

Index

- $N \rightarrow M$ purification protocol 190
- $T - V$ diagram 267
- π -pulse 541
- $\pi/2$ pulse 541
- para*-hydrogen 486, 495
- 2π pulse 541

- absorption 505
- Active transformations 46
- additivity 170
- adiabatic approximation 382, 384
- adiabatic computation 100
- adiabaticity 458
- alphabet 315
- Anti-Jaynes–Cummings Hamiltonian 394
- asymmetric cloning 67
- asymptotic continuity 168
- atom chip 549
- atom-cavity microscope 545
- atomic ensemble 516
- atomic kaleidoscope 545
- atomic spin operator 517
- atomic trajectory 544
- attenuated laser pulses 278
- authentication 275

- base norm 172
- BB84 protocol (Bennett-Brassard) 272
- BBPSSW protocol 187
- beam splitter 151, 153, 300, 321, 547, 576
- Bell
 - measurement 350
- Bell basis 186
- Bell Inequality 135
- Bell measurement 531
- Bell state 186, 257, 260
 - basis 258
 - measurement, BSM 260, 262

- Bell States 337
- Berry phase 383
- bipartite mixed states 125
- bipartite pure states 123
- bipartite system 179
- biseparable 244
- bit-flip error 110
- Bloch ball 40
- Bloch band 402
- Bloch equation 474
- Bloch sphere 360, 436
- Bloch vector 40
- block code 10
- Boolean Function
 - Conjunction 345
 - Disjunction 345
- Boolean function 315
- bound entangled 155
- bound entanglement: bipartite 183
- bound entanglement: multipartite 193
- bound state
 - photon+atom 567
- branch 472
- breeding 191
- bright squeezed states 584
- BSC 8
- Bures distance 165
- bus mode 395

- Caldeira–Leggett model 473
- Calderbank–Shor–Steane code(CSS) 276
- Canonical commutation relations 43
- canonical transformations 530
- Cartan decomposition 493
- cavity 512, 544
- cavity lifetime 544
- Cavity QED 375

- cavity QED 466
- Cavity QED with ions 442
- CD-decomposition of unitary operators 373
- channel
 - binary symmetric 8
 - dephasing 106
 - depolarizing 106
 - discrete 4
 - noiseless 4
 - noisy 4
 - product 107
- channel capacity
 - discrete memoryless 8
 - discrete noiseless 4
 - quantum 108
- channel noise 275, 505
- Characteristic function 44
- characteristic function 150
- charge qubit 481, 494, 496
- charge-box qubit 469
- chord 472
- Cirac–Zoller ’95 395
- Cirac–Zoller gate 436
- circuit theory 472
- Classical Gaussian noise 48
- Clauser, Horne, Shimony, and Holt (CHSH)
 - inequality 136
- Clifford 249
- Clifford group 370
- Cluster state 249, 360
- cluster state 194
- CNOT gate 494, 495, 542
- code
 - block 10
 - CSS 116
 - dual 13
 - Hamming 14
 - quantum 108
 - rate 10
 - repetition 10
 - stabilizer 117
- coherent attack 277
- coherent quantum control 399
- coherent spectroscopy 488
- coherent spin state 519, 525
- Coherent state 43
- coherent state 579
- Coherent states 45
- coherent superposition 542
- coincidence(s) 261
- collective attack 277
- Coloring 25
- commutation relation 150, 298
- commutation relations
 - angular momentum 517
- commutator 154
- Complete positivity 42
- completely positive map
 - Gaussian 529
- composability 275
- Composite phase gate 435
- composite system 256
- Compositeness 24
- Composition 42
- Concurrence 247
- conditional entropy 7, 169
- conditional variance 267
- configuration interaction (CI) 465
- connection 507
- continuous variable quantum communication
 - 297
- continuous variables 147, 297
- continuous variables, CV 263, 264
- control theory 487, 490
- controlled phase flip (CPF) 453, 454, 456, 467
- controlled–not operation 187
- convex roof construction 170
- Cooper pair boxes 550
- correlation matrix 150
- correlation operator 186, 194
- coset 487, 493
- coset leader 15
- Coulomb interaction 458–460, 462–464
- coupling topology 492–494, 496
- criterion 154
 - Duan’s inseparability 154, 155
 - npt 156
 - partial transpose 155
 - Peres-Horodecki 156
 - Simon’s inseparability 157
- cross norm 173
- cryogenic environment 539
- cryptography 30
- CSIGN (controlled Sign gate) 357
- CSS code 116
- current fluctuations 475
- current–voltage relations (CVRs) 473

