

International Workshop on Itinerant-Electron Magnetism

Date

September 25-27, 2015

Place

Science Seminar House, North Campus of Yoshida,
Kyoto University, Kyoto city, Japan

Theme of this workshop

In these several decades, a lot of important approaches have been conducted in order to understand the itinerant-electron magnetism. Among them epoch-making was the great success of the spin-fluctuation theory for weak itinerant ferro- and antiferromagnets by Moriya and Kawabata based upon the self-consistent renormalization of spin fluctuations in 1973 (the SCR theory). Afterwards, the spin fluctuation theory has been developed toward the unified theory between the weakly itinerant and localized moment regimes in the metallic magnets in a phenomenological way by Moriya and Takahashi (1978). Then, the SCR theory has been developed and rearranged in a quantitative way by Takahashi and Moriya in 1985 (Quantitative Aspect of Spin Fluctuations), by which we can compare the experiments and the SCR theory quantitatively by means of a set of (several numbers of) spin-fluctuation parameters.

Furthermore, Takahashi has developed the spin-fluctuation theory in different approaches with some assumptions: the total spin amplitude conservation (TAC) and global consistency (GC) so far (1986~), which possibly leads us to the unified picture of metallic magnetism with a wide variety of itinerant-electron magnets based upon the spin-fluctuation approaches.

Since the novel superconductors with the magnetic origins have been discovered in the strongly correlated electron systems, *e.g.*, the Heavy-Fermion compounds and intermetallics, the organic systems, the high- T_c cuprates, and Fe pnictides, moreover the correlations and interplays between the itinerant magnetism and the so-called exotic superconductivity have been more and more important, and to understand the itinerant-electron characteristics has recently become one of the most difficult and important issues in the solid state sciences.

In this workshop, we wish to bring together an international group of leading theoreticians and experimental scientists on magnetism to discuss advanced topics in condensed matter physics, especially related to spin fluctuations in itinerant-electron magnetism including exotic superconductivity with magnetic origins, and to shape the future development of this field. We also plan to invite young scientists as well as graduate students. We hope that such young scientists have chance to talk with invited speakers and organizers on their own interests. Finally, this workshop is also organized in commemoration of Prof. Y. Takahashi's retirement from University of Hyogo, Japan.

(Kazuyoshi Yoshimura)

Invited Speakers

Rafik Ballou

Institute Néel, CNRS & University Joseph Fourier, Grenoble, France

Nicholas Curro

Department of Physics, University of California, Davis, California, USA

Minghu Fang

Department of Physics, Zhejiang University, Hangzhou, China

Asaya Fujita

Green Magnetic Material Research Center, AIST Chubu, Nagoya, Japan

Swee K. Goh

Department of Physics, The Chinese University of Hong Kong, Hong Kong, China

Jürgen Haase

Faculty of Physics and Earth Sciences, University of Leipzig, Leipzig, Germany

Zenji Hiroi

The Institute for Solid State Physics, The University of Tokyo, Chiba, Japan

Kenji Ishida

Department of Physics, Graduate School of Science, Kyoto University, Japan

Masayuki Itoh

Department of Physics, Graduate School of Science, Nagoya University, Nagoya, Japan

Ryosuke Kadono

Muon Science Laboratory, Institute of Materials Structure Science, KEK, Ibaraki, Japan

Shinsaku Kambe

Advanced Science Research Center, Japan Atomic Energy Agency, Ibaraki, Japan

Toru Sakai

Graduate School of Material Science, University of Hyogo, Hyogo, Japan

Japan Atomic Energy Agency, SPring-8, Sayo, Hyogo, Japan

Noriaki Sato

Department of Physics, Graduate School of Science, Nagoya University, Japan

Yoshinori Takahashi

Graduate School of Material Science, University of Hyogo, Japan

Masashi Takigawa

The Institute for Solid State Physics, The University of Tokyo, Chiba, Japan

Takeshi Waki

Department of Materials Science and Engineering, Graduate School of Engineering, Kyoto University, Japan

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Swee K. Goh

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Jürgen Haase

Faculty of Physics and Earth Sciences, University of Leipzig, Leipzig, Germany

Keiichi Koyama

Graduate School of Science and Engineering, Kagoshima University, Kagoshima, Japan

Masatoshi Murase

Yukawa Institute for Theoretical Physics, Kyoto University, Japan

Kazuo Nishimura

Institute of Economic Research, Kyoto University, Japan

Raivo Stern

National Institute of Chemical Physics & Biophysics, Estonia

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Research Center for Low Temperature and Materials Sciences, Kyoto University, Japan

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Graduate School of Material Science, University of Hyogo, Japan

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Noriaki Sato Department of Physics, Graduate School of Science, Nagoya University, Japan

Hisao Kobayashi Graduate School of Material Science, University of Hyogo, Japan

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Kyoto Convention & Visitors Bureau

Program of Workshop

Friday 25th September

17:00- Get Together (1st Lobby, Graduate School of Science Bldg. No. 6(North))

Saturday 26th September

Opening (9:00-9:30)

Kazuyoshi Yoshimura (Kyoto University, Japan)

“ Itinerant-Electron Magnetic Systems —Experiments and Theories ”

Oral Session 1 (9:30-12:15)

Chair(First half): **Hisao Kobayashi** (University of Hyogo, Japan)

Chair(Second half): **Hironori Sakai** (JAEA, Japan)

9:30 **Yoshinori Takahashi** (University of Hyogo, Japan)

“ Theoretical Development in Itinerant Electron Ferromagnetism ”

10:00 **Jürgen Haase** (University of Leipzig, Germany)

“ Uniform Spin Susceptibility and a New Phase Diagram from NMR of Cuprate Superconductors ”

break (10:30-10:45)

10:45 **Rafik Ballou** (Institute Néel, CNRS & University Joseph Fourier, France)

“ The Spin Liquid Phase Conundrum in the Metallic Magnet YMn_2 ”

11:15 **Ryosuke Kadono** (KEK, Japan)

“ Quasi-One-Dimensional Spin Dynamics at Low Energies in d-electron Heavy-Fermion-like Metals ”

11:45 **Masashi Takigawa** (The University of Tokyo, Japan)

“ NMR Investigations on Novel Fluctuations in f Electrons ”

lunch (12:15-13:30)

Oral Session 2 (13:30-16:00)

Chair(First half): **Chishiro Michioka** (Kyoto University, Japan)

Chair(Second half): **Yoshikazu Tabata** (Kyoto University, Japan)

13:30 **Zenji Hiroi** (The University of Tokyo, Japan)

“ Revisiting the Metal-Insulator Transition of VO_2 : Molecular Orbital Crystallization ”

14:00 **Masayuki Itoh** (Nagoya University, Japan)

“ Heavy-Fermion Behavior and Metal-Insulator Transition in Vanadium Oxides Investigated by NMR ”

14:30 **Shinsaku Kambe** (Japan Atomic Energy Agency, Japan)

“ Distributed Twofold Ordering in URu_2Si_2 ”

15:00 Nicholas Curro (University of California, Davis, USA)
“ NMR Studies of Inhomogeneous Glassy Behavior driven by Nematic Fluctuations in Iron Arsenide Superconductors ”

15:30 Kenji Ishida (Kyoto University, Japan)
“ Nuclear Magnetic Resonance Studies on Ferromagnetic Superconductor UCoGe ”

break (16:00-16:30)

Poster Session (16:30-18:00)

Chair: **Hiroto Ohta** (Tokyo University of Agriculture & Technology, Japan)

Chair: **Yoshihiko Ihara** (Hokkaido University, Japan)

Banquet (18:30-20:30)

Sunday 27th September

Oral Session 3 (9:30-12:45)

Chair(First half): **Hiroaki Ueda** (Kyoto University, Japan)

Chair(Second half): **Hiroyuki Nakamura** (Kyoto University, Japan)

9:30 Takeshi Waki (Kyoto University, Japan)
“ Itinerant Electron Magnetism in Cr-based MAX Phase Compounds ”

10:00 Minghu Fang (Zhejiang University, China)
“ Superconductivity and Itinerant Electron Magnetism in $\text{TlCo}_{2-x}\text{Ni}_x\text{Se}_2$ System ”

10:30 Toru Sakai (University of Hyogo, Japan)
“ Quantum Spin Liquid in the Kagome-Lattice Antiferromagnet and Related Systems ”

break (11:00-11:15)

11:15 Swee K. Goh (The Chinese University of Hong Kong, China)
“ Structural Quantum Criticality in Superconducting $(\text{Ca}_x\text{Sr}_{1-x})_3\text{Rh}_4\text{Sn}_{13}$ ”

11:45 Asaya. Fujita (AIST Chubu, Japan)
“ Entropics: science and engineering of caloric phenomena related to itinerant-electron magnetism and spin fluctuations ”

12:15 Noriaki K. Sato (Nagoya University, Japan)
“ Quantum Critical Behavior in Magnetic Quasicrystals and Approximant Crystals ”

Closing (12:45)

Hiroyuki Nakamura (Kyoto University, Japan)

List of Poster Presenters

- PS-1** Yusuke Amakai (Grad. Sch. of Engineering, Muroran Institute of Technology)
- PS-2** Naoya Emi (Grad. Sch. of Science, Univ. of Hyogo)
- PS-3** Masato Goto (Grad. Sch. of Science, Kyoto Univ.)
- PS-4** Yuya Haraguchi (Grad. Sch. of Science, Kyoto Univ.)
- PS-5** Soshi Ibuka (IMSS, High Energy Accelerator Research Organization)
- PS-6** Yoshihiko Ihara (Grad. Sch. of Science, Hokkaido Univ.)
- PS-7** Shugo Ikeda (Grad. Sch. of Material Science, Univ. of Hyogo)
- PS-8** Masaki Imai (Grad. Sch. of Science, Kyoto Univ.)
- PS-9** Takashi Kanno (Grad. Sch. of Science, Kyoto Univ.)
- PS-10** Mohamed Abdelkareem Kassem (Dept. of Mater. Sci. Eng., Kyoto Univ.)
- PS-11** Noriaki Kimura (Grad. Sch. of Science, Tohoku Univ.)
- PS-12** Shintaro Kobayashi (Grad. Sch. of Science, Kyoto Univ.)
- PS-13** Rikio Konno (Kinki Univ. Technical College)
- PS-14** Takehide Koyama (Grad. Sch. of Material Science, Univ. of Hyogo)
- PS-15** Zhongsheng Liu (Dept. of Materials Science and Engineering, Kyoto Univ.)
- PS-16** Mizuho Maeda (Grad. Sch. of Science, Tohoku Univ.)
- PS-17** Masahiro Manago (Grad. Sch. of Science, Kyoto Univ.)
- PS-18** Takeshi Mito (Grad. Sch. of Material Science, Univ. of Hyogo)
- PS-19** Haruka Morishita (Grad. Sch. of Science, Kyoto Univ.)
- PS-20** Ryo Nakabayashi (Alps Green Device Co.,Ltd.)
- PS-21** Satoru Noguchi (Research Organization for the 21st Century, Osaka Pref. Univ.)
- PS-22** Jun Ohara (Dept. of Physics, Hokkaido Univ.)
- PS-23** Hiroto Ohta (Grad. Sch. of Engineering, Tokyo Univ. of A & T)
- PS-24** Hironori Sakai (Advanced Science Research Center, Japan Atomic Energy Agency)
- PS-25** Hiroya Sakurai (National Institute for Materials Science)
- PS-26** Alisa Shimada (Grad. Sch. of Science, Kyoto Univ.)
- PS-27** Sho Shinohara (Grad. Sch. of Science, Kyoto Univ.)

