QTNS2018

Abstract (poster)

November 7-10, 2018

Program

Wednesday 7		Thursday 8		Friday 9		Saturday 10	
		9:00-9:30	Kishine, Junichiro	9:00-9:30	Nakata, Yosuke	10:00-10:30	Discussion session
Invited talks		9:30-9:50	Kato, Takeo	9:30-9:50	Aono, Tomosuke	10:30-11:00	Coffee
		9:50-10:30	Coffee	9:50-10:30	Coffee	11:00-12:00	Discussion session
		10:30-11:30	Entin-Wohlman, Ora	10:30-11:00	Otsuka, Tomohiro		
11:30-12:50	Registration	11:30–12:00	Yamamoto, Kaoru	11:00-11:30	Shevchenko, Sergey		
12:50-13:00	Opening	12:00-13:00	Hatano, Naomichi	11:30-11:50	Nakagawa, Masaya		
13:00-14:00	Moskalet, Michael	13:00-14:00	Lunch	11:50-12:50	Kwek, Leong-Chuan		
14:00-15:00	Aharony, Ammon	14:00-15:00	Sagawa, Takahiro	12:50-14:00	Lunch		
15:00-15:30	Coffee	15:00-15:20	Shirai, Tatsuhiko	14:00-15:00	Vacchini,Bassano		
15:30-16:30	Tokura, Yasuhiro	15:20-15:40	Mori, Takashi	15:00-15:30	Bastidas, Victor Manuel		
16:30-17:30	Katsumoto, Shingo	15:40-16:10	Coffee	15:30-16:00	Hashimoto, Kazunari		
17:30-19:00	Welcome reception	16:10-16:30	Kato, Akihito	16:00-16:15	Coffee		
		16:30-16:50	Phuc, Nguyen Thanh	16:15-17:15	Esposito, Massimiliano		
		16:50-18:00	Poster	17:15-17:45	Uchiyama Chikako		
				17:45-18:00	Summary (Aharony, A)		
				18:00-20:00	Banquet		

P1

Quantum dissipative dynamics in open systems coupled to hierarchical environments

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Quantum dissipation is an elementary process that determines electronic dynamics in a quantum nanosystem. The electronic system confined in a nanosystem is coupled to a heat bath with infinite degrees of freedom via a local nanoenvironment with a finite degree of freedom. For example, in the scanning near-field optical microscopy, a nanoprobe is interposed between a nanomaterial and a macroscopic measurement system. In this study, we clarify the effect of such a hierarchical structure of the environment on the dissipative dynamics in the nanosystem.

We consider a model, as shown in Fig. 1(a). The nanosystem confined in the nanostructure is considered to be a two-level system. The nanoenvironment locally coupled to the nanosystem is considered to be a twolevel system resonant to the nanosystem. The nonequilibrium behaviour of the nanoenvironment modifies the quantum dynamics in the nanosystem [1, 2]. In this model, quantum dissipation of the nanosystem is treated theoretically as follows. First, the whole of the nanosystyem and nanoenvironment is exactly treated as a single coupled system, whose coupling rate is g. The energy of the whole coupled system is dissipated to a heat bath with a dissipation rate γ, whose process is described by the Lindblad equation. Next, by using the time-dependent projection operators [3, 4], the quantum dissipative dynamics of only the nanosystem, which includes effects of the hierarchical environments consisting of the nanoenvironment and heat bath, is derived.

Figure 1(b) shows the dissipative dynamics of population in the nanosystem coupled to the hierarchical environments in cases of γ =0 and γ =10. In the initial state, the populations in the nanosystem and nanoenvironment are 1 and 0.5, respectively. In the case of γ = 0, the nanosystem is coupled to only the nanoenvironment. The population decreases monotonically and converges to 0.5, which shows the energy dissipation from the nanosystem to nanoenvironment. In the case of γ =10, the nanosystem is coupled to the hierarchical environments. The population decreases below 0.5 and then converges to 0.5 from lower side with nutation, which shows that the dissipation to the heat bath induces the Rabi oscillation between the nanosystem and nanoenvironment. Thus, it was found that the hierarchical structure of the environment has the important effect on the dissipative dynamics of the nanosystem. Furthermore, we will investigate the effect of the nonequilibrium nature of the nanoenvironment and propose a way to control dissipation of the nanosystem by the nanoenvironment.

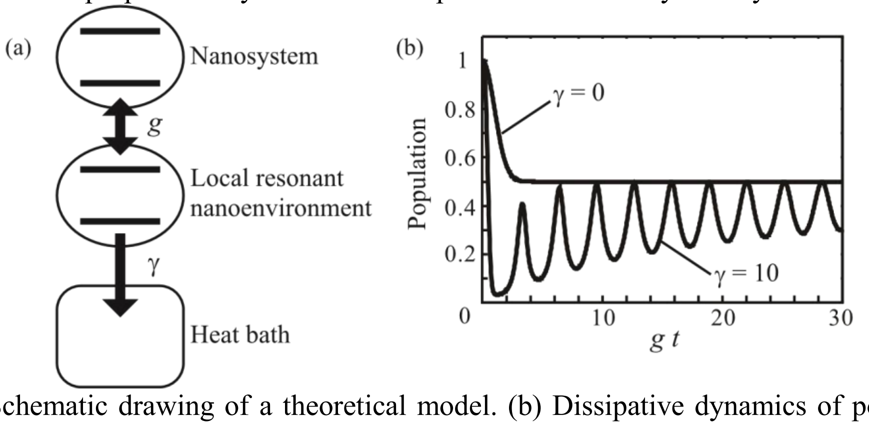

Figure 1: (a) Schematic drawing of a theoretical model. (b) Dissipative dynamics of population in a nanosystem in cases of γ =0 and γ =10.

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P2

Laser-induced DC spin current in Mott insulators

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In this poster, we report our theoretical work on the DC spin current induced by laser irradiation in Mott insulators with a noncentrosymmetric lattice structure [1]. To describe the low-energy spin dynamics in this system, we have started from the Hubbard model in an AC electric field and derived a Heisenberg model where the exchange interaction oscillates in time by using the Floquet theory. The time-periodic Heisenberg model describes the exchange process in the extended Floquet Hilbert space [see Fig. 1(a)], and the exchange interaction is given by

$$J_{\mathrm{eff}}^{\mathrm{ex}}(t) = \sum_{m,n} (-1)^m \frac{4t_0^2 J_{n+m}(F_0) J_{n-m}(F_0)}{U-(n+m)\Omega} \cos(2m\Omega t),$$

where t_0 and U denote transfer integral and on-site Coulomb interaction. Here, we have considered the monochromatic laser, and the Peierls phase is $F(t) = F_0\cos\Omega t$. This result agrees with the previous study [2], which employed the time-dependent canonical transformation.

We have calculated the DC spin current generated by the time-periodic exchange interaction based on the Floquet-Keldysh formalism. To simplify the problem, we have considered a one-dimensional XY spin chain coupled to heat bathes of local phonons, and investigated a non-equilibrium steady state driven by laser. For breaking the inversion symmetry, we have also set both exchange interaction and local magnetic field alternating between two values in the chain. As a results, we have found that the DC spin current is finite when the inversion symmetry is broken and its direction is determined by the low-energy property of the phonon heat bathes.

