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Strategies for braiding and ground state preparation in digital quantum hardware

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Bibliography

- [1] M.A. Nielsen and I. L. Chuang, *Quantum Computation and Quantum Information* (Cambridge University Press, 2010).
- [2] D. DiVincenzo, *The Physical Implementation of Quantum Computation*, Fortschr. Phys. **48**, 771 (2000).
- [3] C. Nayak, S.H. Simon, A. Stern, M. Freedman, and S.D. Sarma, *Non-Abelian Anyons and Topological Quantum Computation*, Rev. Mod. Phys. **80**, 1083 (2008).
- [4] A.Y. Kitaev, *Fault-tolerant quantum computation by anyons*, Annals Phys. **303**, 2 (2003).
- [5] M.H. Freedman, *Quantum Computation and the localization of Modular Functors*, arXiv:quant-ph/0003128.
- [6] J. Alicea, *New directions in the pursuit of Majorana fermions in solid state systems*, Rep. Prog. Phys. **75**, 076501 (2012).
- [7] D. Culcer, A. C. Keser, Y. Li, and G. Tkachov, *Transport in two-dimensional topological materials: recent developments in experiment and theory*, 2D Mater. **7**, 022007 (2020).
- [8] A. Vuik, B. Nijholt, A. R. Akhmerov, and M. Wimmer, *Reproducing topological properties with quasi-Majorana states*, SciPost Phys. **7**, 061 (2019).
- [9] Y. Huang, F. Setiawan, and J.D. Sau, *Disorder-induced half-integer quantized conductance plateau in quantum anomalous Hall insulator-superconductor structures*, Phys. Rev. B **97**, 100501 (2018).
- [10] M. Kayyalha, D. Xiao, R. Zhang, J. Shin, J. Jiang, F. Wang, Y. F. Zhao, R. Xiao, L. Zhang, K. M. Fijalkowski, P. Mandal, M. Winnerlein, C. Gould, Q. Li, L. W. Molenkamp, M. H. W. Chan, N. Samarth, and C. Z. Chang, *Absence of evidence for chiral Majorana modes in quantum anomalous Hall-superconductor devices*, Science **367**, 64 (2020).

Bibliography

- [11] J. Preskill, *Quantum Computing in the NISQ era and beyond*, Quantum **2**, 79 (2018).
- [12] S. Lloyd, *Universal Quantum Simulators*, Science **273**, 1073 (1996).
- [13] I. Buluta and F. Nori, *Quantum Simulators*, Science **326**, 108 (2009).
- [14] B. P. Lanyon, C. Hempel, D. Nigg, M. Müller, R. Gerritsma, F. Zähringer, P. Schindler, J. T. Barreiro, M. Rambach, G. Kirchmair, M. Hennrich, P. Zoller, R. Blatt, and C. F. Roos, *Universal digital quantum simulation with trapped ions*, Science **334**, 57 (2011).
- [15] N. Schuch and F. Verstraete, *Computational complexity of interacting electrons and fundamental limitations of density functional theory*, Nat. Phys. **5**, 732 (2009).
- [16] A.Y. Kitaev, A. Shen, M.N. Vyalyi, *Classical and Quantum Computation*, Amer. Math. Soc., 2002.
- [17] M. Troyer, U.-J. Wiese, *Computational complexity and fundamental limitations to fermionic quantum Monte Carlo simulations*, Phys. Rev. Lett. **94**, 170201 (2005).
- [18] B. Bauer, S. Bravyi, M. Motta, and G. K.-L. Chan, *Quantum Algorithms for Quantum Chemistry and Quantum Materials Science*, Chem. Rev. **120**, 12685 (2020).
- [19] X.-G. Wen, *Quantum Field Theory of Many-Body Systems: From the Origin of Sound to an Origin of Light and Electrons* (Oxford University Press, 2007).
- [20] B.A. Bernevig and T. L. Hughes, *Topological Insulators and Topological Superconductors* (Princeton University Press, 2013).
- [21] C.W.J. Beenakker, *Search for Majorana fermions in superconductors*, Annu. Rev. Con. Mat. Phys. **4**, 113 (2013).
- [22] M.H. Freedman, M. Larsen, and Z. Wang, *A Modular Functor Which is Universal for Quantum Computation*, Commun. Math. Phys. **227**, 605 (2002).
- [23] A.P. Mackenzie and Y. Maeno, *p-wave superconductivity*, Physica B: Cond. Mat. **280**, 148 (2000).
- [24] M. Sato, Y. Ando, *Topological superconductors: a review*, Rep. Prog. Phys. **80**, 076501 (2017).

