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arXiv:1305.0330

Antiferromagnetic states and phase separation in doped AA-stacked graphene bilayers

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We study electronic properties of AA-stacked graphene bilayers. In the single-particle approximation such a system has one electron band and one hole band crossing the Fermi level. If the bilayer is undoped, the Fermi surfaces of these bands coincide. Such a band structure is unstable with respect to a set of spontaneous symmetry violations. Specifically, strong on-site Coulomb repulsion stabilizes antiferromagnetic order. At small doping and low temperatures, the homogeneous phase is unstable, and experiences phase separation into an undoped antiferromagnetic insulator and a metal. The metallic phase can be either antiferromagnetic (commensurate or incommensurate) or paramagnetic depending on the system parameters. We derive the phase diagram of the system on the doping-temperature plane and find that, under certain conditions, the transition from paramagnetic to antiferromagnetic phase may demonstrate re-entrance. When disorder is present, phase separation could manifest itself as a percolative insulator-metal transition driven by doping.

arXiv:1305.0559

Effective models for strong electronic correlations at graphene edges

Manuel J. Schmidt, Michael Golor, Thomas C. Lang, Stefan Wessel

We describe a method for deriving effective low-energy theories of electronic interactions at graphene edges. Our method is applicable to general edges of honeycomb lattices (zigzag, chiral, and even disordered) as long as localized low-energy states (edge states) are present. The central characteristic of the effective theories is a dramatically reduced number of degrees of freedom. As a consequence, the solution of the effective theory by exact diagonalization is feasible for reasonably large ribbon sizes. The quality of the involved approximations is critically assessed by comparing the correlation functions obtained from the effective theory with numerically exact quantum Monte-Carlo calculations. We discuss effective theories of two levels: a relatively complicated fermionic edge state theory and a further reduced Heisenberg spin model. The latter theory paves the way to an efficient description of the magnetic features in long and structurally disordered graphene edges beyond the mean-field approximation.

arXiv:1305.0766

Group theoretical and topological analysis of the quantum spin Hall effect in silicene

Florian Geisser, Jan Carl Budich, Björn Trauzettel

Silicene consists of a monolayer of silicon atoms in a buckled honeycomb structure. It was recently discovered that the symmetry of such a system allows for interesting Rashba spin-orbit effects. A perpendicular electric field is able to couple to the sublattice pseudospin, making it possible to electrically tune and close the band gap. Therefore, external electric fields may generate a topological phase transition from a topological insulator to a normal insulator (or semimetal) and vice versa. The contribution of the present article to the study of silicene is twofold: First, we perform a group theoretical analysis to systematically construct the Hamiltonian in the vicinity of the K points of the Brillouin zone and discover a new, but symmetry allowed term. Subsequently, we identify a tight binding model that corresponds to the group theoretically derived Hamiltonian near the K points. Second, we start from this tight binding model to analyze the topological phase diagram of silicene by an explicit calculation of the Z_2 topological invariant of the band structure. To this end, we calculate the Z_2 topological invariant of the honeycomb lattice in a manifestly gauge invariant way which allows us to include S_z symmetry breaking terms -- like Rashba spin orbit interaction -- into the topological analysis. Interestingly, we find that the interplay of two Rashba terms can generate a non-trivial quantum spin Hall phase in silicene. This is in sharp contrast to the more extensively studied honeycomb system graphene where Rashba spin orbit interaction is known to compete with the quantum spin Hall effect in a potentially detrimental way.

arXiv:1304.7667

Magneto-Josephson effects and Majorana bound states in quantum wires

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A prominent signature of Majorana bound states is the exotic Josephson effects they produce, the classic example being a fractional Josephson current with 4π periodicity in the phase difference across the junction. Recent work established that topological insulator edges support a novel `magneto-Josephson effect', whereby a dissipationless current exhibits 4π-periodic dependence also on the relative orientation of the Zeeman fields in the two banks of the junction. Here, we explore the magneto-Josephson effect in junctions based on spin-orbit coupled quantum wires. In contrast to the topological insulator case, the periodicities of the magneto-Josephson effect no longer follow from an exact superconductor-magnetism duality of the Hamiltonian. We employ numerical calculations as well as analytical arguments to identify the domain configurations that display exotic Josephson physics for quantum-wire junctions, and elucidate the characteristic differences with the corresponding setups for topological insulators edges. To provide guidance to experiments, we also estimate the magnitude of the magneto-Josephson effects in realistic parameter regimes, and compare the Majorana-elated contribution to the coexisting 2\pi-periodic effects emerging from non-Majorana states.