These results imply that the laser irradiation induces a DC spin current in Mott insulators with noncentrosymmetric lattice structure. Its amplitude is also proportional to the fourth of power of the laser amplitude [see Fig. 1(b)]. In Mott insulators, spin relaxation via conduction electrons is absent, and this is an advantage for realizing coherent spin transport. Our study may indicate that Mott insulators are one of the candidate materials of insulator-based spintronics devices.

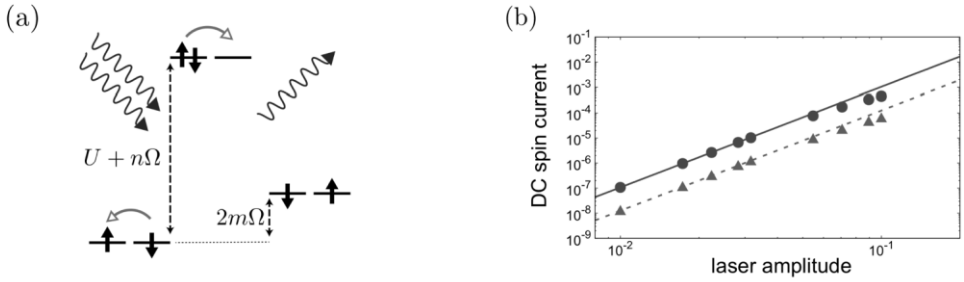

Figure 1: (a)Illustration of the exchange process of electrons in the extended Floquet Hilbert space. (b)Laseramplitude-dependence of the DC spin current.

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P3

Yusuke Furuya

P4

Spectroscopy of double quantum dot spin states by tuning the inter-dot barrier

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Transport spectroscopy of two-spin states in a double quantum dot can be performed by an AC electric field which tunes the energy detuning. This has been demonstrated experimentally in different double dot systems [1, 2]. However, a problem arises when the transition rate between the states is small and consequently the AC-induced current is suppressed. In our work, we use an exact quantum transport model and show that if the AC field tunes the inter-dot tunnel barrier then for large negative detuning, where the spins are in the Heisenberg regime, the transition rate increases drastically resulting in high current. Interestingly, multi-photon resonances are enhanced by orders of magnitude. Our study demonstrates an efficient way to speedup two-spin transitions [3].

References

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P5

The radio-frequency response of linear arrays of mesoscopic Josephson junctions

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We performed a quantitative study of the response of linear arrays of mesoscopic Al-AlOx-Al Josephson junctions to radio-frequency (RF) electromagnetic fields. First, we studied the influence of the RF fields on the $I-V$ characteristics of Cooper-pair tunneling in mesoscopic Josephson junctions. A linear array of Al tunnel junctions was situated at the end of an RF transmission line at the mixing chamber of a dilution refrigerator at base temperature of 40 mK, and its dc characteristics measured while a RF voltage was applied through the transmission line.

We observed the Coulomb blockade (cb) of Cooper-pair tunneling gradually lifted with increase in applied ac power of the RF field V_{ac} in the sub-gigahertz range *irrespective* of its frequency, f (See Figure 1) . This result is dual to microwave-enhanced phase diffusion already observed in a linear array of Josephson junctions with $E_J/E_c > 1$ and relatively higher frequencies of upto 26 GHz.[1]. Our result was resilient to the increase in the threshold voltage for Cooper pair injection into the array caused by a high magnetic field H = 500 Oe applied to the sample.

By comparing our experimental results to simulation using the standard $P(E)$ theory for single junctions (see e.g.[3]), we show that multi-absorption of low frequency photons (classical limit) by a single junction (via the rest of the circuit acting as the environment) leads to Cooper-pair injection into the array thus lifting the Coulomb blockade. However, a suitable fit to the experimental results is only possible after extending the standard $P(E)$ theory The final expression is essentially the time averaged current result recently proposed in [2] applied to the 1D array of small Josephson junctions within the semi-infinite model[3]. Thus, our results suggest that *accurate* low-frequency on-chip RF field/microwave power detection with 1D arrays of Josephson junctions is possible only after considering this effect.

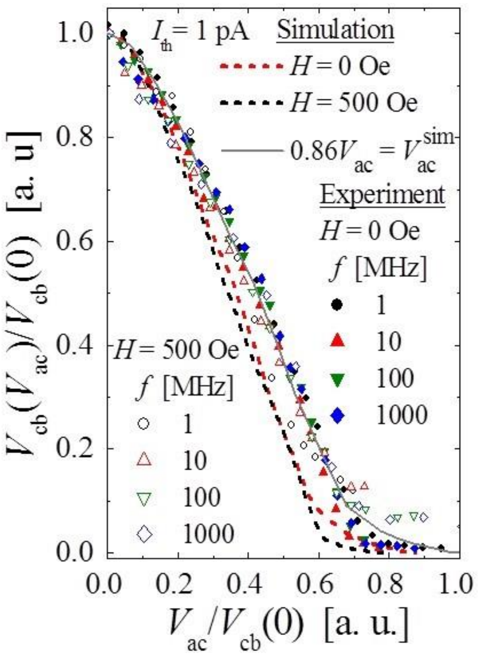

Figure 1: The Coulomb blockade voltage, V_{cb} - RF field amplitude, V_{ac} dependence for magnetic fields H = 0, 500 Oe extracted from measured $I-V$ characteristics for RF field f = 1, 10, 100, 1000 MHz and from their corresponding simulated $I-V$ curves with V_{ac}^{sim} at a threshold current, I_{th} = 1 pA and then normalized by their corresponding RF-free $V_{cb}(0)$ values.

Motivated by this possibility, the RF field emitted by a superconducting single electron transistor (SSET) comprising a pair of direct current superconducting quantum interference device (dcSQUID) was detected. The linear array of Al tunnel junctions was fabricated adjacent to the SSET at a distance 2 μm without any coupling structure. Coulomb blockade was gradually lifted with increase in applied SSET voltage $0 < V < V_{JQP}$ = 0.37 mV where the RF emission by the SSET was through the ac Josephson effect[4] and almost vanished at V = 0.72 mV where sequen-

JQP

tial QP tunneling occurred in the SSET. A similar response of the array was observed for the distance between the array and the SSET up to 30 μm. As expected, the linear array is demonstrably acting as an on-chip detector of RF electromagnetic fields.

References

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P6

Spin-current noise in magnetic bilayer systems

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In the research field of mesoscopic physics, current noise measurement is an important tool to obtain useful information on electronic transport such as determination of the effective charge, evaluation of electron entanglement, and even spin accumulation. In the research field of spintronics, the pure spin current induced by, e.g., spin pumping and spin Seebeck effect (see the left pictures of Fig. 1) is a central research subject. Recently, the noise of this pure spin current has measured by using the inverse spin Hall effect [1]. Although the noise of the pure spin current is expected to have useful information, its theoretical study has, however, been overlooked for a long time, and has just started recently in a few papers [2, 3].

