

# Contents

<b>1</b>	<b>Excitons and Biexcitons in Semiconductors</b>	<b>1</b>
1.1	The Electronic Structure of Excitons	1
1.2	Classification of the Exciton States	12
1.3	Lenard–Dyson Theorem	14
1.4	Effects of Exciton–Exciton Interaction	16
1.5	Excitons Captured by Isoelectronic Impurities	23
<b>2</b>	<b>Exciton Paramagnetic, Paraelectric, and Zero-Field Resonances</b>	<b>27</b>
2.1	Paramagnetic Resonance of Small-Radius Triplet Excitons	29
2.2	Spin-Dependent Intraband Scattering of Triplet Wannier–Mott Excitons on Phonons	32
2.3	Contribution of Hyperfine Interaction to Exciton Paramagnetic Resonance Linewidth	37
2.4	Generation of Coherent Electromagnetic Radiation at Intra- and Interseries Exciton Transitions	40
2.5	Generation of Coherent Magnons in Magnetic Semiconductors	47
2.6	Exciton Paraelectric Resonance	53
2.7	Isotopic Shift of Exciton Paraelectric Resonance in $\text{Cu}_2\text{O}$ Crystals	58
<b>3</b>	<b>Exciton Acoustic Resonance</b>	<b>65</b>
3.1	The Effect of Lattice Vibrations and Free Carriers on Ultrasonic Attenuation in Crystals	66
3.2	Resonant Absorption of Hypersound at Intraband Exciton Scattering on Phonons	69
3.3	Resonant Absorption of Hypersound During Transitions Between Exciton Subbands	71
3.4	Induced Instability in a System of Excitons and Strictly Resonant Hypersonic Phonons	77
3.5	Phonon Maser on the Exciton Transitions	81
3.6	Resonance Absorption of Hypersound by Biexcitons	85

<b>4</b>	<b>Double Resonances</b>	89
4.1	Pikus–Luttinger Method of Invariants and Its Applications to ENDOR and Acoustical ENDOR	90
4.2	One-Phonon Spin–Lattice Relaxation and Acoustically Nonequivalent Nuclei	105
4.3	Localized Biexcitons in the Crystal GaP:N	110
4.4	Exchange and Magnetic Dipole–Dipole Interaction Between Holes in the Localized Biexciton	112
4.5	Double Hole–Nuclear Resonance on Localized Biexcitons in the Crystal GaP:N	117
4.6	Double Radio–Optical Exciton Resonance	120
<b>5</b>	<b>Investigation of Excitons by NMR Spectroscopy Methods</b>	125
5.1	Relaxation of Nuclear Spin via Triplet Excitons	125
5.2	Exciton Knight Shift of NMR Lines	130
5.3	NMR Evidence of Bose–Einstein Condensation of Excitons	132
5.4	Relaxation of Nuclear Spin via Orthobiexcitons	135
5.5	Partial Averaging of the Exciton–Exciton Interaction Under Influence of Terasound	140
<b>6</b>	<b>Interaction of Excitons with Paramagnetic Centers</b>	147
6.1	Spin Relaxation of Deep Centers in Semiconductors via Singlet and Triplet Excitons	148
6.2	Relaxation of Paramagnetic Centers via $\Gamma_6 \otimes \Gamma_8 \otimes \Gamma_1$ Excitons in Cubic Crystals	151
6.3	Shortening of Spin Relaxation Time of Paramagnetic Centers due to Interaction with Excitons	154
6.4	Indirect Interaction of the Paramagnetic Centers via Excitons	157
6.5	The Effect of Giant Spin Splitting of the Exciton Band in Diluted Magnetic Semiconductors	161
6.6	Giant Magneto–Optical Effects in Diluted Magnetic Semiconductors	163
<b>7</b>	<b>Effects of Deep Saturation</b>	171
7.1	Unsteady States of Quantum Systems	172
7.2	Unsteady States of Excitons at Interband Scattering on High-Density Hypersonic Phonons	176
7.3	Unsteady States of Excitons at Intraband Scattering on High-Density Hypersonic Phonons	179
7.4	Quasi-Energy Spectrum for a System with Equidistant Energy Levels	181
<b>8</b>	<b>Basics of Quantum Information Processing</b>	187
8.1	Information and Physics	188
8.2	Quantum Information	190
8.3	Quantum Bits	191
8.4	The Network Model of Quantum Information Processing	193

8.5 Quantum Gates for Single Qubits . . . . . 194

8.6 Two-Qubit Operations . . . . . 195

8.7 Robust Gate Operations . . . . . 197

8.8 Initialization and Readout . . . . . 198

8.9 Decoherence . . . . . 198

8.10 Quantum Communication . . . . . 199

8.11 Quantum Computing with Bose Operators . . . . . 200

**9 Test Systems for Quantum Information Processing . . . . . 207**

9.1 Requirements . . . . . 207

9.2 Semiconductor Quantum Dots . . . . . 209

9.3 The Diamond Nitrogen–Vacancy Center . . . . . 211

9.4 <sup>31</sup>P in Silicon . . . . . 214

9.5 Endohedral Fullerenes . . . . . 217

9.6 Rare-Earth Ions . . . . . 219

9.7 Molecular Magnets . . . . . 222

**10 Conclusions . . . . . 225**

**Appendix A Irreducible Tensor Operators  $Y_M^L(\mathcal{I})$  . . . . . 227**

**Appendix B Matrix of Unitary Operator  $U$  Defined by Means  
of Basis Function Operators of the Irreducible Representations  
of the Symmetry Point Groups . . . . . 229**

**Appendix C Color Symmetry and Time Reversal in Systems  
with Half-Integer Total Spin [392] . . . . . 233**

**Appendix D Operators  $\xi$  and  $\eta$  . . . . . 237**

**Appendix E The Functions  $f_{kj}$  . . . . . 241**

**Appendix F The Wave Functions  $\Phi_M^J(l l')$  . . . . . 245**

**Appendix G Integral  $I(s, t)$  . . . . . 249**

**Appendix H Unitarity of the Spinor Operators and Two-Boson  
Representation of the Angular Momentum [527] . . . . . 251**

**Glossary . . . . . 255**

**References . . . . . 259**

**Index . . . . . 277**