- Decoherence 323
- decoherence 529, 538, 543
- decoherence time T_2 458, 467, 469, 470, 474
- defect mode 564
- DEJMPS protocol 188
- Delft qubit 475
- dense-codeable (DC) states 141
- density operator 485
 - thermal 485
- dephasing channel 106
- depolarization 186
- depolarizing channel 106
- depumping rate 520
- Deutsch's algorithm 88
- Deutsch–Josza Algorithm 90
- Deutsch–Jozsa algorithm 482, 486, 487, 492, 495
- dipole approximation 556
- dipole–dipole interaction 412
- dipole-blockade 413
- discrete log 97
- discrete variables, DV 264
- Displacement operator 44
- displacer 302
- distillability 197
- distillable entanglement 165, 181
 - Rains' bound 172
- distillation 177
- divide-and-conquer 20
- double layer structure 476
- drift term 488
- dual code 13
- dual-homodyne detector 303
- dual-rail encoding 352
- Duan separability criterion 525
- dynamical trapping, Paul trap 425

- eavesdropping 68, 272, 277
- efficiency 259
- eigenvalue 331
- eigenvector 331
- Einstein locality assumption 136
- Einstein Podolsky Rosen argument 135
- Einstein-Podolski-Rosen 541
- electromagnetic field
 - in photonic crystal 564
 - in spherical cavity 558
- Electron shelving 424
- electron spin resonance 481
 - electron spin resonance (ESR) 459, 467
- element distinctness 100
- encoded operator 113
- encoding 456
- Energy constraint 39
- ensemble quantum computing 481, 486, 495
- ensemble states 495
- entangled state 123, 525
 - of atomic ensembles 525
- entanglement 67, 147, 177, 256
 - bipartite 147
 - two-party 147
 - witness 154
- entanglement cost 165
- entanglement criteria 125
- entanglement fidelity 107
- entanglement measures
 - additivity 170
 - additivity on pure states 168
 - asymptotic continuity 168
 - axioms for 167
 - convex roof construction 170
 - cross norm measure 173
 - distillable entanglement 165
 - entanglement cost 165
 - entanglement monotones 167
 - entanglement of formation 169
 - entropy of entanglement 166, 168
 - extremality of distillation and cost 169
 - logarithm of the negativity 171
 - norm based monotones 172
 - ordering of 168
 - regularization 169, 170
 - relative entropy of entanglement 170
 - robustness of entanglement 172
 - squashed entanglement 173
 - uniqueness on pure states 168
- Entanglement monotones 246
- entanglement of distillation 181
- entanglement of formation 169
 - additivity 170
 - strong superadditivity 170
- entanglement pumping 188
- entanglement purification 177
- entanglement swapping 507, 532
- Entanglement witness 245
- entanglement witness
 - decomposable 129
 - nondecomposable (nd-EW) 129

- entanglement witness (EW) 129
- entanglement-based QKD 290
- entropy
 - conditional 7
 - entropy of entanglement 166, 168
 - joint 7
 - Shannon 5
- entropy function 9
- entropy of entanglement 166, 180
- EPR 147, 152
 - pair 255, 258, 260
 - particle 258
- EPR entangled state 525
- error
 - bit-flip 110
 - sign-flip 110
- error basis 109
- error model 198
- error operator 106
- error syndrome 13
- error threshold 204
- error weight 109
- Eulerian path 18
- exchange coupling J 452, 456, 459, 462, 464
 - anisotropic 454
 - antiferromagnetic 458, 462
 - ferromagnetic 462
 - Ising 454
 - transverse (XY) 454
- exchange-only quantum computing 457
- expectation-value quantum computer 482
- experimental control 488, 496
- extension field 11