In this presentation, we consider a normal metal(NM)/ferromagnetic insulator(FI) bilayer system, which is an important platform of spintronics [4]. Starting with a microscopic spin-exchange model, and using the secondorder perturbation with respect to the NM-FI interface coupling [5], we derive expressions of the spin-current noise in terms of the propagators of electrons and magnons. We discuss how temperature dependences of the spin-current noise contain useful information on the microscopic mechanism of the spin-current generation (see the right graph of Fig. 1). We conclude that measurement of the spin-current noise indeed provides a powerful tool in research of spintronics.

This study is a joint research with M. Matsuo (Kavli Institute for Theoretical Physics China), Y. Ohnuma (Kavli Institute for Theoretical Physics China), and S. Maekawa (RIKEN).

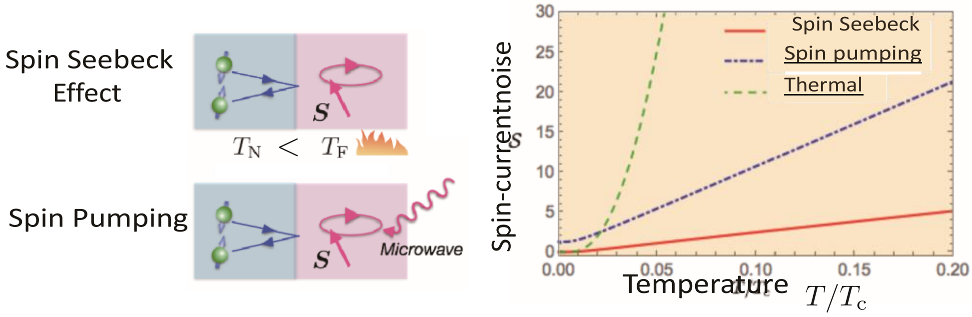

Figure 1: (Left) Schematics of spin-current generation by spin Seebeck effect and spin pumping. (Right) Temperature dependence of the spin-current noise. The temperature is normalized by the Curie temperature of the ferromagnetic insulator. Temperature dependence of thermal spin-current noise is also shown.

References

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P7
Yuki Kawamura

P8

Magnetotransport properties and thermoelectric effect in a device made of Weyl magnet Mn_3Sn

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Recently, Weyl magnets have attracted increasing attention because of their large magnetotransport and thermomagnetic effects, in which the electronic band structure associated with the noncollinear spin configuration is responsible for generating Berry curvature through spin-orbit coupling[1]. Weyl magnets have also attracted much attention in the potential application of a new thermoelectric power generation and heat current sensor. The anomalous Nernst effect (ANE) is a thermoelectric phenomenon typically observed in ferromagnets under the application of a temperature gradient, in which a transverse voltage is induced perpendicular to both the temperature gradients and the magnetization. Recent experimental studies have shown large ANE in a noncollinear antiferromagnetic metal Mn_3Sn with a vanishingly small magnetization[2, 3], whose band structure has the Weyl points near the Fermi level[4]. The anomalous Nernst effect provides a simple and powerful tool to precisely track the position and motion of a domain wall propagating. Recent theoretical and experimental studies have shown that magnetic domains exist in noncollinear antiferromagnetic Weyl magnets[5−7].

In this study, we have investigated the anomalous Nernst effect in a microfabricated antiferromagnetic Weyl magnet Mn_3Sn to detect magnetic domains. Focused ion beam (FIB) and lithography were employed to microfabricate a thermoelectric device made of Mn_3Sn that has a Ta heater with a size of micro order. The magnetoresistance(MR) of Mn_3Sn shows asynmetric behavior in the magnetic field, showing a negative peak and a positive peak for the decreasing and increasing field branch, respectively. According to the results of MR in magnetic multilayers with perpendicular anisotropy, the contribution of magnetic domains is the origin of the asynmetric MR[8]. The step structures are also observed in hysteresis of the anomalous Nernst effect. We discuss the origin of the step structures in the hysteresis and compare the anomalous Nernst effect in the device to that in a bulk single crystal.

References

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P9

Hydrodynamic approach to electric and energy current in the one-dimensional Hubbard model

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Transport properties of strongly correlated electron systems are not well understood even in exactly solvable models such as the one-dimensional Hubbard model, which is solved by the nested Bethe ansatz. In recent years, a hydrodynamic approach for Bethe ansatz solvable models is developed and it is called generalized hydrodynamics [1, 2]. This approach assumes a local distribution of roots of the Bethe ansatz equations and describes the time evolution of these distribution functions. Velocities of the roots are derived by the dressing formalism and they depend on types of Bethe roots, which are classified on the string hypothesis. It enables us to calculate local densities of conserved quantities and associated currents as local equilibrium values.

We study a two-reservoir quench of the one-dimensional Hubbard model by the generalized hydrodynamics. The initial state is two semi-infinite thermal equilibrium states joined at the origin (x =0) and we study its time evolution. Between the two states, an intermediate region appears and expands with time. Local electron density and energy vary with the position x, and their currents flow in this region. For the two equilibrium states, we first calculate filling functions of Bethe roots. Local filling functions at time t are described by those initial values and depend on ray ($\xi \equiv x/t$). Local conserved quantities and associated currents are also ray dependent and derived from local filling functions.

We have calculated charge and energy densities and their currents under the two-reservoir quench [3]. We discuss the roles of complex roots corresponding to bound states when the two initial equilibrium parts have different temperature or chemical potential. In particular, we have considered the case that the initial temperature is infinite in one part and found that the charge density does not change in a finite ξ-region near the boundary of that part although a finite energy current flows there.

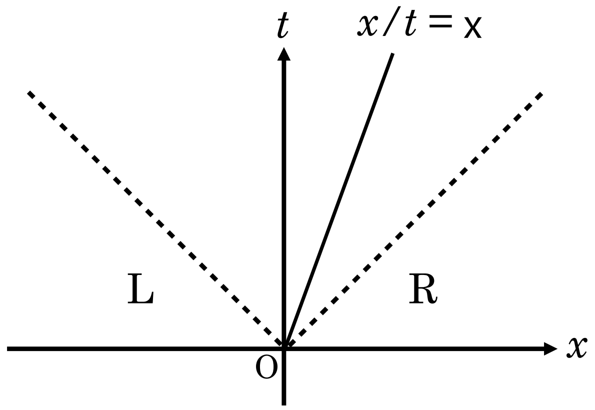

Figure 1: Time evolution upon a two-reservoir quench. In the L and R parts, local quantities do not change from the t =0 equilibrium values on the left and right part, respectively. In the intermediate region, they vary continuously with depending on the ray $\xi = x/t$.

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P10

Evaluation of the fluctuation for transport efficiency in quantum transport

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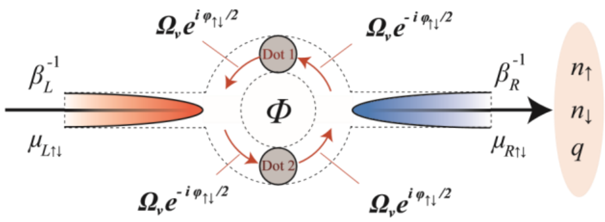
The quantum transport in the view of the quantum thermodynamics of nanoscale circuits, has attracted much attention. In particular, an issue how to realize high efficiency of heat engine is actively studied [1, 2]. The efficiency has been extended into general system that multiple input-currents and output-currents are involved [3]. In the multi-process transport system, the efficiency is defined as a ratio between entropy production rate (EPR) for output currents and that for input currents, which is called the exergy efficiency. Then, we call the EPR for the input currents input-exergy, and one for the output currents output-exergy, respectively. In this work, we focus on the effect of fluctuating currents flowing thorough a mesoscopic system on the efficiencies. For example, in the nanoscale heat engine, the conversion efficiency between the heat and charge currents can fluctuate because each current fluctuates. Then, in order to evaluate the fluctuating efficiency of the heat engine, it is useful to consider the joint probability distribution of the currents and the probability distribution of the efficiency [4, 5].

