Theoretical Solid State Physics and Statistical Mechanics Group

Academic Staff

Professors	Yoshio Kuramoto, Toshio Tsuzuki, Komajiro Niizeki and Hiroshi Yasuhara
Associate Professors	Tetsuo Ogawa, Osamu Sakai and Shin Takagi
Research Physicists	Hiroaki Kusunose, Yasuyuki Kurata, Tatsuya Nakajima, Masahiko Higuchi, Tsuyoshi Hondou, Hiroshi Yamagami and Hisatoshi Yokoyama
Technical Staff	Shunya Suzuki

Secretaries	Aya Ozawa and Tomomi Onodera
Graduate Students	Yoshitaka Matumura and Yoshihiro Yamamoto (D4) Wataru Izumida, Keiko Kurabayashi, Yasuhiro Saiga, Fumiko Takagi and Eigo Yagi (D3) Mitsuhiro Arikawa, Masayuki Nishimura, Noboru Fukushima Nobuhisa Fujita, Shiniji Watanabe and Fumihiko Ishiyama(D2) Takamitsu Ueta, Takanori Endo, Junya Shibata, Mutsuki Takagiwa, Masafumi Horiuchi and Junichiro Watanabe (D1) Rikie Ishii, Yasuo Okajima, Satoru Okumura, Tomoya Kuromaru, Sei Suzuki, Kenichi Nishizawa and Takeshi Fujieda (M2) Akira Ishikawa, Yoshihiro Iwaki, Noriyuki Shibasaki, Nagahiro Takahashi, Kouji Nagata, Aya Maejima, Touichirou Yamamura and Sho Yoshinaga (M1)
Research Students	Kohji Suzuki and Ryu Takayama
Guest Research Fellow	Motomu Takeshige and Takashi Yamamoto

Research Activities

I. THEORY OF STRONGLY CORRELATED ELECTRON SYSTEMS

(*Y. Kuramoto, H. Yokoyama, H. Kusunose, T. Yamamoto, Y. Saiga, M. Arikawa, N. Fukushima, S. Watanabe, T. Ueta, T. Kuromaru, S. Suzuki and A. Maejima*)

1. Orbital Kondo effect and interplay of magnetic and orbital fluctuation effects

Peculiarity of the Kondo effect in the presence of orbital degeneracy is investigated on the basis of scaling equations up to third order. We first formulate a new scaling method with use of the Rayleigh-Schrödinger effective Hamiltonian and the folded diagram technique [1]. On the basis of this method, we investigate an impurity model for $Ce_xLa_{1-x}B_6$ with account of realistic situation with orbital degeneracy [2, 3, 4]. For the case where the f^1-f^0 charge fluctuation is dominant over the f^1-f^2 one, the effective exchange interaction becomes anisotropic with respect to the orbital pseudo spins, and the system deviates from the SU(4) Coqblin-Schrieffer model conventionally adopted. Because of the different characteristic energies for dynamics of electric and magnetic multipoles, scaling with the single Kondo temperature does not apply to physical quantities such as the resistivity and the magnetic susceptibility [2].

Effects of magnetic field on the quadrupolar ordering are investigated with inclusion of fluctuation of order parameters [3, 4, 5]. For the simplest model with the nearest-neighbor quadrupolar interaction, the transition temperature and the specific heat are derived by the use of an effective medium theory proposed by us. The fluctuation effect is so strong that the entropy released at the quadrupolar ordering is only about half of the full value $\ln 4$ even without the Kondo effect.

Magnetization in quadrupolar systems such as $Tm_xYb_{1-x}Te$ and $Ce_xLa_{1-x}B_6$ show peculiar reversal of easy directions as the concentration x is increased. By taking the two-impurity model, Kuromaru explained this phenomena in terms of intersite quadrupolar interaction between rare-earth ions.

2. Ground state and elementary excitations in systems with f^2 configurations

Ground state properties of the one-dimensional Kondo lattice with an f^2 configuration at each site are studied by the density matrix renormalization group method [6, 7]. At half-filling, competition between the Kondo exchange J and the antiferromagnetic intra f-shell exchange I leads to reduction of energy gaps for spin, quasi-particle and charge excitations. The competition also induces attractive force among conduction electrons. As J/I increases the f^2 singlet gives way to the Kondo singlet as the dominant local correlation. In between the nature of quasi-particle excitations changes from the localized character to the itinerant one. Possible metal-insulator transition is discussed which may occur as the ratio J/I is varied by reference to mean-field results and the two impurity Kondo system [6].

3. Stability of striped phases in strongly correlated two-dimensional electrons

By using a variational Monte Carlo technique, stability of the striped phases is studied for the two-dimensional t-J model with the three-site term near 1/8 hole doping [8]. It is found that both diagonally and vertically striped phases are comparable in energy with the $d_{x^2-y^2}$-wave superconducting state in the small-J/t region. Hole-'filled' domain walls prefer diagonal stripes, whereas 'half-filled' domain walls do vertical ones, in accordance with the situation observed in nickelates and cuprates.