- Fabry-Perot 544
- factoring 93
- Factorization 29
- Fast Fourier transform 94
- feed forward 303
- Fermi's Golden rule 561
- fiber-based QKD. 286
- fidelity 186, 259–260, 542
 - entanglement 107
- field
 - extension 11
 - prime 11
- field-ionization 539
- filtering 184
- Filtering operation 239

- five-qubit NMR quantum computer 484
- flat-continuum approximation 561
- flux qubit 469, 475, 481
- Free-space QKD 289
- full controllability 482, 483
- fully entangled 240
- fully separable 243
- fundamental loop 473
- Fusion operations on graph states 375

- gate complexity 492
- Gaussian operations 151
- Gaussian states 45, 147, 149, 151
- Gaussian transformations 300
- generator matrix 13
- geodesic 487, 494
- geodesics
 - Riemannian 493
 - sub-Riemannian 493
- geometric control 481, 487, 494
- Geometric measure of entanglement 247
- geometric phase 382
- Geometric phase gate 440
- GHZ state 181
- Global entanglement 247
- global fidelity 55
- Gottesman/Chuang trick 349
- gradient flow 487–491, 495
- GRAPE algorithm 489, 491
- graph 472
- Graph Isomorphism 30
- graph isomorphism 97
- Graph state 360
- graph state 194
- Grover's Algorithm 98
- Grover's search 98

- Hadamard gate 88
- Hahn–Banach theorem 128
- Hamiltonian path 22
- Hamming code 14
- Hamming distance 10
- Hamming weight 10
- Hanbury Brown and Twiss 547
- Hartree-Fock 465
- hashing 190, 196, 201
- hashing inequality 169
- Heisenberg limit 577
- Heisenberg model 452

- Heisenberg picture 518
- Heisenberg–Langevin equations 521
- Heitler–London approximation 461
- hidden subgroup problem 97, 492
 - abelian 492
- hidden translation problem 97
- hidden variables 136
- high-finesse cavity 549
- Hilbert space 128
- History of quantum computing 423
- Holevo bound 138
- holonomy 383
- homodyne detection 151, 303
- homodyne method 543
- Hubbard model 406, 461, 464
 - derivation 406
 - extended 464
 - Mott insulator 401
 - offsite interaction 406
 - onsite interaction 408
 - superfluid 401
 - tunneling 407
 - tunneling matrix elements 406
- Huffman coding 6
- Hund–Mulliken approximation 461
- hybridization 461, 462, 465
- hyperplane 129

- Identity 316
- IIIa: def:3 127
- impedance $Z(\omega)$ 472, 475
- incomparable states 164
- individual attack 277
- inseparability 155
- inseparable 154
- instance 17
- intensity correlation 547
- interaction phase 411
- Interference 323
- interferometer 576
- ion
 - delta kick 400
 - internal states 393
 - motional states 392
 - phase gate 395
 - quantum control gate 397
 - single qubit gate 394
 - state dependent interaction 395
 - trapping 391
 - two-qubit gate 395
- Ising interaction 483, 489, 492, 493, 496

- Jamiołkowski isomorphism 134
- Jaynes principle 47
- Jaynes–Cummings Hamiltonian 518
- Jaynes–Cummings–Paul model 555, 563
- joint entropy 7
- Josephson device 481, 494, 496
- Josephson junction 469
 - unintended 476

- k-SAT 27
- Königsberg bridges 17
- kinematic phases 411
- Kirchhoff’s laws 473
- KLM scheme (Knill–Laflamme–Milburn) 349
- Kraus operator 239
- Kraus operators 106

- Lamb shift 557, 567
- Lamb–Dicke factor 432
- Lamb–Dicke limit 393
- Landau symbols 19
- Langevin stochastic forces 521
- laser-cooling 544
- leakage 471
- Lie algebra 483, 490, 493, 494, 496
- Lie-algebra 492
- light force 549
- light source 546
- light–atoms interface 515
- line defect 564
- Linear ion crystal 429
- Linear ion trap 427
- linear map 131
- Linear optical quantum computation 375
- linear optics 352
- linear spin chain 493
- local oscillator 520
- Localizable entanglement 241
- LOCC 161, 162, 179
 - asymptotic transformations 164
 - single copy transformations 163
- logarithm of the negativity 171
- logical Heisenberg picture 366
- logical qubit 112
- long distance communication 308

