Abstract

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Magnetization pumping and dynamics in a Dzyaloshinskii-Moriya magnet

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We formulate a phenomenological description of Dzyaloshinskii-Moriya magnets where the single-domain magnetic dynamics experiences magnon current-induced torques (an analog of spin-orbit torques) and leads to magnon-motive forces. We first construct a phenomenological theory based on irreversible thermodynamics, taking into account the symmetries of the system [1]. Furthermore, we confirm that these effects originate from Dzyaloshinskii-Moriya interactions from the analysis based on the stochastic Landau-Lifshitz-Gilbert equation. Our phenomenological results generalize to a general form of Dzyaloshinskii-Moriya interactions and to other systems, such as pyrochlore crystals and chiral magnets. We discuss how the magnonic analog of the spin-orbit torque can influence the motion of magnetic solitons, e.g. skyrmions. Possible applications include spin current generation, magnetization reversal and magnonic cooling (Fig.1).

Figure 1: Single-domain magnetization dynamics induced by microwave field pumps magnon and spin currents by virtue of Dzyaloshinskii-Moriya interactions. This can develop a temperature gradient along the sample. Alternatively, a temperature gradient can result in magnon current and torque on uniform magnetization according to the Onsager reciprocity principle.

References
Thermal vector potential theory of transport induced by temperature gradient

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A microscopic formalism to calculate thermal transport coefficients is presented based on a thermal vector potential, whose time-derivative is related to a thermal force. The formalism is free from unphysical divergences reported to arise when Luttinger's formalism is applied naively, because the equilibrium (diamagnetic) currents are treated consistently. The mathematical structure for thermal transport coefficients are shown to be identical with the electric ones if the electric charge is replaced by energy. The results indicates that the thermal vector potential couples to energy current via the minimal coupling.

References
Spin Transport and Relaxation Mechanism in Disordered Organic Film

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The organic semiconductors (OSC s) are promising candidates for long-distance spin current transport. However, most of the OSCs have a strongly disordered structure, so that the spin current transport and relaxation properties of OSCs have not been fully understood compared with the usual band-like metallic materials. To resolve this problem, we have performed systematic studies of spin current transport and relaxation mechanism in a conducting polymer PEDOT: PSS, in which the PEDOT molecule is highly doped with PSS. In this study, we have carried out spin pumping, electron paramagnetic resonance, and charge transport experiments. The spin pumping experiment allows us to estimate the spin diffusion length (SDL), and the other two experiments were used to determine the spin lifetime and spin diffusion constant, respectively. The experimentally obtained spin lifetime is much shorter than that of non-doped OSCs [1]. This means that the spin relaxation is considerably enhanced in highly doped PEDOT molecules of which nano-scale grains act as trapping centers of hopping transport. Moreover, we have found a longer SDL than the average hopping length, indicating that the spins are almost conserved during the hopping process. These facts suggest the spin relaxation mainly occurs in the nano-grains of PEDOT molecules.

Figure 1: (a) Schematic of the sample structure used for the spin pumping experiment. (b) Magnetic field dependence of the voltage signal in Py/PEDOT:PSS/Pt trilayer for \( \phi = 0^\circ, 90^\circ, \) and \( 180^\circ \).

References
Failure of thermalization and the Generalized Gibbs Ensemble Hypothesis in strongly interacting quantum systems

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Recently, mostly triggered by the spectacular progress of experiments on cold atomic systems, considerable attention has been devoted to the equilibration of closed interacting quantum systems. I will first review some of the most basic concepts of thermalization in closed quantum systems, such as the eigenstate thermalization hypothesis (ETH) and the generalized Gibbs ensemble (GGE) hypothesis. I will then present numerical as well as analytical results for the non-equilibrium time evolution of the spin-$1/2$ anisotropic Heisenberg spin chain, with a choice of dimer product and Néel states as initial states [1]. We find for various short-ranged spin correlators that they deviate significantly from predictions based on the generalized Gibbs ensemble hypotheses in the long-time limit. Computing the asymptotic spin correlators within the recently proposed quench-action formalism, however, excellent agreement is found with the numerical data. These results lead us to the conclusion that the GGE cannot give a complete description of the equilibration of a closed quantum system even for local observables, while the quench-action formalism captures correctly the steady state in this case.