By using this framework, we calculate the average of the exergy efficiency and find a measurement-time dependence. Within Gaussian approximation, which is associated with linear response regime, we obtained an inequality that indicates a similar formula of thermodynamically uncertainty relation (TUR) between the total exergy and the relative uncertainty of each exergy [6]. We will apply our theory to the Aharonov-Bohm-Casher ring realized by double quantum dot (left panel of Fig. 1). In the system, the Aharonov-Bohm effect and the Aharonov-Casher effect are intermixed. By using two effects, we treat up-spin and down-spin currents as two independent components. We illustrate the result for a case of spin transport in this model (right panel of Fig. 1).



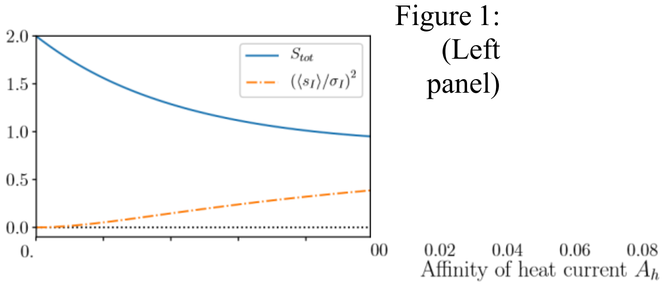


Figure 1: (Left panel) Schematic picture of the double-dot AB-AC ring. The system consists of two single-level quantum dots, left (cold) and right (hot) leads. Temperatures and chemical potentials in the left and right leads are denoted as $\beta_L{}^{-1}/k_B$, $\beta_R{}^{-1}/k_B$, μ_L, and μ_R, respectively. The charge and spin currents are defined as $n\uparrow + n\downarrow$ and $n\uparrow - n\downarrow$, respectively. Phases for up-spin and down-spin φ_σ $(\sigma = \uparrow, \downarrow)$ are independently regulated by using AB phase and AC phase. (Right panel) The total exergy (entropy production rate) and relative fluctuation of the input exergy.

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P11

Dissipationless Edelstein effect in insulator-ferromagnet heterostructures

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Electrical generation and control of magnetic moments are a central subject in the modern field of spintronics. One of the representative methods intensively studied is the Edelstein effect [1], in which an electric current flow generates nonequilibrium spin accumulation through a shift of the Fermi surface in noncentrosymmetric metals with strong spin-orbit coupling, e.g., interface Rashba systems or topological insulator surfaces [2]. In proximity to a ferromagnetic metal the magnetic moment **M** (or a domain wall) of the ferromagnet can be manipulated by an electrical current flow, where a nonequilibrium spin **m** induced by the Edelstein effect generates a torque proportional to **m**×**M**, termed the spin-orbit torque. However, the Joule heating by an electric current has been an obstacle, and magnetization control involving much less dissipation is demanded toward practical applications.

In this study we propose a theoretical framework for current-free Edelstein effect in heterostructures of a band insulator and a ferromagnet. In contrast to the conventional Edelstein effect, this new mechanism is immune to impurity scattering as it relies on virtual transitions between the valence and conduction bands. Furthermore, it requires breaking of not only spatial inversion but also time reversal symmetry. To demonstrate this, we consider a simple two-dimensional band insulator in proximity to a ferromagnet [Fig. 1(a)], where the Rashba spin-orbit coupling arises due to the breaking of mirror symmetry along z axis. Figure 1(b) shows the band structure when the magnetization **M** in the ferromagnet points along z axis [Fig. 1(a)], which shows spin splitting by the combination of the Rashba spin-orbit coupling and exchange coupling to the magnetic moment. By calculating the magnetoelectric tensor by using the Kubo formula, we discover the manifestation of the dissipationless Edelstein effect dependent on the **M** configuration [Fig. 1(c)]. Here we define K_{ij} as $m_i = -\mu_B K_{ij} E_j$, where m_i and E_j denote i component of the magnetization and j component of an external electric field, respectively (μ_B: the Bohr magnton). For instance, when **M** points along z axis ($\theta = \pi/2$), an electric field along x axis induces magnetization along x axis, while it induces magnetization along z axis when **M** points along x direction ($\theta = 0$). In the presentation we also present the symmetry arguments and the finite-frequency results as well as the estimation in a hybrid halide perovskite semiconductor as an example of the band insulator.

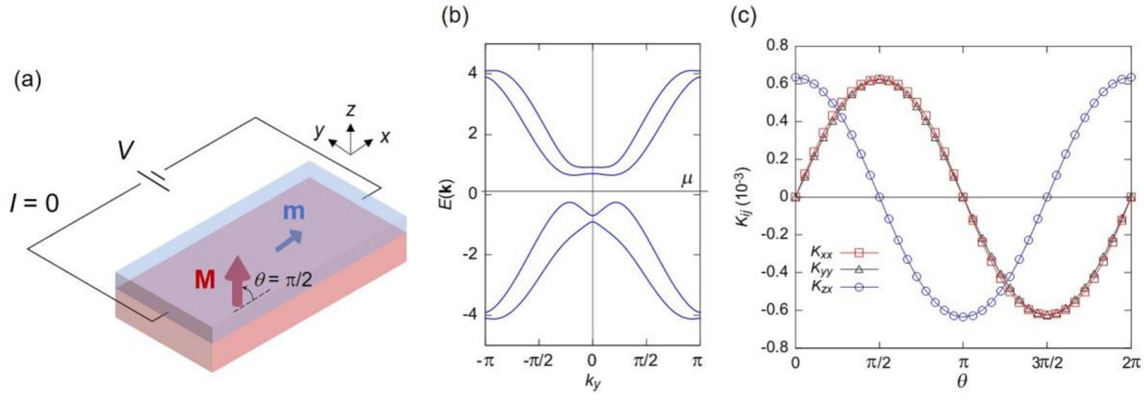

Figure 1: (a) Schematic picture of the band insulator–ferromagnet heterostructure. The magnetization in the ferromagnet, **M**, points along z axis ($\theta = \pi/2$). **m** denotes the magnetization induced by the dissipationless Edelstein effect. V represents the applied voltage. Note that no electric current flows ($I = 0$). (b) Band structure of the insulator in the configuration represented in (a), subject to the Rashba spin-orbit coupling and exchange coupling to the ferromagnet. The chemical potential μ lies within the band gap. (c) Magnetoelectric tensor K_{ij} as a function of the **M** angle θ. θ is defined as $M_x = M\cos\theta$ and $M_z = M\sin\theta$ [see also (a)].

