

Contents

1	Electrodynamics: Foundations	1
1.1	The Law of Induction	2
1.1.1	The Law of Faraday	2
1.1.2	Self- and Mutual Induction	6
1.2	The Maxwell Equations	10
1.3	Electromagnetic Waves	15
1.3.1	Wave Equations	15
1.3.2	Wave Solutions of the Maxwell Equations	24
1.3.3	Properties of Electromagnetic Waves	27
1.4	Energy and Momentum of the Electromagnetic Field	35
1.4.1	Energy Transport by Electromagnetic Waves	35
1.4.2	Momentum Conservation	39
1.5	Electromagnetic Potentials	42
1.6	The Solution of the Inhomogeneous Wave Equation	45
1.7	Details	50
1.7.1	The Transformation of Faraday's Law	50
1.7.2	Some Properties of Plane Electromagnetic Waves	52
1.7.3	Illustration of the Dispersion of Wave Packets	54
1.7.4	The Temporal Mean Value of the Poynting Vector	60
1.7.5	The Elements of the Maxwell Stress Tensor	62
2	Electrodynamics: Applications	65
2.1	Technical Implementation of Induction	65
2.1.1	The AC Generator	66
2.1.2	The Transformer	66
2.2	Wave Propagation	68
2.2.1	Reflection and Refraction in Crystal Optics	69
2.2.2	Wave Propagation in Metals	79
2.2.3	Wave Guides and Wire Waves	83
2.2.4	Diffraction	91
2.3	Generation of Waves: Transmitters	101
2.3.1	Specification of Transmitters	101
2.3.2	The Hertz Dipole	104
2.3.3	Contributions of Higher Multipoles	108

2.3.4	The Complete Multipole Expansion	112
2.3.5	An Exactly Solvable Transmitter Problem	115
2.4	Generation of Waves: The Radiation of Moving Point Charges	119
2.4.1	The Liénard-Wiechert Potentials.....	120
2.4.2	The Classical Bremsstrahlung.....	125
2.4.3	Remarks on the Čerenkov Radiation.....	130
2.5	Details.....	133
2.5.1	The Real and the Ideal Transformer	133
2.5.2	Refraction: Fresnel Formulae and Energy Flow	140
2.5.3	The Telegraph Equation	146
2.5.4	Diffraction.....	147
2.5.5	The Hertz Dipole	157
2.5.6	Multipole Radiation (Higher Multipole Moments)	160
2.5.7	The Complete Multipole Expansion	164
2.5.8	The Centrally Fed, Thin Antenna	168
2.5.9	Calculation of the Liénard-Wiechert Fields	176
2.5.10	The Bremsstrahlung	187
3	Theory of Relativity and Electromagnetism	195
3.1	The Lorentz Transformation	197
3.1.1	The Michelson-Morley Experiment	198
3.1.2	A Simple Derivation of Alternative Transformation Equations.....	201
3.2	Implications of the Lorentz Transformation	205
3.2.1	The Addition Theorem for Velocities.....	205
3.2.2	The Lorentz Contraction	210
3.2.3	The Time Dilatation	213
3.3	The Minkowski Space.....	216
3.3.1	Definition.....	216
3.3.2	The Lorentz Transformation in the $\mathcal{M}(1, 1)$ -world.....	219
3.3.3	Formal Aspects 1: Co- and Contravariant Coordinates	222
3.3.4	Formal Variant 2: Imaginary Time Coordinate.....	229
3.4	Relativistic Mechanics	233
3.4.1	The Four-Velocity.....	234
3.4.2	The Four-Momentum and the Relativistic Energy	236
3.4.3	The Equations of Motion in Relativistic Mechanics	241
3.5	Electrodynamics and the Theory of Relativity	245
3.5.1	The Potential Equations	245
3.5.2	The Field Equations	247
3.5.3	The Relativistic Forces on Charges	253
3.5.4	The Lagrange Equations.....	256
3.6	A Short History of the Aether and Other Historical Remarks.....	260
3.7	Details.....	263
3.7.1	The Aberration	263
3.7.2	The Simple Lorentz Transformation	265

3.7.3	A More General Form of the Lorentz Transformation	267
3.7.4	The Maxwell Equations in Relativistic Notation	277
3.7.5	The Energy-Momentum Tensor	281
3.7.6	The Relativistic Lagrange/Hamilton Formalism	288
A	Literature	293
A.1	Books and Literature Quoted in the Text	293
A.2	Introductory Texts	294
A.3	Electrodynamics	294
A.4	Special Relativity	295
A.5	Mathematics	295
A.6	Special Functions and Handbooks	295
B	Systems of Units in Electrodynamics	297
B.1	The Systems	297
B.2	Tables	304
C	Additional Mathematical Topics	309
C.1	Equations of Vector Analysis	309
C.2	Multiple Products of Vectors	309
C.3	Product Rules for the Application of the ∇ -Operator	310
C.4	Double Application of ∇	310
C.5	Differential Operators in Spherical and Cylinder Coordinates	311
C.5.1	Spherical Coordinates	311
C.5.2	Cylinder Coordinates	311
C.6	Angular Functions	312
C.6.1	Legendre Polynomials $P_l(x)$	312
C.6.2	The Functions $Q_l(x)$	314
C.6.3	Associated Legendre Functions	315
C.6.4	Spherical Harmonics	316
C.7	Radial Functions	318
C.7.1	The Hypergeometric Functions $F(a, b, c; x)$	318
C.7.2	The Confluent Hypergeometric Functions $F(a, c; x)$	320
C.8	Linear Spaces with Non-Euclidean Metric	322
Index		327