In the second half of my talk, I will discuss the semiclassical theory of quantum quench in the sine-Gordon model [2]. I will show that using the asymptotic S-matrix of soliton-soliton scattering, one can determine the correlation function of vertex operators analytically within the semiclassical approximation. Surprisingly, these correlations do not equilibrate, and the system exhibits a memory of the initial state. Moreover, correlations display a diffusive behavior.

References
Negative Coulomb drag in coupled quantum wires

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Coulomb drag is an induction phenomenon of the electric current by another capacitively coupled electric current, purely originating from the long-range nature of the Coulomb interaction. In coupled quantum wires (Fig. 1), positive Coulomb drag of parallel drive and drag currents was theoretically predicted. The positive drag is easily understood in view of the long-range scattering of electrons over the wires. That is, in order to avoid costing the interwire Coulomb potential energy generated by the drive current, the electric current is induced on the drag wire.

In 2006, Yamamoto et al. experimentally observed negative Coulomb drag of antiparallel drive and drag currents [1]. The negative drag was and is highly nontrivial in the naive picture of the long-range scattering of electrons. Initially the Wigner crystallization on the drag wire was deemed responsible for the negative drag because the negative drag was first found in the extremely low electron density region [1]. However, it was later reported that increase of the voltage of the drive and the drag wires caused alternately the positive and the negative drags [2,3]. Such an alternation in the direction of the drag current is unlikely to be explained by the Wigner crystallization on the single wire. Therefore, despite the existence of the fascinating experiments, the negative drag is yet to be clearly understood.

In this talk, we will discuss about our recent theory that explains the negative drag in a minimal setup [4]. The mechanism that we propose is simple. When the electron density of the drive wire is commensurate with the hole density of the drag wire, the particle-hole pairing over the wires occurs, resulting in the positive drag of the hole current, that is, the negative drag of the particle current.

Our simple model leads to the positive and the negative drags on equal footing. On the other hand, the negative drag occurs less easily in experiments than the positive drag does. This inequality originates from a difficulty in achieving the commensurability condition. Here the long-range nature of the Coulomb interaction plays the decisive role. We will show how the long-range Coulomb interaction conquers the difficulty and leads to the negative drag in the actual experiments.

References

Figure 1: Coupled quantum wires
Kondo signature in heat transport via a local two-state system

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Heat and electric transport have several similarities as well as dissimilarities. Fourier's law in heat transport corresponds to Ohm's law in electric transport, and these laws are commonly categorized as diffusive transport. Ballistic transport leads to the quantization of conductance in electric as well as heat transport. The conductance quantum was measured in mesoscopic electric conduction in 1988 [1], and much later, the version of heat transport was also measured [2]. Recently, the concept of thermal diode has also been discussed, and an experiment has been conducted for demonstrating this [3]. Recent progress in transport studies strongly indicates that heat transport analogue exists for many categories of electric transport.

In this talk, we present theoretical study of the Kondo effect in heat transport via a local two-state system [4]. This system is described by the spin-boson Hamiltonian with Ohmic dissipation, which can be mapped onto the Kondo model with anisotropic exchange coupling. We derive the exact formula of thermal conductance, and evaluate it by the Monte Carlo method. Thermal conductance has a scaling form indicating the universal behavior characteristic of the Kondo effect. Below the Kondo temperature, conductance follows the universal temperature dependence proportional to $T^3$, showing nontrivial enhancement. This is a manifestation of strong correlation between system and reservoirs, which is analogous to the Kondo effect in electric transport. We also discuss coupling dependence of heat conductance.