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P12

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P13

Spin-current induced mechanical torque in a chiral molecular junction

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Recently, the spin-orbit interaction (SOI) in molecular junctions attracts a lot of attentions since it is considered to play an important role in electron conduction through chiral molecules. One important consequence induced by the SOI is the spin-filter effect. Recently the spin-filter effect has been observed in experiments of electric conduction through chiral molecules, such as DNA molecules [1]. The effect is called the chiral-induced spin selectivity (CISS) effect. Since such organic molecules do not contain ferromagnetic atoms, it is considered that the only possible origin, which causes the CISS effect, would be the SOI. In general, the mass of atomic elements forming such organic materials are small, and thus the SOI, which is a relativistic effect, is also small. However, a recent theoretical study demonstrates that in a particular condition, the SOI can be enhanced [2]. Since the electric field is generated by nuclei forming the molecule, its dynamics would be connected to the dynamics of the molecule. This observation makes possible the conversion of the spin angular momentum to the mechanical angular momentum. In ferromagnetic materials, such a conversion effect, the gyromagnetic effect, has been known one century before. Recently, the conversion between the spin angular momentum and the mechanical torque has received attentions again in the spintronics community [3]. In the presence of the SOI, if an injected spin changes its direction during the transmission process, the angular momentum would be transferred to the atoms as the back-action. Therefore, one can expect that in the molecular junction setups [1], a finite amount of the spin angular momentum can be converted to the mechanical torque exerting on the chiral molecule, which could induce a rotary motion of the chiral molecule.

In this presentation, we discuss the mechanical torque exerting on a single-stranded DNA induced by a spin polarized current. We consider the single-stranded DNA (ssDNA) connected to the source and drain leads. We adopt a modified tight binding model, in which the SOI is accounted for by the Aharonov-Casher phase. We derive the spin continuity equation based on a microscopic model Hamiltonian introduced in previous publications, e.g. [4]. In the presence of the SOI, the total angular momentum is conserved, since the change in the electron spin is transformed into a mechanical torque acting on the molecule. We perform the numerical calculation, and present that the torque oscillates as a function of the length of the DNA.

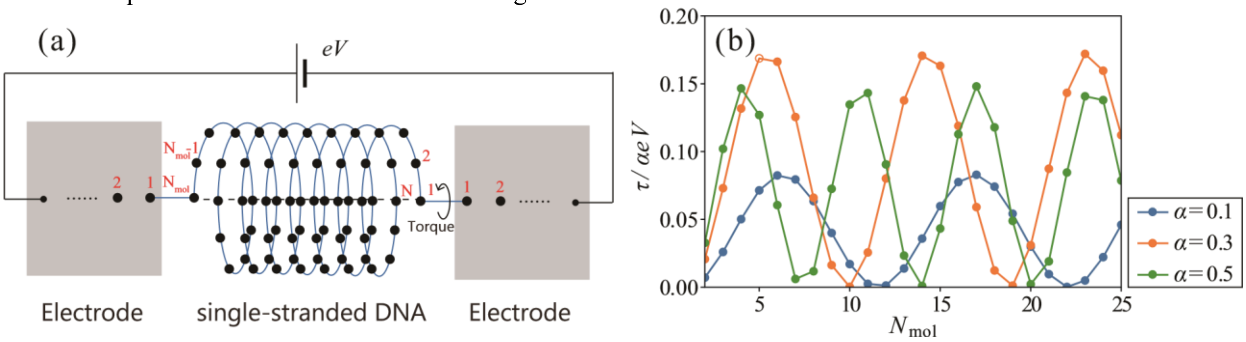

Figure 1: (a) Schematic picture of the ssDNA and the chiral molecurlar junction. The ssDNA can rotate aroud the helical axis due to the mechanical torque. (b) The mechanical torque as a function of the length N_{mol} for various α, the strength of the SOI. The energy of the injected electron is fixed as E=0.

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P14
Ryuta Tezuka

P15

Hydrodynamic optical response of electron fluids in ultrapure metals

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The conventional theory of optical response in metals has been based on the Drude theory, which is based on the assumption that electron-electron scattering is weak enough to ignore and the transport is governed by collisions with defects or phonons. However it has become possible, in recent years, to prepare ultrapure metallic samples, such as $PdCoO_2$ [1], graphene [2], and GaAs/AlGaAs heterostructures [3], where the electron-electron scattering becomes most dominant process governing transport and the Drude theory is no longer valid. This regime is called ”hydrodynamic regime” and described by an emergent hydrodynamical theory [4]. In fact, several observations of hydrodynamic effect in DC transport have already been reported[1, 2, 3]. For example, the authors of Ref. [2] have reported evidence of hydrodynamic transport, showing that doped graphene exhibits an anomalous voltage drop near current injection points, which has been attributed to the formation of whirlpools in the electron flow. On the other hand, optical response in hydrodynamic regime haven't been discussed yet in detail.

In this work, we provide an alternative framework of optical response in hydrodynamic regime. Based on momentum relaxing Navier-Stokes equation, we calculated the optical conductivity of electron fluids and discuss how electromagnetic waves propagate in electron fluids. Consequently, we revealed that, in three-dimensional electron fluids, an electromagnetic wave propagates in two modes due to the nonlocality of electron fluids, which is constrast with the Drude theory, where it propagates in only one mode. Next, we calculated the reflectance and transmittance in two or three dimensional electron fluids. This result provides an optical probe of hydrodynamic effect and enable us to measure the viscosity and Hall viscosity of electron fluids through simple optical techniques.

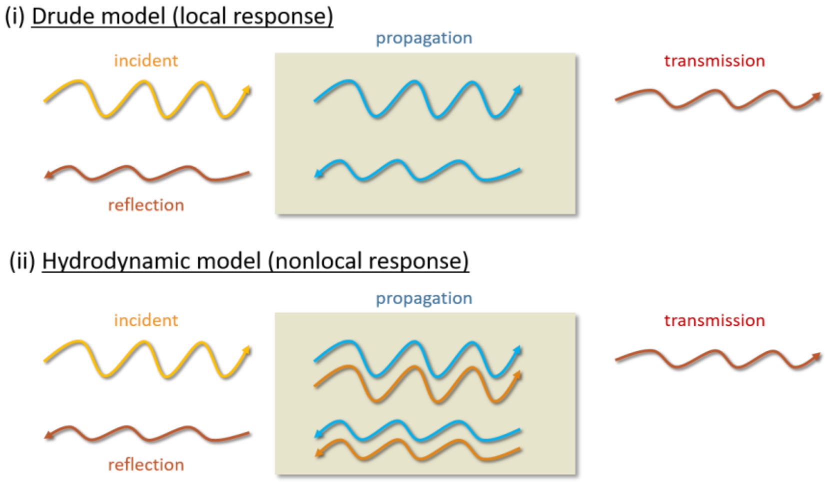

Figure 1: Propagation of electromagnetic waves in Drude regime (i) and hydrodynamic regime (ii). In hydrodynamic regime, two propagation modes exists because of nonlocality of electron fluids.

