

Contents

1	Introduction	1
2	Electrodynamic Properties of a General Physical System	5
2.1	The Maxwell Equations	5
2.2	The System: Lagrangian and Hamiltonian Descriptions	6
2.3	Polarization as a Statistical Property of a System	9
3	General Properties of the Linear Optical Response	11
3.1	Linear Optical Properties	11
3.1.1	Transmission and Reflection at the Boundary Between Two Media	14
3.2	Microscopic Description of Linear Polarization	16
3.3	Asymptotic Properties of Linear Susceptibility	17
3.4	Local Field and Effective Medium Approximation in Linear Optics	19
3.4.1	Homogeneous Media	19
3.4.2	Two-Phase Media	21
4	Kramers-Kronig Relations and Sum Rules in Linear Optics	27
4.1	Introductory Remarks	27
4.2	The Principle of Causality	27
4.3	Titchmarsh's Theorem and Kramers-Kronig Relations	28
4.3.1	Kramers-Kronig Relations for Conductors	29
4.3.2	Kramers-Kronig Relations for the Effective Susceptibility of Nanostructures	30
4.4	Superconvergence Theorem and Sum Rules	31
4.5	Sum Rules for Conductors	33
4.5.1	Sum Rules for the Linear Effective Susceptibilities of Nanostructures	33
4.6	Integral Properties of Optical Constants	34
4.6.1	Integral Properties of the Index of Refraction	35
4.6.2	Kramers-Kronig Relations in Linear Reflectance Spectroscopy	39

VIII Contents

4.7	Generalization of Integral Properties for More Effective Data Analysis	44
4.7.1	Generalized Kramers-Kronig Relations	45
4.7.2	Subtractive K-K Relations	47
5	General Properties of the Nonlinear Optical Response	49
5.1	Nonlinear Optics: A Brief Introduction	49
5.2	Nonlinear Optical Properties	51
5.2.1	Pump-and-Probe Processes	54
5.3	Microscopic Description of Nonlinear Polarization	56
5.4	Local Field and Effective Medium Approximation in Nonlinear Optics	58
5.4.1	Homogeneous Media	58
5.4.2	Two-Phase Media	60
5.4.3	Tailoring of the Optical Properties of Nanostructures	63
6	Kramers-Kronig Relations and Sum Rules in Nonlinear Optics	71
6.1	Introductory Remarks	71
6.2	Kramers-Kronig Relations in Nonlinear Optics: Independent Variables	72
6.3	Scandolo's Theorem and Kramers-Kronig Relations in Nonlinear Optics	73
6.4	Kramers-Kronig Analysis of the Pump-and-Probe System . . .	77
6.4.1	Generalization of Kramers-Kronig Relations and Sum Rules	79
7	Kramers-Kronig Relations and Sum Rules for Harmonic-Generation Processes	83
7.1	Introductory Remarks	83
7.2	Application of Scandolo's Theorem to Harmonic-Generation Susceptibility	83
7.3	Asymptotic Behavior of Harmonic-Generation Susceptibility .	84
7.4	General Kramers-Kronig Relations and Sum Rules for Harmonic-Generation Susceptibility	87
7.4.1	General Integral Properties of Nonlinear Conductors . .	89
7.5	Subtractive Kramers-Kronig Relations for Harmonic-Generation Susceptibility	90
8	Kramers-Kronig Relations and Sum Rules for Data Analysis: Examples	93
8.1	Introductory Remarks	93
8.2	Applications of Kramers-Kronig Relations for Data Inversion	93
8.2.1	Kramers-Kronig Inversion of Harmonic-Generation Susceptibility	94

8.2.2	Kramers-Kronig Inversion of the Second Power of Harmonic-Generation Susceptibility	96
8.3	Verification of Sum Rules for Harmonic-Generation Susceptibility	98
8.4	Application of Singly Subtractive Kramers-Kronig Relations	101
8.5	Estimates of the Truncation Error in Kramers-Kronig Relations	104
8.6	Sum Rules and Static Second-Order Nonlinear Susceptibility	106
9	Modified Kramers-Kronig Relations in Nonlinear Optics	109
9.1	Modified Kramers-Kronig Relations for a Meromorphic Nonlinear Quantity	109
9.2	Sum Rules for a Meromorphic Nonlinear Quantity	112
10	The Maximum Entropy Method: Theory and Applications	115
10.1	The Theory of the Maximum Entropy Method	115
10.2	The Maximum Entropy Method in Linear Optical Spectroscopy	117
10.2.1	Phase Retrieval from Linear Reflectance	117
10.2.2	Study of Surface Plasmon Resonance	120
10.2.3	Misplacement Phase Error Correction in Terahertz Time-Domain Spectroscopy	126
10.3	The Maximum Entropy Method in Nonlinear Optical Spectroscopy	128
11	Conclusions	133
A	MATLAB® Programs for Data Analysis	137
A.1	Program 1: Estimation of the Imaginary Part via Kramers-Kronig Relations	137
A.2	Program 2: Estimation of the Real via Kramers-Kronig Relations	139
A.3	Program 3: Self-Consistent Estimate of the Real and Imaginary Parts of Susceptibility	141
A.4	Program 4: Estimation of the Imaginary Part via Singly Subtractive Kramers-Kronig Relations	142
A.5	Program 5: Estimation of the Real Part via Singly Subtractive Kramers-Kronig Relations	143
	References	145
	Index	159

Kramers-Kronig Relations in Optical Materials Research

Lucarini, V.; Saarinen, J.J.; Peiponen, K.-E.; Vartiainen,
E.M.

2005, X, 162 p. 37 illus., Hardcover

ISBN: 978-3-540-23673-3