radiation pressure ..... 191
11-4 Plane waves in a moving medium ..... 193
11-5 Reflection and refraction at a plane boundary ..... 195
11-6 Waves in conducting media and metallic reflection00
11-7 Group velocity ..... 202
Chapter 12. Conducting Fluids in a Magnetic Field (MAGNETOHYDRODYNAMICS) ..... 205
12-1 "Frozen-in" lines of force ..... 205
12-2 Magnetohydrodynamic waves ..... 207
Chapter 13. Waves in the Presence of Metallic Boundaries ..... 212
13-1 The nature of metallic boundary conditions ..... 212
13-2 Eigenfunctions and eigenvalues of the wave equation ..... 214
13-3 Cavities with rectangular boundaries ..... 218
13-4 Cylindrical cavities ..... 219
13-5 Circular cylindrical cavities ..... 222
13-6 Wave guides ..... 223
13-7 Scattering by a circular cylinder ..... 226
13-8 Spherical waves ..... 229
13-9 Scattering by a sphere ..... 233
Chapter 14. The Inhomogeneous Wave Equation ..... 240
14-1 The wave equation for the potentials ..... 240
14-2 Solution by Fourier analysis ..... 242
14-3 The radiation fields ..... 245
14-4 Radiated energy ..... 248
14-5 The Hertz potential ..... 254
14-6 Computation of radiation fields by the Hertz method ..... 255
14-7 Electric dipole radiation ..... 257
14-8 Multipole radiation ..... 260
14-9 Derivation of multipole radiation from scalar superpotentials ..... 264
14-10 Energy and angular momentum radiated by multipoles ..... 267
Chapter 15. The Experimental Basis for the Theory of Special Relativity ..... 272
15-1 Galilean relativity and electrodynamics ..... 272
15-2 The search for an absolute ether frame ..... 274
15-3 The Lorentz-Fitzgerald contraction hypothesis ..... 278
15-4 "Ether drag" ..... 279
15-5 Emission theories283
Chapter 16. Relativistic Kinematics and the Lorentz Transformation ..... 286
16-1 The velocity of light and simultaneity ..... 286
16-2 Kinematic relations in special relativity ..... 288
16-3 The Lorentz transformation ..... 293
16-4 Geometric interpretations of the Lorentz transformation ..... 301
Chapter 17. Covariance and Relativistic Mechanics ..... 305
17-1 The Lorentz transformation of a four-vector ..... 305
17-2 Some tensor relations useful in special relativity ..... 307
17-3 The conservation of momentum ..... 311
17-4 Relation of energy to momentum and to mass . ..... 313
17-5 'The Minkowski force ..... 316
17-6 The collision of two similar particles ..... 318
17-7 The use of four-vectors in calculating kinematic relations for collisions ..... 320
Chapter 18. Covariant Formulation of Electrodynamics ..... 324
18-1 The four-vector potential ..... 324
18-2 The electromagnetic field tensor ..... 327
18-3 The Lorentz force in vacuum ..... 331
18-4 Covariant description of sources in material media ..... 332
18-5 The field equations in a material medium ..... 334
18-6 Transformation properties of the partial fields ..... 336
Chapter 19. The Lienard-Wiechert Potentials and the Field of a Uniformly Moving Electron ..... 341
19-1 The Liénard-Wiechert potential ..... 341
19-2 The fields of a charge in uniform motion ..... 344
19-3 Direct solution of the wave equation ..... 347
19-4 The "convection potential" ..... 348
19-5 The virtual photon concept ..... 350
Chapter 20. Radiation from an Accelerated Charge ..... 354
20-1 Fields of an accelerated charge ..... 354
20-2 Radiation at low velocity ..... 358
20-3 The case of $\dot{\mathbf{u}}$ parallel to $\mathbf{u}$ ..... 359
20-4 Radiation when the acceleration is perpendicular to the velocity (radiation from circular orbits) ..... 363
20-5 Radiation with no restrictions on the acceleration or velocity ..... 370
20-6 Classical cross section for bremsstrahlung in a Coulomb field ..... 371
20-7 Čerenkov radiation ..... 373
Chapter 21. Radiation Reaction and Covariant Formulation of the Conservation Laws of Electrodynamics . ..... 377
21-1 Covariant formulation of the conservation laws of vacuum electrodynamics ..... 377
21-2 Transformation properties of the "free" radiation field ..... 379
21-3 The electromagnetic energy momentum tensor in material media ..... 380
21-4 Electromagnetic mass ..... 381
21-5 Electromagnetic mass-qualitative considerations ..... 383
21-6 The reaction necessary to conserve radiated energy ..... 386
21-7 Direct computation of the radiation reaction from the retarded fields ..... 387
21-8 Properties of the equation of motion ..... 389
21-9 Covariant description of the mechanical properties of the electromagnetic field of a charge ..... 390
21-10 The relativistic equations of motion ..... 392
21-11 The integration of the relativistic equation of motion ..... 394
21-12 Modification of the theory of radiation to eliminate divergent mass integrals. Advanced potentials ..... 394
21-13 Direct calculation of the relativistic radiation reaction ..... 398
Chapter 22. Radiation, Scattering, and Dispersion ..... 401
22-1 Radiative damping of a charged harmonic oscillator ..... 401
22-2 Forced vibrations ..... 403
22-3 Scattering by an individual free electron ..... 404
22-4 Scattering by a bound electron ..... 407
22-5 Absorption of radiation by an oscillator ..... 407
22-6 Equilibrium between an oscillator and a radiation field ..... 409
22-7 Effect of a volume distribution of scatterers ..... 411
22-8 Scattering from a volume distribution. Rayleigh scattering ..... 414
22-9 The dispersion relation ..... 416
$22-10 \mathrm{~A}$ general theorem on scattering and absorption ..... 419
Chapter 23. The Motion of Charged Particles in Electro- magnetic Fields ..... 425
23-1 World-line description ..... 425
23-2 Hamiltonian formulation and the transition to three- dimensional formalism ..... 427
23-3 Equations for the trajectories ..... 430
23-4 Applications ..... 433
23-5 The motion of a particle with magnetic moment in an electromagnetic field ..... 437
Chapter 24. Hamiltonian Formulation of Maxwell's Equations ..... 446
24-1 Transition to a one-dimensional continuous system ..... 446
24-2 Generalization to a three-dimensional continuum ..... 448
24-3 The electromagnetic field ..... 451
24-4 Periodic solutions in a box. Plane wave representation ..... 454
Appendix I. Units and Dimensions in Electromagnetic Theory ..... 459
Tables: I-1. Conversion Factors. ..... 465
I-2. Fundamental Electromagnetic Relations Valid in vacuo as They Appear in the Various Systems of Units ..... 466
I-3. Definition of Fields from Sources (mks system) ..... 468
1-4. Useful Numerical Relations ..... 469
Appendix II. Useful Vector Relations ..... 470
Table II-1. Vector Formulas ..... 470
Appendix III. Vector Relations in Curvilinear Coordinates. ..... 473
Table III-1. Coordinate Systems ..... 475
Bibliography ..... 479
Index ..... 485

