

Gerd Leuchs, Thomas Beth (Eds.)

Quantum Information Processing



WILEY-VCH GmbH & Co. KGaA

Quantum Information Processing. Edited by G. Leuchs, T. Beth
Copyright © 2003 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim
ISBN: 3-527-40371-X

Contents

List of Contributors

XVII

1 Algorithms for Quantum Systems — Quantum Algorithms (<i>Th. Beth, M. Grassl, D. Janzing, M. Rötteler, P. Wocjan, and R. Zeier</i>)	1
1.1 Introduction	1
1.2 Fast Quantum Signal Transforms	1
1.3 Quantum Error-correcting Codes	3
1.4 Efficient decomposition of quantum operations into given one-parameter groups	5
1.5 Simulation of Hamiltonians	8
References	10
2 Quantum Information Processing and Error Correction with Jump Codes (<i>G. Alber, M. Mussinger, and A. Delgado</i>)	14
2.1 Introduction	14
2.2 Invertible quantum operations and error correction	15
2.3 Quantum error correction by jump codes	17
2.3.1 Spontaneous decay and quantum trajectories	17
2.3.2 Jump codes	19
2.4 Universal quantum gates in code spaces	21
2.4.1 Universal sets of quantum gates for qudit-systems	21
2.4.2 Universal one-qutrit gates	22
2.4.3 A universal entanglement gate	23
2.5 Summary and outlook	25
References	26
3 Computational Model for the One-Way Quantum Computer: Concepts and Summary (<i>R. Raussendorf and H. J. Briegel</i>)	28
3.1 Introduction	28
3.2 The QC_C as a universal simulator of quantum logic networks	30
3.3 Non-network character of the QC_C	35
3.4 Computational model	36
3.5 Conclusion	42
References	42

4	Simulation Tool Development Related to a Combinatorial Quantum Automaton Based on Trapped Ions	44
	<i>(W. Mathis and K. Pahlke)</i>	
4.1	Introduction	44
4.2	Functional description and logic models	46
4.3	Concepts of open quantum system modeling	46
4.4	Modeling of the qubit system dynamics	49
4.5	Two CNOT-gate implementation proposals	49
4.6	Conclusions	50
	References	51
5	Increasing the Size of NMR Quantum Computers	53
	<i>(S. J. Glaser, R. Marx, T. Reiss, T. Schulte-Herbrüggen, N. Khaneja, J. M. Myers, and A. F. Fahmy)</i>	
5.1	Introduction	53
5.2	Suitable molecules	55
5.3	Scaling problem for experiments based on pseudo-pure states	56
5.4	Approaching pure states	58
5.5	Scalable NMR quantum computing based on the thermal density operator	58
5.6	Time-optimal implementation of quantum gates	59
5.7	Conclusion	63
	References	63
6	On Lossless Quantum Data Compression and Quantum Variable–Length Codes	66
	<i>(R. Ahlswede and N. Cai)</i>	
6.1	Introduction	66
6.2	Codes, Lengths, Kraft Inequality and von Neumann Entropy Bound	67
6.2.1	The Codes	67
6.2.2	Length Observable and Average Length of Codewords	68
6.2.3	Kraft Inequality and von Neumann Entropy Bound	68
6.2.4	Base Length	69
6.3	Construct Long Codes from Variable–length Codes	69
6.4	Lossless Quantum Data Compression, if the Decoder is Informed about the Base Lengths	70
6.5	Code Analysis Based on the Base Length	71
6.6	Lossless Quantum Data Compression with a Classical Helper	72
6.7	Lossless Quantum Data Compression for Mixed State Sources	75
6.8	A Result on Tradeoff between Quantum and Classical Resources in Lossy Quantum Data Compression	76
	References	77
7	Entanglement Properties of Composite Quantum Systems	79
	<i>(K. Eckert, O. Gühne, F. Hulpke, P. Hyllus, J. Korbicz, J. Mompart, D. Bruß, M. Lewenstein, and A. Sanpera)</i>	
7.1	Introduction	79

7.2	Separability of composite quantum systems	80
7.2.1	The separability problem	81
7.2.2	Results on the separability problem	82
7.3	The distillability problem	84
7.3.1	Results on the distillability problem	85
7.4	Witness operators for the detection of entanglement	86
7.4.1	Definition and geometrical interpretation of witness operators	86
7.4.2	Results on witness operators	88
7.5	Quantum correlations in systems of fermionic and bosonic states	90
7.5.1	What is different with indistinguishable particles?	90
7.5.2	Results on quantum correlations for indistinguishable particles	91
7.5.3	Implementation of an entangling gate with bosons	93
7.6	Summary	93
	References	93