- Lossy channel 48
- lossy channel 278
- Mach–Zehnder interferometer 323, 576
- macroscopic 451, 469
- macroscopic superposition 417
- magnetic resonance 481
- majorization 127, 163
- majorization criterion 127
- map 131
 - completely positive 132
 - positive (PM) 131
- master equation 474
- Matrices
 - Pauli 332
 - Stochastic 316, 325
- matrix
 - generator 13
 - parity check 13
- Maximal connectedness 241
- maximally entangled states 162
- Maxwell–Bloch equations 518
- Measurement 334
- measurement
 - decoherence in flux qubit 477
 - exchange 465
 - single spin 467
 - spin decoherence time 458, 467
 - spin relaxation time 467
- Metrology 249
- microcavities 466
- micromaser 540
- microscopic 451
- millenium problems 29
- minimum distance 10
 - quantum 113
- Minimum Spanning Tree 32
- mixed state entanglement 181
- Mixing 40
- modes 148
 - bosonic 147
 - optical 148
- momentum 148, 151
- Monogamy of entanglement 241
- motional sideband 394
- multipartite pure state entanglement 180
- multiparty entanglement purification 194
- multiply-controlled NOT gate 493
- mutual information 7
- negative partial transposition (NPT) 126
- negativity 171
- network complexity 481, 493, 495, 496
- network graph 472
- NMR quantum computer 484, 487
- NMR quantum computing 495
- no-cloning theorem 53, 109
- node 472
- noiseless coding theorem 6
- noisy apparatus 197
- noisy coding theorem 8
- noisy operation 198
- Non Abelian Quantum Fourier transform 97
- non-Gaussian transformations 303
- noncloning theorem 259
- nondeterministic polynomial 22
- nonlocality 257, 541
- nonunity gain teleportation 267
- Normal mode decomposition 47
- NP 22
 - NP-complete 28
 - NP-hard 34
- NPT 183
- NSS (nonlinear-sign-shift gate) 357
- Number states 43
- occupation-number qubit 351
- one-time pad 271
- one-way function 30
- One-way quantum computation 359
- open system 549
- operator 148
 - annihilation 148
 - creation 148
 - density 149, 154
 - Hermitian 154
 - symmetrized 149
- operator $>$ super 131
- operator controllability 483
- optical density 520
- optical experiments 544
- optical Feshbach resonance 418
- Optical lattice 374
- optical lattice 401
 - blue detuning 405
 - controlled coherent collision 410
 - geometry 403
 - impurity 417
 - loading 408

