



**Electro
Magnetic
Theory
And
Electro
Dynamics**

Satya Prakash

Contents

CHAPTER 1 : Preliminary Mathematical Concepts (Vectors and Tensors)	1-46
1.0. Introduction	1
1.1. Review of vector algebra	1
1.2. Gradient of a scalar field	10
1.3. Line, surface and volume integrals	11
1.4. Divergence of a vector function	13
1.5. Curl of a vector function	15
1.6. Laplacian, Laplace's and Poisson's equations	18
1.7. Gauss divergence theorem	18
1.8. Stoke's theorem	19
1.9. Green's theorem	21
1-10. Some important formulas from vector analysis	21
1-11. Orthogonal curvilinear coordinates	22
1-12. Differential operators in terms of spherical polar and cylindrical coordinates	27
1-13. Tensors	30
1-14. Fundamentals of tensors	31
1-15. Algebraic operations on tensors	36
1-16. Symmetric and antisymmetric tensors	41
1-17. Invariant tensors	44
<i>Questions and Problems</i>	45-46
CHAPTER 2 : Electrostatic Fields	47-124
2.1. Coulomb's law	47
2.2. The electric field strength	49
2.3. The electrostatic potential	52
2.4. Gauss's theorem	55
2.5. Applications of Gauss's law	57
2.6. Electric field and potential due to an electric dipole	63
2.7. Potential energy of an electric dipole in an external electric field	65
2.8. Interaction of Dipoles	66
2.9. Electric quadrupole and multipoles	68
2-10. Multipole expansion of electric field	69
2-11. Dielectric polarisation	78
2-12. Dielectric constant (Relative permittivity) and displacement vector	80
2-13. External field of a dielectric medium	81
2-14. The electric field in a material medium	83
2-15. Gauss's theorem in a dielectric ; the electric displacement	87
2-16. Electric susceptibility and dielectric constant	89
2-17. Point charge in a dielectric fluid	89
2-18. Boundary conditions on field vectors	91
2-19. Potential and field due to polarised sphere	92
2-20. Dielectric sphere in a uniform field	96
2-21. Molecular field in a dielectric. The Clausius-Mossotti relation	97

2-22. Polar molecules : The Langevin Debye formula	100
<i>Questions and Problems</i>	104-106
CHAPTER 3 : Force and Energy Relations in Electrostatic Field	107-125
3-1. Introduction	107
3-2. Field energy in free space and in dielectric	108
3-3. Energy density of an electrostatic field	110
3-4. Thermodynamical interpretation of electrostatic energy U	112
3-5. Thomson's theorem of extremum free energy	113
3-6. Capacity and capacitors	114
3-7. Work required to charge a capacitor and the energy stored in an electric field	116
3-8. Forces and Torques	116
3-9. Mechanical forces in the electrostatic field	118
3-10. Maxwell stress tensor	122
<i>Questions and Problems</i>	124-125
CHAPTER 4 : Solution of Electrostatic Problems	126-158
4-1. Introduction	126
4-2. Poisson's and Laplace's equations	126
4-3. Uniqueness theorem	129
4-4. Green's reciprocity theorem	130
4-5. Formal solution of potential by Green's function	131
4-6. Method of electrical images	133
4-7. A point charge near an infinite conducting plane	134
4-8. A point charge in front of semi-infinite dielectric	137
4-9. A point charge in front of a conducting sphere	139
4-10. Conducting sphere in a uniform electric field by the method of images	145
4-11. Solution of Laplace's equation in cartesian coordinates	147
4-12. Solution of Laplace's equation in spherical coordinates	150
4-13. Use of Laplace's equation in spherical coordinates in the solution of electrostatic problems	152
4-14. Solution of Laplace's equation in cylindrical coordinates	154
4-15. Use of Laplace's equation in cylindrical coordinates in the solution of electrostatic problems	155
<i>Questions and Problems</i>	158
CHAPTER 5 : Steady Currents	159-173
5-1. Electric current and current density	159
5-2. Expression for current density	160
5-3. Stationary current ; Equation of continuity	161
5-4. Ohm's law and electrical conductivity	162
5-5. Variation of resistance and resistivity with temperature	163
5-6. Lorentz drude theory of electrical conduction	169
5-7. Deduction of Ohm's law from Lorentz Drude theory	171
<i>Questions and Problems</i>	172-173
CHAPTER 6 : Magnetostatics	174-253
6-1. Introduction	174
6-2. Magnetic interactions : Ampere's law of force between current elements	174
6-3. Biot-Savart law	177