- [25] L. Fu and C.L. Kane, *Superconducting Proximity Effect and Majorana Fermions at the Surface of a Topological Insulator*, Phys. Rev. Lett. **100**, 096407 (2008).
- [26] M.R. Norman, *The Challenge of Unconventional Superconductivity*, Science **332**, 196 (2011).
- [27] Q. L. He, L. Pan, A. L. Stern, E. Burks, X. Che, G. Yin, J. Wang, B. Lian, Q. Zhou, E. S. Choi, K. Murata, X. Kou, T. Nie, Q. Shao, Y. Fan, S.-C. Zhang, K. Liu, J. Xia, and K. L. Wang, *Chiral Majorana fermion modes in a quantum anomalous Hall insulator–superconductor structure*, Science **357**, 294 (2017).
- [28] J. Shen, J. Lyu, J. Z. Gao, Y.-M. Xie, C.-Z. Chen, C. Cho, O. Atanov, Z. Chen, K. Liu, Y. J. Hu, K. Y. Yip, S. K. Goh, Q. L. He, L. Pan, K. L. Wang, K. T. Law, and R. Lortz, *Spectroscopic fingerprint of chiral Majorana modes at the edge of a quantum anomalous Hall insulator/superconductor heterostructure*, PNAS **117**, 238 (2020).
- [29] W. Ji and X.-G. Wen, *Conductance Plateau without 1D Chiral Majorana Fermions*, Phys. Rev. Lett. **120**, 107002 (2018).
- [30] A.A. Abrikosov, *The magnetic properties of superconducting alloys*, J. Phys. Chem. Solids **2**, 199 (1957).
- [31] Y. Aharonov and D. Bohm, *Significance of Electromagnetic Potentials in the Quantum Theory*, Phys. Rev. **115**, 485 (1959).
- [32] D. A. Ivanov, *Non-abelian statistics of half-quantum vortices in p-wave superconductors*, Phys. Rev. Lett. **86**, 268 (2001).
- [33] B. Lian, X.-Q. Sun, A. Vaezi, X.-L. Qi, and S.-C. Zhang, *Topological quantum computation based on chiral Majorana fermions*, PNAS **115**, 10938 (2018).
- [34] E.H. Hall, *On a New Action of the Magnet on Electric Currents*, Am. J. Math. **2**, 287 (1879).
- [35] K. v. Klitzing, G. Dorda, and M. Pepper, *New Method for High-Accuracy Determination of the Fine-Structure Constant Based on Quantized Hall Resistance*, Phys. Rev. Lett. **45**, 494 (1980).
- [36] D. C. Tsui, H. L. Stormer, and A. C. Gossard, *Two-Dimensional Magnetotransport in the Extreme Quantum Limit*, Phys. Rev. Lett. **48**, 1559 (1982).

Bibliography

- [37] B.I. Halperin, *Quantized Hall conductance, current-carrying edge states, and the existence of extended states in a two-dimensional disordered potential*, Phys. Rev. B **25**, 2185 (1982).
- [38] S. Datta, *Electronic Transport in Mesoscopic Systems* (Cambridge University Press, 1995).
- [39] R.B. Laughlin, *Anomalous Quantum Hall Effect: An Incompressible Quantum Fluid with Fractionally Charged Excitations*, Phys. Rev. Lett. **50**, 1395 (1983).
- [40] D.J. Clarke, J. Alicea, and K. Shtengel, *Exotic non-Abelian anyons from conventional fractional quantum Hall states*, Nat. Comm. **4**, 1348 (2013).
- [41] W.J. Cook, W.H. Cunningham, W.R. Pulleyblank, and A. Schrijver, *Combinatorial Optimization, First Edition* (John Wiley & Sons, 1998).
- [42] F. Barahona, *On the computational complexity of Ising spin glass models*, J. Phys. A: Math. Gen. **15**, 3241 (1982).
- [43] J. Kempe, A. Kitaev, and O. Regev, *The Complexity of the Local Hamiltonian Problem*, SIAM J. Comput. **35**, 1070 (2006).
- [44] P. Wocjan and S. Zhang, *Several natural BQP-Complete problems*, arXiv:quant-ph/0606179.
- [45] E. Farhi, J. Goldstone, S. Gutmann, and M. Sipser, *Quantum Computation by Adiabatic Evolution*, arXiv:quant-ph/0001106.
- [46] A.Y. Kitaev, *Quantum measurements and the Abelian Stabilizer Problem*, arXiv:quant-ph/9511026.
- [47] J.R. McClean, J. Romero, R. Babbush, and A. Aspuru-Guzik, *The theory of variational hybrid quantum-classical algorithms*, New J. Phys. **18**, 023023 (2016).
- [48] V. Verteletskyi, T.-C. Yen, and A. F. Izmaylov, *Measurement Optimization in the Variational Quantum Eigensolver Using a Minimum Clique Cover*, J. Chem. Phys. **152**, 124114 (2020).
- [49] X. Bonet-Monroig, R. Babbush, and T.E. O'Brien, *Nearly Optimal Measurement Scheduling for Partial Tomography of Quantum States*, Phys. Rev. X **10**, 031064 (2020).

Bibliography

- [50] J. Cotler and F. Wilczek, *Quantum Overlapping Tomography*, Phys. Rev. Lett. **124**, 100401 (2020).
- [51] J. M. Kübler, A. Arrasmith, L. Cincio, and P. J. Coles, *An Adaptive Optimizer for Measurement-Frugal Variational Algorithms*, Quantum **4**, 263 (2020).
- [52] A. Arrasmith, L. Cincio, R.D. Somma, and P. J. Coles, *Operator Sampling for Shot-frugal Optimization in Variational Algorithms*, arXiv:2004.06252.
- [53] K.J. Sung, J. Yao, M. P. Harrigan, N. C. Rubin, Z. Jiang, L. Lin, R. Babbush, and J. R. McClean, *Using models to improve optimizers for variational quantum algorithms*, Quantum Sci. Technol. **5**, 044008 (2020).
- [54] J. Romero, R. Babbush, J. R. McClean, C. Hempel, P. Love, and A. Aspuru-Guzik, *Strategies for quantum computing molecular energies using the unitary coupled cluster ansatz*, Quantum Sci. Technol. **4**, 014008 (2018).
- [55] H. R. Grimsley, S. E. Economou, E. Barnes, and N. J. Mayhall, *An adaptive variational algorithm for exact molecular simulations on a quantum computer*, Nat. Comm. **10**, 3007 (2019).
- [56] D. Wecker, M. B. Hastings, and M. Troyer, *Towards Practical Quantum Variational Algorithms*, Phys. Rev. A **92**, 042303 (2015).
- [57] K. A. Brueckner, *Many-Body Problem for Strongly Interacting Particles. II. Linked Cluster Expansion*, Phys. Rev. **100**, 36 (1955).
- [58] H. F. Trotter, *On the product of semi-groups of operators*, Proc. Ams. Math. Soc. **10**, 545 (1959).
- [59] M. Suzuki, *General theory of fractal path integrals with applications to many-body theories and statistical physics*, J. Math. Phys. **32**, 400 (1991).
- [60] J. D. Whitfield, J. Biamonte, A. Aspuru-Guzik *Simulation of Electronic Structure Hamiltonians Using Quantum Computers*, Mol. Phys. **109**, 735 (2011).
- [61] F. Verstraete, M. M. Wolf, and J. I. Cirac, *Quantum computation and quantum-state engineering driven by dissipation*, Nat. Phys. **5**, 633 (2009).

