

# Contents

<b>Chapter 1</b>	<b>Linear Optics: Wave Propagation in Anisotropic Materials</b>	<b>1</b>
1.1	Lorentz Model—harmonic oscillator model of the refractive index; dispersion and absorption	1
1.2	Anisotropy—tensor form of the dielectric constant; rotation to the principal dielectric axes	6
1.3	Wave Propagation in an Anisotropic Crystal—the two allowed polarizations	8
1.4	The Index Ellipsoid—method to find the polarization directions; uniaxial and biaxial crystals; the extraordinary index at an angle $\theta$ to the optic axis	10
1.5	Refraction at the Surface of an Anisotropic Crystal—the $\mathbf{k}$ vector construction	13
1.6	Applications of Birefringence—compensation of the dispersion of a material; quarter-wave plates and half-wave plates	15
1.7	Orientation of the Crystal	16
1.8	Biaxial Crystals—the two-sheeted $\mathbf{k}$ vector surface; the polarization on these surfaces	17
1.9	Optical Activity	20
1.10	Induced Anisotropy	21
1.11	Electrooptic Effect—the contracted notation for the 18 independent elements; electrooptic modulation; the half-wave voltage	21
<b>Chapter 2</b>	<b>Nonlinear Optics</b>	<b>25</b>
2.1	Introduction—the nonlinearity of the polarization and the generation of sidebands	25
2.2	Nonlinearities of the Polarization—generation of second-harmonic, dc, sum and difference frequencies	26
		vii

2.3	The Anharmonic Oscillator	29
2.4	Definition of the Electric Field—the definition of the electric field with many frequency components; definition of positive and negative frequencies	29
2.5	The Nonlinear Polarization—solution of the anharmonic oscillator equation; expression for the first- and second-order polarization	30
2.6	Extension to Three Dimensions in Three Mutually Interacting Fields—permutation of the frequencies and the indices	32
2.7	Miller's Rule—relation between the second-order susceptibility and the linear susceptibilities	33
2.8	The Coefficients Used Experimentally—relation between $d$ and $\chi$ .	34
2.9	Contraction of the Indices—definition of a column vector $\mathbf{F}$ , contraction of the indices; an example	34
2.10	Crystal Symmetry—derivation of the matrix elements of a representative class; Kleinman's symmetry condition; the nonlinear susceptibility matrix and the piezoelectric matrix	35
2.11	Definition of $d_{\text{eff}}$	37
2.12	An Example	39
2.13	The Coupled Amplitude Equations—derivation of the three coupled amplitude equations that govern a general three-frequency interaction; expressions for output power in the small-signal approximation	41
2.14	The Manley-Rowe Relations—gain in difference frequency generation; the parametric oscillator	44
2.15	Second-Harmonic Generation—the output power per unit area for the small-signal approximation; exact solution of the coupled amplitude equations in the phase-matched case	46
2.16	Output Angle	48
2.17	The Electrooptic Coefficient—relation between the classical electrooptical coefficient and the nonlinear optical coefficient	51
2.18	Nonlinear Interactions in Reflection	52
2.19	Dimensions—relation between MKS units and c.g.s. units	52
<b>Chapter 3 Phase Matching</b>		<b>54</b>
3.1	Introduction—the importance of phase matching to nonlinear interactions	54
3.2	Power Flow in the Non-Phase-Matched Case—coupling of the power back and forth between input and harmonics	54

3.3	Quasi-Phase-Matching Methods—methods to adjust the phase difference periodically	58
3.4	Angle Phase Matching—phase-matching using the birefringence of a crystal. Type I and Type II phase matching—diagrams showing possible interactions for a given phase-matching angle	59
3.5	The Expression for $d_{\text{eff}}$ for the Different Crystal Classes—equations and tables giving the polarization of the output as a function of the polarizations and the direction of transmission of the input	61
3.6	Disadvantages of Angle Phase Matching—the effects of walk-off between the extraordinary and the ordinary rays; divergence of a focused beam	67
3.7	Temperature-Dependent Phase Matching—noncritical phase matching in the $x$ - $y$ plane by temperature tuning of the indices	68
3.8	Phase Matching in Biaxial Crystals	69
3.9	Other Phase-Matching Methods—phase matching in optically active media; phase matching using Faraday rotation; interactions between noncollinear beams	70
3.10	Competing Interactions—simultaneous phase matching between several interactions; absorption of the pump radiation	71
<b>Chapter 4</b>	<b>Nonlinear Materials</b>	<b>73</b>
4.1	Historical Introduction—brief history of the development of nonlinear materials, their use, measurement, and characterization	73
4.2	Quality Assessment of Nonlinear Materials—linear and nonlinear SHG characteristics; effective crystal length	77
4.3	The Accurate Measurement of Optical Nonlinearity—absolute measurements; Maker fringe technique; sign of nonlinearity; pulsed-laser techniques	81
4.4	Kurtz Powder Assessment of Nonlinear Materials	84
4.5	Lithium Niobate—general properties; growth; poling; assessment; refractive indices; effects of composition; damage problems; “hot” $\text{LiNbO}_3$	86
4.6	Barium Sodium Niobate—general properties; growth; poling; detwinning; refractive indices	92
4.7	ADP and KDP—General properties; refractive indices	94

