



Universiteit
Leiden
The Netherlands

Lattice models for Josephson junctions and graphene superlattices

Ostroukh, V.

Citation

Ostroukh, V. (2018, June 27). *Lattice models for Josephson junctions and graphene superlattices*. *Casimir PhD Series*. Retrieved from <https://hdl.handle.net/1887/63217>

Version: Not Applicable (or Unknown)

License: [Licence agreement concerning inclusion of doctoral thesis in the Institutional Repository of the University of Leiden](#)

Downloaded from: <https://hdl.handle.net/1887/63217>

Note: To cite this publication please use the final published version (if applicable).

Cover Page



Universiteit Leiden



The handle <http://hdl.handle.net/1887/63217> holds various files of this Leiden University dissertation.

Author: Ostroukh, V.

Title: Lattice models for Josephson junctions and graphene superlattices

Issue Date: 2018-06-27

Bibliography

- [1] D. Drung, C. Abmann, J. Beyer, A. Kirste, M. Peters, F. Ruede, and T. Schurig. *Highly sensitive and easy-to-use SQUID sensors*. IEEE Transactions on Applied Superconductivity **17**, 699–704 (2007).
- [2] P. Joyez, P. Lafarge, A. Filipe, D. Esteve, and M. H. Devoret. *Observation of parity-induced suppression of Josephson tunneling in the superconducting single electron transistor*. Phys. Rev. Lett. **72**, 2458–2461 (1994).
- [3] I. Chiorescu, Y. Nakamura, C. J. P. M. Harmans, and J. E. Mooij. *Coherent quantum dynamics of a superconducting flux qubit*. Science **299**, 1869–1871 (2003).
- [4] T. Yamamoto, Y. A. Pashkin, O. Astafiev, Y. Nakamura, and J.-S. Tsai. *Demonstration of conditional gate operation using superconducting charge qubits*. Nature **425**, 941 (2003).
- [5] F. W. Strauch, P. R. Johnson, A. J. Dragt, C. J. Lobb, J. R. Anderson, and F. C. Wellstood. *Quantum logic gates for coupled superconducting phase qubits*. Phys. Rev. Lett. **91**, 167005 (2003).
- [6] C. Foley and H. Hilgenkamp. *Why nanoSQUIDs are important: an introduction to the focus issue*. Supercond. Sci. Technol. **22**, 064001 (2009).
- [7] C. A. Hamilton, R. L. Kautz, R. L. Steiner, and F. L. Lloyd. *A practical Josephson voltage standard at 1 V*. IEEE Electron Device Lett. **6**, 623–625 (1985).
- [8] J. Niemeyer, L. Grimm, W. Meier, J. Hinken, and E. Vollmer. *Stable Josephson reference voltages between 0.1 and 1.3 V for high-precision voltage standards*. Appl. Phys. Lett. **47**, 1222–1223 (1985).

- [9] M. Tinkham. *Introduction to superconductivity: second edition*. (Dover Publications, 2004).
- [10] C. W. J. Beenakker, *Three “universal” mesoscopic josephson effects*, in *Transport phenomena in mesoscopic systems*, edited by H. Fukuyama and T. Ando (1992), pp. 235–253.
- [11] R. C. Dynes and T. A. Fulton. *Supercurrent density distribution in Josephson junctions*. *Phys. Rev. B* **3**, 3015–3023 (1971).
- [12] <https://graphene-flagship.eu/> (visited on 2018-04-09).
- [13] Y. Ren, X. Deng, Z. Qiao, C. Li, J. Jung, C. Zeng, Z. Zhang, and Q. Niu. *Single-valley engineering in graphene superlattices*. *Phys. Rev. B* **91**, 245415 (2015).
- [14] M. Yankowitz, J. Xue, D. Cormode, J. D. Sanchez-Yamagishi, K. Watanabe, T. Taniguchi, P. Jarillo-Herrero, P. Jacquod, and B. J. LeRoy. *Emergence of superlattice Dirac points in graphene on hexagonal boron nitride*. *Nature Phys.* **8**, 382 (2012).
- [15] C. Gutiérrez, C.-J. Kim, L. Brown, T. Schiros, D. Nordlund, E. B. Lochocki, K. M. Shen, J. Park, and A. N. Pasupathy. *Imaging chiral symmetry breaking from Kekulé bond order in graphene*. *Nature Phys.* **12**, 950 (2016).
- [16] C. W. Groth, M. Wimmer, A. R. Akhmerov, and X. Waintal. *Kwant: a software package for quantum transport*. *New J. Phys.* **16**, 063065 (2014).
- [17] M. Wimmer. *Quantum transport in nanostructures: from computational concepts to spintronics in graphene and magnetic tunnel junctions*. PhD thesis (University of Regensburg, 2009-12).
- [18] L. Kadanoff and G. Baym. *Quantum statistical mechanics: Green’s function methods in equilibrium and nonequilibrium problems*. (W.A. Benjamin, 1962).
- [19] V. S. Pribiag, A. J. Beukman, F. Qu, M. C. Cassidy, C. Charpentier, W. Wegscheider, and L. P. Kouwenhoven. *Edge-mode superconductivity in a two-dimensional topological insulator*. *Nature Nanotech.* **10**, 593 (2015).
- [20] C. Liu, T. L. Hughes, X.-L. Qi, K. Wang, and S.-C. Zhang. *Quantum spin Hall effect in inverted type-II semiconductors*. *Phys. Rev. Lett.* **100**, 236601 (2008).