Bibliography

- [62] P.O. Boykin, T. Mor, V. Roychowdhury, F. Vatan, and R. Vrijen, *Algorithmic cooling and scalable NMR quantum computers*, PNAS **99**, 3388 (2002).
- [63] D. Kielpinski, B. E. King, C. J. Myatt, C. A. Sackett, Q. A. Turchette, W. M. Itano, C. Monroe, D. J. Wineland, and W. H. Zurek, *Sympathetic cooling of trapped ions for quantum logic*, Phys. Rev. A **61**, 032310 (2000).
- [64] M. Popp, J. J. Garcia-Ripoll, K. G. H. Vollbrecht, and J. I. Cirac, *Ground-state cooling of atoms in optical lattices*, Phys. Rev. A **74**, 013622 (2006).
- [65] M. Metcalf, J. E. Moussa, W. A. de Jong, and M. Sarovar, *Engineered thermalization and cooling of quantum many-body systems*, Phys. Rev. Research **2**, 023214 (2020).
- [66] M. Raghunandan, F. Wolf, C. Ospelkaus, P. O. Schmidt, and H. Weimer, *Initialization of quantum simulators by sympathetic cooling*, Sci. Adv. **6**, eaaw9268 (2020).
- [67] Y. Aharonov, D. Z. Albert, and L. Vaidman, *How the result of a measurement of a component of the spin of a spin-1/2 particle can turn out to be 100*, Phys. Rev. Lett. **60**, 1351 (1988).
- [68] B. Tamir and E. Cohen, *Introduction to Weak Measurements and Weak Values*, Quanta **2**, 7 (2013).
- [69] J. Zhang, Y.-X. Liu, R.-B. Wu, K. Jacobs, F. Nori, *Quantum feedback: theory, experiments, and applications*, Phys. Rep. **679**, 1 (2017).
- [70] F. Ticozzi, L. Viola, *Analysis and synthesis of attractive quantum Markovian dynamics*, Automatica **45**, 2002 (2009).
- [71] H.M. Wiseman, *Quantum theory of continuous feedback*, Phys. Rev. A **49**, 2133 (1994).
- [72] V. P. Belavkin, *Towards the theory of control in observable quantum systems*, Autom. Remote Control **44**, 178 (1983).
- [73] H. M. Wiseman and G. J. Milburn, *Quantum theory of optical feedback via homodyne detection*, Phys. Rev. Lett. **70**, 548 (1993).
- [74] K. Jacobs, *Feedback control using only quantum back-action*, New J. Phys. **12**, 043005 (2010).

- [75] S. Ashhab and F. Nori, *Control-free control: Manipulating a quantum system using only a limited set of measurements*, Phys. Rev. A **82**, 062103 (2010).
- [76] A. Stern, *Anyons and the quantum Hall effect — A pedagogical review*, Ann. Phys. **323**, 204 (2008).
- [77] G. Moore and N. Read, *Nonabelions in the fractional quantum hall effect*, Nucl. Phys. B **360**, 362 (1991).
- [78] N. Read and D. Green, *Paired states of fermions in two dimensions with breaking of parity and time-reversal symmetries and the fractional quantum Hall effect*, Phys. Rev. B **61**, 10267 (2000).
- [79] Sanghun An, P. Jiang, H. Choi, W. Kang, S. H. Simon, L. N. Pfeiffer, K. W. West, and K. W. Baldwin, *Braiding of Abelian and non-Abelian anyons in the fractional quantum Hall effect*, arXiv:1112.3400.
- [80] R. L. Willett, C. Nayak, K. Shtengel, L. N. Pfeiffer, and K. W. West, *Magnetic field-tuned Aharonov-Bohm oscillations and evidence for non-Abelian anyons at $\nu = 5/2$* , Phys. Rev. Lett. **111**, 186401 (2013).
- [81] R. M. Lutchyn, E. P. A. M. Bakkers, L. P. Kouwenhoven, P. Krogstrup, C. M. Marcus, and Y. Oreg, *Realizing Majorana zero modes in superconductor-semiconductor heterostructures*, Nature Rev. Mater. **3**, 52 (2018).
- [82] S. Das Sarma, M. Freedman, and C. Nayak, *Topologically protected qubits from a possible non-Abelian fractional quantum Hall state*, Phys. Rev. Lett. **94**, 166802 (2005).
- [83] A. Stern and B. I. Halperin, *Proposed experiments to probe the non-Abelian $\nu = 5/2$ quantum Hall state*, Phys. Rev. Lett. **96**, 016802 (2006).
- [84] P. Bonderson, A. Kitaev, and K. Shtengel, *Detecting non-Abelian statistics in the $\nu = 5/2$ fractional quantum Hall state*, Phys. Rev. Lett. **96**, 016803 (2006).
- [85] G. E. Volovik, *Fermion zero modes on vortices in chiral superconductors*, JETP Letters. **70**, 609 (1999).
- [86] A. Kitaev, *Unpaired Majorana fermions in quantum wires*, Phys. Usp. **44** (suppl.), 131 (2001).