4. Exact dynamics in one-dimensional quantum systems

We study the dynamical structure factors of the XXZ chain bearing in mind one-dimensional Ising-like antiferromagnets such as $CsCoCl_3$. Two types of the

exchange interaction are considered: one is the nearest-neighbor type, and the other is the inverse-square type. Exact diagonalization and the recursion method are used for finite systems up to 24 sites [9]. The characteristic behavior of the transverse component $S^{xx}(q,\omega)$ in each model is understood in terms of whether the interaction between domain walls is absent or repulsive in the Ising limit. As the Ising anisotropy increases, there appears an energy gap in the magnetic excitation. For the inverse-square type, the opening of the gap is slower than that for the nearest-neighbor type, and the gap depends on the anisotropy parameter in an essentially singular fashion.

Spin and charge dynamics of the long-range supersymmetric t-J model are studied both numerically and analytically [10]. Numerical calculations show that the dynamical spin structure factor is independent of the electron density in the small momentum region. This is the first case where the strong spin-charge separation appears in dynamical properties. Analytically exact expression of the dynamical spin and charge structure factors are also derived in the small momentum region where only two spinons contribute as elementary excitations with fractional statistics. The dynamical properties of the nearest-neighbor supersymmetric t-J model are also discussed for comparison, and complication coming from interaction among quasi-particles is demonstrated.

Exact dynamical correlation functions are derived analytically for the Sutherland model with the SU(n) internal symmetry. The model has an interaction which decays as inverse square of the chord distance between particles on the ring. Both the Green function [11] and the density correlation function [12] are derived with use of a special set of multivariable polynomials called the Jack polynomials with prescribed symmetry. The results are interpreted in terms of elementary excitations which obey neither the Fermi nor Bose statistics but the fractional exclusion statistics.

5. Electronic states in semiconductor multilayers in strong magnetic fields

We study many-electron states in a semiconductor superlattice in strong magnetic fields by the variational Monte Carlo method. Depending on relative strength of the interlayer hopping, intra- and inter-layer Coulomb interactions, the system should behave as either quasi-two-dimensional or three-dimensional ones. By fixing the density so that the 1/3 fractional quantum Hall state is realized in the two-dimensional limit, Suzuki derives a quantum phase transition into a three dimensional ground state with decreasing interlayer distance.

II. COMPUTATIONAL STUDY ON PHYSICS OF STRONGLY CORRELATED ELECTRON SYSTEM

(*O. Sakai, R. Takayama, S. Suzuki, W. Izumida, M. Nishimura, K. Nishizawa and N. Shibasaki*)

1. Dynamical excitation spectra of the strongly correlated systems

Electronic structures of the strongly correlated systems were calculated in various cases by extending Wilson's numerical renormalization group (NRG) method.

We investigated the non-Fermi-liquid (NFL) behavior of the impurity Anderson model (IAM) with non-Kramers doublet ground state of the f^2 configuration

under the tetragonal crystalline electric field (CEF) [13]-[15]. The low energy spectrum is explained by a combination of the NFL and the local-Fermi-liquid parts which are independent with each other. The NFL part of the spectrum has the same form to that of two-channel-Kondo model (TCKM). We have a parameter range that the IAM shows the $-\ln T$ divergence of the magnetic susceptibility together with the positive magneto resistance. We pointed out a possibility that the anomalous properties of $U_xTh_{1-x}Ru_2Si_2$ including the decreasing resistivity with decreasing temperature can be explained by the NFL scenario of the TCKM type. We also investigated an effect of the lowering of the crystal symmetry. It breaks the NFL behavior at around the temperature, $\delta/10$, where δ is the orthorhombic CEF splitting. The temperature dependence of the specific heat in a magnetic field was also calculated. When the magnetic field is very weak there are two peaks: one is a broad peak associated with the NFL behavior begins. The other peak is at very low temperatures and shows a release of the residual entropy which is expected from the NFL state of the TCM type.

We studied how the Kondo effect is affected by the Coulomb interaction between conduction electron. The Kondo temperature is increased by the Coulomb interaction [16].

2. Comprehensive Studies on the Electronic Structure of f-Electron Systems.

A new interpretation of NMR in quadrupolar ordering phase of CeB_6 was presented. The hyperfine coupling between multipolar moments of the Ce ion and the nucleus of B ion was discussed phenomenologically for the antiferro-quadrupolar ordering (AFQ) phase of CeB_6. The longstanding mutual inconsistency between neutron diffraction and NMR in phase II of this magnetic phase diagram can be resolved by considering the induced octupolar moment [17]-[19]. The dynamical excitation in CeB_6 was also studied [20].

The high-resolution angle-resolved photoemission spectra (HR-ARPES) of LaSb measured by experimental group at our department were analyzed based on the band structure calculation [21]. We demonstrated that the band structure obtained by ARPES is contributed to considerably by stationary lines with zero group velocity midway between high-symmetry lines in the Brillouin zone. The overall feature of the band structure shows an excellent agreement with experiment. This supports the new band mapping method developed by the experimentalists.

The magnetic excitation spectra of heavy fermion superconductor, UPd_2Al_3, was studied [22].