- defect suppression 408
 - irreversible scheme 408
- maximally entangled state 415
- red detuning 405
- single qubit gate 409
- site offset 403
- spontaneous emission 405
- state dependence 404
- state dependent interaction 412
- state selective movement 405
- two qubit gate 410
- optical parametric amplification 148
- optical potential 401
- optical qubits 351
- optimal control 494, 495
- optimal control theory 481
- optimization 31
- Overhauser field 468
- parabolic confinement 460
- parallel transport 382
- parametric down-conversion 261
- parametric fluorescence 547
- parity check matrix 13
- partial transposition 125, 171, 183
- partial transposition criterion 126
- Passive transformations 46
- Paul trap, stability diagram 427
- Pauli group 116, 248
- Pauli principle 459, 463
- PBG materials *see* photonic crystals 564
- period finding 93
- Phase conjugation 49
- phase covariant cloning 62
- phase distribution 543
- phase insensitive amplifier 300
- phase qubit 470
- phase sensitivity 577
- phase shifter 300
- Phase space 43
- phase space 579
- phase-space 149, 155
 - displacements 150
 - variables 149
- phonons 468
- photon 512
- photon antibunching 546
- photon bunching 546
- photon number 148, 152
- photon number basis 148
- photon statistics 546
- photon-number splitting attack 278
- photonic band-gap 550
- photonic bandgap materials *see* photonic crystals 564
- photonic crystals 564
 - anisotropic model 565
 - isotropic model 565
 - Lorentzian models 566
- physical qubit 112
- point defect 564
- polynomial reduction 27
- Pontryagin's maximum principle 489–491
- position 148, 151
- positive partial transposition (PPT) 126
- PPT 183
- Prim's algorithm 32
- Primality 24
- prime field 11
- privacy amplification 276
- probabilistic cloning 68
- probabilistic gates 356
- Probability
 - Amplitudes 323, 325
 - Axioms 317
- product channel 107
- Product states 240
- projective special unitary group 490, 491
- Proof Checking 30
- Proof Existence 31
- pseudo-pure state 482, 485, 486
- pseudo-spin system 481, 494, 496
- pseudospin 452, 470
- pure dephasing time T_ϕ 474
- pure state 485, 495
- pure state entanglement 179
- Pure states 40
- purification loop 508
- purification step 185
- QECC 108
- QND interaction 520
- quadratic interactions 147
- quadrature components 298
- quadrature operators 519
 - of atomic ensemble 519
- quadrature-phase amplitudes 264
- quadratures 148, 152

- quantum 147
 - harmonic oscillator 148
 - information applications 147
- Quantum algorithm for binary search 87
- Quantum algorithm for graph problems 87
- Quantum channel 41
- quantum channel 505
- quantum channel capacity 108
- quantum cloning 532
 - coherent states 533
 - into atomic memory 533
- quantum code 108
- quantum communication 178, 202, 505
- Quantum computation
 - Heisenberg picture 366
 - Linear optical 375
 - Measurement-based 359
 - One-way 359
- quantum control 481, 489, 495, 496
- quantum cryptography 286
- quantum dense coding 138, 292, 305
- quantum dot 512
- quantum dots 451, 452, 459
- quantum error correction code (QECC) 275
- Quantum Fourier sampling 92
- Quantum Fourier transform 93, 492
- quantum gate
 - local 483
 - universal 483
- quantum interface 538
- Quantum Interferometry 575
- quantum key distribution 275, 306
- quantum memories 549
- quantum memory 526
 - retrieval 528
 - storage protocol 526
- quantum messengers 549
- quantum noise 520
- quantum non demolition 542
- quantum nondemolition measurements 520
- Quantum operation 41
- quantum phase gate 541
- quantum repeater 505
- quantum repeaters 526
- quantum state detection 424
- quantum teleportation 531
 - of light onto atoms 531
- quantum walks (discrete and continuous) 100
- quantum-beat 548
- Quasifree states 45
- qubit 256, 259
 - atomic 255
 - logical 112
 - material(atomic)
 - embedded in photonic crystal 566
 - embedded in spherical cavity 556
 - quantum electrodynamics of 555
 - physical 112
- Rabi
 - frequency 563
 - oscillations 555, 563
- Rabi frequency 432, 546
- Rabi frequency, Carrier 432
- Rabi frequency, sideband 432
- Rabi pulse 541
- Rains'bound 172
- Raman process 546
- Raman transition 434
- Ramsey experiment 470
- reachability set 483
- realtime measurements 544
- receiver 4
- recoil kicks 549
- recurrence protocol 185, 187, 188, 194
- Redfield equation 474
- reduction 27
- reduction criteria 184
- reduction from factoring to period finding 93
- regularization 169, 170
- relative entropy
 - of entanglement 170
 - regularized 171
 - subadditivity 171
- Relative entropy of entanglement 247
- relaxation time T_1 467, 474
- repeater 505
- resolvent operator 566
- resources 509
- retarded time 518
- reversible classical computation 88
- Reversible Computation 317
- Riemannian symmetric space 493
- Robustness 241
- robustness of entanglement 172
- rotating-wave approximation 557
- RSA 30
- Rydberg atoms 538