References
Quantum pumping in mesoscopic systems
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Linear response theory often starts discussing the effect of time-dependent perturbations with frequency and then takes the zero-frequency limit to obtain intrinsic properties of many-body system, which is in principle equivalent to fluctuation-dissipation theorem. When we modulate more than one parameters, there appears a new time-dependent transport, called pumped transport.

Recently, a lot of interests are focused to the lowest-order non-adiabatic correction to the pumped transport in a static (adiabatic) limit, possibly because this can be a controlled system that can tackle the problem of non-equilibrium statistical physics. Both in classical and quantum setups, this contribution had shown to have a topological character, being expressed by a surface integral of a “Berry” curvature. In this presentation, I show our approach based on generalized quantum master equation [1] and possible extension to more non-adiabatic regimes. Finally, I explain our quantum transport results in quantum dot system coupled two leads, with time-dependent modulation of a tunneling phase and magnetic fields (Fig.1) [1, 2]. Part of this work is supported by JSPS KAKENHI (26247051).

References

Figure 1: quantum dot coupled to two reservoirs with time-dependent modulating parameters.
Luttinger liquid universality after a quantum quench

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We provide strong evidence that the relaxation dynamics of one-dimensional, metallic Fermi systems resulting out of an abrupt amplitude change of the two-particle interaction has aspects which are universal in the Luttinger liquid sense: The leading long-time behavior of certain observables is described by universal functions of the equilibrium Luttinger liquid parameter and the renormalized velocity. A similar type of universality is found for static as well as dynamical correlation functions computed in the steady state reached after the quantum quench. We analytically derive those functions for the Tomonaga-Luttinger model and verify our hypothesis of universality by considering spinless lattice fermions within the framework of the density matrix renormalization group.

References
Some new analytical and numerical approaches to an SU($N$) impurity Anderson model

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We discuss some exact analytical and numerical results obtained for the $N$-orbital Anderson impurity. Specifically, we use several different approaches to study transport and dynamical properties of quantum dots over a wide range of the energy scales:

i) The $1/(N−1)$ expansion for low-energy scale [1,2].

ii) Wilson numerical renormalization group (NRG) also for low-energy scale [3,4].

iii) Finite-$U$ non-crossing approximation (NCA) for intermediate-energy scale [5].

iv) Thermal field theory with a Liouville-Fock space for high-energy scale [6].

The $1/(N−1)$ expansion is a large $N$ approach based on the perturbation theory in $U$, and uses a scaling that keeps $(N−1)U$ a constant in the limit of $N→∞$. At the zeroth order, it provides the Hartree-Fock (HF) approximation. To leading order in $1/(N−1)$ it describes the Hartree-Fock random phase approximation (HF-RPA). Then, the next leading contributions of order $1/(N−1)^2$ terms capture quantum fluctuations beyond the HF-RPA. This approach correctly describes the low-energy Fermi-liquid properties, and is complementary to the NCA which is based on a power series expansion in the hybridization matrix element $V$ with a scaling that keeps $NV^2$ finite for $N→∞$.

The thermal-field-theoretical approach is equivalent to the Keldysh formalism. However, instead of the Keldysh contour, it uses a doubled Hilbert space that is called the Liouville-Fock space to describe the time evolution and the statistical density matrix. With this approach, exact asymptotic form of the interacting Green’s function has been obtained in the high-temperature limit of equilibrium and also in the high-bias limit of a nonequilibrium steady state.

References
The quantum transfer between two environments, especially the pumping phenomena of quantum particles, has been attracted intensive attentions to scientists as well as engineers. In this talk, we focus on the control of quantum heat flux between two environments by modulating environmental temperatures in cyclic and out-of-phase way. This issue has been mostly studied in the adiabatic regime where the relevant quantum system can immediately follow the external driving. In the conventional studies, the feature of quantum pumping is represented with the geometrical phase owing to the formalism of the full counting statistics. In this talk, we report a formula of quantum transfer for an anharmonic junction system with using the full counting statistics, which is generalized to include the nonadiabatic effect. Figure 1 shows the anharmonic junction system which consists of two bosonic environments and a two-level system. In the formulation, a newly added term appears to describe the non-adiabatic effect. It also shows that the quantum transfer depends on the initial condition of the anharmonic junction just before the modulation, as well as the characteristic environmental parameters such as interaction strength and cut-off frequency of spectral density. This means that we can obtain the optimum quantum flux by setting the initial condition of the anharmonic junction.