3. Kondo Effect in Tunneling Phenomena of Quantum Dot Systems.

Based on the numerical renormalization group and the quantum Monte Carlo methods, we calculated the tunneling conductance of the quantum dot systems for which the Kondo effect becomes important [23]- [25]. When the temperature decreases, the paired Coulomb oscillation peaks initially grow without increase of their width. This behavior shows good agreement with recent experimental result. The conductance in the valley region between them gradually increases in calculation, and the paired peaks merge into a broad single peak at extremely low temperature. We showed that the conductance is strongly suppressed by the Zeeman field, when it has been enhanced by the Kondo effect.

We studied the tunneling phenomena when the dot has many orbitals. The interaction effects in the quantum dot leads the sensitivities of the conductance to the temperature through the change of the quantum coherency. We also studied the conductance of a double quantum dot system. It shows an anomaly corresponding to the quantum transition between the Kondo-singlet-like state and the local-spin-singlet-like state.

III. THEORY OF OPTICAL RESPONSES OF LOW-DIMENSIONAL QUANTUM SYSTEMS

(*T. Ogawa, M. Takagiwa, S. Okumura, Y. Okajima, T. Yamamura and A. Ishikawa*)

1. Optical detection of critical exponents in the Tomonaga-Luttinger liquid

Optical responses of the Tomonaga-Luttinger liquid are investigated theoretically in terms of the power-law singularities. Critical exponents in the edge anomalies of valence-band photoemission, core-level photoemission, and one-photon absorption processes reflect different aspects of low-energy critical properties [27].

IV. DYNAMICS OF PHOTOINDUCED STRUCTURAL PHASE TRANSITIONS

(*T. Ogawa, M. Takagiwa, S. Okumura, Y. Okajima, T. Yamamura and A. Ishikawa*)

1. Domino effects in photoinduced structural change in one-dimensional systems

The possibility of occurrence of cooperative structural changes is investigated with a minimal model composed of localized electrons and classical lattices under the adiabatic approximation. In particular, the relaxation after one-photon absorption at a site is examined in detail. This relaxation proceeds in two steps. First, a local structural change is created due to the lattice relaxation associated with the local electronic excitation. After the spontaneous emission of a photon, this local structural change (a) remains locally, (b) induces a global structural change cooperatively, or (c) disappears and returns to the initial phase. Dynamical features of the case (b) are shown to be characterized by the domino effect. This global structural change occurs only when the intersite interaction is short-ranged and moderately strong [26].

2. Photoinduced nucleation theory in one-dimensional systems

Photoinduced nucleation of a kink-antikink pair in a one-dimensional system is investigated theoretically, using a model composed of localized two-level electrons and classical lattices, which has two structural phases. We treat the case of the finite-ranged intersite interaction, in order to discuss the crossover from short-ranged to long-ranged interaction. In particular, we focused on the structural change induced by a one-site photo-excitation. When a single site is excited, a local structural change is created around the excited site at first. After the emission of a photon from the excited site, this local structural change (a) remains

local, (b) grows into a kink-antikink pair, or (c) disappears and the system returns to the initial phase. Nucleation of a kink-antikink pair occurs only when the intersite interaction is short-ranged and moderately strong. The motion of the kinks is also examined [29].

3. Dynamics of photoinduced structural transitions: From mean-field picture to nucleation picture

A photoinduced structural change is treated as a nonequilibrium phase transition to investigate its nonlinear response with a minimal model composed of localized electrons and classical lattices under the adiabatic approximation. Special attention is paid to the difference between the mean-field treatment and the local nucleation picture of the nonequilibrium transition. In particular, the relaxation after one-photon absorption *at a site* is examined in detail from the view point of the classical nucleation. There are three types of evolution after the spontaneous emission of a photon; a local structural change (a) remains locally, (b) induces cooperatively a global structural change, or (c) disappears and returns to the initial phase, depending on the strength and range of the intersite coupling between the local lattice distortions. Dynamical features of the case (b) are characterized by the domino effect [30].

V. CONTROL OF QUANTUM COHERENCE IN PHOTON AND MATERIAL FIELDS

(*T. Ogawa*)

1. Jaynes-Cummings model under continuous measurement: Weak chaos in a quantum system induced by unitarity collapse

We show that a system managed by quantum theory bears chaotic behavior induced by *unitarity collapse* in its time development. Nonunitary time evolution of the Jaynes-Cummings (JC) model, the interacting system consisting of two subsystems (a two-level atom and a quantized photon field), under a continuous quantum-nondemolition (QND) measurement of the photon number is investigated. In the regime of weak coupling between the subsystems, the measured system shows the Rabi oscillation and the decrease of the photon number variance, which mimic the unmeasured JC system and the photon field under the continuous QND photodetection, respectively. In the strong coupling regime, the quantum system shows a nonintegrable nature, that is, it yields *weak chaos* characterized by both the broad continuous power spectrum and the decaying correlation function due to the lack of quantum recurrence [28].