- Satisfiability 27
- scalability 451, 485–487, 492, 495
- Schmidt decomposition 124, 148, 152, 179
- Schmidt measure 240, 246
- Schmidt normal form 238
- Schmidt rank 246
- Schrödinger cat 543
- Schrödinger cat state 299
- secure state distribution 203
- Segmented ion trap 444
- self-adjoint map 131
- self-homodyning 520
- separability class 243
- separable 154
- separable state 125
- separable states 162
- Shannon entropy 5
- Shannon’s Theorem 347
- Shor’s algorithm 94
- shrinking factor 60, 66
- sidebands 521
- sifting 274
- sign-flip error 110
- signal transfer 267
- Simon’s algorithm 92
- single-atom transistor 417
- single-mode squeezer 300
- single-photon source 548
- singlet–triplet crossing 462
- special unitary group 490, 491
- spectral function $J(\omega)$ 475
- spin
 - decoherence time 467, 469
 - electron 452, 458
 - nuclear 468
 - relaxation time 467
- spin cluster qubits 458
- spin–orbit coupling 455, 458, 468
- spin-1/2 541
- Split 240
- split 243
- spontaneous emission 540, 546, 555
 - in photonic crystals 566
 - in spherical cavities 556
- square-root of SWAP gate 453, 456
- squashed entanglement 173
- squeezed state 151, 524
 - of atomic ensemble 524
 - one-mode 151, 153
 - two-mode 147, 152, 153, 155, 157
- squeezed states 581
- squeezed vacuum state 299
- squeezed vacuum states 581
- squeezing 148, 151, 152
- stabilizer code 117
- Stabilizer Formalism 365
- stabilizer group 116, 248
- standard array 15
- standard form 153, 157
- Stark effect 539
- Stark eigenstate 412
- state estimation 64
- State space 40
- state transformation 179
- state-dependent cloning 54
- States 40
- Stokes vector 517
- strip-line resonators 550
- strong coupling 544
- strong phase reference pulse 281
- super additivity 108
- superconducting 538
- superconducting qubit 469
- superradiance 549
- supporting hyperplane 245
- symplectic matrix 150
- tangle 247
- technical noise 520
- Teleportation 443
- teleportation 255–268
 - unconditional 262
- Teleportation algorithm 443
- tensor product 318, 343
- thermal stat 495
- thermal state 152, 485, 486
- threshold 200
- time complexity 481, 492, 493, 495, 496
- time-optimal 483, 487, 492–496
- time-symmetric pulses 455
- Toffoli 342
- TOFFOLI-gate 494
- trace distance 165
- transformations 151
 - active 151
 - Gaussian unitary 151
 - linear 151
 - passive 151

- symplectic 151
- transmitter 4
- Traveling Salesman Problem 33
- tree 472
- Two qubit quantum gate 434
- two-colorable graph 194
- two-level system 556
- two-mode squeezer 300
- two-mode squeezing 530

- uncertainty relation 150
 - N -mode 150
 - Heisenberg 150
- unconditional security 277
- Unitarity 325, 331
 - Special 331
- Unitary operation 41
- unitary orbit 483, 487, 488
- unity gain teleportation 267
- universal cloning 63
- universal gate 496
- universal gate set 87, 454, 455, 457, 466
- universal quantum simulators 413
 - Heisenberg Hamiltonian 415
 - Ising interaction 414
 - one-qubit term 414
 - quantum phase transition 416

- two-qubit term 414

- vacuum Rabi oscillation 541
- vacuum state 299
- vacuum-Rabi frequency 546
- vacuum-Rabi period 544
- vacuum-Rabi splitting 546
- Vernam cipher 271
- Vibrational eigenmodes of an ion crystal 430
- visibility 471
- von Neumann entropy 152

- Wannier function 402
- Werner state 187
- Weyl correspondence 149, 150
- Weyl operator 44
- Wigner function 44, 148, 149, 152, 155, 298, 543
- words
 - ϵ -typical 6
- worst case 19

- XOR gate 453, 455, 457, 467

- yield 182, 197

- Zeeman coupling 452, 459, 461, 468, 469
- Zeeman level 546