8 Non-Classical Gaussian States in Noisy Environments

	<i>(S. Scheel and D.-G. Welsch)</i>	96
8.1	Introduction	96
8.2	Gaussian states and Gaussian operations	96
8.2.1	Classicality	98
8.2.2	CP maps and partial measurements	98
8.2.3	Separability and entanglement	99
8.3	Entanglement degradation	100
8.4	Quantum teleportation in noisy environments	102
8.4.1	Imperfect teleportation	103
8.4.2	Teleportation fidelity	104
8.4.3	Choice of the coherent displacement	106
	References	107

9 Quantum Estimation with Finite Resources

	<i>(T. C. Btschorr, D. G. Fischer, H. Mack, W. P. Schleich, and M. Freyberger)</i>	109
9.1	Introduction	109
9.2	Quantum Devices and Channels	110
9.3	Estimating Quantum Channels	111
9.4	Entanglement and Estimation	111
9.4.1	Estimation using Single Qubits	112
9.4.2	Estimation using Entangled States	114
9.5	Generalized Estimation Schemes	116
9.5.1	Estimation with Two Channels	116
9.5.2	What is the Optimal Reference Channel?	117
9.5.3	Estimation with Werner States	118
9.6	Outlook	119
	References	120

10 Size Scaling of Decoherence Rates

<i>(C. S. Maierle and D. Suter)</i>	121
10.1 Introduction	121
10.2 Decoherence Models	122
10.3 Collective and independent decoherence	123
10.4 Average decoherence rate as a measure of decoherence	124
10.5 Decoherence rate scaling due to partially correlated fields	126
10.6 Conclusion	130
References	130

11 Reduced Collective Description of Spin-Ensembles

<i>(M. Michel, H. Schmidt, F. Tonner, and G. Mahler)</i>	131
11.1 Introduction	131
11.2 Operator representations	132
11.3 Hamilton models	134
11.3.1 Symmetry-constrained networks	134
11.3.2 Topology-constrained networks	135
11.4 State models	135
11.4.1 Totally permutation-symmetric subspace	136
11.4.2 Collective 1-particle excitations	136
11.4.3 1-parameter families of non-pure states	136
11.4.4 Families of separable states: “modules”	137
11.5 Ensembles	137
11.5.1 Trajectories and ergodicity	137
11.5.2 Leakage and storage capacity	139
11.5.3 Mixing strategies	142
11.5.4 State construction and separability	143
11.6 Summary and outlook	143
References	144

12 Decoherence in Resonantly Driven Bistable Systems

<i>(S. Kohler and P. Hänggi)</i>	145
12.1 Introduction	145
12.2 The model and its symmetries	145
12.3 Coherent tunneling	147
12.4 Dissipative tunneling	151
12.5 Conclusions	155
12.6 Acknowledgments	156
References	156

13 Entanglement and Decoherence in Cavity QED with a Trapped Ion

<i>(W. Vogel and Ch. DiFidio)</i>	157
13.1 Introduction	157
13.2 Decoherence effects	158
13.3 Greenberger-Horne-Zeilinger state	160

13.4 Photon-number control	162
13.5 Entanglement of separated atoms	164
13.6 Summary	166
References	166
14 Quantum Information Processing with Ions Deterministically Coupled to an Optical Cavity	
<i>(M. Keller, B. Lange, K. Hayasaka, W. Lange, and H. Walther)</i>	168
14.1 Introduction	168
14.2 Deterministic coupling of ions and cavity field	169
14.3 Single-ion mapping of cavity-modes	171
14.4 Atom-photon interface	174
14.5 Single-photon source	176
14.6 Cavity-mediated two-ion coupling	178
References	180
15 Strongly Coupled Atom-Cavity Systems	
<i>(A. Kuhn, M. Hennrich, and G. Rempe)</i>	182
15.1 Introduction	182
15.2 Atoms, Cavities and Light	182
15.2.1 Field Quantization in a Fabry-Perot Cavity	183
15.2.2 Two-Level Atom	183
15.2.3 Three-Level Atom	184
15.2.4 Adiabatic Passage	186
15.3 Single-Photon Sources	187
15.3.1 Vacuum-Stimulated Raman Scattering	188
15.3.2 Deterministic single-photon sequences	189
15.4 Summary and Outlook	192
References	193
16 A Relaxation-Free Verification of the Quantum Zeno Paradox on an Individual Atom	
<i>(Ch. Balzer, Th. Hannemann, D. Reiß, Ch. Wunderlich, W. Neuhauser, and P. E. Toschek)</i>	196
16.1 Introduction	196
16.2 The hardware and basic procedure	197
16.3 First scheme: Statistics of the sequences of equal results	200
16.4 Second scheme: Driving the ion by fractionated π -pulses	202
16.5 Conclusions	205
16.6 Survey of related work	206
References	208

17 Spin Resonance with Trapped Ions: Experiments and New Concepts*(K. Abich, Ch. Balzer, T. Hannemann, F. Mintert, W. Neuhauser, D. Reiß, P. E. Toschek, and Ch. Wunderlich)***210**