VI. THEORETICAL STUDY OF ONE-ELECTRON STATES IN SOLIDS

(*H. Yasuhara, H. Yamagami, M. Higuch T. Endo, M. Horiuchi and S. Yoshinaga*)

1. Influence of Coulomb interaction on the Fermi hole in an electron liquid

From the diagrammatic analysis, it is proved that the spin-parallel part of the static structure factor of an electron liquid has the exact asymptotic form for q$\gg p_f$:$S^{\uparrow\uparrow}(\mathbf{q}) - 1 = 4(\alpha r_s/\pi)(p_f/q)^6 d^2 g^{\uparrow\uparrow}(\mathbf{r})/d(p_f r)^2|_{p_f r=0} + \cdots, \alpha = (4/9\pi)^{1/3}$, where p_f is the Fermi wave number and $g^{\uparrow\uparrow}(\mathbf{r})$ the spin-parallel pair correlation function. The second derivative of the spin-parallel pair correlation function at zero separation is evaluated in the particle-particle ladder approximation. [31]

2. Relativistic current- and spin-density functional theory

A new formulation of a relativistic current- and spin-density functional theory is proposed. By choosing the charge density and the magnetization density as the two basic variables, a single-particle equation is derived in a form suitable to an isolated atom or ion. The effect of the orbital current is included implicitly through the spin-orbit interaction and explicitly through the Zeeman term in which the spin and the orbital angular momenta couple with an effective magnetic field. The effective magnetic field is given by the variation of the exchange and correlation energy functional with respect to the magnetization density which consists of the spin and the orbital angular momentum density, and should be determined self-consistently. [32].

3. Relativistic calculations of the Fermi surfaces for f-electron materials within a local-density approximation

The electronic structures and the Fermi surface of f-electron materials which belong to the valence-fluctuation regime are calculated by using a fully relativistic linear augmented plane wave method with the exchange-correlation potential in a local-density approximation. We compare the calculated Fermi surface with the experiments of the dHvA effect. [33, 34]

4. Development of Fully-Relativistic Spin-Polarized LAPW Method and its Applications.

The linearized-augmented-plan-wave (LAPW) method [35] was generalized to case of an all-electron fully-relativistic spin-polarized self-consistent band calculation based on the relativistic spin-density functional theory. Inside spheres around nuclei, the Bloch function is expanded by spherical-symmetry bases and their energy-derivatives, each of which is solved by the corresponding spin-polarized coupled Dirac equation (SPCDE) including a coupling of $j = \ell - 1/2$ with $j = \ell + 1/2$ partial state through the magnetic field. In the interstitial region, the relativistic plane wave is used as a conventional basis function. The core states inside the spheres were treated on the same footing of the SPCDE in all iterative processes. This band theory was applied to BCC Fe, HCP Gd and uranium monochalcogenides US, USe and UTe as an interesting example of the ferromagnetic 3d, 4f and 5f systems, respectively [35]. Also, the band calculations of LaB_6 [36] and CrP [37] are performed as non-magnetic compounds, and detail analyses of experimental results measured by the angle-resolved photoemission [36] and dHvA effect [37] was done by means of the band structure and the Fermi surface.

5. Strong electron correlation in localized state.

A formulation was proposed to treat the ground-state properties of an assembly of electrons, interacting mutually through the Coulomb potential and

confined by an external potential V whose maximum is finite so that both bound and extended continuum states appear as eigen states for the one-body Hamiltonian composed of the electron kinetic energy and V. These extended states are found to play a crucial role in incorporating the effect of electron correlation into the localized ground-state many-electron wave function. As an illustration of our formalism, the ground-state energy of a He atom was calculated and compared rather successfully with experiment as well as the results in other serious numerical methods. Special attention was paid to the pair function in this system in order to elucidate a qualitative difference from that in the homogeneous electron gas. This function shows clearly that the two electrons with opposite spins in He correlate strongly over quite a long range in contrast to the common expectation that the ground-state wave function for the He atom can be described accurately in the Hartree-Fock approximation [38].

6. Ab-initio studies on electronic and magnetic properties of uranium compounds.

The electronic structures and the Fermi surface of some uranium compounds, UB_2 [39, 40, 41], USb [42], URu_2Si_2 and UPd_2Al_3 [43], are calculated by using a fully-relativistic spin-polarized LAPW (RSPLAPW) method with the exchange-correlation potential in a local-density approximation. This method can apply to non-magnetic materials, and the band calculations for paramagnetic UB_2 was done to compare its Fermi surface with the experiments of the dHvA effect [39, 40, 41]. As a result, the origin of dHvA branches and the magnitude of cyclotron mass were well explained by the $5f$-itinerant model. The uranium nonpunictide USb has a triple-**k** magnetic structure below the Néel temperature of 214 K. The band structure and magnetic moments were obtained by a non-collinear version of RSPLAPW method [42]. The 5f states, which hybridize with the 6d states, are split due to the internal magnetic field. The 5f bands are separated from the Fermi level. The energetically-5f-localized behavior explains the small specific heat coefficient at low temperature. As for URu_2Si_2 and UPd_2Al_3, it is well known to show antiferromagnetic orders with small magnetic moments. From self-consistent calculations, the magnetic moments are in good agreements to the values measured by neutron-scattering. From the SPRLAPW calculations, the small moments can be interpreted as a strong cancellation between the spin and orbit moment.