- [21] L. Du, I. Knez, G. Sullivan, and R.-R. Du. *Robust helical edge transport in gated InAs/GaSb bilayers*. Phys. Rev. Lett. **114**, 096802 (2015).
- [22] C. W. J. Beenakker, D. I. Pikulin, T. Hyart, H. Schomerus, and J. P. Dahlhaus. *Fermion-parity anomaly of the critical supercurrent in the quantum spin-Hall effect*. Phys. Rev. Lett. **110**, 017003 (2013).
- [23] S.-P. Lee, K. Michaeli, J. Alicea, and A. Yacoby. *Revealing topological superconductivity in extended quantum spin Hall Josephson junctions*. Phys. Rev. Lett. **113**, 197001 (2014).
- [24] U. Essmann and H. Träuble. *The direct observation of individual flux lines in type II superconductors*. Phys. Lett. A **24**, 526–527 (1967).
- [25] J. C. Cuevas and F. S. Bergeret. *Magnetic interference patterns and vortices in diffusive SNS junctions*. Phys. Rev. Lett. **99**, 217002 (2007).
- [26] A. Abrikosov. *The magnetic properties of superconducting alloys*. J. Phys. Chem. Solids **2**, 199–208 (1957).
- [27] C.-Y. Hou, C. Chamon, and C. Mudry. *Electron fractionalization in two-dimensional graphenelike structures*. Phys. Rev. Lett. **98**, 186809 (2007).
- [28] V. Cheianov, V. Fal’ko, O. Syljuåsen, and B. Altshuler. *Hidden Kekulé ordering of adatoms on graphene*. Solid State Communications **149**, 1499–1501 (2009).
- [29] J. A. M. van Ostaay, A. R. Akhmerov, C. W. J. Beenakker, and M. Wimmer. *Dirac boundary condition at the reconstructed zigzag edge of graphene*. Phys. Rev. B **84**, 195434 (2011).
- [30] G. Tkachov, P. Burset, B. Trauzettel, and E. M. Hankiewicz. *Quantum interference of edge supercurrents in a two-dimensional topological insulator*. Phys. Rev. B **92**, 045408 (2015).
- [31] I. Knez, R.-R. Du, and G. Sullivan. *Andreev reflection of helical edge modes in InAs/GaSb quantum spin Hall insulator*. Phys. Rev. Lett. **109**, 186603 (2012).

