CMT Journal club, 6.10.2015, Marcel Serina

1. **Exchange-interaction of two spin qubits mediated by a superconductor**

   F. Hassler, G. Catelani, H. Bluhm; *arXiv:1509.06380*

2. **Two-Dimensional Superconductor with a Giant Rashba Effect: One-Atom-Layer Tl-Pb Compound on Si(111)**

   A.V. Matetskiy, S. Ichinokura, L.V. Bondarenko, A.Y. Tupchaya, D.V. Gruznev, A.V. Zotov, A.A. Saranin, R. Hobara, A. Takayama, S. Hasegawa; *PRL 115, 147003*

   A one-atom-layer compound made of one monolayer of Tl and one-third monolayer of Pb on a Si(111) surface having 33 periodicity was found to exhibit a giant Rashba-type spin splitting of metallic surface-state bands together with two-dimensional superconducting transport properties. Temperature-dependent angle-resolved photoelectron spectroscopy revealed an enhanced electron-phonon coupling for one of the spin-split bands. In situ micro-four-point-probe conductivity measurements with and without magnetic field demonstrated that the (Tl, Pb)/Si(111) system transformed into the superconducting state at 2.25 K, followed by the Berezinskii-Kosterlitz-Thouless mechanism. The 2D Tl-Pb compound on Si(111) is believed to be the prototypical object for prospective studies of intriguing properties of the superconducting 2D system with lifted spin degeneracy, bearing in mind that its composition, atomic and electron band structures, and spin texture are already well established.

3. **Quantum Oscillations without a Fermi Surface and the Anomalous de Haas–van Alphen Effect**

   J. Knolle, N. R. Cooper; *PRL 115, 146401*

   The de Haas–van Alphen effect (dHvAE), describing oscillations of the magnetization as a function of magnetic field, is commonly assumed to be a definite sign for the presence of a Fermi surface (FS). Indeed, the effect forms the basis of a well-established experimental procedure for accurately measuring FS topology and geometry of metallic systems, with parameters commonly extracted by fitting to the Lifshitz-Kosevich (LK) theory based on Fermi liquid theory. Here we show that, in contrast to this canonical situation, there can be quantum oscillations even for band insulators of certain types. We provide simple analytic formulas describing the temperature dependence of the quantum oscillations in this setting, showing strong deviations from LK theory. We draw connections to recent experiments and discuss how our results can be used in future experiments to accurately determine, e.g., hybridization gaps in heavy-fermion systems.

4. **Simple operation sequences to couple and interchange quantum information between spin qubits of different kinds**

   S. Mehl, D. P. DiVincenzo; *PRB 92, 115448*

   Efficient operation sequences to couple and interchange quantum information between quantum dot spin qubits of different kinds are derived using exchange interactions. In the qubit encoding of a single-spin qubit, a singlet-triplet qubit, and an exchange-only (triple-dot) qubit, some of the single-qubit interactions remain on during the entangling operation; this greatly simplifies the operation sequences that construct entangling operations. In the ideal setup, the gate operations use the intraqubit exchange interactions only once, and entangling operations with gate times similar to typical single-qubit operations are constructed. The limitations of the entangling sequences are discussed, and it is shown how quantum information can be converted between different kinds of quantum dot spin qubits. These gate sequences are useful for large-scale quantum computation because they show that different kinds of coded spin qubits can be combined easily, permitting the favorable physical properties of each to be employed.

5. **Fractional topological phases in three-dimensional coupled-wire systems**

   T. Meng; *PRB 92, 115152*

   It is shown that three-dimensional systems of coupled quantum wires support fractional topological phases composed of closed loops and open planes of two-dimensional fractional quantum Hall subsystems. These phases have topologically protected edge states, and are separated by exotic quantum phase transitions corresponding to a rearrangement of fractional quantum Hall edge modes. Some support for the existence of an extended exotic critical phase separating the bulk gapped fractional topological phases is given. Without electron-electron interactions, similar but unfractionalized bulk gapped phases based on coupled integer quantum Hall states exist. They are separated by an extended critical Weyl semimetal phase.