Bibliography

- [87] R. M. Lutchyn, J. D. Sau, and S. Das Sarma, *Majorana fermions and a topological phase transition in semiconductor-superconductor heterostructures*, Phys. Rev. Lett. **105**, 077001 (2010).
- [88] Y. Oreg, G. Refael, and F. von Oppen, *Helical liquids and Majorana bound states in quantum wires*, Phys. Rev. Lett. **105**, 177002 (2010).
- [89] P. Bonderson, M. Freedman, and C. Nayak, *Measurement-only topological quantum computation*, Phys. Rev. Lett. **101**, 010501 (2008).
- [90] J. Alicea, Y. Oreg, G. Refael, F. von Oppen, and M. P. A. Fisher, *Non-Abelian statistics and topological quantum information processing in 1D wire networks*, Nature Phys. **7**, 412 (2011).
- [91] B. van Heck, A. R. Akhmerov, F. Hassler, M. Burrello, and C. W. J. Beenakker, *Coulomb-assisted braiding of Majorana fermions in a Josephson junction array*, New J. Phys. **14**, 035019 (2012).
- [92] S. Vijay and L. Fu, *Braiding without braiding: Teleportation-based quantum information processing with Majorana zero-modes*, Phys. Rev. B **94**, 235446 (2016).
- [93] T. Karzig, C. Knapp, R. M. Lutchyn, P. Bonderson, M. B. Hastings, C. Nayak, J. Alicea, K. Flensberg, S. Plugge, Y. Oreg, C. M. Marcus, and M. H. Freedman, *Scalable designs for quasiparticle-poisoning-protected topological quantum computation with Majorana zero-modes*, Phys. Rev. B **95**, 235305 (2017).
- [94] A. R. Akhmerov, J. Nilsson, and C. W. J. Beenakker, *Electrically detected interferometry of Majorana fermions in a topological insulator*, Phys. Rev. Lett. **102**, 216404 (2009).
- [95] J. Nilsson and A. R. Akhmerov, *Theory of non-Abelian Fabry-Perot interferometry in topological insulators*, Phys. Rev. B **81**, 205110 (2010).
- [96] D. J. Clarke and K. Shtengel, *Improved phase gate reliability in systems with neutral Ising anyons*, Phys. Rev. B **82**, 180519(R) (2010).
- [97] C.-Y. Hou, F. Hassler, A. R. Akhmerov, and J. Nilsson, *Probing Majorana edge states with a flux qubit*, Phys. Rev. B **84**, 054538 (2011).

- [98] X.-L. Qi, T. L. Hughes, and S.-C. Zhang, *Chiral topological superconductor from the quantum Hall state*, Phys. Rev. B **82**, 184516 (2010).
- [99] L. Fu and C. L. Kane, *Probing neutral Majorana fermion edge modes with charge transport*, Phys. Rev. Lett. **102**, 216403 (2009).
- [100] A. C. Potter and L. Fu, *Anomalous supercurrent from Majorana states in topological insulator Josephson junctions*, Phys. Rev. B **88**, 121109(R) (2013).
- [101] S. Park and P. Recher, *Detecting the exchange phase of Majorana bound states in a Corbino geometry topological Josephson junction*, Phys. Rev. Lett. **115**, 246403 (2015).
- [102] P. Fendley, M. P. A. Fisher, and C. Nayak, *Edge states and tunneling of non-Abelian quasiparticles in the $\nu = 5/2$ quantum Hall state and $p + ip$ superconductors*, Phys. Rev. B **75**, 045317 (2007).
- [103] E. Grosfeld and A. Stern, *Observing Majorana bound states of Josephson vortices in topological superconductors*, PNAS **108**, 11810 (2011).
- [104] J. Keeling, I. Klich, and L. S. Levitov, *Minimal excitation states of electrons in one-dimensional wires*, Phys. Rev. Lett. **97**, 116403 (2006).
- [105] C. W. Groth, M. Wimmer, A. R. Akhmerov, and X. Waintal, *Kwant: A software package for quantum transport*, New J. Phys. **16**, 063065 (2014).
- [106] P. W. Brouwer, *Scattering approach to parametric pumping*, Phys. Rev. B **58**, R10135(R) (1998).
- [107] B. Tarasinski, D. Chevallier, J. A. Hutasoit, B. Baxevanis, and C. W. J. Beenakker, *Quench dynamics of fermion-parity switches in a Josephson junction*, Phys. Rev. B **92**, 144306 (2015).
- [108] J. Dubois, T. Jullien, F. Portier, P. Roche, A. Cavanna, Y. Jin, W. Wegscheider, P. Roulleau, and D. C. Glattli, *Minimal-excitation states for electron quantum optics using levitons*, Nature **502**, 659 (2013).
- [109] Junying Shen, Jian Lyu, Jason Zheshen Gao, Chui-Zhen Chen, Chang-woo Cho, Lei Pan, Zhijie Chen, Kai Liu, Y. J. Hu, K. Y. Yip, S. K. Goh, Qing Lin He, Kang L. Wang, Kam Tuen Law, and Rolf Lortz, *Spectroscopic evidence of chiral Majorana modes in a*