VII. ATOMIC AND ELECTRONIC STRUCTURES OF APERIODIC SYSTEMS

(*K. Niizeki, E. Yagi, N. Fujita, K. Kurabayashi and N. Takahashi*)

1. Symmetrical Staircase in the Profile of Lattice-Modulation Period versus Pr-Concentration in $Bi_2Sr_2\,(Ca_{1-x}Pr_x)\,Cu_2O_{8+\delta}$

The variation of the lattice-modulation period p_a of the "incommensurate" phase $Bi_2Sr_2\ (Ca_{1-x}Pr_x)\ Cu_2O_{8+\delta}$ $(0 \leq x \leq 0.72)$ with Pr-concentration x was examined by means of electron diffraction [44]. The plot of p_a versus x exhibits roughly a linear decrease but it has a structure of a staircase. The period of each stair, p_a, agrees with a value expected for a commensurate structure. We observed nine stairs which are symmetrically arranged; the central stair corresponds to the primary structure with a simple modulation, and a stair on the

left (or right) corresponds to a structure which is derived from the primary structure by introducing an advanced (or delayed) discommensuration. The observed structures cover a full range of commensurate structures predicted theoretically.

2. Localization of Electronic Wave Functions in Quasicrystals

It is known that all the wave functions of the conventional model of quasicrystals are critical with respect to localization. The origin of absence of localization for the case of the conventional model is believed to be the Conway's theorem which characterizes the distribution of the local patterns of atomic potentials. However, the real potential is the self-consistent one which will violate the theorem because it is a sum of extended potentials exhibiting undulation known as the Friedel oscillation. Therefore we have performed a numerical calculation of the one-electron properties of a model quasicrystal in the Hartree-Fock-Slater approximation. A preliminary result indicates that all the wave functions are localized.

VIII. THE STRUCTURAL AND ELECTRONIC PROPERTIES OF SULFUR UNDER HIGH PRESSURE

(*K. Niizeki*)

We have performed band structure calculations of high-pressure phases of sulfur within the local-density functional formalism and the norm-conserving pseudopotential method to investigate the structural stability of the rhombohedral structure phase of sulfur and a new structural model with decreasing pressure [45].

IX. REFORMULATION OF THE THERMODYNAMICS

(*K. Niizeki*)

The central proposition of the thermodynamics is the entropy principle which consists of two parts: i) every thermodynamical system has a variable of state called entropy, and ii) the sum of the entropies of the thermodynamics systems never decreases on any thermodynamics process performed using the systems. The entropy principle is one of the fundamental laws in physics. It is asserted in most textbook in the thermodynamics that the entropy principle is derived deductively from the three basic laws, namely, the zeroth, first and second laws of the thermodynamics. Unfortunately, there are a lot of serious logical jumps in the conventional presentation of the thermodynamics. This is the reason why the thermodynamics is one of the most hard subjects in the curriculum of physics. I have succeeded in reformulating the thermodynamics, so that all the serious logical jumps are eliminated. I am now writing a textbook based on the new formulation.

X. THEORY OF QUANTUM HALL SYSTEMS

(*K. Niizeki, T. Nakajima and J. Watanabe*)

1. Bilayer quantum Hall system and fractional quantum Hall effect

We have investigated the coherent nature of the ground states for the bilayer quantum Hall system at the total Landau-level filling of $\nu = 1/m$ (m: odd integer) [46]. We found that we can use a 'squeezed-vacuum' state conceived in quantum optics to give the ground-state wave function in the bilayer quantum Hall ferromagnet. This was derived in the boson approximation, where a particle-hole pair creation across the symmetric-antisymmetric gap is regarded as a boson. In terms of the pseudospin describing the layers, the state is also a spin-squeezed state, where the degree of squeezing is controlled by the layer separation and the interlayer tunneling amplitude.

We have also examined the bilayer $\nu = 1$ quantum Hall system from the viewpoint of the localization-delocalization transition. The localization properties have been investigated extensively by using the Hartree-Fock approximation.

We have also reviewed the theories and experiments on the fractional quantum Hall effect [47].

XI. THEORY OF MACROSCOPIC QUANTUM PHNOMENA

(*S. Takagi, Y. Yamamoto, J. Shibata, R.Ishii, Y. Iwaki and K. Nagata*)

1. Particle Tracks and the Mechanism of Decoherence in a Model Bubble Chamber

We put forward a toy model for a 'bubble chamber' and study its interaction with an incoming object particle. We discuss the notion of particle 'tracks' inside the bubble chamber and analyze the mechanisms that provoke a loss of quantum mechanical coherence (decoherence). The model is solvable and provides interesting insights into some of the most salient features of the interaction between a microscopic particle and a macroscopic device. [48].

2. The World of Quantum

Quantum theory and its contemporary implications are reviewed in a pedagogical manner with emphasis on conceptual aspects and modern development including macroscopic quantum phenomena. [49].

XII. RENOMALIZATION THEORY OF STRONGLY INTERACTING QUANTUM SYSTEMS (*T. Fujieda and T. Tsuzuki*)

1. The flow equation method of renormalization

Infinitesimal unitary transformation is applied to strongly interacting quantum many-body system to obtain a set of flow equations in the first order differential form of flow parameter. The generator of transformation is chosen to be that proposed by Wegner which is able to diagonalize the Hamiltonian without

resonance anomaly. Applying this method to a spin-boson system we have obtained the flow equations in which interactions are eliminated up to two-boson processes precisely. They are different from those found in previous works. The reasons of discrepancy are clarified. The main one is a lack of consideration with respect to the symmetry of interaction induced by the transformation. Numerical study has been done, finding a critical strength α of spin-boson interaction for the localization-delocalization transition to be less than 1/2. Correlation functions are under study by use of the generator obtained.

