

CONTENTS

ADVERTISEMENT 1

ONE VECTOR ANALYSIS

1.1	VECTOR ALGEBRA	7	
1.1.1	<i>Vector Operations</i>	7	
1.1.2	<i>Vector Algebra: Component Form</i>	10	
1.1.3	<i>Triple Products</i>	13	
1.1.4	<i>How Vectors Transform</i>	14	
1.2	DIFFERENTIAL CALCULUS	16	
1.2.1	<i>"Ordinary" Derivatives</i>	16	
1.2.2	<i>Gradient</i>	17	
1.2.3	<i>The Operator ∇</i>	20	
1.2.4	<i>Divergence</i>	21	
1.2.5	<i>The Curl</i>	22	
1.2.6	<i>Product Rules</i>	24	
1.2.7	<i>Second Derivatives</i>	26	
1.3	INTEGRAL CALCULUS	28	
1.3.1	<i>"Ordinary" Integration</i>	28	
1.3.2	<i>The Fundamental Theorem for Gradients</i>	29	
1.3.3	<i>The Fundamental Theorem for Divergences</i>	31	
1.3.4	<i>The Fundamental Theorem for Curls</i>	35	

1.3.5	<i>Relations Among the Fundamental Theorems</i>	38
1.3.6	<i>Divergence-Less and Curl-Less Fields</i>	40
1.4	CURVILINEAR COORDINATES	40
1.4.1	<i>Spherical Polar Coordinates</i>	40
1.4.2	<i>Cylindrical Coordinates</i>	45
1.5	THE ROLE OF VECTOR CALCULUS IN ELECTRODYNAMICS	46

TWO ELECTROSTATICS

2.1	THE ELECTROSTATIC FIELD	49
2.1.1	<i>Introduction</i>	49
2.1.2	<i>Coulomb's Law</i>	50
2.1.3	<i>The Electric Field</i>	51
2.1.4	<i>Continuous Charge Distributions</i>	52
2.2	DIVERGENCE AND CURL OF ELECTROSTATIC FIELDS	56
2.2.1	<i>Field Lines and Gauss's Law</i>	56
2.2.2	<i>The Divergence of \mathbf{E}</i>	60
2.2.3	<i>Applications of Gauss's Law</i>	61
2.2.4	<i>The Curl of \mathbf{E}</i>	66
2.3	ELECTRIC POTENTIAL	68
2.3.1	<i>Introduction to Potential</i>	68
2.3.2	<i>Comments on Potential</i>	69
2.3.3	<i>Poisson's Equation and Laplace's Equation</i>	73
2.3.4	<i>Potential of a Charge Distribution</i>	74
2.3.5	<i>Summary; Electrostatic Boundary Conditions</i>	77
2.4	WORK AND ENERGY IN ELECTROSTATICS	79
2.4.1	<i>The Work Done in Moving a Charge</i>	79
2.4.2	<i>The Energy of a Point Charge Distribution</i>	80
2.4.3	<i>The Energy of a Continuous Charge Distribution</i>	82
2.4.4	<i>Comments on Electrostatic Energy</i>	83
2.5	CONDUCTORS	85
2.5.1	<i>Basic Properties of Conductors</i>	85
2.5.2	<i>Induced Charges</i>	87

2.5.3	<i>The Surface Charge on a Conductor; the Force on a Surface Charge</i>	90
2.5.4	<i>Capacitors</i>	91

THREE SPECIAL TECHNIQUES FOR CALCULATING POTENTIALS

3.1	LAPLACE'S EQUATION AND UNIQUENESS THEOREMS	96
3.1.1	<i>Introduction</i>	96
3.1.2	<i>Laplace's Equation in One Dimension</i>	97
3.1.3	<i>Laplace's Equation in Two Dimensions</i>	98
3.1.4	<i>Laplace's Equation in Three Dimensions</i>	100
3.1.5	<i>Boundary Conditions for Laplace's Equation</i>	101
3.1.6	<i>Conductors and the Second Uniqueness Theorem</i>	103
3.2	THE METHOD OF IMAGES	106
3.2.1	<i>The Classic Image Problem</i>	106
3.2.2	<i>The Induced Surface Charge</i>	108
3.2.3	<i>Force and Energy</i>	108
3.2.4	<i>Other Image Problems</i>	109
3.3	SEPARATION OF VARIABLES	112
3.3.1	<i>Cartesian Coordinates</i>	112
3.3.2	<i>Spherical Coordinates</i>	121
3.4	MULTIPOLE EXPANSION	129
3.4.1	<i>Approximate Potential at Large Distances</i>	129
3.4.2	<i>The Monopole and Dipole Terms</i>	131
3.4.3	<i>Origin of Coordinates in Multipole Expansions</i>	133
3.4.4	<i>The Electric Field of a Dipole</i>	134

