

# Contents

<b>Preface to the First Edition</b>	<b>xv</b>
<b>Preface to the Second Edition</b>	<b>xix</b>
<b>Chapter 1. Basic Equations for Electromagnetic Fields</b>	<b>1</b>
1.1 Maxwell's Equations	1
1.2 Wave Equations	3
1.3 Conservation Laws	4
1.4 Scalar Theory of Optical Problems	6
1.5 Lorentz's Reciprocity Theorem	7
1.6 Integral Equations for the Electromagnetic Field. The Extinction Theorem	8
1.6.1 The vector form of Green's theorem	9
1.6.2 Integral theorems	10
1.6.3 Integral theorems for scalar fields	13
1.6.4 Natural modes	15
1.6.5 Other extensions and uses of the extinction theorem	15
Problems	16
References	17
<b>Appendix 1.1: A Generalized Extinction Theorem         and Its Role in Scattering Theory</b>	<b>18</b>
<b>Chapter 2. Angular Spectrum Representation         of Wavefields</b>	<b>33</b>
2.1 Introduction	33
2.2 Expansion of Scalar Wavefields into Plane Waves in Source-Free Regions	34

2.3	Connection between $U(x, y, z)$ and its Boundary Value at $z = 0$	36
2.4	Wavelength Resolution Limit	38
2.5	On the Validity of the Angular Spectrum Representation	39
2.6	An Alternative Representation in Angular Variables	40
2.7	Source-Free Fields	41
2.7.1	Source-free fields satisfying the homogeneous Helmholtz equation everywhere and having components propagating in all directions	42
2.7.2	Source-free fields propagating in a half-space	44
2.8	Asymptotic Approximation to Source-Free Fields	45
2.8.1	Fields propagating in a half-space free of sources	45
2.8.2	Fields satisfying the Helmholtz equation everywhere and with angular components propagating in all directions	47
2.9	Angular Spectrum Representation of Electromagnetic Fields	47
2.10	Divergent and Convergent Spherical Waves and their Angular Spectrum Representation	48
2.11	Optical Beams: Diffraction-Free Beams	51
2.12	Asymptotic Approximations to Angular Spectrum Representations	55
2.12.1	Approximations for $0 < \theta < \pi/2$ , $0 \leq \phi \leq 2\pi$	56
2.12.2	Approximations for $\theta = \pi/2$	56
2.12.3	Approximations in the axial direction	57
2.13	Contribution of the Evanescent Components in the Asymptotic Expressions	58
	Problems	65
	References	70
<b>Chapter 3.</b>	<b>Radiated and Scattered Fields</b>	<b>73</b>
3.1	Radiated Fields from a Localized Charge-Current Distribution	74
3.2	Angular Spectrum Representation of Radiated Fields	74
3.3	The Field and the Intensity Radiated in the Far Zone	76
3.4	Scalar Theory of Radiated Wavefields	77
3.5	Examples of Radiation Fields: Charged Particle with Two-Dimensional Motion	78
3.5.1	Field due to a charged particle moving in vacuum	79

3.5.2	Particle moving uniformly in vacuum	81
3.5.3	Čerenkov radiation	83
3.6	Integro-Differential Equations for the Scattered Electromagnetic Field in a Time-Independent Medium. Angular Spectrum Representation Outside the Strip $0 < z < L$	86
3.7	Angular Spectrum Representation of the Scattered Electromagnetic Field Inside the Strip $0 < z < L$	88
3.7.1	Scattered field outside the scattering volume	88
3.7.2	Scattered field inside the scattering volume. The slowly varying amplitude approximation	91
3.8	The First Born Approximation	94
3.9	Scattering from a Weakly Fluctuating Random Medium	97
3.10	Scalar Approach to Scattered Scalar Wavefields	100
3.10.1	The first Born approximation for scalar wavefields	102
3.10.2	The Rytov approximation	103
3.10.3	The Eikonal approximation	105
3.11	Multiple Scattering Theories	108
	Problems	109
	References	114
<b>Chapter 4. Mathematical Properties of Radiated and Scattered Fields</b>		<b>117</b>
4.1	Introduction	117
4.2	The Angular Spectrum of Wavefields in Free-Space as the Boundary Value of an Entire Function	117
4.3	Consequences for Radiated and Scattered Fields	118
4.4	Consequences for Homogeneous and Evanescent Components	121
4.5	Consequences for Source-Free Fields	124
4.6	Conclusions and Extensions	125
	Problems	126
	References	127
<b>Appendix 4.1: Entire Functions of Exponential Type</b>		<b>128</b>
<b>Appendix 4.2: Dispersion Relations</b>		<b>133</b>
<b>Appendix 4.3: The Whittaker–Shannon Sampling Theorem</b>		<b>137</b>