Bibliography

- quantum anomalous Hall insulator/superconductor heterostructure*, arXiv:1809.04752.
- [110] C. W. von Keyserlingk, S. H. Simon, and B. Rosenow, *Enhanced bulk-edge Coulomb coupling in fractional Fabry-Perot interferometers*, Phys. Rev. Lett. **115**, 126807 (2015).
 - [111] E. Bocquillon, V. Freulon, F. D. Parmentier, J.-M Berroir, B. Plaçais, C. Wahl, J. Rech, T. Jonckheere, T. Martin, C. Grenier, D. Ferraro, P. Degiovanni, and G. Fève, *Electron quantum optics in ballistic chiral conductors*, Ann. Physik **526**, 1 (2014).
 - [112] S. Das Sarma, M. Freedman, and C. Nayak, *Majorana zero modes and topological quantum computation*, npj Quantum Inf. **1**, 15001 (2015).
 - [113] M. Leijnse and K. Flensberg, *Introduction to topological superconductivity and Majorana fermions*, Semicond. Sci. Technol. **27**, 124003 (2012).
 - [114] A. Stern, F. von Oppen, and E. Mariani, *Geometric phases and quantum entanglement as building blocks for non-Abelian quasiparticle statistics*, Phys. Rev. B **70**, 205338 (2004).
 - [115] M. Stone and S.-B. Chung, *Fusion rules and vortices in $p_x + ip_y$ superconductors*, Phys. Rev. B **73**, 014505 (2006).
 - [116] C. W. J. Beenakker, P. Baireuther, Y. Herasymenko, I. Adagideli, Lin Wang, and A. R. Akhmerov, *Deterministic creation and braiding of chiral edge vortices*, arXiv:1809.09050.
 - [117] G. Strübi, W. Belzig, M.-S. Choi, and C. Bruder, *Interferometric and noise signatures of majorana fermion edge states in transport experiments*, Phys. Rev. Lett. **107**, 136403 (2011).
 - [118] L. Chirolli, J. P. Baltanás, and D. Frustaglia, *Chiral Majorana interference as a source of quantum entanglement*, Phys. Rev. B **7**, 155416 (2018).
 - [119] Yan-Feng Zhou, Zhe Hou, Peng Lv, X.C. Xie, and Qing-Feng Sun, *Magnetic flux control of chiral Majorana edge modes in topological superconductor*, Sci. China-Phys. Mech. Astron. **61**, 127811 (2018).
 - [120] I. Klich, *An elementary derivation of Levitov's formula*, in: *Quantum Noise in Mesoscopic Physics*, NATO Science Series II, **97**, 397 (2003).

- [121] J. E. Avron, S. Bachmann, G. M. Graf, and I. Klich, *Fredholm determinants and the statistics of charge transport*, Commun. Math. Phys. **280**, 807 (2008).
- [122] I. Klich, *A note on the full counting statistics of paired fermions*, J. Stat. Mech. P11006 (2014). When comparing formulas, note that Klich has a factor of two in the anticommutator of Majorana operators.
- [123] C. W. J. Beenakker, *Annihilation of colliding Bogoliubov quasiparticles reveals their Majorana nature*, Phys. Rev. Lett. **112**, 070604 (2014).
- [124] M. E. Fisher and R. E. Hartwig, *Toeplitz determinants: Some applications, theorems, and conjectures*, Adv. Chem. Phys. **15**, 333 (1968).
- [125] R. E. Hartwig and M. E. Fisher, *Asymptotic behavior of Toeplitz matrices and determinants*, Rational Mech. Anal. **32**, 190 (1969).
- [126] C. W. J. Beenakker, *Random-matrix theory of Majorana fermions and topological superconductors*, Rev. Mod. Phys. **87**, 1037 (2015).
- [127] J. S. Bell, *On the Einstein Podolsky Rosen paradox*, Phys. Phys. Fiz. **1**, 195 (1964).
- [128] N. Brunner, D. Cavalcanti, S. Pironio, V. Scarani, and S. Wehner, *Bell nonlocality*, Rev. Mod. Phys. **86**, 419 (2014).
- [129] B. S. Cirel'son, *Quantum generalizations of Bell's inequality*, Lett. Math. Phys. **4**, 93 (1980).
- [130] J. Uffink, *Quadratic Bell Inequalities as Tests for Multipartite Entanglement*, Phys. Rev. Lett. **88**, 230406 (2002).
- [131] B. S. Tsirel'son, *Quantum analogues of the Bell inequalities. The case of two spatially separated domains*, J. Sov. Math. **36**, 557–570 (1987).
- [132] L. J. Landau, *Empirical two-point correlation functions*, Found. Phys. **18**, 449 (1988).
- [133] Ll. Masanes, *Necessary and sufficient condition for quantum-generated correlations*, arXiv:quant-ph/0309137.

