CMT Journal Club by Kouki Nakata on 27 Oct. 2015

✓ Generalized Bloch theorem and chiral transport phenomena

Naoki Yamamoto

Phys. Rev. D **92**, 085011(2015)

Bloch theorem states the impossibility of persistent electric currents in the ground state of nonrelativistic fermion systems. We extend this theorem to generic systems based on the gauged particle number symmetry and study its consequences on the example of chiral transport phenomena. We show that the chiral magnetic effect can be understood as a generalization of the Bloch theorem to a nonequilibrium steady state, similarly to the integer quantum Hall effect. On the other hand, persistent axial currents are not prohibited by the Bloch theorem and they can be regarded as Pauli paramagnetism of relativistic matter. An application of the generalized Bloch theorem to quantum time crystals is also discussed.

✓ The Schrieffer-Wolff Transformation for Periodically-Driven Systems: Strongly-Correlated Systems with Artificial Gauge-Fields

Marin Bukov, Michael Kolodrubetz, Anatoli Polkovnikov

arXiv:1510.02744

We generalise the Schrieffer-Wolff transformation to periodically-driven systems using Floquet theory. The method is applied to the periodically-driven, strongly-interacting Fermi-Hubbard model, for which we identify two regimes resulting in different effective low-energy Hamiltonians. In the non-resonant regime, we realize an interacting spin model coupled to a static gauge field with a non-zero flux per plaquette. In the resonant regime, where the driving frequency is equal to the Hubbard interaction, we derive an effective Hamiltonian featuring doublon association and dissociation processes. The ground state of this Hamiltonian undergoes a phase transition between an ordered phase and a gapless Luttinger liquid phase. One can tune the system between different phases by changing the strength of the driving potential.

✓ Violation of the Wiedemann-Franz Law in Hydrodynamic Electron Liquids

Alessandro Principi and Giovanni Vignale

Phys. Rev. Lett. 115, 056603 – Published 31 July 2015

The Wiedemann-Franz law, connecting the electronic thermal conductivity to the electrical conductivity of a disordered metal, is generally found to be well satisfied even when electron-electron (e−e) interactions are strong. In ultraclean conductors in the hydrodynamic regime, however, large deviations from the standard form of the law are expected, due to the fact that e−e interactions affect the two conductivities in radically different ways. Thus, the standard Wiedemann-Franz ratio between the thermal and the electric conductivity is reduced by a factor $1+\tau/\tau_{eeth}$, where $1/\tau$ is the momentum relaxation rate and τ_{eeth} is the relaxation time of the thermal current due to e−e collisions. Here we study the density and temperature dependence of $1/\tau_{eeth}$ of two-dimensional electron liquids. We show that at low temperature

1/τeeth is 8/5 of the quasiparticle decay rate; remarkably, the same result is found in doped graphene and in conventional electron liquids in parabolic bands.

✓ Scaling laws for nonlinear electromagnetic responses of Weyl fermion

Takahiro Morimoto, Naoto Nagaosa

arXiv:1510.02185

We theoretically propose that the Weyl fermion in two-dimensions shows the giant nonlinear responses to electromagnetic fields in terahertz region. A scaling form is obtained for the current and magnetization as functions of the normalized electromagnetic fields E/Eω and B/Bω, where the characteristic electric (magnetic) field Eω (Bω) depends on the frequency ω as ℏω2/evF (ℏω2/ev2F), and is typically of the order of 800 V/cm (8 mT) in the terahertz region. Applications of the present theory to graphene and surface state of a topological insulator are discussed.

✓ Weyl Mott Insulator

Takahiro Morimoto, Naoto Nagaosa

arXiv:1508.03203

Relativistic Weyl fermion (WF) often appears in the band structure of three dimensional magnetic materials and acts as a source or sink of the Berry curvature, i.e., the (anti-)monopole. It has been believed that the WFs are stable due to their topological indices except when two Weyl fermions of opposite chiralities annihilate pairwise. Here, we theoretically show for a model including the electron-electron interaction that the Mott gap opens for each WF without violating the topological stability, leading to a topological Mott insulator dubbed {¥it Weyl Mott insulator } (WMI). This WMI is characterized by several novel features such as (i) energy gaps in the angle-resolved photo-emission spectroscopy (ARPES) and the optical conductivity, (ii) the nonvanishing Hall conductance, and (iii) the Fermi arc on the surface with the penetration depth diverging as approaching to the momentum at which the Weyl point is projected. Experimental detection of the WMI by distinguishing from conventional Mott insulators is discussed with possible relevance to pyrochlore iridates.