XIII. PHYSICS ON NOISE-INDUCED-TRANSPORT IN MULTISTABLE SYSTEMS (*F. Takagi, T. Hondou and T. Tsuzuki*)

1. Chaotic-noise-induced energy conversion

How efficiently can noise be transformed into coherent energy? We answered this question by estimating the rate of energy conversion of chaotic noise into work analytically and numerically[50].

2. Energetic analysis of a forced thermal ratchet

We first estimated the rate of energy conversion of external fluctuation into work by a forced thermal ratchet. We showed that the dependence of energetic efficiency on the strength of thermal noise is qualitatively different from that of the probability current[51].

3. Irreversible operation in a stalled state of Feynman's ratchet

We considered the Langevin dynamics which describes the transducer of thermal fluctuation into mechanical work. In the frame of Feynman's ratchet, we prove that irreversibility is unavoidable in operating the transducer if the system is described by the conventional Langevin equation with two degree of freedom, where the degree correspond to two heat baths of different temparatures[52].

References

[1] *Perturbative renormalization of multi-channel Kondo-type models*, Y. Kuramoto, European J. Phys. B **5** (1998) 457–464.

[2] *Orbital Kondo effect in $Ce_xLa_{1-x}B_6$: scaling analysis*, H. Kusunose and Y. Kuramoto, Phys. Rev. B **59** (1999) 1902–1991.

[3] *Fluctuation of orbital and magnetic moments in orbitally degenerate systems*, H. Kusunose, N. Fukushima and Y. Kuramoto, Physics of Strongly Correlated Electron Systems, JJAP Series 11 (ed. T. Komatsubara et al, Publication Office, Japanese Journal of Applied Physics, 1999) p.185–187.

[4] *Entanglement of spin and orbital degrees of freedom in f-electron systems*, Y. Kuramoto, H. Kusunose, N. Fukushima and T. Kuromaru, Proc. 4th Int. Symposium on Advanced Physical Fields (G. Kido ed., National Research Institute for Metals) (1999) p.33–36.

[5] *Effects of a magnetic field on fluctuation of the quadrupolar ordering — application to the phase diagram of CeB_6—*, N. Fukushima and Y. Kuramoto, J. Phys. Soc. Jpn. **68** (1998) 2460–2468.

[6] *Spin, charge and quasi-particle gaps in the one-dimensional Kondo lattice with f^2 configuration*, S. Watanabe, Y. Kuramoto, T. Nishino and N. Shibata, J. Phys. Soc. Jpn. **68** (1999) 159–165 .

[7] *Ground state and elementary excitation gaps in the one-dimensional Kondo lattice with f^2 configuration*, S. Watanabe, Y. Kuramoto, T. Nishino and N. Shibata, Physics of Strongly Correlated Electron Systems, JJAP Series 11 (ed. T. Komatsubara et al, Publication Office, Japanese Journal of Applied Physics, 1999) p.106–108.

[8] *Stability of the striped phase in the two-dimensional t-J model: A variational Monte Carlo study*, K. Kobayashi and H. Yokoyama, Physica B **259-261** (1999) 506–508.

[9] *Dynamical structure factors of the spin-1/2 XXZ chain with inverse-square exchange and Ising anisotropy*, Y. Saiga and Y. Kuramoto, J. Phys. Soc. Jpn. **67** (1998) 1319–1331.

[10] *Exact dynamics of one-dimensional t-J model with long-range interaction*, Y. Saiga, M. Arikawa and Y. Kuramoto, Physics of Strongly Correlated Electron Systems, JJAP Series 11 (ed. T. Komatsubara et al, Publication Office, Japanese Journal of Applied Physics, 1999) p.138–140.

[11] *Jack polynomials with prescribed symmetry and hole propagator of spin Calogero-Sutherland model*, Y. Kato and T. Yamamoto: J. Math. A: Math. Gen. **31** (1998) 9171–9184.

[12] *Dynamical correlation functions of the spin Calogero-Sutherland model*, T. Yamamoto and M. Arikawa, J. Phys. A: Math. Gen. **32** (1999) 3341–3356.

[13] *Numerical Renormalization Group Study of non-Fermi-liquid State on Dilute Uranium Systems*, Y. Shimizu, O. Sakai and S. Suzuki, J. Phys. Soc. Jpn. **67** (1998) 2395-2407.

[14] *Study on Non-Fermi-Liquid Properties*, O. Sakai, Physics of Strongly Correlated Electron Systems, JJAP Series 11 (ed. T. Komatsubara et al, Publication Office, Japanese Journal of Applied Physics, 1999) p.141-144.

[15] *Numerical Renormalization Group Study on the Non-Fermi-Liquid Behavior of Impurity Anderson Model with Non-Kramers Doublet State*, O. Sakai, Y. Shimizu and S. Suzuki, Physics of Strongly Correlated Electron

Systems, JJAP Series 11 (ed. T. Komatsubara et al, Publication Office, Japanese Journal of Applied Physics, 1999) p.148–150.