- PS-28** Atsushi Suzuki (Grad. Sch. of Engineering, Tokyo Univ. of A & T)
- PS-29** Kenta Takao (Dept. of Materials Science and Engineering, Kyoto Univ.)
- PS-30** Yasuaki Tanioku (Dept. of Chemistry, Grad. Sch. of Science, Kyoto Univ.)
- PS-31** Naohito Tsujii (National Institute for Materials Science)
- PS-32** Hangdong Wang (Dept. of physics, Hangzhou Normal Univ.)
- PS-33** Yusuke Watanabe (Grad. Sch. of Engineering, Tokyo Univ. of A & T)
- PS-34** Takayoshi Yamanaka (Grad. Sch. of Science, Kyoto Univ.)
- PS-35** Ichihiko Yamauchi (High Energy Accelerator Research Organization (KEK))
- PS-36** Yao Zhang (Grad. Sch. of Science, Kyoto Univ.)
- PS-37** Soshi Yoshinaga (Grad. Sch. of Science and Engineering, Kagoshima Univ.)

Abstracts

**-Oral Presenters-
16 Presentations**

Theoretical development in itinerant electron ferromagnetism

Yoshinori Takahashi

Graduate School of Material Science, University of Hyogo, Ako-gun 678-1297, Japan

It is known that the Curie-Weiss law temperature dependence of magnetic susceptibility of itinerant electron weak ferromagnets is derived from the self-consistent treatment of the non-linear effect of thermal spin fluctuations. Since the main interest in this approach has been restricted only to the temperature dependence of the magnetic susceptibility, several difficulties have still remained unresolved. For instance, the spontaneous magnetic moment remains finite at the critical point, and the critical magnetization.

The purpose of this review is to show that both the critical behaviors of temperature and external magnetic field dependence have to be treated on the same footing, in order to overcome the above difficulties. We show that the spin amplitude conservation against temperature and external magnetic field variations plays a predominant role in this respect. The zero-point fluctuation amplitude has also to be included in the total amplitude for this purpose. curve violates the scaling law relation of the theory of phase transition.

An interesting aspect of this approach is that the amplitude conservation is regarded as an ordinary differential equation for the ratio of the external field H to the magnetization M , i.e. H/M , as the function of M . Therefore, the main target of the theory is to find the functional relation between the moment M and the external field H . We show how various temperature and field dependent behaviors, e.g. the magnetic isotherms in the ground state and at the critical point as well as the temperature dependence of the magnetic susceptibility and the spontaneous magnetic moment, are actually derived as its solutions. These obtained results obtained theoretically are fairly in good agreement with experiments.

Saturday 26th Sept. Oral Session 1 at 10:00

Uniform Spin Susceptibility and a New Phase Diagram from NMR of Cuprate Superconductors

Jürgen Haase

Faculty of Physics and Earth Science, University of Leipzig, D-04103 Leipzig, Germany

We will summarize our recent findings on the NMR shifts of cuprates, which must be described with three components that have rather different temperature and doping dependences. We also show that the charge contents of the bonding orbitals of copper as well as oxygen, determined with NMR, give a very different perspective on the cuprate phase diagram. For example, it relates the superfluid density to the oxygen charge content.

Saturday 26th Sept. Oral Session 1 at 10:45

The spin liquid phase conundrum in the metallic magnet YMn_2

R. Ballou

Institut Néel, C.N.R.S. & U.G.A., 38042 Grenoble, France

Neutron scattering on single crystals reveal that the disorder phase of the geometrically frustrated itinerant antiferromagnet YMn_2 distinguishes itself by short ranged dynamical correlations reminiscent of a spin liquid. Under pressure this phase persists down to the lowest temperature, where an heavy fermion behaviour unexpected for 3d itinerant electrons is then observed. The origin and nature of this disorder phase remain puzzling. I shall describe its main experimental characteristics, in particular as probed by neutron scattering.

Saturday 26th Sept. Oral Session 1 at 11:15

Quasi-one-dimensional spin dynamics at low energies in d -electron heavy-fermion-like metals

Ryosuke Kadono

Muon Science Laboratory and Condensed Matter Research Center, Institute of Materials Structure Science, High Energy Accelerator Research Organization (KEK), Tsukuba, Ibaraki 305-0801, Japan

It is inferred from muon spin relaxation (μ SR) study that the spin fluctuation rate (ν) in a class of transition metal compounds, LiV_2O_4 , $\text{Y}(\text{Sc})\text{Mn}_2$, and $\text{YMn}_2\text{Zn}_{20}$ that exhibit heavy fermion-like behavior, is characterized by a linear dependence on temperature, $\nu \propto T$. Considering that the transition metal ions (V and Mn) in these compounds share a common feature of comprising pyrochlore lattice, the underlying spin dynamics is understood by the spin correlation of the intersecting Hubbard chains that provides a model of the pyrochlore lattice. This strongly suggests the crucial role of t_{2g} orbitals as one-dimensional (1D) chains that are under strong geometrical constraint of pyrochlore lattice structure, and further supports the theoretical scenario that the 1D-3D dimensional crossover due to coupling between these chains developing at lower temperatures is the origin of the heavy fermion behavior.

NMR investigations on novel fluctuations in f electrons

**M. Takigawa¹, T. Taniguchi¹, M. S. Grbić^{1,2}, M. Yoshida¹, H. Takeda¹,
M. Tsujimoto¹, Y. Matsumoto¹, K. Kimura¹, K. Kuga¹, and S. Nakatsuji¹**

1 Institute for Solid State Physics, University of Tokyo, Kashiwa 277-8581, Japan

2 Faculty of Science, University of Zagreb, P.O. Box 331, HR-10002 Zagreb, Croatia

NMR is a powerful tool to identify broken symmetry and associated fluctuations in f-electron materials. In this talk I will discuss two recent examples. First material is α -YbAlB₄, which is a heavy fermi liquid at zero magnetic field. From the nuclear relaxation rate at B sites, we found field induced quantum criticality in magnetic fields with no sign of symmetry change. Second material is PrTi₂Al₂₀, in which a Pr ion has the non-magnetic Γ_3 doublet ground state. From though symmetry analysis of the angle resolved Al-NMR spectra, we identified ferro-quadrupolar ordering near 2K. Although this is a non-magnetic phase transition, the nuclear relaxation rate shows a large enhancement, indicating a new type of multipolar fluctuations.

Revisiting the Metal—Insulator Transition of VO₂: Molecular Orbital Crystallization

Zenji Hiroi

Institute for Solid State Physics, University of Tokyo, Kashiwa, Chiba 277-8581, Japan

The metal-insulator transition (MIT) of VO₂ is revisited with particular emphasis on the structural instability of the rutile compounds toward dimer structures. Ti substitution experiments reveal that the MIT is robust up to 20% Ti⁴⁺ substitution (hole doping) and occurs even in extremely thin V-rich lamellas of a few nm thick in spinodally decomposed TiO₂-VO₂ composites [1-3], indicating that the MIT takes on an essentially local character and suggesting that either electron correlation or Peierls (Fermi-surface) instability plays a minor role on the MIT. It is pointed out through a broad perspective of crystal chemistry on the rutile-related compounds that VO₂ and another MIT compound NbO₂ in the family happen to lie just on the borderline between the two structural groups with the rutile structure and the distorted structures characterized by the formation of dimer molecules with metal-metal bonding. It is also shown that the two compounds of the rutile form do not follow the general trends in structure observed for the other rutile compounds, giving clear evidence of an inherent structural instability in the two compounds. The MITs of VO₂ and NbO₂ are natural consequences of structural transitions between the two groups, as all the d electrons are trapped in molecular orbitals of dimers at low temperatures in the dimer phases. Dimer phases are ubiquitous in transition metal compounds with chain-like structures made of face- or edge-sharing octahedra, such as MoBr₃, NbCl₄, Ti₄O₇, and V₄O₇, the latter two of which also exhibit MITs probably of the same structural origin. In a broader sense, dimer phases belong to "molecular orbital crystals" in which virtual molecules made of transition metal atoms, such as dimers, trimers or larger ones, are stabilized by generating metal—metal bonding at low temperatures. Molecular orbital crystallisations are often observed in many transition metal compounds that comprise edge-sharing octahedron networks of various connectivities.

- [1] Z. Hiroi, H. Hayamizu, T. Yoshida, Y. Muraoka, Y. Okamoto, J. Yamaura, and Y. Ueda: Chem. Mater. **25**, 2202 (2013).
- [2] Z. Hiroi, Prog. Solid State Chem. **43**, 47 (2015).
- [3] Z. Hiroi, T. Yoshida, J. Yamaura, and Y. Okamoto: APL Materials **3**, 062508 (2015).

Heavy-fermion behavior and metal-insulator transition in vanadium oxides investigated by NMR

M. Itoh¹, H. Takeda¹, Y. Kato¹, M. Yoshioka¹, S. Aoyama¹, T. Jinno¹,
Y. Shimizu¹, S. Niitaka², H. Takagi^{3,4}, and Y. Ueda⁵

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2 RIKEN Advanced Science Institute, 2-1 Hirosawa, Wako, Saitama 351-0198, Japan

*3 Department of Physics, Graduate School of Science, University of Tokyo, 7-3-1 Hongo,
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4 Max Plank Institute for Solid State Research, Heisenbergstrasse 1, 70569 Stuttgart, Germany

5 Toyota Physical and Chemical Research Institute, Nagakute 480-1192, Japan

The metal-insulator transition (MIT) accompanied by the electron-orbital reformation is one of intensively investigated phenomena in strongly correlated electron systems. In the spinel vanadium oxide LiV_2O_4 , which is a typical material showing the heavy-fermion behavior in the d electron systems, undergoes the MIT from the low-pressure, P , metallic phase to the high- P insulating one at about 7 GPa. We have made NMR measurements on a powder sample up to 10 GPa to investigate the magnetic properties and the MIT in LiV_2O_4 [1]. The MIT was found to be accompanied by the possible formation of a spin-singlet cluster to release the geometrical frustration. Knight shifts and nuclear spin-lattice relaxation rates monitored the presence of two crossovers in the P versus temperature T phase diagram, one from weak ferromagnetic fluctuations to antiferromagnetic fluctuations and another from the heavy-Fermi liquid to the weakly correlated metal. The mechanism of the MIT at 150 K in V_6O_{13} is also discussed on the basis of the single-crystal NMR results [2]. We found that the MIT is ascribed to the $3d$ orbital order leading to the nonmagnetic dimer in the V1 zigzag chain, whereas the V2-V3 chain has paramagnetic moments on the V3 site with the singly occupied d_{xy} orbital and the unoccupied V2 site. Thus the site-selective MIT was concluded to take place in V_6O_{13} .

[1] H. Takeda, Y. Kato, M. Yoshimura, Y. Shimizu, M. Itoh, S. Niitaka, and H. Takagi, Phys. Rev. B, **92**, 045103 (2015).

[2] Y. Shimizu, S. Aoyama, T. Jinno, M. Itoh, and Y. Ueda, Phys. Rev. Lett., **114**, 166403 (2015).