- [32] S. Hart, H. Ren, T. Wagner, P. Leubner, M. Mühlbauer, C. Brüne, H. Buhmann, L. W. Molenkamp, and A. Yacoby. *Induced superconductivity in the quantum spin hall edge*. Nature Phys. **10**, 638 (2014).
- [33] X. Shi, W. Yu, Z. Jiang, B. Andrei Bernevig, W. Pan, S. Hawkins, and J. Klem. *Giant supercurrent states in a superconductor-InAs/GaSb-superconductor junction*. J. Appl. Phys. **118**, 133905 (2015).
- [34] H.-Y. Hui, A. M. Lobos, J. D. Sau, and S. Das Sarma. *Proximity-induced superconductivity and Josephson critical current in quantum spin Hall systems*. Phys. Rev. B **90**, 224517 (2014).
- [35] U. Smilansky. *Exterior–interior duality for discrete graphs*. J. Phys. A **42**, 035101 (2009).
- [36] J. T. Chalker and P. D. Coddington. *Percolation, quantum tunnelling and the integer Hall effect*. J. Phys. C: Solid State Physics **21**, 2665 (1988).
- [37] B. Kramer, T. Ohtsuki, and S. Kettemann. *Random network models and quantum phase transitions in two dimensions*. Phys. Rep. **417**, 211–342 (2005).
- [38] Y. Jiang, X. Lu, and F. Zhai. *Standard form of the scattering matrix for time reversal symmetric system*. arXiv:1310.3733 (2013).
- [39] C. W. J. Beenakker. *Universal limit of critical-current fluctuations in mesoscopic Josephson junctions*. Phys. Rev. Lett. **67**, 3836–3839 (1991).
- [40] P. Brouwer and C. Beenakker. *Anomalous temperature dependence of the supercurrent through a chaotic Josephson junction*. Chaos, Solitons & Fractals **8**, Chaos and Quantum Transport in Mesoscopic Cosmos, 1249–1260 (1997).
- [41] U. Ledermann, A. L. Fauchère, and G. Blatter. *Nonlocality in mesoscopic josephson junctions with strip geometry*. Phys. Rev. B **59**, R9027–R9030 (1999).
- [42] V. Barzykin and A. M. Zagoskin. *Coherent transport and nonlocality in mesoscopic SNS junctions: anomalous magnetic interference patterns*. Superlatt. Microstruct. **25**, 797–807 (1999).

- [43] J. P. Heida, B. J. van Wees, T. M. Klapwijk, and G. Borghs. *Non-local supercurrent in mesoscopic Josephson junctions*. Phys. Rev. B **57**, R5618–R5621 (1998).
- [44] Y. Harada, S. Jensen, T. Akazaki, and H. Takayanagi. *Anomalous magnetic flux periodicity of supercurrent in mesoscopic SNS josephson junctions*. Physica C **367**, 229–233 (2002).
- [45] L. Fu and C. L. Kane. *Josephson current and noise at a superconductor/quantum-spin-Hall-insulator/superconductor junction*. Phys. Rev. B **79**, 161408 (2009).
- [46] Q.-Z. Wang, X. Liu, H.-J. Zhang, N. Samarth, S.-C. Zhang, and C.-X. Liu. *Quantum anomalous hall effect in magnetically doped InAs/GaSb quantum wells*. Phys. Rev. Lett. **113**, 147201 (2014).
- [47] S. V. Mironov, A. S. Mel’nikov, and A. I. Buzdin. *Double path interference and magnetic oscillations in cooper pair transport through a single nanowire*. Phys. Rev. Lett. **114**, 227001 (2015).
- [48] C. Li, A. Kasumov, A. Murani, S. Sengupta, F. Fortuna, K. Napolskii, D. Koshkodaev, G. Tsirlina, Y. Kasumov, I. Khodos, R. Deblock, M. Ferrier, S. Guéron, and H. Bouchiat. *Magnetic field resistant quantum interferences in josephson junctions based on bismuth nanowires*. Phys. Rev. B **90**, 245427 (2014).
- [49] D. Giuliano and I. Affleck. *The Josephson current through a long quantum wire*. J. Stat. Mech. Theory Exp. **2013**, P02034 (2013).
- [50] E. Akkermans, A. Auerbach, J. E. Avron, and B. Shapiro. *Relation between persistent currents and the scattering matrix*. Phys. Rev. Lett. **66**, 76–79 (1991).
- [51] M. Z. Hasan and C. L. Kane. *Colloquium: Topological insulators*. Rev. Mod. Phys. **82**, 3045–3067 (2010).
- [52] C. L. Kane and E. J. Mele. *Quantum spin Hall effect in graphene*. Phys. Rev. Lett. **95**, 226801 (2005).
- [53] M. König, S. Wiedmann, C. Brüne, A. Roth, H. Buhmann, L. W. Molenkamp, X.-L. Qi, and S.-C. Zhang. *Quantum spin Hall insulator state in HgTe quantum wells*. Science **318**, 766–770 (2007).
- [54] B. van Wees, G. Meijer, J. Kuipers, T. Klapwijk, W. v. d. Graaf, and G. Borghs. *Breakdown of the quantum hall effect in InAs/AlSb quantum wells due to counterflowing edge channels*. Phys. Rev. B **51**, 7973–7976 (1995).