Bibliography

- [134] J. F. Clauser, M. A. Horne, A. Shimony, and R. A. Holt, *Proposed Experiment to Test Local Hidden-Variable Theories*, Phys. Rev. Lett. **23**, 880 (1969).
- [135] M. Navascués, S. Pironio, and A. Acín, *A convergent hierarchy of semidefinite programs characterizing the set of quantum correlations*, New J. Phys. **10**, 073013 (2008).
- [136] J. Silman, S. Pironio, and S. Massar, *Device-Independent Randomness Generation in the Presence of Weak Cross-Talk*, Phys. Rev. Lett. **110**, 100504 (2013).
- [137] N. H. Lindner, E. Berg, G. Refael, and A. Stern, *Fractionalizing Majorana Fermions: Non-Abelian Statistics on the Edges of Abelian Quantum Hall States*, Phys. Rev. X **2**, 041002 (2012).
- [138] M. Cheng, *Superconducting proximity effect on the edge of fractional topological insulators*, Phys. Rev. B **86**, 195126 (2012).
- [139] A. Vaezi, *Fractional topological superconductor with fractionalized Majorana fermions*, Phys. Rev. B **87**, 035132 (2013).
- [140] R. S. K. Mong, D. J. Clarke, J. Alicea, N. H. Lindner, P. Fendley, C. Nayak, Y. Oreg, A. Stern, E. Berg, K. Shtengel, and M. P. A. Fisher, *Universal Topological Quantum Computation from a Superconductor-Abelian Quantum Hall Heterostructure*, Phys. Rev. X **4**, 011036 (2014).
- [141] J. Klinovaja and D. Loss, *Parafermions in an Interacting Nanowire Bundle*, Phys. Rev. Lett. **112**, 246403 (2014).
- [142] J. Klinovaja and D. Loss, *Time-reversal invariant parafermions in interacting Rashba nanowires*, Phys. Rev. B **90**, 045118 (2014).
- [143] J. Alicea and P. Fendley, *Topological Phases with Parafermions: Theory and Blueprints*, Annu. Rev. Condens. Matter Phys. **7**, 119 (2016).
- [144] A. Romito and Y. Gefen, *Ubiquitous Nonlocal Entanglement with Majorana Zero Modes*, Phys. Rev. Lett. **119**, 157702 (2017).
- [145] J. Bulte, A. Bednorz, C. Bruder, and W. Belzig, *Noninvasive Quantum Measurement of Arbitrary Operator Order by Engineered Non-Markovian Detectors*, Phys. Rev. Lett. **120**, 140407 (2018).

- [146] A. Carmi and E. Cohen, *On the Significance of the Quantum Mechanical Covariance Matrix*, Entropy **20**, 500 (2018).
- [147] A. Bednorz and W. Belzig, *Proposal for a cumulant-based Bell test for mesoscopic junctions*, Phys. Rev. B **83**, 125304 (2011).
- [148] Ll. Masanes, A. Acin, and N. Gisin, *General properties of nonsignaling theories*, Phys. Rev. A **73**, 012112 (2006).
- [149] A. Carmi and E. Cohen, *Relativistic independence bounds nonlocality*, Sci. Adv. **5**, eaav8370 (2019).
- [150] K. Snizhko, R. Egger, and Y. Gefen, *Measurement and control of a Coulomb-blockaded parafermion box*, Phys. Rev. B **97**, 081405 (2018).
- [151] L.-B. Fu, *General Correlation Functions of the Clauser-Horne-Shimony-Holt Inequality for Arbitrarily High-Dimensional Systems*, Phys. Rev. Lett. **92**, 130404 (2004).
- [152] L.-B. Fu, J.-L. Chen, and X.-G. Zhao, *Maximal violation of the Clauser Horne-Shimony-Holt inequality for two qutrits*, Phys. Rev. A **68**, 022323 (2003).
- [153] E. Arthurs and J. L. Kelly, *On the Simultaneous Measurement of a Pair of Conjugate Observables*, Bell Syst. Tech. J. **44**, 725 (1965).
- [154] L. M. Johansen and P. A. Mello, *Quantum mechanics of successive measurements with arbitrary meter coupling*, Phys. Lett. A **372**, 5760–5764 (2008).
- [155] M. A. Ochoa, W. Belzig, and A. Nitzan, *Simultaneous weak measurement of noncommuting observables: a generalized Arthurs-Kelly protocol*, Sci. Rep. **8**, 15781 (2018).
- [156] K. J. Resch and A. M. Steinberg, *Extracting Joint Weak Values with Local, Single-Particle Measurements*, Phys. Rev. Lett. **92**, 130402 (2004).
- [157] J. S. Lundeen and A. M. Steinberg, *Experimental Joint Weak Measurement on a Photon Pair as a Probe of Hardy’s Paradox*, Phys. Rev. Lett. **102**, 020404 (2009).
- [158] D. Litinski, *Magic State Distillation: Not as Costly as You Think*, Quantum **3**, 205 (2019).

Bibliography

- [159] A. Peruzzo, J. McClean, P. Shadbolt, M.-H. Yung, X.-Q. Zhou, P. J.Love, A. Aspuru-Guzik, and J. L. O'Brien, *A variational eigenvalue solver on a photonic quantum processor*, Nat. Comm. **5**, 4213 (2014).
- [160] J. McClean, S. Boixo, V. Smelyanskiy, R. Babbush, and H. Neven, *Barren plateaus in quantum neural network training landscapes* , Nat. Comm. **9**, 4812 (2018).
- [161] P.-L. Dallaire-Demers, J. Romero, L. Veis, S. Sim, and A. Aspuru-Guzik, *Low-depth circuit ansatz for preparing correlated fermionic states on a quantum computer*, Quantum Sci. Technol. **4**, 045005 (2019).
- [162] E. Farhi, J. Goldstone, and S. Gutmann, *A Quantum Approximate Optimization Algorithm*, arXiv:1411.4028.
- [163] S. Lloyd, *Quantum approximate optimization is computationally universal* , arXiv:1812.11075.
- [164] A. Kandala, A. Mezzacapo, K. Temme, M. Takita, M. Brink, J. M.Chow, and J. M. Gambetta, *Hardware-efficient Variational Quantum Eigensolver for Small Molecules and Quantum Magnets* , Nature **549**, 242 (2017).
- [165] R. Sagastizabal, X. Bonet-Monroig, M. Singh, M. Rol, C. Bultink, X. Fu, C. Price, V. Ostroukh, N. Muthusubramanian, A. Bruno, M. Beekman, N. Haider, T. O'Brien, and L. DiCarlo, *Error Mitigation by Symmetry Verification on a Variational Quantum Eigensolver*, Phys. Rev. A **100**, 010302 (2019).
- [166] G. Guerreschi and M. Smelyanskiy, *Practical optimization for hybrid quantum-classical algorithms*, arXiv:1701.01450.
- [167] O. Higgott, D. Wang, and S. Brierley, *Variational Quantum Computation of Excited States*, Quantum **3**, 156 (2019).
- [168] S. Endo, T. Jones, S. McArdle, X. Yuan, and S. Benjamin, *Variational quantum algorithms for discovering Hamiltonian spectra*, Phys. Rev. A **99**, 062304 (2019).
- [169] K. M. Nakanishi, K. Fujii, and S. Todo, *Sequential minimal optimization for quantum-classical hybrid algorithms*, Phys. Rev. Research **2**, 043158 (2020).