Saturday 26th Sept. Oral Session 2 at 14:30

Distributed twofold Ordering in URu₂Si₂

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In the hidden-ordered state of URu₂Si₂, a modest breaking of the fourfold symmetry was suggested in previous ²⁹Si NMR basal-plane field rotation measurements [1]. Based on the detail analysis of ²⁹Si NMR linewidth, the occurrence of a distribution of twofold local fields at the Si sites is suggested even in a high-quality single crystal [2]. A possible model for the distributed two-fold ordering will be discussed.

[1] S. Kambe *et al*, Phys. Rev. Lett. **110** (2013) 246406.

[2] S. Kambe *et al*, Phys. Rev. B **91** (2015) 035111.

NMR studies of inhomogeneous glassy behavior driven by nematic fluctuations in iron arsenide superconductors

A. P. Dioguardi¹, M. M. Lawson¹, B. T. Bush¹, J. Crocker¹, K. R. Shirer¹, D. M. Nisson¹, T. Kissikov¹, S. Ran¹, S. L. Bud'ko², P. C. Canfield², Jiun-Haw Chu³, I. R. Fisher³, and N. J. Curro¹

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The iron arsenide superconductors exhibit multiple phase transitions upon doping, including antiferromagnetism, unconventional superconductivity, and electronically-driven nematic ordering that breaks C_4 rotation symmetry. Orthorhombic distortions of the lattice in the nematic phase form perpendicular twin domains, and strong coupling between the spin and orbital degrees of freedom ensure that the antiferromagnetically ordered Fe spins lie along either of these two orthogonal directions. Upon doping, the nematic and antiferromagnetic ordering temperatures are suppressed, yet strong antiferromagnetic and nematic fluctuations persist in the paramagnetic state beyond optimal doping, even in the absence of long range order. Here we demonstrate that these fluctuations are inhomogeneous and glassy, reflecting a broad distribution of locally frustrated domains. This behavior arises because the dopants introduce quenched random fields that couple to the nematic order. These results suggest that disorder-induced frustration plays a significant role in suppressing long-range antiferromagnetic order and in the emergence of superconductivity.

Nuclear Magnetic Resonance Studies on Ferromagnetic Superconductor UCoGe

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2 Department of Physics, Graduate School of Science Nagoya Univ. 464-8602

3 Institute for Materials Research, Tohoku Univ. 980-8577

We report ^{59}Co nuclear magnetic resonance (NMR) and nuclear quadrupole resonance (NQR) studies on the single crystalline ferromagnetic (FM) superconductor UCoGe, which exhibits FM ordering at $T_{\text{Curie}} = 2.5$ K and superconductivity below $T_{\text{Super}} = 0.57$ K [1]. We studied the coexistence state from the microscopic point of view, and showed that superconductivity occurs in the FM region and that superconductivity and ferromagnetism originate from U 5f electrons [2]. We also studied the spin-dynamic properties from the measurements of $1/T_1$ and Knight shift along the each crystalline axis. The results show that both static and dynamic susceptibilities possess the strong Ising anisotropy along the c axis being the easy axis and that the FM fluctuations are predominant at low temperatures and persist even below T_{Curie} [3]. From the angle-resolved NMR measurements, we found that the magnetic field along the c axis ($H \parallel c$) strongly suppresses both the FM Ising-type fluctuations and superconductivity in the same way [4]. In addition, $1/T_1$ in the field along the b axis (H_b) increases above $\mu_0 H_b > 5$ T, indicating that the FM fluctuations are enhanced. Interestingly, the superconducting critical field also increases, indicating that the superconductivity becomes robust in the same H_b region [5]. These results strongly suggest that the characteristic FM fluctuations tuned by external fields induce unique spin-triplet superconductivity in UCoGe, which is also supported by the recent Knight-shift measurements in the superconducting state [6].

[1] N. T. Huy *et al.*, Phys. Rev. Lett. **99**, 067006 (2007).

[2] T. Ohta *et al.*, J. Phys. Soc. Jpn. **79**, 023707 (2010).

[3] Y. Ihara *et al.*, Phys. Rev. Lett. **105**, 206403 (2010).

[4] T. Hattori *et al.*, Phys. Rev. Lett. **108**, 066403 (2012).

[5] T. Hattori *et al.*, J. Phys. Soc. Jpn. **83**, 073708 (2014).

[6] T. Hattori *et al.*, Phys. Rev. B **88**, 085127 (2013).

Sunday 27th Sept. Oral Session 3 at 9:30

Itinerant electron magnetism in Cr-based MAX phase compounds

T. Waki, Z. Liu, Y. Tabata, and H. Nakamura

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MAX phase compounds ($M_{n+1}AX_n$ where $n = 1$ to 3 ; M is an early transition metal, A is an A-group metal, and X is carbon or nitrogen) consist of alternated MX and A layers. These materials are potentially interesting in a view point of low dimensional magnetism, although the magnetism in these materials has been unexplored. We have recently revealed that some of Cr-based MAX phase compounds are magnetically active and undergo a magnetic phase transition. We will report characteristics of the itinerant electron magnetism in the Cr-based MAX phase materials.

Superconductivity and Itinerant Electron Magnetism in $\text{TlCo}_{2-x}\text{Ni}_x\text{Se}_2$ System

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A series of single crystals $\text{TlCo}_{2-x}\text{Ni}_x\text{Se}_2$ were successfully grown by using a self-melting method. The measurements of their structure, resistivity, magnetic susceptibility, specific heat and upper critical field were carried out. We have made the first observation of superconductivity in TlNi_2Se_2 at $T_c = 3.7$ K, and it appears to involve heavy electrons with an effective mass $m^* = (14-20) m_b$, as inferred from the normal-state electronic specific heat and the upper critical field, $H_{c2}(T)$. It was found that the TlCo_2Se_2 is an antiferromagnet with Néel temperature $T_N = 89$ K, and that the T_N value for $\text{TlCo}_{2-x}\text{Ni}_x\text{Se}_2$ system varies non-monotonically with the Ni content x , and reaches a maximum $T_N = 129$ K at $x = 0.8$. The AFM long-range order disappears in the compound with $x = 1.8$. At the same time we determined their magnetic structure by the Neutron diffraction experiments. A new magnetic and superconducting phase diagram for $\text{TlCo}_{2-x}\text{Ni}_x\text{Se}_2$ system was obtained, which is similar to that in cuprate- or iron-based, as well as the heavy-fermion superconductors. We will present the discussions on its superconductivity in this system using the electronic structure determined by ARPES, the thermal conductivity results, *et al.* TlNi_2Se_2 , as a d -electron system with heavy electron superconductivity may be a bridge between cuprate- or iron-based, and the conventional heavy-fermion superconductors.

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- [2] C. Hong, Z. Zhang, S. Y. Zhou, J. Pan, Y. Xu, Hangdong Wang, Qianhui Mao, Minghu Fang, J. K. Dong, and S. Y. Li; Multigap nodeless superconductivity in nickel chalcogenide TlNi_2Se_2 *Phys. Rev. B* **90**, 060504(R) (2014).
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- [4] N. Xu, C. E. Matt, P. Richard, A. van Roekeghem, S. Biermann, X. Shi, S.-F. Wu, H. W. Liu, D. Chen, T. Qian, N. C. Plumb, M. Radovic, Hangdong Wang, Qianhui Mao, Jianhua Du, Minghu Fang, J. Mesot, H. Ding, M. Shi; Camelback-shaped band reconciles heavy electron behavior with weak electronic Coulomb correlations in superconducting TlNi_2Se_2 , arXiv:1412.7016.

Sunday 27th Sept. Oral Session 3 at 10:30

Quantum Spin Liquid in the Kagome-Lattice Antiferromagnet and Related Systems

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The $S=1/2$ kagome-lattice antiferromagnet is one of interesting frustrated quantum spin systems. The system is supposed to exhibit the quantum spin liquid in the ground state, which was proposed as an origin of the high-temperature superconductivity. The spin gap is an important physical quantity to characterize the spin liquid behavior. Whether the $S=1/2$ kagome-lattice antiferromagnet is gapless or has a finite spin gap, is still unsolved issue. Because any recently developed numerical calculation methods are not enough to determine it in the thermodynamic limit. Our large-scale numerical diagonalization up to 42-spin clusters and a finite-size scaling analysis indicated that the $S=1/2$ kagome-lattice antiferromagnet is gapless in the thermodynamic limit[1]. It is consistent with the $U(1)$ Dirac spin liquid theory of the kagome-lattice antiferromagnet[2,3]. On the other hand, some density matrix renormalization group (DMRG) calculations supported the gapped Z_2 topological spin liquid theory[4,5]. Our recent numerical diagonalization analysis on the magnetization process of a distorted kagome-lattice antiferromagnet indicated that the perfect kagome-lattice system is just on a quantum critical point[6]. It would be a possible reason why it is difficult to determine whether the perfect kagome-lattice antiferromagnet is gapless or gapped.

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Sunday 27th Sept. Oral Session 3 at 11:15

Structural Quantum Criticality in Superconducting (Ca_xSr_{1-x})₃Rh₄Sn₁₃

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The quasiskutterudite superconductor Sr₃Rh₄Sn₁₃ features a pronounced anomaly in electrical resistivity at $T^* \sim 138\text{K}$. We show that the anomaly is caused by a second-order structural transition, which can be tuned to 0 K by applying physical pressure and chemical pressure via the substitution of Ca for Sr. A broad superconducting dome is centered around the structural quantum critical point. Detailed analysis of the tuning parameter dependence of T^* as well as insights from lattice dynamics calculations strongly support the existence of a structural quantum critical point at ambient pressure when the fraction of Ca is 0.9 (*i.e.*, $x_c=0.9$). This establishes the (Ca_xSr_{1-x})₃Rh₄Sn₁₃ series as an important system for exploring the physics of structural quantum criticality without the need of applying high pressures.

Entropics: science and engineering of caloric phenomena related to itinerant-electron magnetism and spin fluctuations

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Control of spin degree of freedom is recently regarded as a new basis for thermal managements such as spin-caloritronics and thermoelectronics. We are now proposing a new concept 'Entropics', which makes the most of entropic change owing to the spin degree of freedom, as well as a charge and an orbital ones in solid-state matters. This concept also develops the path to new caloric devices such as magnetic refrigeration. Current researches of the magnetic refrigeration focus on ambient temperature range where a specific heat of solids is mostly composed of a non-magnetic phonon load. Therefore, the magnetocaloric effect caused by latent heat of the first-order magnetic phase transition is the center of attention.

La(Fe_xSi_{1-x})₁₃ system exhibits an itinerant electron metamagnetic (IEM) transition above the Curie temperature T_C . Magnitude of the latent heat is connected to $\Delta S T_C$ where ΔS is a difference of entropy between the ferromagnetic and the paramagnetic states, being strongly influenced by spin fluctuations. A conventional Rhodes-Wohlfarth (RW) ratio of this system holds the value of about 1.2, indicating that the magnetic state is an itinerant type but actually close to the localized moment limit. In such a case, the disordered local moment (DLM) picture may be appropriate. By hydrogenation or partial substitution for La by Ce, the IEM transition and the DLM nature are preserved, while partial substitution for Si by Al increases the RW value and the IEM transition becomes vague.

Another example of itinerant spin-correlated caloric phenomena is the barocaloric effect in Mn₃GaN, which exhibits the first-order antiferromagnetic-paramagnetic transition at the Néel temperature T_N around room temperature. A large entropic change is derived from the thermodynamic relation when magnitude of volume change at T_N is remarkable against stability of the ordered state against external pressures. A large volume change at T_N is correlated with shrinkage of the DLM due to a frustration induced by lattice symmetry of this compounds. Consequently, the frustration is a key factor for enhancement of the barocaloric effect.

