

Contents

Introduction	page 1
Part I Quantum information	3
1 Quantum bits and quantum gates	5
1.1 The Bloch sphere	6
1.2 Density matrices and Pauli matrices	8
1.3 Quantum logic gates	10
1.4 Quantum networks	13
1.5 Initialization and measurement	15
1.6 Experimental methods	17
Further reading	17
Exercises	17
2 An atom in a laser field	19
2.1 Time-dependent systems	19
2.2 Sudden jumps	20
2.3 Oscillating fields	22
2.4 Time-dependent perturbation theory	24
2.5 Rabi flopping and Fermi's Golden Rule	25
2.6 Raman transitions	27
2.7 Rabi flopping and Ramsey fringes	29
2.8 Measurement and initialization	31
Further reading	31
Exercises	31
3 Spins in magnetic fields	33
3.1 The nuclear spin Hamiltonian	33
3.2 The rotating frame	35
3.3 On- and off-resonance excitation	37
3.4 The vector model	38
3.5 Spin echoes	39
3.6 Measurement and initialization	40
Further reading	40
Exercises	41

4 Photon techniques	42
4.1 Spatial encoding	42
4.2 Polarization encoding	44
4.3 Single-photon sources and detectors	45
4.4 Conventions	46
Further reading	46
Exercises	47
5 Two qubits and beyond	48
5.1 Direct products	48
5.2 Matrix forms	49
5.3 Two-qubit gates	50
5.4 Networks and circuits	51
5.5 Entangled states	52
Further reading	53
Exercises	53
6 Measurement and entanglement	55
6.1 Measuring a single qubit	55
6.2 Ensembles and the no-cloning theorem	58
6.3 Fidelity	59
6.4 Local operations and classical communication	61
Further reading	63
Exercises	63
Part II Quantum computation	65
7 Principles of quantum computing	67
7.1 Reversible computing	67
7.2 Quantum parallelism	69
7.3 Getting the answer out	70
7.4 The DiVincenzo criteria	70
Further reading	71
Exercises	72
8 Elementary quantum algorithms	73
8.1 Deutsch's algorithm	73
8.2 Why it works	75
8.3 Circuit identities	77
8.4 Deutsch's algorithm and interferometry	78
8.5 Grover's algorithm	78
8.6 Error correction	80
8.7 Decoherence-free subspaces	82
Further reading	83
Exercises	83

9 More advanced quantum algorithms	85
9.1 The Deutsch–Jozsa algorithm	85
9.2 The Bernstein–Vazirani algorithm	87
9.3 Deutsch–Jozsa and period finding	88
9.4 Fourier transforms and quantum factoring	90
9.5 Grover's algorithm	91
9.6 Generalizing Grover's algorithm	94
9.7 Quantum simulation	96
9.8 Experimental implementations	97
Further reading	97
Exercises	98
10 Trapped atoms and ions	99
10.1 Ion traps	99
10.2 Atom traps and optical lattices	100
10.3 Initialization	102
10.4 Decoherence	103
10.5 Universal logic	104
10.6 Two-qubit gates with ions	105
10.7 Two-qubit gates with atoms	106
10.8 Massive entanglement	109
10.9 Readout	110
Further reading	111
Exercises	111
11 Nuclear magnetic resonance	113
11.1 Qubits	113
11.2 Initialization	115
11.3 Decoherence	116
11.4 Universal logic	116
11.5 Readout	119
Further reading	122
Exercises	122
12 Large-scale quantum computers	124
12.1 Trapped ions	124
12.2 Optical lattices	125
12.3 NMR	126
12.4 Other approaches	126
Further reading	128
Part III Quantum communication	129
13 Basics of information theory	131
13.1 Classical information	132

13.2	Mutual information	135
13.3	The communication channel	137
13.4	Connection to statistical physics	138
	Further reading	139
	Exercises	139
14	Quantum information	140
14.1	The density operator	140
14.2	Global and local measurements	142
14.3	Information content of a density operator	144
14.4	Joint entropy and mutual information	145
14.5	Quantum channels	146
	Further reading	150
	Exercises	151
15	Quantum communication	152
15.1	Parametric down-conversion	152
15.2	Quantum dense coding	154
15.3	Quantum teleportation	156
15.4	Entanglement swapping	159
	Further reading	161
	Exercises	161
16	Testing EPR	163
16.1	Bell inequalities	163
16.2	GHZ states	167
	Further reading	170
	Exercises	170
17	Quantum cryptography	171
17.1	One-time pads and the Vernam cipher	171
17.2	The BB84 protocol	172
17.3	The Ekert91 protocol	174
17.4	Experimental setups	175
	Further reading	177
	Exercises	178
	Appendix: Quantum mechanics	179
	<i>References</i>	192
	<i>Index</i>	196