FOUR ELECTROSTATIC FIELDS IN MATTER

4.1	POLARIZATION	138
4.1.1	<i>Dielectrics</i>	138
4.1.2	<i>Induced Dipoles</i>	139

4.1.3	<i>Alignment of Polar Molecules</i>	141
4.1.4	<i>Polarization</i>	144
4.2	THE FIELD OF A POLARIZED OBJECT	144
4.2.1	<i>Bound Charges</i>	144
4.2.2	<i>Physical Interpretation of Bound Charge</i>	147
4.2.3	<i>The Field Inside a Dielectric</i>	150
4.3	THE ELECTRIC DISPLACEMENT	152
4.3.1	<i>Gauss's Law in the Presence of Dielectrics</i>	152
4.3.2	<i>A Deceptive Parallel</i>	155
4.4	LINEAR DIELECTRICS	156
4.4.1	<i>Susceptibility, Permittivity, Dielectric Constant</i>	156
4.4.2	<i>Special Problems Involving Linear Dielectrics</i>	161
4.4.3	<i>Force and Energy in Dielectric Systems</i>	166
4.4.4	<i>Polarizability and Susceptibility</i>	170

FIVE MAGNETOSTATICS

5.1	THE LORENTZ FORCE LAW	174
5.1.1	<i>Magnetic Fields</i>	174
5.1.2	<i>Magnetic Forces</i>	176
5.1.3	<i>Currents</i>	180
5.2	THE BIOT-SAVART LAW	184
5.2.1	<i>Steady Currents</i>	184
5.2.2	<i>The Magnetic Field of a Steady Current</i>	185
5.3	THE DIVERGENCE AND CURL OF B	190
5.3.1	<i>Straight-Line Currents</i>	190
5.3.2	<i>The Divergence of B</i>	192
5.3.3	<i>The Curl of B</i>	193
5.3.4	<i>Ampère's Law</i>	194
5.3.5	<i>Comparison of Magnetostatics and Electrostatics</i>	201
5.4	MAGNETIC VECTOR POTENTIAL	203
5.4.1	<i>The Vector Potential</i>	203
5.4.2	<i>Summary; Magnetostatic Boundary Conditions</i>	208
5.4.3	<i>Multipole Expansion of the Vector Potential</i>	210

SIX MAGNETOSTATIC FIELDS IN MATTER

6.1	MAGNETIZATION	218
6.1.1	<i>Diamagnets, Paramagnets, Ferromagnets</i>	218
6.1.2	<i>Torques and Forces on Magnetic Dipoles</i>	219
6.1.3	<i>Effect of Magnetic Field on Atomic Orbits</i>	222
6.1.4	<i>Magnetization</i>	224
6.2	THE FIELD OF A MAGNETIZED OBJECT	225
6.2.1	<i>Bound Currents</i>	225
6.2.2	<i>Physical Interpretation of Bound Currents</i>	227
6.2.3	<i>The Magnetic Field Inside Matter</i>	229
6.3	THE AUXILIARY FIELD H	230
6.3.1	<i>Ampère's Law in Magnetized Materials</i>	230
6.3.2	<i>A Deceptive Parallel</i>	233
6.4	LINEAR AND NONLINEAR MEDIA	234
6.4.1	<i>Magnetic Susceptibility and Permeability</i>	234
6.4.2	<i>Ferromagnetism</i>	237

SEVEN ELECTRODYNAMICS

7.1	ELECTROMOTIVE FORCE	243
7.1.1	<i>Ohm's Law</i>	243
7.1.2	<i>Electromotive Force</i>	250
7.1.3	<i>Motional emf</i>	252
7.2	FARADAY'S LAW	257
7.2.1	<i>Electromagnetic Induction</i>	257
7.2.2	<i>Inductance</i>	263
7.2.3	<i>Energy in Magnetic Fields</i>	268