17.1 Introduction	210
17.2 Self-learning estimation of quantum states	211
17.3 Experimental realization of quantum channels	213
17.4 New concepts for QIP with trapped ions	215
17.4.1 Spin resonance with trapped ions	216
17.4.2 Simultaneous cooling of axial vibrational modes	219
17.5 Raman cooling of two trapped ions	220
References	222

18 Controlled Single Neutral Atoms as Qubits*(V. Gomer, W. Alt, S. Kuhr, D. Schrader, and D. Meschede)***224**

18.1 Introduction	224
18.2 Cavity QED for QIP	225
18.3 Single Atom Controlled Manipulation	225
18.4 How to prepare exactly 2 atoms in a dipole trap?	226
18.5 Optical dipole trap	227
18.6 Relaxation and decoherence	227
18.7 Qubit conveyor belt	229
18.8 Outlook	229
18.9 Acknowledgement	229
References	230

19 Towards Quantum Logic with Cold Atoms in a CO₂-Laser Optical Lattice*(G. Cennini, G. Ritt, C. Geckeler, R. Scheunemann, and M. Weitz)***235**

19.1 Introduction	235
19.2 Entanglement and Beyond	236
19.3 Quantum Logic and Far-detuned Optical Lattices	237
19.4 Resolving and Addressing cold atoms in single lattice sites	239
19.5 Recent work	242
References	244

20 Quantum Information Processing with Atoms in Optical Micro-Structures*(R. Dumke, M. Volk, T. Müther, F. B. J. Buchkremer, W. Ertmer, and G. Birkl)***246**

20.1 Introduction	246
20.2 Microoptical Elements for Quantum Information Processing	247
20.3 Experimental Setup	248
20.4 Scalable Qubit Registers Based on Arrays of Dipole Traps	249
20.5 Initialization, Manipulation and Readout	250
20.6 Variation of Trap Separation	251
20.7 Implementation of Qubit Gates	252
References	255

21 Quantum Information Processing with Neutral Atoms on Atom Chips	
<i>(P. Krüger, A. Haase, R. Folman, and J. Schmiedmayer)</i>	257
21.1 Introduction	257
21.2 The atom chip	257
21.3 Quantum information processing	259
21.3.1 The Qubit	259
21.3.2 Entangling Qubits	260
21.3.3 Input/Output	262
21.4 Noise and decoherence	262
21.5 Summary and conclusion	263
21.6 Acknowledgements	264
References	264
22 Fabrication and Measurement of Aluminum and Niobium Based Single-Electron Transistors and Charge Qubits	
<i>(W. Krech, D. Born, M. Mihalik, and M. Grajcar)</i>	266
22.1 Introduction	266
22.2 Motivation for this Work	267
22.3 Sample Preparation	268
22.3.1 Scheme of the Junction Preparation Technique	268
22.3.2 Fabrication of Tunnel Devices: SET and Charge Qubit Structures	269
22.4 Experimental Results	270
22.5 Conclusions	272
References	275
23 Quantum Dot Circuits for Quantum Computation	
<i>(R. H. Blick, A. K. Hüttel, A. W. Holleitner, L. Pescini, and H. Lorenz)</i>	277
23.1 Introduction	277
23.2 Realizing quantum bits in double quantum dots	278
23.3 Controlling the electron spin in single dots	285
23.4 Summary	290
References	290
24 Multiphoton Entanglement	
<i>(M. Bourennane, M. Eibl, S. Gaertner, N. Kiesel, C. Kurtsiefer, M. Zukowski, and H. Weinfurter)</i>	292
24.1 Introduction	292
24.2 Entangled multi-photon state preparation	293
24.3 Experiment	294
24.4 Quantum correlations	295
24.5 Bell Inequality	297
24.6 Entanglement robustness	298
24.7 Conclusions	299
References	299

25 A Quantum Optical XOR Gate	
<i>(H. Becker, K. Schmid, W. Dultz, W. Martienssen, and H. Roskos)</i>	301
25.1 Introduction	301
25.2 Double Bump Photons	301
25.3 The XOR Gate	303
25.4 Quad bump photons	306
25.5 Outlook	307
References	307
26 Quantum Structure of Fiber Solitons and Quantum Communication	
<i>(G. Leuchs, N. Korolkova, Ch. Silberhorn, O. Glöckl, and S. Lorenz)</i>	308
26.1 Introduction	308
26.2 Quantum correlations and entanglement	309
26.3 Multimode quantum correlations	310
26.3.1 Intra-pulse quantum correlations	311
26.3.2 Higher-order solitons and soliton collisions	313
26.4 Generation of bright EPR-entangled beams	314
26.5 Direct experimental test of non-separability	316
26.6 Polarization variables	318
References	319
Index	323