Reference
In this talk I will discuss the topological Kondo effect, which is predicted to be observable in mesoscopic superconducting hybrid devices with more than one pair of Majorana bound states. The Majorana bound states then non-locally encode an effective "spin" degree of freedom which is exchange-coupled to external (normal-conducting) leads. In a setting where Coulomb interactions are pronounced, a novel "topological" Kondo effect characterized by the orthogonal symmetry group emerges. Transport experiments in this system should be able to detect robust non-Fermi liquid behavior of multi-channel Kondo type, both in the conductance and the shot noise properties. I will also describe how to probe the competition between resonant Andreev scattering and topological Kondo physics.
Quantum transport phenomena in 3D topological insulator thin films

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The three-dimensional (3D) topological insulator (TI) is a novel state of matter as characterized by two-dimensional (2D) metallic Dirac states on its surface. Quantum transport in 3D-TI has recently been attracting much attention such as half integer quantum Hall effect (QHE) and quantum anomalous Hall effect (QAHE) in terms of breaking time reversal symmetry on surface Dirac states. These quantized phenomena in 3D TIs have been extensively studied in Bi-based chalcogenides such as Bi\textsubscript{2}Se\textsubscript{3}, Bi\textsubscript{2}Te\textsubscript{3}, Sb\textsubscript{2}Te\textsubscript{3} and their combined/mixed compounds in both bulk and thin films form [1]. Here, we report the realization of the QHE and QAHE on the surface Dirac states in (Bi\textsubscript{1-x}Sb\textsubscript{x})\textsubscript{2}Te\textsubscript{3} films (x = 0.84 and 0.88) and its Cr-doped compound Cr\textsubscript{y}(Bi\textsubscript{1-y}Sb\textsubscript{y})\textsubscript{2}Te\textsubscript{3} (x = 0.2, y = 0.78), respectively. In the pristine (Bi\textsubscript{1-x}Sb\textsubscript{x})\textsubscript{2}Te\textsubscript{3} with electrostatic gate-tuning of the Fermi level in the bulk band gap under magnetic field, the QH states of filling factor $\nu = \pm 1$ are resolved with quantized Hall resistance of $R_{yx} = \pm h/e^2$ and zero longitudinal resistance (Fig. 1), owing to the formation of chiral edge modes at top/bottom surface Dirac states [2]. In the magnetically doped compound, quantization of $R_{yx} = \pm h/e^2$ and transition with magnetization reversal are observed [3]. In the presentation, detail transport features of both quantization behaviors will be discussed. These observations of the quantization of Hall effects in 3D TI films may pave a way toward TI-based electronics.

References

Mesoscopic topological insulator
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Topological insulator (TI) exhibits a protected surface state, which is gapless in its
dispersion, realizing an ideal auxiliary 2D system for conducting electrons. Transport
characteristics of such surface states are susceptible to nanoscale formation of the
sample; here we highlight the surface states of TI nanofilms [1], nanowires [2] and
nanoparticles [3]. A more elaborate example of such a nanostructure is a patterned
surface intended for realizing a topologically protected nanocircuit [4]. We study how
the effects of finite size (associated with nanoscale formation of the sample) and of
disorder determine and vary the transport characteristics of TI surface states.

As a specific example I will discuss in some detail the case of a weak TI nanofilm,
which exhibits quasi-1D helical modes circulating around the periphery of the film. We
focus on an even-odd feature in its transport characteristics [(de)localization properties] with respect to the number of stacked layers [1], and cast a mesoscopic viewpoint on the
physics of topological insulators.