- [55] B.-M. Nguyen, A. A. Kiselev, R. Noah, W. Yi, F. Qu, A. J. A. Beukman, F. K. de Vries, J. van Veen, S. Nadj-Perge, L. P. Kouwenhoven, M. Kjaergaard, H. J. Suominen, F. Nichele, C. M. Marcus, M. J. Manfra, and M. Sokolich. *Decoupling edge versus bulk conductance in the trivial regime of an InAs/GaSb double quantum well using corbino ring geometry*. Phys. Rev. Lett. **117**, 077701 (2016).
- [56] F. Nichele, H. J. Suominen, M. Kjaergaard, C. M. Marcus, E. Sajadi, J. A. Folk, F. Qu, A. J. A. Beukman, F. K. de Vries, J. van Veen, S. Nadj-Perge, L. P. Kouwenhoven, B.-M. Nguyen, A. A. Kiselev, W. Yi, M. Sokolich, M. J. Manfra, E. M. Spanton, and K. A. Moler. *Edge transport in the trivial phase of InAs/GaSb*. New J. Phys. **18**, 083005 (2016).
- [57] I. Tamm. *On the possible bound states of electrons on a crystal surface*. Phys. Z. Soviet Union **1** (1932).
- [58] W. Shockley. *On the surface states associated with a periodic potential*. Phys. Rev. **56**, 317–323 (1939).
- [59] J. Bardeen. *Surface states and rectification at a metal semiconductor contact*. Phys. Rev. **71**, 717–727 (1947).
- [60] A. Furukawa. *Dependence of electron accumulation in AlSb/InAs quantum well on thin surface materials of InAs and GaSb*. Appl. Phys. Lett. **62**, 3150–3152 (1993).
- [61] L. Ö. Olsson, C. B. M. Andersson, M. C. Håkansson, J. Kanski, L. Ilver, and U. O. Karlsson. *Charge accumulation at InAs surfaces*. Phys. Rev. Lett. **76**, 3626–3629 (1996).
- [62] K. Flensberg, J. B. Hansen, and M. Octavio. *Subharmonic energy-gap structure in superconducting weak links*. Phys. Rev. B **38**, 8707–8711 (1988).
- [63] M. T. Allen, O. Shtanko, I. C. Fulga, A. Akhmerov, K. Watanabe, T. Taniguchi, P. Jarillo-Herrero, L. S. Levitov, and A. Yacoby. *Spatially resolved edge currents and guided-wave electronic states in graphene*. Nature Phys. **12**, 128 (2016).
- [64] W. Haberkorn, H. Knauer, and J. Richter. *A theoretical study of the current-phase relation in Josephson contacts*. Phys. Status Solidi A **47**, K161–K164 (1978).

- [65] A. Rasmussen, J. Danon, H. Suominen, F. Nichele, M. Kjaergaard, and K. Flensberg. *Effects of spin-orbit coupling and spatial symmetries on the Josephson current in SNS junctions*. Phys. Rev. B **93**, 155406 (2016).
- [66] H. J. Suominen, J. Danon, M. Kjaergaard, K. Flensberg, J. Shabani, C. J. Palmstrøm, F. Nichele, and C. M. Marcus. *Anomalous Fraunhofer interference in epitaxial superconductor-semiconductor Josephson junctions*. Phys. Rev. B **95**, 035307 (2017).
- [67] M. Ben Shalom, M. Zhu, V. Fal’ko, A. Mishchenko, A. Kretinin, K. Novoselov, C. Woods, K. Watanabe, T. Taniguchi, A. Geim, et al. *Quantum oscillations of the critical current and high-field superconducting proximity in ballistic graphene*. Nature Phys. **12**, 318–322 (2016).
- [68] T. Yokoyama, M. Eto, and Y. V. Nazarov. *Josephson current through semiconductor nanowire with spin-orbit interaction in magnetic field*. J. Phys. Soc. Jpn. **82**, 054703 (2013).
- [69] H. Meier, V. I. Fal’ko, and L. I. Glazman. *Edge effects in the magnetic interference pattern of a ballistic SNS junction*. Phys. Rev. B **93**, 184506 (2016).
- [70] S. Russo, M. Kroug, T. M. Klapwijk, and A. F. Morpurgo. *Experimental observation of bias-dependent nonlocal Andreev reflection*. Phys. Rev. Lett. **95**, 027002 (2005).
- [71] J. A. M. van Ostaay, A. R. Akhmerov, and C. W. J. Beenakker. *Spin-triplet supercurrent carried by quantum hall edge states through a Josephson junction*. Phys. Rev. B **83**, 195441 (2011).
- [72] P. Recher, E. V. Sukhorukov, and D. Loss. *Andreev tunneling, Coulomb blockade, and resonant transport of nonlocal spin-entangled electrons*. Phys. Rev. B **63**, 165314 (2001).
- [73] A. Furusaki. *DC Josephson effect in dirty SNS junctions: numerical study*. Physica B **203**, 214–218 (1994).
- [74] J. M. Rowell. *Magnetic field dependence of the Josephson tunnel current*. Phys. Rev. Lett. **11**, 200–202 (1963).
- [75] V. E. Calado, S. Goswami, G. Nanda, M. Diez, A. R. Akhmerov, K. Watanabe, T. Taniguchi, T. M. Klapwijk, and L. M. Vandersypen. *Ballistic Josephson junctions in edge-contacted graphene*. Nature Nanotech. **10**, 761–764 (2015).