6.4.	The force on a current carrying conductor and Lorentz force	178
6.5.	The definition of \mathbf{B} without using the concept of magnetic poles and some other useful information	179
6.6.	Some applications of Biot-Savart law	180
6.7.	Magnetic Induction \mathbf{B} and magnetic intensity \mathbf{H}	192
6.8.	Ampere's law in circuital form	193
6.9.	Applications of Ampere's law	197
6.10.	Curl of magnetic induction \mathbf{B}	200
6.11.	Divergence of magnetic induction \mathbf{B}	201
6.12.	Magnetic scalar potential	202
6.13.	Equivalence of small current loop and a magnetic dipole	203
6.14.	Magnetic vector potential	205
6.15.	Applications of vector potential	209
6.16.	A magnetic dipole in a magnetic field	215
6.17.	Magnetisation	218
6.18.	Currents in material media	219
6.19.	Vacuum displacement current	220
6.20.	Definition and role of magnetic field intensity	221
6.21.	Magnetic materials : Magnetic susceptibility and permeability	222
6.22.	Hysteresis and Rowland ring method \mathbf{B} — \mathbf{H} curve	224
6.23.	Uses of hysteresis cycle	227
6.24.	Measurement of susceptibility	229
6.25.	Langevin's theory of diamagnetism	232
6.26.	Langevin's theory of paramagnetism	235
6.27.	Weiss's theory of ferromagnetism	238
6.28.	Antiferromagnetism	240
6.29.	Ferrimagnetism, Ferrites	242
5.30.	Boundary conditions on field vectors	243
6.31.	Uniformly magnetised sphere in an external field	244
6.32.	The magnetic circuit	246
6.33.	Magnetic energy	250
	<i>Questions and Problems</i>	252-253

CHAPTER 7 : Electromagnetic Induction	254–291	
7.1.	Introduction	254
7.2.	Faraday's laws of electromagnetic induction	255
7.3.	Faraday's laws from Lorentz force	256
7.4.	A conducting rod moving through a uniform magnetic field	257
7.5.	Induction law for moving circuits	258
7.6.	Varying magnetic field	269
7.7.	Faraday's laws in universal form	261
7.8.	Self-Induction : self Inductance	272
7.9.	Mutual Induction : mutual Inductance	277
7.10.	Combination of two inductances	283
7.11.	Coupling of two coils with flux linkage : Coefficient of coupling	284
7.12.	Magnetic energy stored in inductance	285
	<i>Questions and Problems</i>	288-291

CHAPTER 8 : Maxwell's Equations and Electromagnetic Waves

8-1. Introduction	292-341
8-2. Equation of continuity	292
8-3. Maxwell's postulate ; Displacement current	292
8-4. Physical interpretation of Maxwell's postulate	293
8-5. Maxwell's equations and their empirical basis	295
8-6. Derivation of Maxwell's equations	296
8-7. Maxwell's equations in integral form ; Physical Significance of Maxwell's equations	297
8-8. Maxwell's equations in some particular cases	298
8-9. Electromagnetic energy and Poynting theorem	300
8-10. Poynting vector	302
8-11. The wave equation	305
8-12. Plane electromagnetic waves in free space	308
8-13. Plane electromagnetic waves in non-conducting isotropic medium	310
8-14. Plane electromagnetic waves in anisotropic non-conducting medium	316
8-15. Plane electromagnetic waves in conducting medium	321
8-16. A simple model for dynamic conductivity	325
8-17. Propagation of electromagnetic waves in ionised gases	332
8-18. Polarisation of electromagnetic waves	333
Questions and Problems	336
	338-341

CHAPTER 9 : Applications of Electromagnetic waves I : Reflection and Refraction (Including Wave Guides and Resonant Cavities)

9-1. Introduction	342-405
9-2. Boundary conditions at the surface of discontinuity	342
9-3. Reflection and refraction of-electromagnetic waves at the interface of non-conducting media	345
9-4. Fresnel's equations (Dynamic properties of reflection and refraction)	348
9-5. Experimental verification of Fresnel's equations	355
9-6. Reflection and transmission coefficients at the interface between two non-conducting media	357
9-7. Brewster's angle and degree of polarisation	360
9-8. Total internal reflection	362
9-9. Reflection from a conducting plane	366
9-10. Group velocity	374
9-11. Propagation of electromagnetic waves between parallel conducting planes	375
9-12. Waves guides	379
9-13. Rectangular wave guide	385
9-14. Circular wave guide	390
9-15. Resonant Cavities	396
Questions and Problems	404-405

CHAPTER 10 : Applications of Electromagnetic Waves II : Dispersion and Scattering 406-432