Quantum critical behavior in magnetic quasicrystals and approximant crystals

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Quasicrystals (QCs) are intermetallic alloys that possess aperiodic structures with diffraction symmetries forbidden to the conventional crystals. Their electronic states are believed to be neither extended nor localized, but such a critical state remains to be experimentally established. Recently, we reported that the Au-Al-Yb QC shows quantum critical phenomena that are characterized by similar critical indices to those of Yb-based heavy fermions [1]. In contrast, no divergence was observed in the relevant Au-Al-Yb approximant crystal (AC), a phase whose unit cell has atomic decorations that look like the QC. From these results, we suggested that the observed quantum criticality in the QC is related to the critical state unique to the QCs. To gain further information on the physical properties, we studied the substitution effect of constituent elements on the magnetism and found that the Au-Al-Yb QC and AC are located near the border of the divalent and trivalent states of the Yb ion [2]. In the presentation, we review the magnetic properties of these novel QCs and ACs, together with our recent observation of superconductivity in the Au-Ge-Yb ACs with the Tsai-type cluster [3].

[1] K. Deguchi *et al.*, Nat. Mat. **11**, 1013 (2012).

[2] S. Matsukawa *et al.*, J. Phys. Soc. Jpn. **83**, 034705 (2014).

[3] K. Deguchi *et al.*, J. Phys. Soc. Jpn. **84**, 023705 (2015).

Abstracts

**-Poster Presenters-
36 Presentations**

Magnetic Properties and Thermal Expansion of Amorphous RE-Mn Alloys

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Amorphous (a-)Ce-Mn alloys show a large thermal expansion in the wide temperature region with a paramagnetic state. In the low-temperature region, the thermal expansion coefficient α increases with decreasing temperature and exhibits a maximum. It is pointed out that the origin of this behavior is caused by the enhancement of the magnetic contribution of the specific heat by the formation of the heavy-fermion state for Ce 4f-electron [1, 2]. On the other hand, it has been considered that the large α at around room temperature of a-Ce-Mn arises from an itinerant magnetism with a large spin fluctuation of Mn 3d-electron. Actually, such spin fluctuation contribution to α has already been reported to exist in Mn-based amorphous alloy [3]. In this work, in order to investigate the magnetic contribution to the thermal expansion for amorphous Mn-alloys, we have measured susceptibility and thermal expansion for a-RE-Mn alloys (RE = Y, La and Ce). The susceptibility of a-RE-Mn alloy in the high-temperature region shows a Curie-Weiss (CW) behavior for all the samples. The effective paramagnetic moment p_{eff} per formula unit for a-RE-Mn estimated from the CW-law is $1.31 \mu_B$ for Y, $2.58 \mu_B$ for La and $0.63 \mu_B$ for Ce. The thermal expansion coefficient α at room temperature for a-RE-Mn is $18 (10^{-6} \text{ K}^{-1})$ for Y, $12 (10^{-6} \text{ K}^{-1})$ for La and $38 (10^{-6} \text{ K}^{-1})$ for Ce. From these results, we found that the p_{eff} decreases with increasing α . In this workshop, we would like to discuss the relation between the p_{eff} and α for the amorphous Mn-alloys.

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- [2] Y. Amakai, et al., J. Phys. Soc. Jpn., 80(2011) SA057.
- [3] A. Fujita, et al., Mater. Trans. JIM, 36(1995)852.

NMR and NQR studies of URu₂Si₂ and isostructural nonmagnetic references

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The uranium heavy fermion compound URu₂Si₂ has been attracting much interest since its discovery almost 30 years ago, because of its fascinating properties, including the mysterious phase transition at $T_{\text{HO}} = 17.5$ K, whose order parameter has not been identified (so-called "hidden order (HO)"), and its unconventional superconductivity below $T_c = 1.4$ K. Among a wide variety of experimental reports on this compound, studies using nuclear magnetic resonance (NMR) and nuclear quadrupole resonance (NQR) techniques have played an important role in providing microscopic information on the issues of the HO and superconducting (SC) phases. In order to give more quantitative analysis to already reported NMR and NQR data on URu₂Si₂, we have carried out these measurements on ThRu₂Si₂ and LaRu₂Si₂, which are the nonmagnetic references of URu₂Si₂. For URu₂Si₂, nuclear spin lattice relaxation rate $1/T_1$ measured by ²⁹Si-NMR and ¹⁰¹Ru-NQR are known to be proportional to temperature (*i.e.* $1/T_1 \propto T$) just above T_{HO} and in the HO phase. This suggests that the HO and the SC transition occur in the itinerant regime of $5f$ electrons. We have measured $1/T_1$ of ThRu₂Si₂ by ²⁹Si-NMR measurements and compared it with the data on URu₂Si₂. When magnetic field was applied along the c axis of the crystal (*i.e.* $c \parallel H$), the data of $1/T_1$ on both compounds coincident with each other in the HO phase, while $1/T_1$ of URu₂Si₂ is largely enhanced than those of ThRu₂Si₂ when field was applied perpendicular to the c axis ($c \perp H$). By considering that T_1 reflects the components of magnetic fluctuations perpendicular to the applied field, we found that there exist Ising-like spin fluctuations along the c axis in the HO phase of URu₂Si₂. We will also present detailed NQR data measured at the Ru site and discuss the mean valence of U ions.

**Various Ground States and Magnetically Excited States
in the $S = 1/2$ Ti^{3+} Kagomé Antiferromagnets
 $A_2B\text{Ti}_3\text{F}_{12}$ (A, B : Alkali Metal)**

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Geometrically frustrated antiferromagnets have been studied intensively from a viewpoint of infinite degeneracy of the ground state over the past few decades. In particular, $S = 1/2$ kagomé antiferromagnets are of great interests owing to the combination of spin frustration and strong quantum fluctuation. As candidates of the ground state, theorists have proposed some unique nonmagnetic ground states such as a gapped^[1] and a gapless^[2] spin liquid state, and a valence bond crystal state^[3]. In addition, under high magnetic fields, a $1/3$ magnetization plateau and a jump of the magnetization from $7/9$ to 1 are expected to appear^[4,5].

In this presentation, we report magnetic properties of new $S = 1/2$ kagomé antiferromagnets $A_2B\text{Ti}_3\text{F}_{12}$ using single crystals. We found three Ti^{3+} fluorides $\text{Rb}_2\text{NaTi}_3\text{F}_{12}$, $\text{Cs}_2\text{NaTi}_3\text{F}_{12}$, and $\text{Cs}_2\text{KTi}_3\text{F}_{12}$, which are the first $S = 1/2$ kagomé system consisting of magnetic Ti^{3+} ions. The structure of $A_2B\text{Ti}_3\text{F}_{12}$ can be understood as ordered structure of the modified pyrochlore. Magnetic Ti^{3+} ions form slightly distorted kagomé lattices, and the distortion becomes large as ionic radii of A and B decrease. The kagomé layer is well separated by the layers of nonmagnetic A^+ and B^+ ions.

All the three compounds have nearly the same Curie-Weiss temperature of -45 K, and show neither magnetic ordering nor spin freezing down to 2K. The results of the magnetic and heat capacity measurements at low temperatures are markedly different from each other, suggesting different ground states. The ground states are considered to be a sort of a valence bond crystal state for $\text{Rb}_2\text{NaTi}_3\text{F}_{12}$, a gapless disordered state for $\text{Cs}_2\text{NaTi}_3\text{F}_{12}$, and a gapped disordered state for $\text{Cs}_2\text{KTi}_3\text{F}_{12}$. Moreover, the magnetization curves of $\text{Cs}_2\text{NaTi}_3\text{F}_{12}$ and $\text{Cs}_2\text{KTi}_3\text{F}_{12}$ show anomalies at approximately $1/3$ of the full magnetic moment. These anomalies are considered to be the signs of theoretically proposed $1/3$ magnetization plateau.

[1] N. Elstner *et al*, Phys. Rev. B **50**, 6871 (1994).

[2] S. Ryu *et al*, Phys. Rev. B **75**, 184406 (2007).

[3] J. B. Marston *et al*, J. Appl. Phys. **69**, 5962 (1991).

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[5] J. Schulenburg *et al*, Phys. Rev. Lett. **88**, 167207 (2002).

Magnetic properties of $S = 1/2$ frustrated cluster magnets $\text{Li}_2\text{In}_{1-x}\text{Sc}_x\text{Mo}_3\text{O}_8$

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Frustrated cluster magnets are expected to produce novel physics derived from the spin frustration effect with the charge fluctuation within a magnetic cluster. In our previous investigations, it was found that for $\text{Li}_2\text{AMo}_3\text{O}_8$ ($A = \text{In}, \text{Sc}$), although their magnetic properties are attributed to the same magnetic cluster lattice, their ground states are completely different from each other; while $\text{Li}_2\text{InMo}_3\text{O}_8$ exhibits a conventional magnetic ordering with 120° structure, $\text{Li}_2\text{ScMo}_3\text{O}_8$ shows a spin liquid like condensation [1]. In this work, we investigated the magnetic properties of $S = 1/2$ frustrated magnetic cluster system $\text{Li}_2\text{In}_{1-x}\text{Sc}_x\text{Mo}_3\text{O}_8$ in order to reveal the origin of the difference of their magnetism. For substituted compounds $\text{Li}_2\text{In}_{1-x}\text{Sc}_x\text{Mo}_3\text{O}_8$, XRD patterns of samples demonstrated successful synthesis, and suggest monotonic-decrease of cell parameters from $\text{Li}_2\text{InMo}_3\text{O}_8$ to $\text{Li}_2\text{ScMo}_3\text{O}_8$. From the magnetic susceptibility and heat capacity measurements, it was found that the ground state is disordered one for $x > 0.1$. The effective magnetic moment for $\text{Li}_2\text{In}_{1-x}\text{Sc}_x\text{Mo}_3\text{O}_8$ estimated from the high temperature Curie-Weiss fitting to magnetic susceptibility does not show the linear relation against x value and take a minimum at $x = 0.5$. Moreover, it was observed that $\text{Li}_2\text{In}_{1-x}\text{Sc}_x\text{Mo}_3\text{O}_8$ with $0.3 < x < 0.9$ exhibits the disappearance of partial paramagnetic spins without any magnetic orderings. Such the behavior is also observed in the cluster magnet $\text{LiZn}_2\text{Mo}_3\text{O}_8$ with the same magnetic lattice of $\text{Li}_2\text{AMo}_3\text{O}_8$. These facts suggest that a cation-disordering suppresses the low-temperature magnetic moment, which may come from the emergence of a valence bond glass state among cluster spins.

[1] Y. Haraguchi *et al.*, Phys. Rev. B **92**, 014409 (2015).

Spin and phonon dispersion near the magnetic order-order transition in Mn_3Pt

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Mn_3Pt is a Cu_3Au -type metallic antiferromagnet with $T_N = 485$ K. It shows magnetic order-order transition at $T_t = 400$ K. In the high-temperature ordered phase, which is known as F-phase, two third of Mn are ordered collinearly and one third of Mn are fluctuating. On the other hand, in the low temperature phase, which is called D-phase, Mn moments form a triangular spin structure. The F- to D-phase transition leads to a dramatic decrease in Mn moment from 3.3 to $2.2\mu_B/\text{Mn}$ and in lattice volume by 2.25% . Much uncertainty still exists about the relation between spin and lattice on this transition.