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P16

Full-counting statistics of information content and heat quantity in the steady state and the optimum capacity

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The laws of physics limit the performance of information processing. The quantum limits of information transmission through a quantum communication channel have long been discussed [1]. In information theory, a model communication system consists of a transmitter, a channel, and a receiver [2] [Fig. 1 (a)]. The physically relevant part is the channel through which a signal produced by the transmitter reaches the receiver. A measure of the performance of a channel is capacity C, the maximum possible rate at which information can be transmitted without error. For mesoscopic quantum electric conductors, the scattering theory was developed to analyze the entropy current as well as the capacity [3]. However, there are not many works in this direction.

Here, we consider a bipartite quantum conductor [Fig. 1 (b)] and analyze the information exchange between the subsystems [4]. We evaluate fluctuations of self-information associated with the reduced density matrix of a subsystem subjected to a constraint of the local heat quantity. By exploiting the multi-contour Keldysh technique [5, 6], we calculate the R´enyi entropy, or the information generating function, from which the probability distribution of the conditional self-information is derived. We present an equality, that relates the optimum capacity of information transmission between the subsystems and the R´enyi entropy of order 0. We apply our theory to a two terminal quantum dot and analyze the probability distributions. We point out that at the steady state, the reduced density matrix and the operator of the local heat quantity of the subsystem may be commutative.

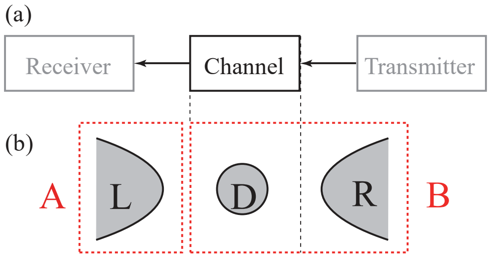

Figure 1: (a) A model of the communication system. A transmitter-generated signal is sent through a channel to a receiver. We focus on the signal transmission process through the channel. (b) A quantum conductor (single-level quantum dot) coupled to the left and right leads. We regard the quantum conductor as the communication channel. The right lead corresponds to the transmitter, which generates thermal and shot noise as signals. The left lead corresponds to the receiver side. We regard the left lead as subsystem A and the quantum conductor and the right lead as subsystem B.

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P17

Symmetry analysis of electrically-switchable antiferromagnets

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Decades of efforts in the field of spintronics have extensively enhanced the controllability of spins in electronic devices [1]. The concept of spin electronics is widespread in the field of the condensed matter physics; *e. g.* superconductor and topological materials. Recently, the possibility of manipulations of antiferromagnets is attracting much attention as a novel subfield of spintronics, that is, *antiferromagnetic spintronics*. Although antiferromagnetic order is seemingly insensitive to external fields due to its “staggered” nature, recent studies proposed various frameworks of the control of antiferromagnetic domains by making use of polarized current, spin current, and so on [2]. Especially, the switching scheme using current-induced antiferroic magnetizations (Antiferromagnetic Edelstein effect, AFM Edelstein effect) is promising candidate. After theoretical proposals, the domain switching has been confirmed experimentally [3, 4]. The experimental works, however, have been achieved in only a few materials, while physical properties of the AFM Edelstein effect have been clarified by theoretical works. Thus, it is highly required for further developments in antiferromagnetic spintronics to explore more candidate materials.

In our work, we present a symmetry analysis of the domain switching of antiferromagnets. Based on group-theoretical approaches such as the representation theory and magnetic point groups, we clarify a criterion for the electrically-switchable antiferromagnets and identify dozens of new candidate materials. Furthermore, the criterion suggests a link between the switchable antiferromagnets and ferroic alignment of toroidal moments, namely, ferro-toroidic order [5]. We also discuss the emergent properties of switchable antiferromagnets derived from the ferro-toroidic order. Those toroidic properties may lead to a complete read-out of the antiferromagnetic domains and promote more elaborate experimental works in the switchable antiferromagnets.

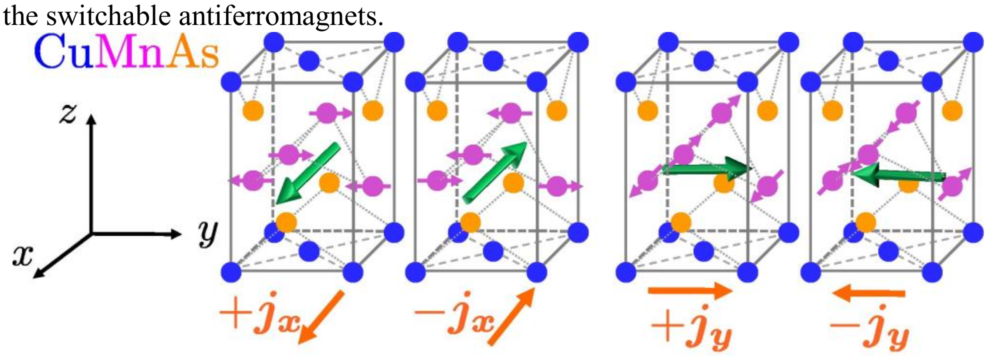

Figure 1: Correspondence between the antiferromagnetic domains and toroidal moments in CuMnAs, an candidate material for antiferromagnetic spintronics. The green (purple)-colored arrows represent the toroidal (magnetic) moments. The electric current stabilizing each domain is depicted.

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P18

Correlation of currents in remote arrays of small Josephson junctions through the quasiparticle excitation

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Capacitively coupled one-dimensional arrays of small Josephson junctions hold the promise to be used as a precise current duplicator and multiplier when the arrays are biased near the Coulomb blockade threshold [1, 2], although the mechanism of the current duplication has not been understood sufficiently. We have found that, even a pair of arrays without deliberate coupling capacitances shows a large cross correlation of their currents with their separation up to as long as 30 μm, which is considerably greater than their effective mutual Coulomb interaction distance. This remote correlation of currents would be the basis of the current duplication.

In this study, we shed light on this remote current correlation by investigating the effect of the current in a onedimensional array of small Josephson junctions on the characteristics of a superconducting single electron transistor (SSET) fabricated 30 μm apart from the array [Fig. 1(a)]. The samples were fabricated with mesoscopic $Al/AlO_x/Al$ junctions, and the array has 20 junctions in series. Measurements were performed by using a compact dilution refrigerator with a base temperature of 70 mK.

Figure 1(c) shows typical Coulomb oscillations of the SSET with its bias voltage fixed at the superconducting current peak measured at varied bias voltages, V_a, of the remote array. The values of V_a are indicated by the dots with numbers on the current (I_a)–voltage (V_a) characteristics of the array in Fig. 1 (b). For the case of small V_a in the Coulomb blockade region (bias points 1–9), $2e$ periodic Coulomb oscillations were observed in the SSET, reflecting the Cooper-pair tunneling. However, when a finite current I_a starts flowing in the array with V_a raised beyond these points (to bias points 10–14), the peaks of the current oscillations in the SSET begin to be suppressed. Raising V_a further, the $2e$ periodic oscillations in the SSET split and eventually get modulated to e periodic oscillations (bias points above 15).

The observed change from $2e$ to e periodicity signifies the occurrence of quasiparticle excitation in the electrodes of the SSET induced by the current in the array [3]. When an array is biased near the Coulomb blockade threshold, the generation of nonequilibrium quasiparticles in the electrode will trigger the current through the array [4]. Thus, the remote current correlation between junction arrays possibly originates from this current-induced remote quasiparticle excitation.