arXiv:1305.0818
Topological insulators in strained graphene at weak interaction
Bitan Roy, Igor F. Herbut

The nature of the electronic ground states in strained undoped graphene at weak interaction between electrons is discussed. After providing a lattice realization of the strain-induced axial magnetic field we numerically find the self-consistent solution for the time reversal symmetry breaking quantum anomalous Hall order-parameter, at weak second-nearest-neighbor repulsion between spinless fermions. The anomalous Hall state is obtained in both uniform and nonuniform axial magnetic fields, with the spatial profile of the order-parameter resembling that of the axial field itself. When the electron spin is included, the time reversal symmetric anomalous spin Hall state becomes slightly preferred energetically at half filling, but the additional anomalous Hall component should develop at a finite doping.

arXiv:1304.7725
Spread of correlations in long-range interacting systems
Philipp Hauke, Luca Tagliacozzo

Understanding the dynamics of many-body systems is crucial for understanding, e.g., thermalization or transmission of information. Nevertheless, little is known in the case of quantum systems with long-range interactions. Here, we analyze the long-range Ising model in a transverse field, where interactions decay as a power-law with distance $\propto r^{-\alpha}$, $\alpha>0$. Using complementary numerical and analytical techniques, we identify three dynamical regimes: short-range-like with an emerging light cone for $\alpha>2$; weakly long-range for $1<\alpha<2$ without a clear light cone but with a finite propagation speed of excitations; and fully non-local for $\alpha<1$ with instantaneous transmission of correlations. This last regime breaks generalized Lieb--Robinson bounds. Numerical calculation of the entanglement spectrum demonstrates that the usual picture of propagating quasi-particles remains valid for long-range interactions. This allows an intuitive interpretation in terms of qualitative changes to the spin-wave dispersion, leading to diverging quasi-particle velocities in the long-range regime. Our results may be tested in state-of-the-art trapped-ion experiments.

arXiv:1305.0409
Detecting Topological Entanglement Entropy in a Lattice of Quantum Harmonic Oscillators
Tommaso F. Demarie, Trond Linjordet, Nicolas C. Menicucci, Gavin K. Brennen

The Kitaev surface-code model is the most studied example of a topologically ordered phase and typically involves four-spin interactions on a two-dimensional surface. A universal signature of this phase is topological entanglement entropy (TEE), but due to low signal to noise, it is extremely difficult to observe in these systems, and one usually resorts to measuring anyonic statistics of excitations or non-local string operators to reveal the order. We describe a continuous-variable analog to the surface code using quantum harmonic oscillators on a two-dimensional lattice, which has the distinctive property of needing only two-body nearest-neighbor interactions for its creation. Though such a model is gapless, the ground state can be simply prepared by measurements on a finitely squeezed and gapped two-dimensional cluster state, which does not have topological order. Asymptotically, the TEE grows linearly with the squeezing parameter, and we show that its mixed-state generalization, the topological mutual information, is robust to some forms of state preparation error and can be detected simply using single-mode quadrature measurements. Finally, we discuss scalable implementation of these methods using optical and circuit-QED technology.

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Majorana Fermions from Landau Quantization in a Superconductor and Topological-Insulator Hybrid Structure
Rakesh P. Tiwari, U. Zülicke, and C. Bruder

Phys. Rev. A 87, 042340 (2013)
Dynamic generation of topologically protected self-correcting quantum memory
Daniel Becker, Tetsufumi Tanamoto, Adrian Hutter, Fabio L. Pedrocchi, and Daniel Loss