✓ Quantum Information Meets Quantum Matter -- From Quantum Entanglement to Topological Phase in Many-Body Systems

Bei Zeng, Xie Chen, Duan-Lu Zhou, Xiao-Gang Wen

arXiv:1508.02595

This is the draft version of a textbook, which aims to introduce the quantum information science viewpoints on condensed matter physics to graduate students in physics (or interested researchers). We keep the writing in a self-consistent way, requiring minimum background in quantum information science. Basic knowledge in undergraduate quantum physics and condensed matter physics is assumed. We start slowly from the basic ideas in quantum information theory, but wish to eventually bring the readers to the frontiers of research in condensed matter physics, including topological phases of matter, tensor networks, and symmetry-protected topological phases.

✓ Opportunities at the Frontiers of Spintronics

Axel Hoffmann and Sam D. Bader

Phys. Rev. Applied **4**, 047001 (2015)

The field of spintronics, or magnetic electronics, is maturing and giving rise to new subfields. These new directions involve the study of collective spin excitations and couplings of the spin system to additional degrees of freedom of a material, as well as metastable phenomena due to perturbations that drive the system far from equilibrium. The interactions lead to possibilities for future applications within the realm of energy-efficient information technologies. Examples discussed herein include research opportunities associated with (i) various spin-orbit couplings, such as spin Hall effects, (ii) couplings to the thermal bath of a system, such as in spin Seebeck effects, (iii) spin-spin couplings, such as via induced and interacting magnon excitations, and (iv) spin-photon couplings, such as in ultrafast magnetization switching due to coherent photon pulses. These four basic frontier areas of research are giving rise to new applied disciplines known as spin orbitronics, spin caloritronics, magnonics, and spin photonics, respectively. These topics are highlighted in order to stimulate interest in the new directions that spintronics research is taking and to identify open issues to pursue.

✓ Rayleigh-Jeans condensation of pumped magnons in thin film ferromagnets

Andreas Rückriegel, Peter Kopietz

arXiv:1507.01717

We show that the formation of a magnon condensate in thin ferromagnetic films can be explained within the framework of a classical stochastic non-Markovian Landau-Lifshitz-Gilbert equation where the properties of the random magnetic field and the dissipation are determined by the underlying phonon dynamics. We have numerically solved this equation for a tangentially magnetized yttrium-iron garnet film in the presence of a parallel parametric pumping field. We obtain a complete description of all stages the nonequilibrium time evolution of the magnon gas which is in excellent agreement with experiments. Our calculation proves that the experimentally observed condensation of magnons in yttrium-iron garnet at room temperature is a purely classical phenomenon which should be called Rayleigh-Jeans rather than Bose-Einstein condensation.

✓ Quantum magnonics: magnon meets superconducting qubit

Yutaka Tabuchi, et al., and Yasunobu Nakamura

arXiv:1508.05290

The techniques of microwave quantum optics are applied to collective spin excitations in a macroscopic sphere of ferromagnetic insulator. We demonstrate, in the single-magnon limit, strong coupling between a magnetostatic mode in the sphere and a microwave cavity mode. Moreover, we introduce a superconducting qubit in the cavity and couple the qubit with the magnon excitation via the virtual photon excitation. We observe the magnon-vacuum-induced Rabi splitting. The hybrid quantum system enables generation and characterization of non-classical quantum states of magnons.

✓ **Magnon spintronics**

A. V. Chumak, V. I. Vasyuchka, A. A. Serga & B. Hillebrands

Nat. Phys. **11**, 453 (2015)

Magnon spintronics is the field of spintronics concerned with structures, devices and circuits that use spin currents carried by magnons. Magnons are the quanta of spin waves: the dynamic eigen-excitations of a magnetically ordered body. Analogous to electric currents, magnon-based currents can be used to carry, transport and process information. The use of magnons allows the implementation of novel wave-based computing technologies free from the drawbacks inherent to modern electronics, such as dissipation of energy due to Ohmic losses. Logic circuits based on wave interference and nonlinear wave interaction can be designed with much smaller footprints compared with conventional electron-based logic circuits. In this review, after an introduction into the basic properties of magnons and their handling, we discuss the inter-conversion between magnon currents and electron-carried spin and charge currents; and concepts and experimental studies of magnon-based computing circuits.