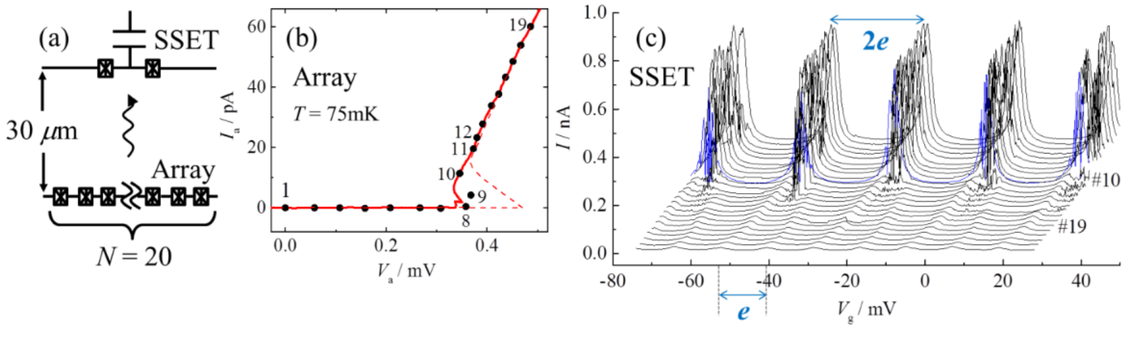

Figure 1: Coulomb oscillations of the SSET with their $2e$ periodicity modulated to e by the bias voltage of the remote array. Inter-device distance was 30 μm. The measurement temperature was 75 mK. (a) schematic device arrangement. (b) I_a–V_a characteristics of the array. (c) $2e$ to e modulation of the Coulomb oscillations of the SSET.

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P19

Measurement Superoperator of Balanced Homodyne Detection with Limited Time Resolution

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Balanced homodyne detection is widely used to obtain the information on the field quadrature operator of an optical signal mode, $\hat{x} = \hat{a} + \hat{a}^\dagger$, with $\hat{a}$ and $\hat{a}^\dagger$ being the annihilation and the creation operators of the mode. After the signal mode is split into two output modes by a 50/50 beam splitter mixing with the other input of coherent light with the same frequency, i.e., the local oscillator, the two outputs are independently detected by two photodetectors (see Fig.1). The difference in detected photon number during an interval τ, N, is the random variable that is recorded as the outcome of the homodyne detection. Previous theoretical research shows that the statistical average, E[N], is proportional to the quantum-mechanical average of the quadrature operator, $\mathrm{E}[N] \propto \langle \hat{x} \rangle$, in the short interval limit $\tau \to 0$ [1]. So far, however, their relation regarding higher-order cumulants have not been unveiled systematically.

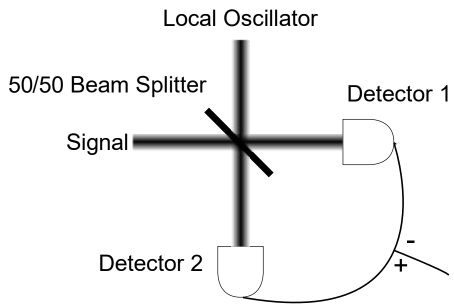

Figure 1: Schematic figure of optical balanced homodyne detection. After the signal mode is mixed with the local oscillator by a 50/50 beam splitter, the two output modes are detected by two different photodetectors. The difference in detected photon number is recorded.

In actual measurements, the continuous limit is not taken because there is a resolution limit of time. Taking the resolution limit into account, in this study, we clarify the explicit form of the superoperator that describes the homodyne detection with a calculation of the nonequilibrium detection dynamics during finite interval τ. We also obtain the measurement probability distribution of the homodyne detection from the measurement superoperator. As a result, it is found that while the superoperator has no direct relation to the projection operator of $\hat{x}$, the probability distribution of scaled N given by the superoperator is the same as the one of the projective measurement of $\hat{x}$ except for Gaussian measurement noise in the case of strong local oscillator. It is remarkable that the variance of the measurement noise, σ, has a fundamental trade-off relation to the detection loss during τ, L, which is described by the following equality in the ideal case;

$$\sigma(e^L - 1) = 1.$$

(1) In the continuous limit of $\tau \to 0$, the measurement superoperator reduces to the stochastic quantum master equation derived by Wiseman and Milburn [1].

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P20

Markovian Quantum Master Equation in the Non-adiabatic Regime

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The Markovian quantum master equation (QME) plays an important role for the study of nonequilibrium statistical physics. The structure of this framework is transparent, the generality of its derivation is sufficient, and the approximations applied are well defined, especially when the system Hamiltonian is time-independent. However, in situations where the system Hamiltonian is time-dependent, there is currently no general way of rigorously constructing the Markovian QME, despite the growing importance of the quantum dynamics driven by a time-dependent external field, such as adiabatic quantum computation and quantum annealing. One possible way to circumvent this difficulty is to assume the slow temporal change of the system Hamiltonian $\hat{H}_S(t)$. In this context, an important assumption employed by many authors is the adiabatic regime that satisfies the ordinary adiabatic theorem, in which any nonadiabatic transitions are suppressed [1]. There has been thus a wide recognition that the framework is valid only in the adiabatic regime.

Here, we study the conditions to justify the Markovian QME for the time-dependent system Hamiltonian. By introducing a temporal change time scale for $\hat{H}_S(t)$, we then find that the Markovian QME is naturally derived *without the adiabatic theorem*. We further find that in a broad range of situations there is no need to even assume the slow temporal change of $\hat{H}_S(t)$ compared to the decay time scale of the bath correlation function, τ_B [2].

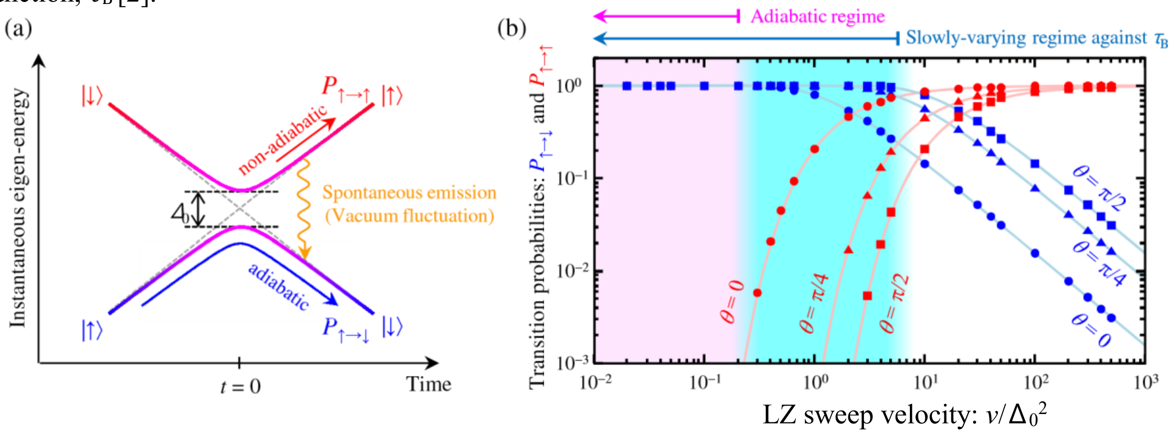

Figure 1: (a) The dissipative Landau-Zener model. When the bath is at zero temperature, there is no thermal excitation and relaxation but only the spontaneous emission can occur due to the vacuum fluctuation. (b) The transition probabilities. Symbols: the numerical results by the Markovian QME. Solid lines: the exact probabilities.