In this study, we performed an inelastic neutron scattering experiment at $T \sim 400$ K to clarify the spin and lattice dynamics in the F-phase near the transition. A 20 g of single crystal was synthesized by the Bridgman method. The high intensity chopper spectrometer 4SEASONS installed at J-PARC/MLF was utilized.

The spin wave dispersion measured around $\mathbf{Q} = (1, -0.5, 0)$ was isotropic along $[100]$, $[110]$ and $[111]$ direction within the measurement accuracy. The fitting with the equation, $E^2 = c^2q^2 + \Delta^2$, yields $c = 190$ meVÅ and $\Delta = 3.3$ meV, where E is excitation energy and q is wave number away from $\mathbf{Q}$. At 419 K, c and δ were reported to be 130 meVÅ and 3.5 meV by the previous report [1] This indicates that the small decrease in temperature makes the spin wave stiffness hard as much as 50% . This is qualitatively consistent with the rapid increase in the magnetic moment with decreasing temperature in F-phase.

The phonon stiffness of the longitudinal acoustic mode along $[100]$ was found to be about 20 meVÅ, which is relatively soft compared to other Mn alloys such as γFeMn . This is reasonably consistent with the elastic stiffness C_{11} showing small value as reported by ultrasonic study.

[1] Y. Yamaguchi *et al.*, Physica B **180** & **181** (1992) 235.

**^{13}C NMR study of Fe spin dynamics in
 $\beta''\text{-(BEDT-TTF)}_4[(\text{H}_3\text{O})\text{Fe}(\text{C}_2\text{O}_4)_3]\cdot\text{C}_6\text{H}_5\text{Br}$**

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A layered organic superconductor $\beta''\text{-(BEDT-TTF)}_4[(\text{H}_3\text{O})\text{Fe}(\text{C}_2\text{O}_4)_3]\cdot\text{C}_6\text{H}_5\text{Br}$ shows superconductivity on the conducting BEDT-TTF layers below the superconducting transition temperature $T_c = 4$ K. The magnetism of this salt is dominated by the localized Fe spin located at the insulating layers. The coupling between localized Fe spins and conducting π electron induces intriguing phenomena, such as field-induced superconductivity, which has been suggested in a similar organic superconductor $\lambda\text{-(BETS)}_2\text{FeCl}_4$. We have investigated the π electron-Fe spin coupling from the ^{13}C NMR spectroscopy carried out in a wide field range between 2 T up to 19 T. At low temperatures, the ^{13}C NMR spectrum is strongly shifted and broadened by the local field created by Fe spins. We subtracted the dipole contribution from Fe spins to the total shift, and found that the Fe spins create large exchange field to the π electrons, which is antiparallel to the external magnetic field. When the exchange field compensates the external field, we can expect the field-induced superconducting transition. We also measured the nuclear spin-lattice relaxation rate $1/T_1$ in high magnetic fields. The Fe spin dynamics is suppressed in high field, which is suitable to stabilize superconductivity because the pair breaking effects by fluctuating magnetic field can be suppressed. When the Fe spin contribution is suppressed in high field, the underlying π electron contribution can be investigated. We found a gap-like behavior in the π electron system, which lead us to expect a charge instability as observed in a sister compound with nonmagnetic ions $\beta''\text{-(BEDT-TTF)}_4[(\text{H}_3\text{O})\text{Ga}(\text{C}_2\text{O}_4)_3]\cdot\text{C}_6\text{H}_5\text{NO}_2$

Study of magnetism and superconductivity in EuFe_2As_2

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The correlation between magnetism and superconductivity in EuFe_2As_2 has been investigated using the ^{57}Fe and ^{151}Eu nuclear forward scattering experiments and dc magnetic susceptibility under high pressure. We find a microscopic coexistence of bulk superconductivity and magnetism at the Fe and Eu sublattices. In the superconducting state, the direction of magnetic moment at the Fe sublattice modulates toward the [001] axis, while no change of the magnetic structure at the Eu sublattice was observed. The magnetic hyperfine field of the Fe sublattice shows no clear anomaly at the superconducting transition temperature. Consequently, the magnetic structure of the Fe sublattice strongly correlates superconductivity and two order parameters are uncompetitive in the coexistence phase.

The study of the ground state of the itinerant-electron magnet $\text{Sr}_{1-x}\text{Ca}_x\text{Co}_2\text{P}_2$

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The layered compound SrCo_2P_2 with ThCr_2Si_2 -type structure is a nearly ferromagnetic metal and shows itinerant-electron metamagnetic transition at the field of 60 T [1]. The transition field decreases by Ca substitution. We performed ^{31}P NMR measurement to study dynamical magnetic properties of $\text{Sr}_{1-x}\text{Ca}_x\text{Co}_2\text{P}_2$. We measured their Knight shift K and spin-lattice relaxation rate divided by temperature $1/T_1T$, and investigated their character of spin fluctuations. SrCo_2P_2 has anisotropic spin fluctuations and larger transverse fluctuations in the ab plane. The transverse fluctuations in the ab plane become small with Ca substitution. We have found the relation between the transverse fluctuations in ab plane and metamagnetic transition field in $\text{Sr}_{1-x}\text{Ca}_x\text{Co}_2\text{P}_2$.

[1] M. Imai *et al.*, Phys. Rev. B **90**, 014407 (2014).

The magnetism and magnetic anisotropy in the layered system $\text{KCo}_2(\text{Se}_{1-x}\text{S}_x)_2$

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The ThCr_2Si_2 -type layered compound family has a quasi-two-dimensional tetragonal lattice and shows various interesting physical properties. In this family of ThCr_2Si_2 -type compounds, KCo_2X_2 compounds with $X = \text{Se}, \text{S}$ are itinerant ferromagnets with $T_C = 74 \text{ K}$ [1] and 127 K [2], respectively. The KCo_2X_2 compound has the layered structure in which K layer and CoX layer stack alternately, thus the two-dimensional interaction is thought to be dominant. Since there have not been many reports of physical properties of the two-dimensional itinerant ferromagnet so far, this system is expected to be one of the most typical examples. For researching anisotropy, a single crystal is desirable to synthesize. Here, we succeeded in synthesizing $\text{KCo}_2(\text{Se}_{1-x}\text{S}_x)_2$ single crystals, and in measuring magnetic properties. As a result, the Curie and Weiss temperatures increase with increasing x . However, the ratio of effective magnetic moment (p_{eff}) and spontaneous magnetic moment (p_s), p_{eff}/p_s , hardly changes. A large magnetic anisotropy exists in this system as seen in a large difference in Weiss temperatures derived from the data with $H \parallel ab$ plane and $H \parallel c$ axis together with a huge anisotropy magnetic-field. From the temperature dependence of magnetic susceptibility and isothermal magnetization, we calculated the spin fluctuation parameters according to self-consistent renormalization [3] and Takahashi's theories of spin fluctuations [4], and analyzed the itinerant ferromagnetic behaviors by the spin-fluctuation theories.

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Drastic effect of the hole doping in the strongly correlated semiconductor FeSb₂

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Several Fe-based narrow gap semiconductors, such as FeSb₂ and FeSi, have been labeled as a Kondo insulator, however, the actual mechanism of the gap opening in these systems is controversial. Hence many investigations to understand it, including the carrier doping ones, have been carried out. We report the Mn-substitution effects, corresponding to the hole doping effects, on the electronic properties of FeSb₂ using single crystals of Fe_{1-x}Mn_xSb₂ grown by the high temperature Sb flux method. The orthorhombic *Pnnm* structure was confirmed by powder x-ray diffraction (XRD) for the pure and Mn-substituted samples and their crystal structure parameters were refined using the Rietveld method. The chemical composition was investigated by Wavelength-dispersive X-ray spectroscopy (WDX). We found the solubility limit of Mn in FeSb₂ is $x \sim 0.05$ and the monotonic changes of the lattice constants with increasing the actual Mn concentration. A drastic change from semiconducting to metallic electronic transports was found at very low Mn concentration below $x \sim 0.02$. Our results indicate that the small amount hole doping makes a drastic change in the electronic state in FeSb₂ as well as the electron doping does: a closing of the narrow-gap or emergence of the DOS inside the gap.

Quantum Critical Point of Itinerant-Electron Metamagnet UCoAl

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UCoAl is known as an itinerant-electron metamagnet. The first-order metamagnetic transition occurs at $H_m=0.6$ T and its critical temperature T_{cr} is about 11K. The non-Fermi liquid (NFL) behavior is found in the paramagnetic state. Relatively low H_m and T_{cr} with the NFL behavior indicate that UCoAl is situated in a proximity to ferromagnetic order and is expected to be reachable to the so-called quantum critical point (QCP) of itinerant-electron ferromagnet by applications of pressure and magnetic field. In order to verify the existence of the QCP in UCoAl we performed the AC magnetic susceptibility measurements under pressure and determined T - P - H phase diagram.

The AC magnetic susceptibility can determine the critical point (CP) precisely since its real part diverges toward the CP and its imaginary part detects a hysteresis vanishing at the CP.

The obtained T - P - H phase diagram and its QCP are different from the previous report by Aoki, et al. The present study indicates that QCP is located at $P \sim 2.8$ GPa and $H \sim 13$ T. From the comparison between our result and the previous one, we discuss an unusual nature of the magnetic phase diagram realized in UCoAl.

Magnetic properties of new ternary chalcogenides $ACrX_2$ ($A = \text{Li, Na}$, $X = \text{Se, Te}$) with triangular lattices

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Trivalent chromium compounds show various magnetic properties, which are originating in the interplay between the antiferromagnetic direct $d-d$ exchange interaction and ferromagnetic superexchange interaction[1]. These interactions can compete with each other in chromium sulfides, selenides and tellurides, while the former interaction is dominant in chromium oxides. Among them, we focus on triangular-lattice compounds $ACrX_2$ ($A = \text{Li, Na}$, $X = \text{chalcogen atoms}$), in which various magnetic structures are realized owing to not only the interplay between these two interactions but also geometrical frustration and the two-dimensional nature of spin correlations. For example, LiCrS_2 , NaCrS_2 , and KCrS_2 exhibit a 120° spin structure, an incommensurate helical spin structure, and an A-type antiferromagnetic structure, respectively [2]. Here, we report on magnetic properties of three new compounds, LiCrSe_2 , LiCrTe_2 , and NaCrTe_2 . To our knowledge, these three compounds have not been reported yet. LiCrTe_2 and NaCrTe_2 are antiferromagnets with positive Curie-Weiss temperatures as well as KCrS_2 , NaCrSe_2 , and KCrSe_2 [2-4]. Thus, the ferromagnetic superexchange interaction is dominant within a layer, and ferromagnetic layers are coupled antiferromagnetically. In contrast, LiCrSe_2 has a negative Curie-Weiss temperature and shows a first-order like antiferromagnetic transition, which are different from those of LiCrTe_2 and NaCrTe_2 . In this presentation, we will discuss the origin of the difference among these three compounds.

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Theory of thermal expansion in antiferromagnetic superconductors

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We investigate the temperature dependence of thermal expansion of antiferromagnetic superconductors below the Neel temperature. The Neel temperature is assumed to be much higher than the superconducting transition temperature. Therefore, the staggered magnetization is approximately constant in the coexistent phase. The isotropic singlet superconducting gap is used. This theory is based on the single band model of antiferromagnetic superconductors to which theory of ferromagnetic superconductors is extended. We derive a free energy and thermal expansion from this single band model. We find that thermal expansion increases exponentially with temperature at low temperatures. On the other hand, it has the power-law behavior near the superconducting transition temperature.