7.3	MAXWELL'S EQUATIONS	273
7.3.1	<i>Electrodynamics Before Maxwell</i>	273
7.3.2	<i>How Maxwell Fixed Up Ampère's Law</i>	274
7.3.3	<i>Maxwell's Equations and Magnetic Charge</i>	276
7.3.4	<i>Maxwell's Equations Inside Matter</i>	277
7.3.5	<i>Boundary Conditions</i>	280
7.4	POTENTIAL FORMULATION OF ELECTRODYNAMICS	282
7.4.1	<i>Scalar and Vector Potentials</i>	282
7.4.2	<i>Gauge Transformations</i>	283
7.4.3	<i>Coulomb Gauge and Lorentz Gauge</i>	284
7.4.4	<i>Lorentz Force Law in Potential Form</i>	286
7.5	ENERGY AND MOMENTUM IN ELECTRODYNAMICS	287
7.5.1	<i>Newton's Third Law in Electrodynamics</i>	287
7.5.2	<i>Poynting's Theorem</i>	288
7.5.3	<i>Maxwell's Stress Tensor</i>	291

EIGHT

ELECTROMAGNETIC WAVES

8.1	THE WAVE EQUATION	295
8.1.1	<i>Introduction</i>	295
8.1.2	<i>The Wave Equation in One Dimension</i>	297
8.1.3	<i>Sinusoidal Waves</i>	300
8.1.4	<i>Polarization</i>	304
8.1.5	<i>Boundary Conditions: Reflection and Transmission</i>	306
8.2	ELECTROMAGNETIC WAVES IN NONCONDUCTING MEDIA	309
8.2.1	<i>Monochromatic Plane Waves in Vacuum</i>	309
8.2.2	<i>Energy and Momentum of Electromagnetic Waves</i>	313
8.2.3	<i>Propagation Through Linear Media</i>	315
8.2.4	<i>Reflection and Transmission at Normal Incidence</i>	316
8.2.5	<i>Reflection and Transmission at Oblique Incidence</i>	318
8.3	ELECTROMAGNETIC WAVES IN CONDUCTORS	324
8.3.1	<i>The Modified Wave Equation</i>	324
8.3.2	<i>Monochromatic Plane Waves in Conducting Media</i>	327
8.3.3	<i>Reflection and Transmission at a Conducting Surface</i>	330

8.4	DISPERSION	333
8.4.1	<i>The Frequency Dependence of ϵ, μ, and σ</i>	333
8.4.2	<i>Dispersion in Nonconductors</i>	335
8.4.3	<i>Free Electrons in Conductors and Plasmas</i>	340

NINE

ELECTROMAGNETIC RADIATION

9.1	DIPOLE RADIATION	345
9.1.1	<i>Retarded Potentials</i>	345
9.1.2	<i>Electric Dipole Radiation</i>	350
9.1.3	<i>Magnetic Dipole Radiation</i>	356
9.1.4	<i>Radiation from an Arbitrary Distribution of Charges and Currents</i>	360
9.2	RADIATION FROM A POINT CHARGE	365
9.2.1	<i>Liénard-Wiechert Potentials</i>	365
9.2.2	<i>The Fields of a Point Charge in Motion</i>	370
9.2.3	<i>Power Radiated by a Point Charge</i>	375
9.3	RADIATION REACTION	380
9.3.1	<i>The Abraham-Lorentz Formula</i>	380
9.3.2	<i>The Physical Origin of the Radiation Reaction</i>	384

TEN

ELECTRODYNAMICS AND RELATIVITY

10.1	THE SPECIAL THEORY OF RELATIVITY	388
10.1.1	<i>Einstein's Postulates</i>	388
10.1.2	<i>The Geometry of Relativity</i>	396
10.1.3	<i>The Lorentz Transformations</i>	406
10.1.4	<i>The Structure of Spacetime</i>	412

10.2	RELATIVISTIC MECHANICS	420
10.2.1	<i>Proper Time and Proper Velocity</i>	420
10.2.2	<i>Relativistic Energy and Momentum</i>	422
10.2.3	<i>Relativistic Kinematics</i>	426
10.2.4	<i>Relativistic Dynamics</i>	430
10.3	RELATIVISTIC ELECTRODYNAMICS	435
10.3.1	<i>Magnetism as a Relativistic Phenomenon</i>	435
10.3.2	<i>How the Fields Transform</i>	437
10.3.3	<i>The Field Tensor</i>	445
10.3.4	<i>Electrodynamics in Tensor Notation</i>	448
10.3.5	<i>Potential Formulation of Relativistic Electrodynamics</i>	451

APPENDIX A

VECTOR CALCULUS IN CURVILINEAR COORDINATES

INTRODUCTION	454
NOTATION	454
GRADIENT	455
DIVERGENCE	456
CURL	458
LAPLACIAN	460

APPENDIX B

UNITS

INDEX	465
-------	-----