- [170] D. Gottesman, *Stabilizer Codes and Quantum Error Correction*, PhD Dissertation, California Institute of Technology (1997).
- [171] B.T. Gard, L. Zhu, G.S. Barron, N.J. Mayhall, S.E. Economou, and E. Barnes, *Efficient symmetry-preserving state preparation circuits for the variational quantum eigensolver algorithm*, NPJ Quantum Inf. **6**, 10 (2020).
- [172] J. Kirkwood and L. Thomas, *Expansions and phase transitions for the ground state of quantum Ising lattice systems*, Commun. Math. Phys. **88**, 569 (1983).
- [173] S. Bravyi, D. DiVincenzo, and D. Loss, *Polynomial-time algorithm for simulation of weakly interacting quantum spin systems*, Commun. Math. Phys. **284**, 481 (2008).
- [174] M. Reiher, N. Wiebe, K. M. Svore, D. Wecker, and M. Troyer, *Elucidating reaction mechanisms on quantum computers*, Proc. Nat. Acad. Sci. USA **114**, 7555 (2017).
- [175] J.-S. Xu, M.-H. Yung, X.-Y. Xu, S. Boixo, Z.-W. Zhou, C.-F. Li, A. Aspuru-Guzik, and G.-C. Guo, *Demon-like algorithmic quantum cooling and its realization with quantum optics*, Nat. Photonics **8**, 113 (2014).
- [176] S. McArdle, T. Jones, S. Endo, Y. Li, S. Benjamin, and X. Yuan, *Variational ansatz-based quantum simulation of imaginary time evolution*, npj Quant. Inf. **5**, 75 (2019).
- [177] M. Motta, C. Sun, A. T. K. Tan, M. J. O'Rourke, E. Ye, A. J. Minnich, F. G. S. L. Brandao, and G. K.-L. Chan, *Determining eigenstates and thermal states on a quantum computer using quantum imaginary time evolution*, Nat. Phys. **16**, 205 (2020).
- [178] O. Kyriienko, *Quantum inverse iteration algorithm for programmable quantum simulators*, npj Quantum Information **6**, 7 (2020).
- [179] S. Kretschmer, K. Luoma, and W.T. Strunz, *Collision model for non-Markovian quantum dynamics*, Phys. Rev. A **94**, 012106 (2016).
- [180] D. W. Berry, G. Ahokas, R. Cleve, and B. C. Sanders, *Efficient Quantum Algorithms for Simulating Sparse Hamiltonians*, Comm. Mat. Phys. **270**, 359 (2007).

Bibliography

- [181] M. Suzuki, *Generalized Trotter's formula and systematic approximants of exponential operators and inner derivations with applications to many-body problems*, Comm. Mat. Phys. **51**, 183 (1976).
- [182] Z.-C. Yang, A. Rahmani, A. Shabani, H. Neven, and C. Chamon, *Optimizing Variational Quantum Algorithms using Pontryagin's Minimum Principle*, Phys. Rev. X **7**, 021027 (2017).
- [183] A. Bapat and S. Jordan, *Bang-bang control as a design principle for classical and quantum optimization algorithms*, Quant. Inf. Comp. **19**: 424-446 (2019).
- [184] F. G. Brandao and K. M. Svore, *Quantum Speed-Ups for Solving Semidefinite Programs*, IEEE FOCS **555**, 415 (2017).
- [185] J. Wang, F. Sciarrino, A. Laing, and M. G. Thompson, *Integrated photonic quantum technologies*, Nat. Photonics **14**, 273 (2020).
- [186] R. van Handel, J. K. Stockton, and H. Mabuchi, *Modelling and feedback control design for quantum state preparation*, J. Opt. B **7**, 10 (2005).
- [187] I. Bloch, *Quantum coherence and entanglement with ultracold atoms in optical lattices*, Nat. **453**, 1016 (2008).
- [188] L. C. Kwek, Z. Wei, and B. Zeng, *Measurement-Based Quantum Computing with Valence-Bond-Solids*, Int. J. Mod. Phys. B (2012).
- [189] J.-W. Pan, C. Simon, C. Brukner, A. Zeilinger, *Entanglement purification for quantum communication*, Nature **410**, 1067 (2001).
- [190] X.-Y. Luo, Y.-Q. Zou, L.-N. Wu, Q. Liu, M.-F. Han, M. K. Tey, and L. You, *Deterministic entanglement generation from driving through quantum phase transitions*, Science **355** 620 (2017).
- [191] J.G. Bohnet, B.C. Sawyer, J. W. Britton, M.L. Wall, A.M. Rey, M. Foss-Feig, and J. J. Bollinger, *Quantum spin dynamics and entanglement generation with hundreds of trapped ions*, Science **352**, 1297 (2016).
- [192] R. Stockill, M.J. Stanley, L. Huthmacher, E. Clarke, M. Hugues, A.J. Miller, C. Matthiesen, C. Le Gall, and M. Atatüre, *Phase-Tuned Entangled State Generation between Distant Spin Qubits*, Phys. Rev. Lett. **119**, 010503 (2017).