[16] *Single Impurity Anderson Model with Coulomb Repulsion between Conduction Electrons on the Nearest Neighbour Ligand Orbital*,
R. Takayama and O. Sakai,
J. Phys. Soc. Jpn. **67** (1998) 1844–1847.

[17] *Interplay of Field-Induced Multipoles in CeB_6*,
R. Shiina, O. Sakai, H. Shiba and P. Thalmeier,
J. Phys. Soc. Jpn. **67** (1998) 941–949.

[18] *Antiferro-Quadrupolar Ordering and Field-Induced Multipoles in f-Electron Systems: CeB_6 and TmTe*,
R. Shiina, H. Shiba and O. Sakai, Physics of Strongly Correlated Electron Systems, JJAP Series 11 (ed. T. Komatsubara et al, Publication Office, Japanese Journal of Applied Physics, 1999) p.176–178.

[19] *Physics of Multipolar Ordering of CeB_6 in Applied Magnetic Field* (in Japanese)
R. Shiina and O. Sakai,
Solid State Physics **33** (1998) 631–643.

[20] *Theory of Multipolar Excitations in CeB_6*,
P. Thalmeier, R. Shiina, H. Shiba and O. Sakai,
J. Phys. Soc. Jpn. **67** (1998) 2363–2371.

[21] *High-Resolution Angle-Resolved Photoemission Study of LaSb*,
H. Kumigashira, H.-D Kim, T. Ito, A. Ashihara, T. Takahashi, T. Suzuki, M. Nishimura, O. Sakai, Y. Kaneta and H. Harima,
Phys. Rev. B **58** (1998) 7675–7680.

[22] *Observation of Two Low-energy Responses in UPd_2Al_3 -Interaction of Magnetic and Superconductivity?*,
N. Sato, N. Aso, B. Roessli, G. H. Lander, T. Komatubara, Y. Endoh, and O. Sakai,
J. of Alloys and Compounds **271-273** (1998) 433–436.

[23] *Kondo Effect in Single Quantum Dot Systems -Study with Numerical Renormalization Group Method-*,
W. Izumida, O. Sakai and Y. Shimizu, J. Phys. Soc. Jpn. **67** (1998) 2444–2454.

[24] *Kondo Effect in Electron Tunneling through Quantum Dots*,
O. Sakai, W. Izumida and S. Suzuki,
Proceedings of the 4th International Symposium on Advanced Physical Fields: Quantum Phenomena in Advanced Materials at High Magnetic Fields, March 9–11, 1999, Tsukuba, Japan ed. G. Kido (1999) p.143–146.

[25] *Kondo Effect in Quantum Dots* (in Japanese)
O. Sakai and W. Izumida, Parity **13** No.12 (1998) p.80–82.

[26] *Domino effects in photoinduced structural change in one-dimensional systems*,
K. Koshino and T. Ogawa, J. Phys. Soc. Jpn. **67** (1998) 2174–2177.

[27] *Optical detection of critical exponents in the Tomonaga-Luttinger liquid*,
T. Ogawa, Physica B **249** (1998) 185–190.

[28] *Jaynes-Cummings model under continuous measurement: Weak chaos in a quantum system induced by unitarity collapse*,
T. Fukuo, T. Ogawa and K. Nakamura, Phys. Rev. A **58** (1998) 3293–3302.

[29] *Photoinduced nucleation theory in one-dimensional systems*,
K. Koshino and T. Ogawa, Phys. Rev. B **58** (1998) 14804–14811.

[30] *Dynamics of photoinduced structural transitions: From mean-field picture to nucleation picture*, T. Ogawa and K. Koshino, in *Physics and Chemistry of Solids* (Wroclaw, 1998) p. 131–138.

[31] *Influence of Coulomb interaction on the Fermi hole in an electron liquid*,
M. Horiuchi, T. Endo and H. Yasuhara, Physica A **255** (1998) 48–64.

[32] *Single-particle equation of relativistic current- and spin- density functional theory and its application to the atomic structure of the lanthanide series*,
M. Higuchi and A. Hasegawa, J. Phys. Soc. Jpn. **67** (1998) 2037–2047.

[33] *Magnetoresistance and de Haas-van Alphen Oscillation Both in the Normal and Superconducting Mixed States of* $CeRu_2$,
M. Hedo, Y. Inada, K. Sakurai, E. Yamamoto, Y. Haga, Y. Onuki, S. Takahashi, M. Higuchi, T. Maehira and A. Hasegawa, Philosophical Magazine B **77** (1998) 975–1000.

[34] *Fermi Surface of 5f-electron compounds*,
T. Maehira, M. Higuchi, M. Nakamura and A. Hasegawa, J. Phys. :Condens. Matter **10** (1998) 11565–11579.

[35] *All-Electron Spin-Polarized Relativistic Linearized APW method: Electronic and Magnetic Properties of BCC Fe, HCP Gd and Uranium Monochalcogenides*,
H. Yamagami, J. Phys. Soc. Jpn. **67** (1998) 3176–3190.