NMR study of EuNi_2Si_2 with trivalent Eu

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Magnetism in Europium (Eu) compounds is related to the electronic configuration of Eu ion. When the valence of Eu ion is divalent, this ion bears a large $4f$ magnetic moment. On the other hand, when Eu ion is in a trivalent state, the system shows the Van Vleck paramagnetism because of the $J=0$ ground state of the $4f^6$ configuration. In most of intermetallic Eu compounds, Eu^{2+} state rather than Eu^{3+} state tends to be stable. Then intermetallic Eu^{3+} compounds have been poorly studied. EuNi_2Si_2 is categorized as the Eu^{3+} system but its magnetic properties have not been reported. We performed ^{31}Si nuclear magnetic resonance (NMR) measurement to investigate microscopically magnetic properties of EuNi_2Si_2 . Temperature dependence of Knight shift and $1/(T_1T)=\text{constant}$ behavior at low temperatures clearly show the Van Vleck paramagnet of EuNi_2Si_2 . We discuss an additional contribution to $1/(T_1T)$ which was observed at high temperatures.

Electron correlation in Pauli paramagnetic Cr_2AlC , Cr_2GaC and Cr_2GeC

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Cr_2AlC , Cr_2GaC and Cr_2GeC are classical MAX phase compounds, for which successful synthesis of bulk equilibrium phases has been reported in an early stage. Although it has been established that they are Pauli paramagnetic down to the lowest temperature, the extent of the exchange enhancement depends on the A element ($A = \text{Al}$, Ga and Ge). In the present report, we will show the nature of electron correlation and the extent of exchange enhancement by analyzing low-temperature resistivity, specific heat, and susceptibility and evaluating the Kadowaki-Woods and Wilson ratios.

Transport properties in the vicinity of the critical point of the metamagnetic transition in UCoAl

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UCoAl is an itinerant-electron metamagnet which shows a 1st order transition accompanied by a hysteresis. The phase transition line in the H – T plane terminates at the critical point (CP). Although many researches have been focused on the behavior in the metamagnetic transition of UCoAl, little attention has been drawn to the nature of CP and the supercritical region. We shed light on this region and revealed some anomalies in the transport properties of this material.

We have performed magnetization, transverse magnetoresistance, and Hall effect measurements on an identical sample. We determined the CP to be $(T_{\text{cr}}, H_{\text{cr}}) = (9.8 \pm 0.2 \text{ K}, 8.2 \pm 0.1 \text{ kOe})$ from the magnetization measurement.

The transverse magnetoresistance $\rho_{xx}(H)$ shows an unusual increase not at the thermodynamically determined CP but in the supercritical region. Furthermore, we found the enhancement of the magnetic component in the resistivity $\Delta\rho_{xx}(T)$ at the temperature at which the susceptibility $\chi(T)$ becomes maximum. This enhancement probably relates to the maximum of $\chi(T)$ which is argued in terms of the phenomenological spin-fluctuation theory. We think that spin fluctuation in UCoAl strongly affects not only magnetic but also transport properties.

As for the Hall effect, we evaluated the normal and anomalous Hall coefficient R_0 and R_S on the basis of the general form of the ferromagnetic Hall resistivity $\rho_{xy} = R_0 B + 4\pi R_S M$. The temperature dependences of R_0 and R_S are different from those of usual ferromagnets especially at high temperatures. A new model to interpret the Hall effect of UCoAl as well as itinerant-electron metamagnets is highly needed.

Study of Superconducting Sr_2RuO_4 with Nuclear Magnetic Resonance and Nuclear Quadrupole Resonance

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A layered ruthenate superconductor Sr_2RuO_4 is one of an unconventional superconductor ($T_c = 1.5\text{K}$) and exhibits various interesting properties. This is one of possible spin-triplet superconductors (SCs), suggested with Knight shift and neutron scattering measurements. It is pointed out from muon spin relaxation and Kerr effect measurements that the time reversal symmetry is broken in the SC state. This origin is regarded as the chiral edge current resulted from chiral spin-triplet SC, but the current itself has not been detected yet. Furthermore, anomalous magnetic fluctuations along the c -axis appear in the SC state. A theoretical model is suggested that the magnetic fluctuations are result of dynamics of d -vector, the order parameter of spin-triplet SC. However, the magnetic fluctuations have not been detected with other measurements and further study is necessary for revealing the anomalous behavior.

More recently, it is found that the SC-normal phase transition is first-order phase transition at upper critical field at low temperature. Because the orbital depairing mechanism lead to second-order phase transition, there is a possibility that another depairing mechanism exists in this region. Pauli effect lead to first-order transition, but this is not consistent with the spin-triplet SC, whose spin susceptibility remains constant. Therefore novel depairing mechanism might exist, but no theory can explain this anomalous behavior.

We carried out nuclear magnetic resonance (NMR) and nuclear quadrupole resonance (NQR) on superconducting Sr_2RuO_4 to detect the above anomalies. We found that nuclear spin-spin relaxation rate $1/T_2$ is enhanced in the SC state in zero magnetic field. Furthermore, we tried to find some anomaly related to the first-order transition at high magnetic field region through Knight shift and spin-lattice relaxation rate $1/T_1$.

In this presentation, we will report our recent results and discuss the origin of the enhancement of the $1/T_2$ in the SC state.

Electronic states in the pressure-induced magnetically ordered phase in SmB_6 Systems

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SmB_6 with the cubic CaB_6 -type structure has been intensively studied since the 1960s because of its notable features, for example, an intermediate valence state (Sm valence is about 2.6) and a semiconducting property with a narrow gap (50 – 100 K). It is known from transport measurements that the insulating gap is suppressed with increasing pressure, resulting in the appearance of a metallic phase. Recently, a new magnetically ordered phase has been found above 6 GPa, so that interest in this compound has been renewed. The physical properties of SmB_6 involve many key factors common to a wide variety of strongly correlated electron systems, such as valence, insulating gap, magnetism, and the Kondo effect. However, especially in the metallic and magnetic phases, the details of Sm-4*f* states have not been clarified yet. First, we have carried out ^{11}B -nuclear magnetic resonance (NMR) measurement under pressure in order to investigate microscopically how the insulating gap is modified by pressure. Nuclear spin lattice relaxation rate $1/T_1$ reflects the density of states (DOS) at the Fermi energy. The results of the ^{11}B -NMR measurements up to 6 GPa, just below the critical pressure for the nonmagnetic-magnetic transition, suggest that the gap at least does not decrease with pressure, contrary to what had been believed from the transport measurements. Next, we have performed x-ray absorption spectroscopy (XAS) measurements of SmB_6 , aiming at investigating how the delocalized Sm-4*f* electrons changes with pressure. Pressure-induced transitions from nonmagnetic to magnetic phases in several Yb heavy fermion compounds with almost localized Yb-4*f* electrons have been studied by the XAS measurements so far. However, the present result seems to differ somewhat from them. The inconsistency between the results from the macroscopic transport measurements and the present NMR study will be discussed in detail. We will also present the results of the XAS measurements.

Magnetic anisotropy of $\text{Sr}_{1-x}\text{La}_x\text{Fe}_{12}\text{O}_{19}$ studied using single crystals

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The hexagonal ferrite $\text{SrFe}_{12}\text{O}_{19}$ with the magnetoplumbite structure is well-known as material for permanent magnets owing to its strong uniaxial anisotropy. Anisotropy field of $\text{LaFe}_{12}\text{O}_{19}$ with the same structure is reported to be higher than that of $\text{SrFe}_{12}\text{O}_{19}$ at low temperature [1]. Nevertheless, few studies on this material have been reported. This is because the preparation of single-phase samples is difficult owing to the metastability of $\text{LaFe}_{12}\text{O}_{19}$. Recently, a systematic study of substituted materials $\text{Sr}_{1-x}\text{La}_x\text{Fe}_{12}\text{O}_{19}$ using polycrystalline samples was reported [2], and the important role of Fe^{2+} was proposed. However, details of the magnetic anisotropy is unknown, therefore a investigation using single crystals is required.

We obtained single crystals of $\text{Sr}_{1-x}\text{La}_x\text{Fe}_{12}\text{O}_{19}$ in the range of $0 \leq x \leq 0.8$ by the traveling solvent floating zone (TSFZ) method. The typical size of single crystals is 4 mm in diameter and 70 mm in length. Using these single crystals, we measured magnetization processes along the axis of hard magnetization at 5 K. The anisotropy field decreases as the amount of La substitution increases in the range of $0 \leq x \leq 0.4$, and it takes a minimum. In the range of $x > 0.4$, it increases and, interestingly, magnetization curves shows nonlinear behavior.

Based on these results, we will discuss the role of Fe^{2+} in the origin of magnetic anisotropy of this system.

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Properties of spin fluctuation in amorphous $\text{Hf}_{1-x}\text{Ta}_x\text{Fe}_2$ alloys

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The amorphous $\text{Hf}_{1-x}\text{Ta}_x\text{Fe}_2$ alloys show the itinerant electron ferromagnetism in agreement with the Rhodes-Wohlfarth curve from a moderate magnetic moment for $x = 0$ to the weak limit for $x = 1$. [1] A continuous increase of the magnetization at 4.2 K as a function of the applied field up to 35 T and linear relationship in the Arrott plots have been observed for all x concentrations. The characteristic temperatures T_0 , T_A of the itinerant-ferromagnetic spin fluctuation in these amorphous alloys have been evaluated from Takahashi's theory. They are found to show systematic dependence on the x concentration and almost consistent with the theoretical curve of the generalized Rhodes-Wohlfarth plot (T_C/T_0 vs. P_{eff}/P_s plot). Furthermore, it is confirmed that the magnetization curve for $x = 0$ in the vicinity of T_c has a linearity in the M^4 vs. H/M plot, though the itinerant ferromagnetic moment is not very weak. In this session, we would like to discuss these experimental results on the standpoint of spin fluctuation theory in detail.

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Spin fluctuation and giant magnetoresistance in CeSi

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CeSi has an antiferromagnetic ordering below $T_N = 5.6$ K [1], which is characterized by a commensurate sinusoidal or square wave magnetic structure of the wave vector $q = (0, 1/2, 1/16)$ [2], showing a metamagnetic transition at $B_c = 0.6$ T [1]. It shows a large negative magnetoresistance proportional to the fourth power of the magnetization at 4.2 K [3], and a peculiar behavior of the anomalous Hall resistance [4]. Kondo effect is very weak in CeSi [1,5]. Recently, magnetocaloric effect (MCE) was studied in CeSi polycrystals by Snyman *et al.* [6]. They calculate the anisotropic exchange parameters from the analysis of the MCE data. In this paper, we present the temperature-dependent resistivity data under several magnetic fields. We note that temperature dependence of magnetoresistivity around T_N is similar to that of the isothermal change in entropy reported by Snyman *et al.* [5]. From the analysis of low temperature data, we show that the suppression to the spin fluctuation is dominant in the paramagnetic region above B_c , although the change of the residual resistance due to the metamagnetic transition appears. The results will be discussed by the spin fluctuation theory in weakly ferromagnetic materials [7].

