Contents

Entanglement, Bell Inequalities and Decoherence in Particle Physics
R.A. Bertlmann 1
1 Introduction 1
1.1 Particle Physics 2
2 QM of K-mesons 3
2.1 Strangeness 3
2.2 CP Violation 4
2.3 Strangeness Oscillation 4
2.4 Regeneration of K_S 5
3 Analogies and Quasi-Spin 6
4 Time Evolution – Unitarity 7
5 Bell Inequalities for Spin-$\frac{1}{2}$ Particles 9
6 Bell Inequalities for K-mesons 11
6.1 Analogies and Differences 12
6.2 Bell-CHSH Inequality – General Form 13
6.3 Bell Inequality for Time Variation 14
6.4 Bell Inequality for Quasi-Spin States – CP Violation 15
7 Decoherence in Entangled $K^0\bar{K}^0$ System 18
7.1 Density Matrix 19
7.2 Model 21
7.3 Entangled Kaons 22
7.4 Measurement 23
7.5 Experiment 24
8 Connection to Phenomenological Model 26
9 Entanglement Loss – Decoherence 28
9.1 Von Neumann Entropy 29
9.2 Separability 30
9.3 Entanglement of Formation and Concurrence 33
10 Outlook 36
References 41

Quantum Gates and Decoherence
S. Scheel, J.K. Pachos, E.A. Hinds and P.L. Knight 47
1 Introduction 47
1.1 Why Quantum Information Processing? 47
1.2 Quantum Gates vs. Classical Gates 48
2 Atomic Realisation – Atom Chips and the Mott Transition in Optical Lattices 51
2.1 Bose–Einstein Condensates and the Mott Transition 51
2.2 Quantum Computation with a 1D Optical Lattice 54
2.3 Experimental Realization with Atom Chips 58
3 Photonic Realisation – Passive Linear Optics and Projective Measurements 60
3.1 Qubit Encoding and Single-Qubit Operations 60
3.2 Measurement-Induced Nonlinearities 61
3.3 Construction of Simple Quantum Gates 64
3.4 Multi-Mode Gates 66
3.5 Conditional Dynamics and Scaling of Success Probabilities 67
4 Decoherence Mechanisms – QED in Causal Dielectric Media 69
4.1 Decoherence Mechanisms Affecting Atoms and Photons 69
4.2 Field Quantisation in Causal Media 71
4.3 Thermally Induced Spin Flips Near Metallic Wires 74
4.4 Imperfect Passive Optical Elements 77
References 80

Spin-Based Quantum Dot Quantum Computing
X. Hu 83
1 Introduction 83
2 General Features of the Quantum Dot Quantum Computing Schemes 84
2.1 Classification of the QC Schemes 84
2.2 GaAs Quantum Dot QC Architecture 86
2.3 Si Quantum Dot QC Architecture 86
2.4 Si Donor Nuclear Spin QC Architecture 87
2.5 Si Donor Electron Spin QC Architecture 88
3 Electron Spin Coherence in Semiconductors 89
3.1 Spin Decoherence Channels in Semiconductors 91
3.2 Spectral Diffusion for Electron Spins 92
4 Spin Manipulations and Exchange 94
4.1 Spin Hamiltonian in a GaAs Double Quantum Dot: Coulomb Interaction and Pauli Principle 94
4.2 Implications of Si Conduction Band Structure to Electron Exchange 99
4.3 Single Spin Detection Schemes 103

4.4 Approaches to Generate and Detect Electron Spin Entanglement in Quantum Dots ... 104
5 Current Experimental Status ... 105
5.1 Single Electron Trapping in Horizontal QDs ... 105
5.2 Single Spin Detection ... 106
5.3 Electron-Nuclear Spin Interaction in QDs ... 107
5.4 Fabrication of Donor Arrays in Si ... 108
6 Summary ... 108
References ... 109

Microscopic Theory of Coherent Semiconductor Optics
T. Meier and S.W. Koch ... 115
1 Introduction ... 115
2 Semiclassical Theory ... 118
3 Time-Dependent Hartree–Fock Approximation ... 119
3.1 Excitonic Linear Absorption Spectra in Different Dimensions ... 122
4 Many-Body Coulomb Correlations ... 125
4.1 Second-Order Born Approximation ... 125
4.2 Density-Dependent Exciton Saturation and Broadening ... 129
4.3 Dynamics-Controlled Truncation Scheme: Coherent $\chi^{(3)}$-Limit ... 132
4.4 Signatures of Coherent Four-Particle Correlations in $\chi^{(3)}$ ... 140
4.5 Dynamics-Controlled Truncation Scheme: Coherent $\chi^{(5)}$-Limit ... 145
4.6 Signatures of Coherent Four-Particle Correlations Up to $\chi^{(5)}$. 145
5 Conclusions and Outlook ... 148
References ... 150

Exciton and Polariton Condensation
D. Porras, J. Fernandez-Rossier and C. Tejedor ... 153
1 Introduction ... 153
1.1 Coherence ... 154
1.2 Condensation ... 156
1.3 Bosonic Limit of Excitons ... 156
2 Exciton Condensation: Standard Theory ... 157
2.1 Non-Interacting Bosons ... 157
2.2 Weakly Interacting Bosons ... 158
2.3 Interacting Electron-Hole Pairs: Excitonic Insulator ... 159
2.4 Electron-Hole Liquid ... 164
3 Emission of Light ... 164
4 Magnetoexcitons ... 167
5 Multicomponent Condensates ... 168
5.1 Phase Diagram ... 168
5.2 Coherence Effects ... 170

6 Polariton Condensation 172
6.1 Polariton Dynamics 173
6.2 Evolution of the Polariton Distribution: Macroscopic Occupation 178
7 Polariton Laser 180
7.1 Equation of Motion for the Density Matrix 181
7.2 Emission Spectrum 182
7.3 Related Work 185
8 Summary 186
References 187