[36] *Electron Correlation Effects Observed in Surface Resonance States of* LaB_6*(110)*,
A. Kakizaki, A. Harasawa, A. Kimura, H. Yamagami and S. Kunii, Magnetism and Electronic Correlations in Local-Moment Systems, Edited by M. Donath, P. A. Dowben and W. Nolting (World Scientific, Singapol, 1999) p. 431–439.

[37] *de Haas-van Alphen Effect in CrP*,
T. Nozue, H. Kobayashi, H. Yamagami, T. Suzuki and T. Kamimura, J. Magn. Soc. Jpn. **23** (1999) 430–432.

[38] *Strong Electron Correlation in a Localized State Described in Terms of Extended States: General Formulation and Illustration in a Helium Atom*,
H. Yamagami and Y. Takada, J. Phys. Soc. Jpn. **67** (1998) 2695–2714.

[39] *de Haas-van Alphen Effect and Energy Band Structure in UB_2*,
E. Yamamoto, Y. Haga, T. Honma, Y. Inada, D. Aoki, M. Hedo, Y. Yoshida, Y. Yamagami and Y. Ōnuki, J. Phys. Soc. Jpn. **67** (1998) 3171–3175.

[40] *Fermi Surface of UB_2 studied by the de Haas-van Alphen oscillation*,
E. Yamamoto, T. Honma, Y. Haga, Y. Inada, D. Aoki, M. Hedo, Y. Yoshida, Y. Yamagami and Y. Ōnuki, Physica B **259-261** (1999) 1085–1086.

[41] *De Haas-van Alphen Effect of UB_2, UB_4 and UGa_3*,
E. Yamamoto, T. Honma, Y. Haga, D. Aoki, M. Hedo, Y. Inada, R. Settai, H. Yamagami and Y. Ōnuki, Physics of Strongly Correlated Electron Systems, JJAP Series 11 (ed. T. Komatsubara et al, Publication Office, Japanese Journal of Applied Physics, 1999) 209–211.

[42] *Electronic Structure of USb in the Non-Collinear Magnetic State*,
H. Yamagami, Physica B **259-261** (1999) 236–237.

[43] *Electronic and Magnetic Properties of f-Electron Systems in Relativistic Spin-Polarized LAPW Method*,
H. Yamagami, Physics of Strongly Correlated Electron Systems, JJAP Series 11 (ed. T. Komatsubara et al, Publication Office, Japanese Journal of Applied Physics, 1999) 206–208.

[44] *Symmetrical Staircase in the Profile of Lattice-Modulation Period versus Pr-Concentration in $Bi_2Sr_2(Ca_{1-x}Pr_x)Cu_2O_{8+\delta}$*,
T. Onozuka and K. Niizeki, J. Phys. Soc. Jpn. **67** (1998) 2984–2987.

[45] *The Structural and Electronic Properties of Sulfur Under High Pressure*,
A. Nishikawa, K. Niizeki and K. Shindo, phys. stat. sol. (b) **211** (1999) 373–378.

[46] *Coherent states in the bilayer fractional quantum Hall ferromagnet*,
T. Nakajima and H. Aoki, Physica B **249-251** (1998) 828–831.

[47] *Theory of Interacting Electrons vol. III Fractional Quantum Hall Effect*,
T. Nakajima and H. Aoki (University of Tokyo Press, 1999), (a textbook in Japanese, p.200).

[48] *Particle Tracks and the Mechanism of Decoherence in a Model Bubble Chamber*,
R. Blasi, S. Pascazio and S. Takagi, Phys. Lett. **A 250**(1998) 230–240.

[49] *The World of Quantum* in The New Frontier of Science/Technology (1) ed. H.Sato et al (A book in Japanese),
S. Takagi, (Iwanami-Shoten Publishers, Tokyo, 1999) 119–144.

[50] Transformtion of dynamical fluctuation into coherent energy,
T. Hondou, J. Phys. Soc. Jpn. **67** (1998) 1818–1821.

[51] Energetics of a forced thermal ratchet,
H. Kamegawa, T. Hondou and F. Takagi, Phys. Rev. Lett. **80** (1998) 5251–5254.

[52] Irreversible operation in a stalled state of Feynman's ratchet,
T. Hondou and F. Takagi, J. Phys. Soc. Jpn. **67** (1998) 2974–2976.

Doctor Thesis (1999.3)

D1) *Kondo Effect in Quantum Dot Systems*,
Wataru Izumida
D2) *Dynamics and Quasi-Particle Picture of One-Dimensional Quantum Systems with Long-Range Interaction*,
Yasuhiro Saiga

Master Thesis (1999.3)

M1) *On the Coherency of Two Independent Bose Condensates*,
Rikie Ishii
M2) *Dynamics of Photoinduced Phase Transitions*,
Yasuo Okajima
M3) *Nonlinear Optical Response Theory for a Few Exciton System*,
Satoru Okumura
M4) *Effects of Quadrupolar Interaction on Magnetic Anisotropy of Localized f Electrons*,
Tomoya Kuromaru
M5) *Phase Transitions in Multilayer Electron Systems in Strong Magnetic Fields*,
Sei Suzuki
M6) *Study on Magnetic Proerties of Low Density Carrier Magnetic Semiconductors*,
Kenichi Nishizawa
M7) *Flow Equation Method of Renormalization*,
Takeshi Fujieda