- [76] S. Hart, H. Ren, M. Kosowsky, G. Ben-Shach, P. Leubner, C. Brüne, H. Buhmann, L. W. Molenkamp, B. I. Halperin, and A. Yacoby. *Controlled finite momentum pairing and spatially varying order parameter in proximitized HgTe quantum wells*. *Nature Phys.* **13**, 87 (2017).
- [77] M. Kim, D. Jeong, G.-H. Lee, Y.-S. Shin, H.-W. Lee, and H.-J. Lee. *Tuning locality of pair coherence in graphene-based Andreev interferometers*. *Sci. Rep.* **5**, 8715 (2015).
- [78] F. Bergeret and J. Cuevas. *The vortex state and Josephson critical current of a diffusive sns junction*. *J. Low Temp. Phys.* **153**, 304–324 (2008).
- [79] M. Alidoust, G. Sewell, and J. Linder. *Non-fraunhofer interference pattern in inhomogeneous ferromagnetic josephson junctions*. *Phys. Rev. Lett.* **108**, 037001 (2012).
- [80] M. Alidoust and K. Halterman. *Proximity induced vortices and long-range triplet supercurrents in ferromagnetic Josephson junctions and spin valves*. *J. Appl. Phys.* **117**, 123906 (2015).
- [81] M. Amundsen and J. Linder. *General solution of 2d and 3d superconducting quasiclassical systems: coalescing vortices and nanoisland geometries*. *Sci. Rep.* **6**, 22765 (2016).
- [82] J. Bardeen, R. Kümmel, A. E. Jacobs, and L. Tewordt. *Structure of vortex lines in pure superconductors*. *Phys. Rev.* **187**, 556–569 (1969).
- [83] A. F. Andreev. *The thermal conductivity of the intermediate state in superconductors*. *Sov. Phys. JETP* **19**, 1228–1231 (1964).
- [84] C. W. J. Beenakker and H. van Houten. *Josephson current through a superconducting quantum point contact shorter than the coherence length*. *Phys. Rev. Lett.* **66**, 3056–3059 (1991).
- [85] I. O. Kulik and A. N. Omel’Yanchuk. *Properties of superconducting microbridges in the pure limit*. *Sov. J. Low Temp. Phys. (Engl. Transl.)* **3**, 459 (1977).
- [86] T. Yokoyama, M. Eto, and Y. V. Nazarov. *Anomalous Josephson effect induced by spin-orbit interaction and Zeeman effect in semiconductor nanowires*. *Phys. Rev. B* **89**, 195407 (2014).

- [87] P. Rakyta, A. Kormányos, and J. Cserti. *Magnetic field oscillations of the critical current in long ballistic graphene Josephson junctions*. Phys. Rev. B **93**, 224510 (2016).
- [88] M. Z. Hasan, H. Lin, and A. Bansil. *Warping the cone on a topological insulator*. Physics **2**, 108 (2009).
- [89] L. Fu. *Hexagonal warping effects in the surface states of the topological insulator Bi₂Te₃*. Phys. Rev. Lett. **103**, 266801 (2009).
- [90] O. M. Auslaender, L. Luan, E. W. Straver, J. E. Hoffman, N. C. Koshnick, E. Zeldov, D. A. Bonn, R. Liang, W. N. Hardy, and K. A. Moler. *Mechanics of individual isolated vortices in a cuprate superconductor*. Nature Phys. **5**, 35 (2009).
- [91] A. Finkler, D. Vasyukov, Y. Segev, L. Neeman, Y. Anahory, Y. Myasoedov, M. Rappaport, M. Huber, J. Martin, A. Yacoby, and E. Zeldov. *Nano-sized SQUID-on-tip for scanning probe microscopy*. J. Phys. Conf. Ser. **400**, 052004 (2012).
- [92] D. Roditchev, C. Brun, L. Serrier-Garcia, J. C. Cuevas, V. H. L. Bessa, M. V. Milošević, F. Debontridder, V. Stolyarov, and T. Cren. *Direct observation of Josephson vortex cores*. Nature Phys. **11**, 332 (2015).
- [93] F. Chiodi, M. Ferrier, S. Guéron, J. C. Cuevas, G. Montambaux, F. Fortuna, A. Kasumov, and H. Bouchiat. *Geometry-related magnetic interference patterns in long SNS josephson junctions*. Phys. Rev. B **86**, 064510 (2012).
- [94] B. Crouzy and D. A. Ivanov. *Magnetic interference patterns in long disordered Josephson junctions*. Phys. Rev. B **87**, 024514 (2013).
- [95] A. Fert. *Origin, development, and future of spintronics*. Angew. Chem. Int. Ed. **47**, Nobel lecture, 5956–5967 (2008).
- [96] D. Awschalom and N. Samarth. *Trend: spintronics without magnetism*. Physics **2**, 50 (2009).
- [97] T. Kuschel and G. Reiss. *Spin orbitronics: charges ride the spin wave*. Nat. Nanotech. **10**, 22 (2015).
- [98] P. Recher and B. Trauzettel. *A defect controls transport in graphene*. Physics **4**, 25 (2011).