4.8	Lithium Iodate—general properties; refractive indices	98
4.9	Proustite—general properties; refractive indices	99
<b>Chapter 5 Second-Harmonic Generation</b>		<b>102</b>
5.1	Introduction	102
5.2	Plane Wave Interactions—low-conversion efficiency solutions; high conversion	102
5.3	Finite Beam Size—small beam area: limitations of focusing; optimum focusing for $TEM_{00}$ mode; phase-matching limitations for multimode beams; effects of source linewidth	105
5.4	Effects of Mode Structure on SHG—SHG from randomly phased modes	108
5.5	SHG from Mode-Locked Lasers	111
5.6	Intracavity SHG—Three- and four-level laser rate equations with SHG; optimum coupling	112
5.7	Picosecond Time Domain Measurements by SHG	120
<b>Chapter 6 Parametric Up-Conversion</b>		<b>124</b>
6.1	Introduction—sum frequency generation; limitation to up- conversion; introductory theory; infrared detection; single- and multiple-mode approaches	124
6.2	General Points—Manley–Rowe relations; quantum-conver- sion efficiency for multimode converter	127
6.3	Focused Beams—Small area $A$ ; single-mode operations; optimum focusing	128
6.4	Effects of Phase Matching Tuning—tunable infrared frequency; tuning ranges Frequency Bandwidth—narrow- and broad-band operation Solid Acceptance Angle for Infrared Radiation—critical, noncritical, and noncollinear phase matching	130 130 132 134
6.5	Comparison of the Single-Mode and Multimode Up-Con- verters—blackbody modes and number of quanta per mode; relative sensitivity of multimode and single-mode up-converters in various situations; optimization	139
6.6	Noise Properties—comparison of up-converter and photocon- ductive detectors; characteristics of the up-converter as infrared detector; parametrically generated noise in the up- converter	142

CONTENTS	xi
6.7 Parametric Image Converters	
Principles—simple theory of image transfer	146
Mode Analysis—use of analysis of Section 6.5 for evaluation of image converter; sensitivity to blackbody sources	149
6.8 Experimental Status of Up-Conversion	152
<b>Chapter 7 Optical Parametric Amplification and Oscillation</b>	<b>153</b>
7.1 Introduction—the Manley–Rowe relations; gain in difference frequency generation; comparison with microwave parametric oscillators	153
7.2 Amplifier and Oscillator Gain Coefficients—solution of the coupled equations; gain coefficient for the amplifier and for the oscillator	154
7.3 Effects of Phase Mismatch	156
7.4 Parametric Oscillation—the first oscillator of Giordmaine and Miller; the continuous-wave oscillator of Smith	157
7.5 Mode Hopping and the Cluster Effect—frequency and amplitude instabilities of the doubly resonant oscillator	161
7.6 Power Limiting and Gain Saturation—Siegman’s power limiter; saturation of the gain; coupling between the oscillator and the pump; the ring resonant oscillator	164
7.7 More Stable Configurations—servo control of the doubly resonant oscillator; the backward wave oscillator; the singly resonant parametric oscillator	169
7.8 Noise in the Optical Parametric Amplifier	173
7.9 Requirements for the Laser Pump—the multimode pump of Harris; pump requirements for the singly resonant oscillator	174
<b>Appendix 1 Tensors</b>	<b>177</b>
<b>Appendix 2 Nonlinear Optical Susceptibilities</b>	<b>180</b>
<b>References</b>	<b>186</b>
<b>Index</b>	<b>197</b>