10-1. Introduction	406
10-2. Dispersion : Normal and Anomalous	407
10-3. Dispersion in gases	408
10-4. Experimental demonstration of anomalous dispersion in gases	416
10-5. Dispersion in liquids and solids	416
10-6. Scattering and scattering parameters	420
10-7. Theory of scattering of electromagnetic waves	421

10.8. Polarisation of scattered light	427
10.9. Coherence and Incoherence of scattered light	428
<i>Questions and Problems</i>	430-432
CHAPTER 11 : Electromagnetic Potentials and Spherical Waves	433-458
11.1. Electromagnetic vector and scalar potentials	433
11.2. Non-uniqueness of electromagnetic potentials and concept of gauge	436
11.3. Lorentz gauge	437
11.4. Coulomb or transverse gauge	439
11.5. Hertz vector	441
11.6. Lorentz force in terms of electromagnetic potentials	443
11.7. Hertz's solution of wave equation : Hertzian oscillator	445
11.8. Spherical waves	451
<i>Questions and Problems</i>	457-458
CHAPTER 12 : Electrodynamics of a moving charge and radiating systems	459-512
12.1. Introduction	459
12.2. Solution of inhomogeneous wave equation by Fourier analysis	459
12.3. Lienard-Wiechert potentials	463
12.4. The electromagnetic fields from Lienard-Wiechert potentials of a moving point charge	466
12.5. The electromagnetic fields a uniformly moving point charge	470
12.6. Radiation from an accelerated charge at low velocity-Larmor's formula	473
12.7. Radiation from an accelerated charge at high velocity-Relativistic generalisation of Larmor's formula	476
12.8. Angular distribution of radiation emitted by an accelerated charge	479
12.9. Radiation damping : the Abraham Lorentz formula	484
12.10. Cherenkov radiation	485
12.11. Radiation due to an oscillating electric dipole	490
12.12. Electric quadrupole radiation	497
12.13. Radiation due to a small current element	499
12.14. Radiation from a thin linear antenna	501
12.15. Radiation from a linear half wave antenna	505
12.16. Antenna array	507
<i>Questions and Problems</i>	511-512
CHAPTER 13 : Propagation of Radio Waves	513-534
13.1. Introduction	513
13.2. Types of wave propagation	513
13.3. Propagation of ground or surface waves	514
13.4. Propagation of space waves	515
13.5. Effect of earth's curvature on space wave propagation	516
13.6. Atmospheric effects on space wave propagation	517
13.7. Ionosphere and its stratification	518
13.8. Effect on ionosphere on the propagation of Radio waves : Eccles Larmor theory	519
13.9. The vertical Hept	522
13.10. Skip distance and maximum usable frequency (MUF)	522
13.11. Fading	525
13.12. Effect of earth's magnetic field on radio wave propagation Appleton Hertree formula	526
13.13. Elementary idea of micro wave and optical communication, the communication satellite	532
<i>Questions and Problems</i>	534

CHAPTER 14 : Plasma Physics

14.1. Plasma : An introduction	534-554
14.2. Conditions for plasma existence	535
14.3. Occurrence of plasma	535
14.4. Charged particle in electric and magnetic fields	538
(1) Charged particle in uniform constant electric field	539
(2) Charged particle in homogeneous magnetic field	539
(3) Charged particle in simultaneous electric and magnetic fields	542
(4) Charged particle in non-homogeneous magnetic field	543
14.5. Magneto-hydrodynamics	544
14.6. Magnetic confinement-Pinch Effect	545
14.7. Instabilities in a pinched plasma column	549
14.8. Plasma-waves	551
Questions and Problems	551
	553-554

CHAPTER 15 : Relativistic Electrodynamics

15.1. Introduction	555-599
15.2. Transformation of differential operators	555
15.3. Invariance of D' Alembertian operator	558
15.4. Invariance of charge	560
15.5. Transformation of charge density	561
15.6. Electric field measured in different frames of reference	562
15.7. Minkowski space : Introduction	562
15.8. Geometrical interpretation of Lorentz transformations of space and time	565
15.9. Four vectors	566
15.10. Lorentz transformations for space and time in four vector form	567
15.11. Transformation for charge and current densities	569
15.12. Transformation of electromagnetic potentials A and ϕ	570
15.13. Lorentz condition in covariant form	573
15.14. Invariance (or covariance) of Maxwell field equations in terms of four vectors	575
15.15. The electromagnetic field tensor	575
15.16. Maxwell's equations in covariance four tensor form	578
15.17. Lorentz transformations of electric and magnetic fields	579
15.18. Lorentz force on a charged particle	583
15.19. The invariants of the electromagnetic field	590
15.20. Electromagnetic field due to a moving charge	591
15.21. Lorentz force in covariant form	592
Questions and Problems	595
Index	597-599
	600-603