- [99] D. Pesin and A. H. MacDonald. *Spintronics and pseudospintronics in graphene and topological insulators*. Nature Mater. **11**, 409 (2012).
- [100] C. Mudry. *Two-dimensional materials: heavy going*. Nature Phys. **12**, 895 (2016).
- [101] C. Gutiérrez. *Visualizing ordered electronic states in epitaxial graphene*. PhD thesis (Columbia University, 2015).
- [102] C. Chamon. *Solitons in carbon nanotubes*. Phys. Rev. B **62**, 2806–2812 (2000).
- [103] V. V. Cheianov, O. Syljuåsen, B. L. Altshuler, and V. Fal’ko. *Ordered states of adatoms on graphene*. Phys. Rev. B **80**, 233409 (2009).
- [104] K. K. Gomes, W. Mar, W. Ko, F. Guinea, and H. C. Manoharan. *Designer Dirac fermions and topological phases in molecular graphene*. Nature **483**, 306 (2012).
- [105] G. Giovannetti, P. A. Khomyakov, G. Brocks, P. J. Kelly, and J. van den Brink. *Substrate-induced band gap in graphene on hexagonal boron nitride: ab initio density functional calculations*. Phys. Rev. B **76**, 073103 (2007).
- [106] G. Giovannetti, M. Capone, J. van den Brink, and C. Ortix. *Kekulé textures, pseudospin-one dirac cones, and quadratic band crossings in a graphene-hexagonal indium chalcogenide bilayer*. Phys. Rev. B **91**, 121417 (2015).
- [107] A. H. Castro Neto, F. Guinea, N. M. R. Peres, K. S. Novoselov, and A. K. Geim. *The electronic properties of graphene*. Rev. Mod. Phys. **81**, 109–162 (2009).
- [108] C. W. J. Beenakker. *Andreev reflection and Klein tunneling in graphene*. Rev. Mod. Phys. **80**, 1337–1354 (2008).
- [109] Y. Aharonov and A. Casher. *Ground state of a spin-1/2 charged particle in a two-dimensional magnetic field*. Phys. Rev. A **19**, 2461–2462 (1979).
- [110] X. G. Wen and A. Zee. *Winding number, family index theorem, and electron hopping in a magnetic field*. Nucl. Phys. B **316**, 641–662 (1989).

-
- [111] M. I. Katsnelson and M. F. Prokhorova. *Zero-energy states in corrugated bilayer graphene*. Phys. Rev. B **77**, 205424 (2008).
 - [112] J. Kailasvuori. *Pedestrian index theorem à la Aharonov-Casher for bulk threshold modes in corrugated multilayer graphene*. Europhys. Lett. **87**, 47008 (2009).
 - [113] S. K. Wang and J. Wang. *Valley precession in graphene superlattices*. Phys. Rev. B **92**, 075419 (2015).
 - [114] B. Trauzettel, D. V. Bulaev, D. Loss, and G. Burkard. *Spin qubits in graphene quantum dots*. Nature Phys. **3**, 192 (2007).
 - [115] M. Polini, F. Guinea, M. Lewenstein, H. C. Manoharan, and V. Pellegrini. *Artificial honeycomb lattices for electrons, atoms and photons*. Nature Nanotech. **8**, 625 (2013).