Bibliography

- [193] J.K. Stockton, R. van Handel, and H. Mabuchi, *Deterministic Dicke-state preparation with continuous measurement and control*, Phys. Rev. A **70**, 022106 (2004).
- [194] C. Marr, A. Beige, and G. Rempe, *Entangled state preparation via dissipation-assisted adiabatic passages*, Phys. Rev. A **68**, 033817 (2003).
- [195] B. Kraus, H. P. Büchler, S. Diehl, A. Kantian, A. Micheli, and P. Zoller, *Preparation of entangled states by quantum Markov processes*, Phys. Rev. A **78**, 042307 (2008).
- [196] A. Pechen and H. Rabitz, *Teaching the environment to control quantum systems*, Phys. Rev. A **73**, 062102 (2006).
- [197] X.-Q. Shao, T.-Y. Zheng, and S. Zhang, *Engineering steady three-atom singlet states via quantum-jump-based feedback*, Phys. Rev. A **85**, 042308 (2012).
- [198] Y. Lin, J.P. Gaebler, F. Reiter, T.R. Tan, R. Bowler, Y. Wan, A. Keith, E. Knill, S. Glancy, K. Coakley, A.S. Sørensen, D. Leibfried, and D.J. Wineland, *Preparation of Entangled States through Hilbert Space Engineering*, Phys. Rev. Lett. **117**, 140502 (2016).
- [199] Z. Liu, L. Kuang, K. Hu, L. Xu, S. Wei, L. Guo, and X.-Q. Li, *Deterministic creation and stabilization of entanglement in circuit QED by homodyne-mediated feedback control*, Phys. Rev. A **82**, 032335 (2010).
- [200] A. Pechen, N. Il'in, F. Shuang, and H. Rabitz, *Quantum control by von Neumann measurements*, Phys. Rev. A **74**, 052102 (2006).
- [201] L. Roa, A. Delgado, M. L. Ladrón de Guevara, and A. B. Klimov, *Measurement-driven quantum evolution*, Phys. Rev. A **73**, 012322 (2006).
- [202] S. Roy, J.T. Chalker, I.V. Gornyi, and Y. Gefen, *Measurement-induced steering of quantum systems*, Phys. Rev. Research **2**, 033347 (2020).
- [203] M. Ippoliti, M. J. Gullans, S. Gopalakrishnan, D. A. Huse, and V. Khemani, *Entanglement phase transitions in measurement-only dynamics*, Phys. Rev. X **11**, 011030, (2021).

Bibliography

- [204] T. Grigoletto and F. Ticozzi, *Stabilization via feedback switching for quantum stochastic dynamics*, arXiv:2012.08712.
- [205] A. Larrouy, S. Patsch, R. Richaud, J.-M. Raimond, M. Brune, C. P. Koch, and S. Gleyzes, *Fast Navigation in a Large Hilbert Space Using Quantum Optimal Control*, Phys. Rev. X **10**, 021058 (2020).
- [206] S. Fu, G. Shi, A. Proutiere, and M. R. James, *Feedback Policies for Measurement-based Quantum State Manipulation*, Phys. Rev. A **90**, 062328 (2014).
- [207] I. Affleck, T. Kennedy, E. H. Lieb, and H. Tasaki *Rigorous results on valence-bond ground states in antiferromagnets*, Phys. Rev. Lett. **59**, 799 (1987).
- [208] O. Zilberberg, A. Romito, D. J. Starling, G. A. Howland, C. J. Broadbent, J. C. Howell, and Y. Gefen, *Null Values and Quantum State Discrimination*, Phys. Rev. Lett. **110**, 170405 (2013).
- [209] M. Hein, J. Eisert, and H. J. Briegel, *Multi-party entanglement in graph states*, Phys. Rev. A **69**, 062311 (2004).
- [210] M. Fannes, B. Nachtergaelie, and R. F. Werner, *Finitely correlated states on quantum spin chains*, Commun. Math. Phys. **144**, 443 (1992).
- [211] P. W. Anderson, *Infrared Catastrophe in Fermi Gases with Local Scattering Potentials*, Phys. Rev. Lett. **18**, 1049 (1967).
- [212] W. Dür, G. Vidal, and J. I. Cirac, *Three qubits can be entangled in two inequivalent ways*, Phys. Rev. A **62**, 062314 (2000).
- [213] P. Kumar, K. Snizhko, and Y. Gefen, *Engineering two-qubit mixed states with weak measurements*, Phys. Rev. Research **2**, 042014(R) (2020).
- [214] S. Borah, B. Sarma, M. Kewming, G. J. Milburn, and J. Twamley, *Measurement-Based Feedback Quantum Control with Deep Reinforcement Learning for a Double-Well Nonlinear Potential*, Phys. Rev. Lett. **127**, 190403 (2021).
- [215] D. Bondarenko, P. Feldmann, *Quantum autoencoders to denoise quantum data*, Phys. Rev. Lett. **124**, 130502 (2020).

Bibliography

- [216] C.J.C.H. Watkins, *Learning from delayed rewards*, Ph.D. dissertation, Psychology Dept. Univ. of Cambridge, UK (1989).
- [217] G.A. Rummery, M. Niranjan, *On-line Q-learning using connectionist systems*, Engineering Dept. Univ. of Cambridge, UK (1994).