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Photoinduced itinerant ferromagnetism in copper octacyanomolybdates

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Photoswitchable magnets based on octacyanomolybdates of the square antiprism configuration have been attracting much interest. Among others the copper-molybdenum bimetallic assemblies $\text{Cu}_2[\text{Mo}(\text{CN})_8] \cdot n\text{H}_2\text{O}$ exhibit reversible photomagnetism [1]. Irradiation of the non-magnetic ground state with green light induces a macroscopic magnetization, while further irradiation with orange light reduces this ferromagnetism. In order to reveal the microscopic picture of this phototunable magnetism, we simulate the time-evolution of the photoexcited state.

We establish a relevant extended Hubbard Hamiltonian and draw a ground-state (before photoexcitation) phase diagram. At low temperatures, the initial nonmagnetic charge-disproportionate state closely competes with an itinerant ferromagnetic state. Then, we directly observe photoinduced dynamics by numerically solving the time-dependent Schrödinger equation. We reproduce the photoinduced nonmagnetic-to-ferromagnetic phase transition. Angle-resolved photoemission spectroscopy (ARPES) spectra are also calculated. Upon the appearance of a global magnetization, a band structure is strikingly changed and excited electrons are distributed over the whole Brillouin zone. We further monitor optical conductivity spectra during the phase conversion to find that the induced ferromagnetic state shows the Drude component. This metallization precedes the magnetization. The band structure and the conductivity spectrum elucidate that the photoinduced itinerant ferromagnetic state may differ from the ground-state ferromagnetism.

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Itinerant electronic ferromagnetism in layered compounds Ae_2ScO_3CoPn ($Ae = Sr, Ba$, $Pn = P, As$)

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We synthesized polycrystalline samples of layered compounds Ae_2ScO_3CoPn ($Ae = Sr, Ba$, $Pn = P, As$) and studied their magnetism to clarify the relation between itinerant electronic ferromagnetism (IEF) and crystal structure of compounds with $CoPn$ conductive layers. As a result of magnetic measurements, ferromagnetic ordering was observed in cases of Sr_2ScO_3CoAs and Ba_2ScO_3CoAs with the Curie temperature of $T_C = 48$ K and 30 K, respectively. For the case of $Pn = P$, both Sr_2ScO_3CoP and Ba_2ScO_3CoP were found to show a Curie-Weiss type paramagnetism. Especially, for the case of Sr_2ScO_3CoP , the electronic state was found to locate at ferromagnetic quantum critical point (QCP). Therefore, these compounds can be lined up in order of strength of IEF as Sr_2ScO_3CoAs , Ba_2ScO_3CoAs , Sr_2ScO_3CoP and Ba_2ScO_3CoP . These results show that IEF becomes strong with increase of ion size of Ae and weakens with increase of that of Pn . This means that tendency of strongness of IEF cannot be understood by dependence on volume of a unit cell in the case of $CoPn$ layers unlike the case of three dimensional IEF. This anomalous relationship between IEF and crystal structure must be characteristic of IEF in an anisotropic crystal structure and indicates the importance of local structures of conductive layers.

Incommensurate to commensurate antiferromagnetism in CeRhAl₄Si₂: ²⁷Al NMR Study

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²⁷Al NMR experiments have been performed using a single crystal of CeRhAl₄Si₂, which is an antiferromagnetic Kondo-lattice compound with successive antiferromagnetic transitions of $T_{N1}=14$ K and $T_{N2}=9$ K at zero external field. In the paramagnetic state, Knight shifts, quadrupolar frequency, and asymmetric parameter of electrical field gradient on the Al sites have been determined, which has a local orthorhombic symmetry. The transferred hyperfine coupling constants are also determined. The relaxation rates suggest that $4f$ electrons behave as local moments in the high temperatures of $T > T_{N1}$. From the NMR spectral analyses, the antiferromagnetic structure below T_{N2} is consistent with a proposed model by neutron diffraction experiment, and the intermediate antiferromagnetic state between T_{N1} and T_{N2} is discussed to be along with an incommensurate modulation of the antiferromagnetic moments.

Nearly ferromagnetism of CaRuO_3

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Solid solution system of $\text{Sr}_{1-x}\text{Ca}_x\text{RuO}_3$ is one of the most important compounds for the study of itinerant-electron magnetism, because it changes from weak ferromagnet at $x = 0$ to nearly ferromagnet at $x = 1$ passing a quantum critical point at $x = 0.7$. Although the nearly ferromagnetism has been proven by NMR measurements, tiny spontaneous magnetization was later observed below 90 K and so the nearly ferromagnetism has been suspected by some people for about 15 years. Considering the importance of these compounds, this situation is undesirable.

In the presentation, we will show the following things about the spontaneous magnetization. (1) The spontaneous magnetization is enhanced when a sample is annealed under an inert atmosphere. (2) It is reduced when a sample is heated in oxygen gas but does not disappear. (3) It disappears when a sample is synthesized under a high pressure and slowly cooled down after the synthesis. (4) It appears below 40 K when a sample was thermally quenched after the high-pressure synthesis. These facts indicate that the intrinsic nature of CaRuO_3 is nearly ferromagnetic, and the spontaneous magnetization is caused by oxygen nonstoichiometry and other crystal defects. More than 1 atom of partial oxygen pressure is needed to synthesize a stoichiometric sample. The ferromagnetic behavior induced by the crystal defects seems to be consistent with the fact that ferromagnetic behavior was observed in $\text{CaRu}_{1-x}\text{M}_x\text{O}_3$ ($M = \text{Ti}, \text{Fe}$), where certain disorder was introduced. In addition to these results, we will show temperature dependence of Seebeck coefficient of the solid-solution system. It shows a characteristic dip at a low temperature according to a theoretical anticipation, and a deepest dip appears at the quantum critical point.

Free energy landscape analysis of two-dimensional $S = 1/2$ Heisenberg Antiferromagnets on Triangular and Kagome lattices

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Among two-dimensional magnetic systems, the triangular lattice (edge-shared) and the kagome lattice (corner-shared) are typical cases of spin-frustrations in antiferromagnetic systems, showing exotic quantum behaviors, one of which phenomena appears in the magnetization processes, particularly, the characteristic behavior of magnetization plateau. Until now, although the magnetic plateau was reported in both triangular and kagome systems with $S = 1/2$, the behavior in the kagome system is quite different from that of a typical magnetization plateau. In our study, the model is two-dimensional $S = 1/2$ Heisenberg antiferromagnet on the triangular lattice as a small finite-size cluster. We examine the relationship between free-energy landscape and magnetization processes in this model. Then we compare it with the kagome lattice. From the viewpoint of free-energy landscape, we discuss whether we can understand the difference of their physical nature, or not. In order to adjust the system size as well as the shape of the system, we compare it with other shapes of finite-size clusters. We also examine the spin systems with S other than $S = 1/2$ to discuss the generality of this numerical study.

Syntheses and physical properties of the triangular lattice antiferromagnet, $\text{Li}A^{\text{II}}M^{\text{III}}\text{F}_6$

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Antiferromagnetic compounds with the triangular lattice often show interesting physical properties caused by geometrically frustrated spins. Among various two-dimensional triangular lattice compounds, we focus on $\text{Li}A^{\text{II}}M^{\text{III}}\text{F}_6$, where A^{II} is a nonmagnetic divalent ion and M^{III} is a magnetic trivalent $3d$ metal ion. Most of the $\text{Li}A^{\text{II}}M^{\text{III}}\text{F}_6$ compounds have the honeycomb lattice consisting of alternately arranged Li and M^{III} . Consequently, M^{III} forms the triangular lattice. Each layer of the triangular lattice is separated by A^{II} having relatively large ionic radii. Although there are many kinds of ions that can occupy in A^{II} sites and M^{III} sites[1], synthesis-methods and physical properties have not been reported yet.

We synthesized $\text{Li}A^{\text{II}}M^{\text{III}}\text{F}_6$ ($A=\text{Ca}, \text{Sr}, \text{Cd}$), and measured their physical properties. They show negative Weiss temperatures indicating dominant antiferromagnetic interactions. In addition, we succeeded in growth of the pure single crystals of LiCaVF_6 and LiCdVF_6 , and found that they exhibit magnetic anisotropy at low temperature and an unusual magnetic transition. We are going to report their synthesis-methods and the detail of physical properties, and discuss their transition.

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Synthesis and study of electronic state of $\text{Sr}_2\text{CrO}_2\text{Co}_2\text{As}_2$ with CoAs conduction layers

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For the understanding of electronic state of CoAs layers, we synthesized $\text{Sr}_2\text{CrO}_2\text{Co}_2\text{As}_2$, a new member of compounds with CoAs layers and its partially substituted systems $\text{Sr}_2\text{CrO}_2(M_x\text{Co}_{1-x})_2\text{As}_2$ ($M = \text{Fe}, \text{Ni}$), and measured magnetization of these compounds. As a result of magnetic measurement for $\text{Sr}_2\text{CrO}_2\text{Co}_2\text{As}_2$, itinerant electrons of CoAs layers do not show itinerant electronic ferromagnetism unlike other compounds with CoAs layers. In addition, both Fe and Ni partially substituted systems also do not show ferromagnetism down to 2 K. These results indicate that absence of ferromagnetism in $\text{Sr}_2\text{CrO}_2\text{Co}_2\text{As}_2$ is not due to spontaneous carrier doping to Co but due to other reasons, e.g. due to the wider width of the conduction band. Since the lattice parameter along a -axis seems not so small for realization of ferromagnetism of magnetic moments of Co, it seems necessary to take into account the local structure like CoAs_4 tetrahedrons for understanding of the electronic state of $\text{Sr}_2\text{CrO}_2\text{Co}_2\text{As}_2$.

Paramagnetic-to-nonmagnetic transition in antiperovskite nitride Cr_3GeN studied by ^{14}N -NMR and μSR

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The antiperovskite type nitride Cr_3GeN forms the tetragonal structure [1] with the space group $P4_21m$ at room temperature. It shows a tetragonal ($P4_21m$) to tetragonal ($I4/mcm$) structural transition with a large hysteresis at 300–400 K [2]. The magnetic susceptibility of Cr_3GeN shows Curie-Weiss type temperature dependence at high temperature, and almost temperature independent behavior below room temperature.

In this research, we carried out μSR and ^{14}N -NMR measurements to reveal the microscopic magnetic ground state of Cr_3GeN . In the μSR measurement, gradual relaxations that are nearly temperature independent below room temperature were observed, indicating that Cr_3GeN is magnetically inactive. In the ^{14}N -NMR measurement, a quadrupole-split spectrum was obtained at around $^{14}K = 0$. The temperature dependence of $^{14}(1/T_1)$ shows a Korringa relation. These experimental results suggest that the ground state of Cr_3GeN is Pauli paramagnetic state, without antiferromagnetic long range order.

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La, Co substitution effects on magnetic anisotropy of the M-type hexagonal ferrite $\text{SrFe}_{12}\text{O}_{19}$ using single crystals

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$\text{SrFe}_{12}\text{O}_{19}$ is widely used as a magnetic material of hard magnets because of its high coercivity, which is closely related to its uniaxial magnetic anisotropy. $\text{SrFe}_{12}\text{O}_{19}$ has a magnetoplumbite-type structure (Space group $P6_3/mmc$). It is reported that the magnetic anisotropy field H_A of $\text{SrFe}_{12}\text{O}_{19}$ is enhanced by La, Co substitution[1]. However, almost all the previous studies of these substances were conducted using polycrystalline samples, which means that their results include the effects of orientations and grain boundaries. Therefore, we should use single crystals in order to characterize the magnetic anisotropy without these extrinsic effects.