<b>Chapter 5. S-Matrix and Reciprocity</b>	<b>138</b>
5.1 Representation of Fields Outside a Scatterer	139
5.2 Definition of the S-Matrix	143
5.3 Reciprocity and Unitarity	143
5.4 The S-Matrix for Scalar Wavefields	145
5.5 The Partitioned S-Matrix	146
5.6 Incident Plane Wave	149
5.7 Incident Source-Free Field	150
5.8 The Generalized Transmission and Reflection Coefficients	151
5.9 The Transition Matrix	153
5.10 The Generalized Transmission and Reflection Coefficients for an Incident Source-Free Field	154
5.11 The Generalized Stokes Relations	158
5.12 Example: Stokes Relations for Stratified Media	161
5.13 Reciprocity of the Impulse Response for Scattering from Inhomogeneous Media	164
5.13.1 Definition of the impulse response	164
5.13.2 Reciprocity relations	167
Problems	168
References	170
<b>Chapter 6. Elements of the Theory of Diffraction</b>	<b>171</b>
6.1 The Scalar Theory of Diffraction	172
6.2 Uniqueness of the Solution. Boundary Conditions	174
6.3 The Kirchhoff Approximation	175
6.4 The Rayleigh–Sommerfeld Diffraction Integrals	177
6.5 The Rayleigh–Sommerfeld Integrals and the Angular Spectrum Representation	180
6.6 Reciprocity, Diffraction for Small Angles	182
6.7 The Fresnel Approximation	185
6.8 The Fraunhofer Approximation	188
6.9 Comparison with the Angular Spectrum Representation	189
6.9.1 Fresnel approximation	189
6.9.2 Fraunhofer approximation	190
6.10 Example: Scalar Theory of Diffraction by a Circular Aperture	191
6.11 Theory of the Boundary Diffraction Wave	193
6.11.1 The vector potential	193

6.11.2	A mathematically consistent interpretation of the Kirchhoff diffraction integral	197
6.12	Comparison with Experiment	198
6.13	Debye Approximation. Symmetries of Focused Wavefields and Phase Anomaly Near the Focus	201
6.14	Vector Theory of Diffraction	205
6.15	Uniqueness of the Electromagnetic Solution. Boundary Conditions	207
6.16	Three Vector Formulations of Diffraction	208
6.17	The Fraunhofer Approximation for the Vector Solution. Comparison with the Scalar Result	209
6.18	Diffraction Problems and the Extinction Theorem	211
	Problems	212
	References	215
<b>Chapter 7.</b>	<b>Scattering from Rough Surfaces</b>	<b>217</b>
7.1	Introduction	217
7.2	Statistical Characterization of Random Rough Surfaces	219
7.3	Boundary Condition for Scattering from Perfectly Conductive Surfaces	219
7.4	Angular Spectrum Representation	220
7.5	The Kirchhoff Approximation	222
7.5.1	Example: scattering of a linearly polarized plane wave	225
7.5.2	The mean scattered intensity	226
7.5.3	On the validity of the Kirchhoff approximation	228
7.6	The Method of Small Perturbations	231
7.6.1	Expansions for the mean scattered intensity	233
7.6.2	On the range of validity of the method of small perturbations	235
7.7	The Rayleigh Method	242
7.8	Illustration of the Scattering Equations for One-Dimensional Surfaces	244
7.9	Numerical Solution of the Scattering Equations	246
7.9.1	Numerical generation of random surfaces	246
7.9.2	Numerical calculation of the scattering integrals	247
7.10	Scattering from Deeply Rough Surfaces. Enhanced Backscattering	249