As an example, our results are demonstrated in Fig. 1 by applying the framework to the dissipative LandauZener model, the exact transition probabilities of which are analytically known at zero temperature [3]. In this model [Fig. 1(a)], a system of the Landau-Zener model [$\hat{H}_S(t) = \frac{vt}{2}\hat{\sigma}_z + \frac{\Delta_0}{2}\hat{\sigma}_x$] is coupled with a bosonic bath [$\hat{H}_B = \sum_j \omega_j \hat{b}_j^\dagger \hat{b}_j$] through an interaction Hamiltonian $\hat{H}_{SB} = \sum_j \frac{g_j}{2}(\cos\theta\hat{\sigma}_z + \sin\theta\hat{\sigma}_x)(\hat{b}_j + \hat{b}_j^\dagger)$. In Fig. 1(b), the numerical results by the Markovian QME show good agreement with the exact probabilities even in the nonadiabatic regime. This means that the applicable range of the Markovian QME is well beyond the widespread belief. Details will be presented at the symposium.

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P21

Haruyuki Yamamoto

P22

Enhancement of the superconducting gap induced by dissipation

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When we consider the effects of dissipation such as loss of particles or inelastic scattering, Hamiltonian of the system is no longer Hermitian but could be non-Hermitian because dissipation may cause non-unitary dynamics of the system, leading to the decay of eigenstates. In recent years, non-Hermitian quantum systems have been extensively studied both experimentally and theoretically [1–4]. However, most of the previous studies dealt with systems without interaction and there have been few studies focusing on quantum many-body phenomena.

In this study, we investigate how the BCS superconductivity, a prototypical example of quantum many-body phenomena, changes its character when the effects of dissipation are taken into account. In the presence of twoparticle loss, the attractive potential forming Cooper pairs becomes complex. Such a situation can be realized experimentally, for example, as the Orbital Feshbach Resonance (OFR) where the interaction between the ground $^1S_0$ state and excited $^3P_0$ state in ultracold alkaline-earth atoms becomes complex because of dissipation. Furthermore, as the experiments to realize superfluids using OFR by controlling the interaction between different orbitals have been actively conducted these days, it is particularly important to investigate the stability of superfluids in the system under dissipation. We calculate the free energy from the partition function using Hubbard-Stratonovich transformation and neglecting quantum and space fluctuations. Then we obtain the gap equation for the dissipative superconducting system by minimizing the real part of free energy focusing on short-time non-Hermitian dynamics. From this gap equation, we find a remarkable phenomenon, i.e. unusual enhancement of a superconducting gap due to dissipation (Figure 1), implying that the attractive interaction forming Cooper pairs under inelastic scattering is effectively enhanced. We finally show how the BCS mean-field theory in open quantum systems is changed from its Hermitian one and the corresponding superconducting gap under dissipation is expressed by the expectation value of fermionic operators.

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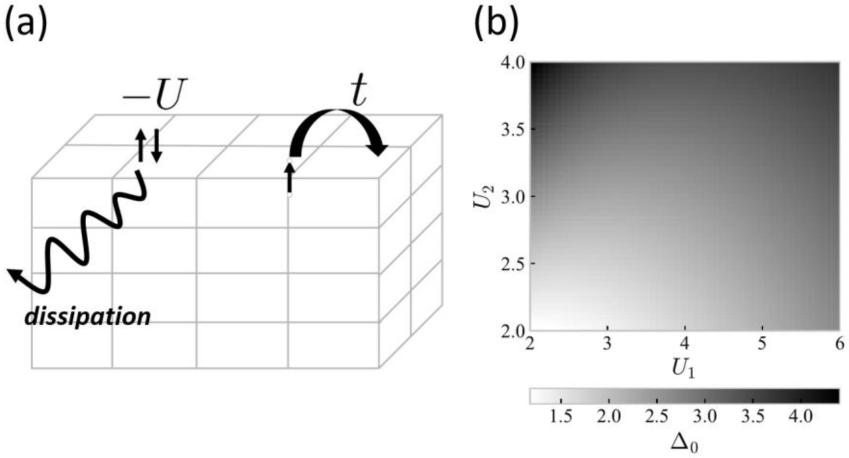

Figure 1: (a) Schematic diagram of the dissipative superconducting model, (b) Variation of the gap size depending on the complex interaction via dissipation. U_1 and U_2 represent the real part and imaginary part of the potential relatively. Δ_0 is the superconducting gap.

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P23

Quantum thermodynamics in cavity QED system

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The cavity QED system, which is composed of matter and photons in a cavity, is one of the best playgrounds for quantum physics. It is also viewed as a thermodynamic system [1, 2] when it is excited and deexcited by thermal baths as in Fig. 1. In this presentation, we show two results in the thermodynamic cavity QED system, which are concerned with the first and second laws of thermodynamics, respectively.

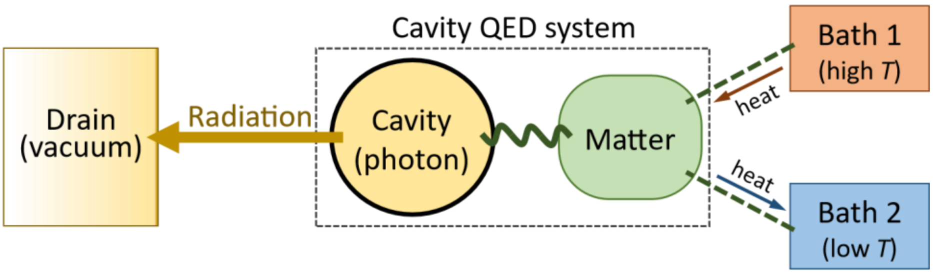

Figure 1: A schematic picture of a cavity QED system with thermal baths and a drain (receiving radiation).

The first result is a decomposition of radiation energy [3]. In the setup shown in Fig. 1, a part of energy is transferred from the cavity QED system in the form of radiation. From the thermodynamic viewpoint, it is of interest to investigate whether this energy transfer is regarded as work or heat. Here, we provide a proper decomposition into the work and heat, which justifies the intuition that the coherent part (such as laser) corresponds to work and incoherent one (such as thermal radiation) to heat. We also show that the energy conservation (the first law) is valid in the decomposition.

The second result is the fluctuation theorem. In the setup shown in Fig. 1, the entropy flow due to (the heat part of) the radiation from the cavity QED system diverges because the drain (an external system that receives the radiation) is in the vacuum state (zero-temperature state). This causes the naive fluctuation theorem meaningless. Here, taking the absolute irreversibility [4] (which the current setup contains) into consideration, we provide a modified fluctuation theorem, which is free from the divergent entropy flow. We also derive the second-law-like inequality from the modified fluctuation theorem.

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