6. **Majorana zero-energy modes and spin current evolution in mesoscopic superconducting loop systems with spin-orbit interaction**

   Guo-Qiao Zha, L. Covaci, F. M. Peeters, Shi-Ping Zhou; *PRB 92, 094516*

   The Majorana zero modes and persistent spin current in mesoscopic d-wave-superconducting loops with spin-orbit (SO) interaction are investigated by numerically solving the spin-generalized Bogoliubov–de Gennes equations self-consistently. For some appropriate strength of the SO coupling, Majorana zero-energy states and sharp jumps of the spin-polarized currents can be observed when the highest energy levels cross the Fermi energy in the spectrum, leading to spin currents with opposite chirality flowing near the inner and outer edges of the sample. When the threaded magnetic flux turns on, four flux-dependent patterns of the persistent spin current with step-like features show up, accompanied by Majorana edge modes at flux values where the energy gap closes. Moreover, the Majorana zero mode is highly influenced by the direction of the Zeeman field. A finite in-plane field can lead to the gap opening since the inversion symmetry is broken. Remarkably, multiple Majorana zero-energy states occur in the presence of an out-of-plane field h_z, and the number of steps in the spin current evolution can be effectively tuned by the field strength due to the shift of Majorana zero modes. Finally, when the loop sample contains surface indentation defects, zero-energy modes can always show up in the presence of an appropriate h_z. Interestingly, multiple Majorana states may be present in the system with a corner defect even if h_z=0.

7. **Physical Implementation of a Majorana Fermion Surface Code for Fault-Tolerant Quantum Computation**

   S. Vijay, L. Fu; *arXiv:1509.08134*

   We propose a physical realization of a commuting Hamiltonian of interacting Majorana fermions realizing Z_2 topological order, using an array of Josephson-coupled topological superconductor islands. The required multi-body interaction Hamiltonian is naturally generated by a combination of charging energy induced quantum phase-slips on the superconducting islands and electron tunneling. Our setup improves on a recent proposal for implementing a Majorana fermion surface code, a 'hybrid' approach to fault-tolerant quantum computation that combines (1) the engineering of a stabilizer Hamiltonian with a topologically ordered ground state with (2) projective stabilizer measurements to implement error correction and a universal set of logical gates. Our hybrid strategy has advantages over the traditional surface code architecture in error suppression and single-step stabilizer measurements, and is widely applicable to implementing stabilizer codes for quantum computation.

8. **Thermodynamics and efficiency of an autonomous on-chip Maxwell's demon**

   A. Kutvonen, J. Koski, T. Ala-Nissilä; *arXiv:1509.08288*

   In his famous letter in 1870, Maxwell describes how Joule's law can be violated "only by the intelligent action of a mere guiding agent", later coined as Maxwell's demon by Lord Kelvin. In this letter we study thermodynamics of information using an experimentally feasible Maxwell's demon setup based a single electron transistor capacitively coupled to a single electron box, where both the system and the Demon can be clearly identified. Such an engineered on-chip Demon measures and performes feedback on the system, which can be observed as cooling whose efficiency can be adjusted. We present a detailed analysis of the system and the Demon, including the second law of thermodynamics for bare and coarse grained entropy production and the flow of information as well as efficiency of information production and utilization. Our results demonstrate how information thermodynamics can be used to improve functionality of modern nanoscale devices.

9. **Trivial and inverted Dirac bands, and emergence of quantum spin Hall states in graphene on transition-metal dichalcogenides**

   M. Gmitra, D. Kochan, P. Högl, J. Fabian; *arXiv:1510.00166*

   Proximity orbital and spin-orbital effects of graphene on monolayer transition-metal dichalcogenides (TMDCs) are investigated from first-principles. The Dirac band structure of graphene is found to lie within the semiconducting gap of TMDCs for sulfides and selenides, while it merges with the valence band for tellurides. In the former case the proximity-induced staggered potential gaps and spin-orbit couplings (all on the meV scale) of the Dirac electrons are established by fitting to a phenomenological effective Hamiltonian. While graphene on MoS_2, $MoSe_2$, and WS_2 has a topologically trivial band structure, graphene on WSe_2 exhibits inverted bands. Using a realistic tight-binding model we find topologically protected helical edge states for graphene zigzag nanoribbons on WSe_2, demonstrating the quantum spin Hall effect. This model also features "half-topological states", which are protected against time-reversal disorder on one edge only.