In this study, we grew single crystals of $\text{Sr}_{1-x}\text{La}_x\text{Fe}_{12-y}\text{Co}_y\text{O}_{19}$ and characterized the magnetic properties. We used the traveling solvent floating zone method to grow these single crystals and succeeded in obtaining large single crystal rods with a typical diameter of 4mm. In the previous report[2], the maximum amount of substitution is $x = y = 0.4$ and its H_A is 18kOe. In contrast, H_A of our single crystals with the same amount of substitution is 26kOe, which is considerably larger than that of polycrystalline samples.

In this presentation, we will report magnetic anisotropy as a function of La concentration x and Co concentration y and discuss the origin of the magnetic anisotropy in this system.

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Transport property of $\text{FeSi}_{1-x}\text{Ge}_x$ across the nonmagnetic-ferromagnetic transition

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Narrow gap semiconductors including d- and f-electron systems are attractive materials for thermoelectric application. So far, Fe-based semiconductors such as FeSi_2 and Fe_2VAl have been reported to show good thermoelectric properties. In this paper, we report on the thermoelectric properties of $\text{FeSi}_{1-x}\text{Ge}_x$. FeSi crystallizes in the cubic B20 type structure and is a well-known narrow gap semiconductor with $\Delta = 0.06$ eV. When Si is partially replaced by Ge, the compound shows a phase transition from a nonmagnetic semiconductor to an itinerant ferromagnet at $\text{FeSi}_{0.75}\text{Ge}_{0.25}$ [1]. Thus it is of interest how the thermoelectric property can change in the $\text{FeSi}_{1-x}\text{Ge}_x$ compound when x is varied to cross $x \sim 0.25$, since the system can be a narrow gap semiconductor with strong spin fluctuation. We synthesized polycrystalline samples of $\text{FeSi}_{1-x}\text{Ge}_x$ and measured their magnetic and transport properties. Relation between the spin fluctuation and the thermoelectric properties will be discussed.

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Superconductivity in a new layered nickel-selenide CsNi₂Se₂

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The physical properties of CsNi₂Se₂ were characterized by electrical resistivity, magnetization and specific heat measurements. We found that the stoichiometric CsNi₂Se₂ compound undergoes a superconducting transition at $T_c=2.7\text{K}$. A large Sommerfeld coefficient γ_n ($\sim 77.90 \text{ mJ/mol}\cdot\text{K}^{-2}$), was obtained from the normal state electronic specific heat. However, the Kadowaki-Woods ratio of CsNi₂Se₂ was estimated to be about $0.041\times 10^{-5} \mu\Omega\cdot\text{cm}(\text{mol}\cdot\text{K}^2/\text{mJ})^2$, indicating the absence of strong electron-electron correlations. In the superconducting state, we found that the zero-field electronic specific heat data, $C_{es}(T)$ ($0.5\text{K} \leq T < 2.6\text{K}$), can be well fitted with a two-gap BCS model, indicating the multi-gap feature of CsNi₂Se₂. In the end, the comparison with the density functional theory (DFT) calculations suggested that the large γ_n in these nickel-selenide superconductors may be related to the large Density of States (DOS) at the fermi surface.

Anomalous antiferromagnetic state in $\text{Nd}_2\text{Co}_{12}\text{P}_7$

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For understanding the magnetic property of localized magnetic moment located in itinerant electronic systems, we synthesized single crystals of ternary compound $\text{Nd}_2\text{Co}_{12}\text{P}_7$ by Sn flux method and measured the temperature dependence of magnetizations $M(T)$ in low fields and magnetization curves $M(H)$ up to 55 T. The $M(T)$ shows that the Co moments are ordered ferromagnetically at $T_C = 142$ K. However, $M(T)$ decreases monotonically with the decrease of temperature below 70 K and the value of $M(T)$ at 2 K suggests antiferromagnetism. This means that $\text{Nd}_2\text{Co}_{12}\text{P}_7$ constructs an antiferromagnetic order at low temperatures without the occurrence of magnetic phase transition. From this result we conclude that the magnetization of Nd sublattice have a value same as the magnetization of Co sublattice and the Nd moments are aligned antiparallel to the Co moments at 2 K in $\text{Nd}_2\text{Co}_{12}\text{P}_7$. The fact that the value of Nd moment is smaller than the theoretical value is supported from the value of saturated magnetization observed from the $M(H)$ measurements. We expect that localized Nd moment is induced by the ferromagnetic Co moment in $\text{Nd}_2\text{Co}_{12}\text{P}_7$.

NMR study on CeCoIn₅/YbCoIn₅ superlattices: the electronic state at the interface between heavy fermion compound and normal metal

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Recently, the technique of fabricating epitaxial superlattices consisting of heavy-fermion compounds and conventional metals has been developed and provides a new research field on f-electron systems[1,2]. For example, superlattice-superconductors CeCoIn₅/YbCoIn₅ show the strong enhancement of H_{c2}/T_c [2] with decreasing CeCoIn₅ layer-thickness, where H_{c2} is superconducting upper critical field at $T = 0$ K and T_c is critical temperature. In these superlattices, the heterostructure would play a key role, but its magnetic and electronic properties have not been explored at the microscopic level. To investigate the magnetic and electronic properties in each block-layer(BL) of the superlattices, we performed nuclear magnetic resonance(NMR) measurement, which is one of the most suitable microscopic probes, on the CeCoIn₅/YbCoIn₅ superlattices as well as the thin films of CeCoIn₅ and YbCoIn₅. By comparing the spectra of these samples, we succeeded in identifying the ¹¹⁵In NMR signals arising from the CeCoIn₅ and YbCoIn₅ layers in the superlattices, separately. We measured nuclear spin relaxation rate($1/T_1$) in each BL, and found that $1/T_1$ of Ce-BL is suppressed with decreasing thickness of Ce-BL, although $1/T_1$ of Yb-BL is essentially unchanged with $1/T_1$ of the YbCoIn₅ thin film. This suggests that each BL is isolated and the proximity of f-electron with magnetic moment to nonmagnetic Yb-BL is unlikely. In addition, we compared the NMR spectra obtained in superlattices with different thickness of Ce-BL, and identified ¹¹⁵In-NMR signals arising from interfaces of heterostructures. From the measurement of $1/T_1$, we found that antiferromagnetic fluctuations are spatially varied along the *c*-axis even in the one Ce-BL.

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Magnetic anisotropy in the geometrically frustrated itinerant magnet $\text{Y}_{1-x}\text{Sc}_x\text{Mn}_2$

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The origin of heavy quasi-particle state in the transition metal based intermetallic compound $\text{Y}_{1-x}\text{Sc}_x\text{Mn}_2$ remains as an enigmatic problem in itinerant electron magnetism. $\text{Y}_{1-x}\text{Sc}_x\text{Mn}_2$ has the cubic C15 Laves phase structure with a space group $Fd\bar{3}m$, where the Mn atoms form a pyrochlore lattice. YMn_2 ($x = 0$) shows a first-order magnetic transition at around 100 K accompanied by a long-wavelength (~ 400 Å) helical spin structure. The magnetic ordering is suppressed by chemical pressure due to partial substitution of Y by Sc and large electronic contribution to the specific heat (~ 150 mJ/mol/K²) has been found in the paramagnetic state in place of the magnetic ordering. To investigate the microscopic magnetism of $\text{Y}_{1-x}\text{Sc}_x\text{Mn}_2$, we performed muon spin rotation/relaxation (μSR) experiments under a transverse field of 6 T for polycrystalline samples of $\text{Y}_{1-x}\text{Sc}_x\text{Mn}_2$ ($x = 0.05, 0.07$, and 0.09). We observed asymmetric broadening of the fast Fourier-transformed (FFT) μSR spectra at low temperature independent with Sc content. The FFT- μSR spectra were successfully analyzed as a powder pattern reflecting a symmetry of the expected muon site. We also found the observed broadening of the internal field at the muon site was explained by taking into account the huge in-plane magnetic anisotropy of the d-electron magnetic moments. This result indicates that the in-plane magnetic anisotropy conserves even in the paramagnetic heavy quasi-particle state of $x = 0.09$ sample.

Effect of Co substitution on the magnetic properties in $\text{Fe}_x\text{Co}_{1-x}\text{Ga}_3$

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Nearly ferromagnetic behaviors were observed in $\text{Fe}_x\text{Co}_{1-x}\text{Ga}_3$ system by chemical substitution of Co for Fe in diamagnetic mother compound FeGa_3 , with turning the semiconducting to metallic. The electrical resistivity of mother compound FeGa_3 shows a Kondo-semiconductor-like behavior, and gives the energy gap of FeGa_3 approximately as 0.4 eV, while CoGa_3 shows metallic conductivity in the measurement of electrical resistivity. Both the mother compound, FeGa_3 and CoGa_3 , have no magnetic orderings. Therefore with the electron doping by Co substitution in $\text{Fe}_x\text{Co}_{1-x}\text{Ga}_3$, the system turns a paramagnetic metal. The magnetization of $\text{Fe}_x\text{Co}_{1-x}\text{Ga}_3$ increases first by the Co substitution and turns nearly ferromagnetic, then the magnetization decreases and $\text{Fe}_x\text{Co}_{1-x}\text{Ga}_3$ turns a diamagnetic metal. While the electron doping of FeGa_3 by Ge substitution in FeGa_3 , $\text{FeGa}_{3-y}\text{Ge}_y$ becomes a weakly ferromagnetic metal. The magnetic properties of $\text{Fe}_x\text{Co}_{1-x}\text{Ga}_3$ are studied by the self-consistent renormalization theory and Takahashi's theory. We obtained all the spin-fluctuation parameters, fourth order expansion coefficients of magnetic free energy ($\bar{F}_1$), the magnetic susceptibility on the ground state $\chi(0)$, the energy width of the dynamical spin fluctuation spectrum (T_0), the width of the distribution of the dynamical susceptibility in the q space (T_A), analyzed by the magnetic measurements. The difference between magnetic properties of electron doping FeGa_3 , the $\text{Fe}_x\text{Co}_{1-x}\text{Ga}_3$ and $\text{FeGa}_{3-y}\text{Ge}_y$ system, will be reported.

Magnetic properties of weak itinerant electron ferromagnet CrAlGe

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Crystal structure and magnetic properties of Cr-based ternary compound CrAlGe were investigated. CrAlGe has an orthorhombic TiSi₂-type structure. Cr atom occupied the 8a-site, and both atoms of Al and Ge were at the 16f-site in the structure. The spontaneous magnetic moment M_0 , effective magnetic moment M_{eff} and Curie temperature T_C of CrAlGe were determined to be $0.41 \mu_B/\text{f.u.}$, $1.89 \mu_B/\text{f.u.}$ and 80 K, respectively. On the basis of Takahashi's theory [1,2], the energy width of the dynamical spin fluctuation spectrum T_0 and the dispersion of the static magnetic susceptibility in the wave vector space T_A were evaluated to be 1.0×10^3 K and 4.0×10^3 K, respectively. The square of the spontaneous magnetization $M_0(T)^2$ was proportional to T^2 below 30 K. However, the $M_0(T)^2$ was proportional to $T^{4/3}$ in the wide temperature range from 30 K to the T_C . By applying high pressure, T_C decreases. The obtained results suggest that CrAlGe is a weak itinerant-electron-ferromagnet.

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