7.10.1	Comparison of experimental data and numerical results from one-dimensional surfaces	252
7.11	Scattering from Metal and Dielectric Rough Surfaces	253
7.11.1	Example: one-dimensional surfaces	256
7.12	Diffraction from Periodic Surfaces: Reflection Gratings	261
7.13	Variation of the Diffracted Intensities	265
	Problems	268
	References	271
<b>Chapter 8.</b>	<b>Propagation and Scattering of Phase-Conjugate Wavefields</b>	<b>275</b>
8.1	Introduction	276
8.2	Phase-Conjugation of Wavefields Propagating in Free Space	279
8.2.1	Phase-conjugation of fields that propagate into the same half-space	279
8.2.2	Phase-conjugation of fields that propagate into complementary half-spaces	284
8.3	Scattering and Distortion Correction by Phase-Conjugation	288
8.3.1	Self-consistent formulation	291
8.3.2	Multiple bounce approach	293
8.4	Other Studies	296
	Problems	297
	References	300
<b>Chapter 9.</b>	<b>Inverse Diffraction</b>	<b>302</b>
9.1	The Inverse Wavefield Propagator	303
9.2	Alternative Form of the Inverse Propagator	305
9.3	Inversion Formula for Fields without Evanescent Components	306
9.4	Connection with the Reciprocity Theorem of Phase-Conjugated Wavefields	306
9.5	Connection with the Pseudoscopic Image in Holography	307
9.6	System Approach to Inverse Diffraction	310
9.7	Degrees of Freedom	312
9.8	Representation by Eigenfunctions	314
9.9	Ill-Posed Nature of Inverse Diffraction	316
9.10	The Problem of Phase Retrieval	319

9.11 Conclusions and Other Studies	321
Problems	322
References	323
<b>Chapter 10. Inverse Source and Scattering Problems in Optics</b>	<b>326</b>
10.1 Introduction	326
10.2 Formulation of Inverse Source and Scattering Problems	328
10.3 Information Content of One Experiment	330
10.4 Integral Equations for Fields over Arbitrary Surfaces	334
10.4.1 Vector theory	334
10.4.2 Scalar theory	336
10.5 Information Contained in the Imaging Equation. Physical Meaning of the Backpropagation Equation	337
10.6 Ambiguity in Inverse Source and Scattering Problems. Nonradiating Sources and Nonscattering Scatterers	340
10.6.1 Eigenfunction analysis	343
10.7 Reconstruction Using Fourier Series	345
10.8 Diffraction Tomography	347
10.8.1 The central slice theorem	347
10.8.2 Principles of computed tomography	349
10.8.3 The basic equation of diffraction tomography	351
10.8.4 The filtered backpropagation equation	352
10.8.5 The geometrical optics limit	356
10.8.6 An example	357
10.9 Other Inverse Scattering Methods Multiple Scattering Approaches	358
Problems	361
References	362
<b>Chapter 11. Fundamentals of Near Field Optics (NFO)</b>	<b>366</b>
11.1 Introduction	367
11.2 The Optical Signal at the Tip	369
11.3 Inverse Scattering Problem in Near Field Optics	371
11.4 Inverse Scattering. Coherence. Artifacts	373
11.5 Surface Plasmon Polaritons	375
11.5.1 An example of existence of surface polariton excitations	379

11.6	Reciprocity and Unitarity of the S-Matrix of Fields Containing Evanescent Components	382
11.6.1	Transmission and reflection coefficients containing evanescent components	383
11.6.2	Reciprocity relations for transmission and reflection coefficients with evanescent components	385
11.6.3	Reciprocity relations for the S-matrix	387
11.7	Time-Reversal Symmetry of the S-Matrix of Fields Containing Evanescent Components	390
11.7.1	Time-reversal invariance. Consequence for the S-matrix	390
11.7.2	Time-reversal invariance and reciprocity	391
11.8	Superresolution by Near Field Propagation in Left-Handed Material Slabs	392
11.9	Slab of Ideal Dispersiveless and Absorptionless Left-Handed Material	394
11.9.1	Field inside a left-handed medium	394
11.9.2	Field transmitted by a slab of lossless left-handed material	396
11.9.3	Singularity of the propagator inside the slab of left-handed material	397
11.10	Field Transmitted by an Absorbing Slab. Image Resolution	400
11.10.1	Resolution of the LHM slab lens and the inverse diffraction propagator	403
	Problems	407
	<b>Appendix 11.1: Lorentz's Reciprocity Theorem with Sources</b>	407
	<b>Appendix 11.2: Generalized Stokes Relations for Fields Containing Evanescent Components</b>	408
	References	409
	<b>Author Index</b>	<b>415</b>
	<b>Subject Index</b>	<b>423</b>