ISSP Workshop

Present and Future of Neutron Scattering Research on Condensed Matter Physics
～Future Perspective of US-Japan Cooperative Program on Neutron Scattering～

June 4 – 5, 2018

Program and Abstracts

Organized by

The University of Tokyo
The Institute for Solid State Physics

Time table

	June 4 (Mon)	June 5 (Tue)
am	Registration Opening Session **Session 1** History of US-Japan cooperative program/ISSP activity reports **Session 2** Spectrometers in ORNL	**Session 5** Reports from US/ISSP Activity Report/Neutron scientists **Session 6** Neutron scientists/ ISSP Activity Report
noon	Lunch	Lunch Business Meeting
pm	Poster session **Session 3** Activity reports from US, JAEA activity report **Session 4** Crystal growth / Neutron scientists /Complimentary use	**Session 7** J-PARC/Crystal growth/ Neutron user **Session 8** Discussions on future of US-Japan cooperative program Closing Session
evening	Banquet	

Program

ORAL

4th June

8 :30 Registration

9 :00 Opening, Objective of Workshop
Director of ISSP, H. Mori

Objective of workshop, T. Masuda

Session 1 History of US-Japan cooperative program/ISSP activity reports
9:15 Y. Fujii, Thirty-seven Years Old US-Japan Cooperative Program to be Revitalized
9:45 T. Masuda, ISSP University of Tokyo, Collective excitations near quantum criticality in the geometrically frustrated antiferromagnet $CsFeCl_3$
10:15 Y. Uwatoko, ISSP University of Tokyo, High pressure apparatus for neutron diffraction measurements

10:45 Coffee break

Session 2 Spectrometers in ORNL
11:00 J. Fernandez-Baca, ORNL, Status of the MANTA project and the future of CTAX
11:30 I. Zaliznyak, BNL, Neutron Spectroscopy and Polarization Analysis on HYSPEC.

12:00 Lunch

13:00 Poster Session

Session 3 Activity reports from US, JAEA activity report
14:30 M. Frontzek, ORNL, The upgraded diffractometer at HFIR, HB-2C: $WAND^2$
14:55 N. Ikeda, Okayama University, Charge Ordering Model for Spin and Charge Frustrated System $YbFe_2O_4$
15:20 T. Nakajima, RIKEN, Magnetic orders and excitations in multiferroic Y-type hexaferrites

15:45 K. Kaneko, JAEA, Systematic neutron scattering study on Eu intermetallics

16:10 Coffee break

Session 4 Crystal growth / Neutron scientists /Complimentary use

16:30 Z. Hiroi, ISSP University of Tokyo, Searching for frustrated magnets with the benefit of neutron experiments

17:00 K. Iwasa, Ibaraki University, Neutron and x-ray scattering studies on semimetal systems $Ce_3Tr_4Sn_{13}$ (*Tr*: transition metal)

17:25-17:50 A.Q.R. Baron, RIKEN, Opportunities with Inelastic *X-Ray* Scattering

18:30 Banquet

5th June

Session 5 Reports from US/ISSP Activity Report/Neutron scientists

9:00 M. D. Lumsden, ORNL, Neutron Scattering Research Highlights from ORNL

9:30 T. J. Sato, Tohoku University, Nonreciprocal Magnons in Noncentrosymmetric Magnets

10:00 H. Tanaka, Tokyo Institute of Technology, Magnetic Excitations in the Spin-1/2 Triangular-Lattice Heisenberg Antiferromagnet $Ba_3CoSb_2O_9$

10:30 M. Hase, NIMS, Magnetic excitations in antiferromagnetic alternating spin-3/2 chain compounds $RCrGeO_5$

10:55 Coffee break

Session 6 Neutron scientists/ ISSP Activity Report

11:10 H. Kageyama, Kyoto University, The role of neutron science in solid state chemistry

11:40 C. Lee, AIST, Development of thermoelectric materials using rattling and lone pairs

12:05 M. Fujita, Tohoku University, Oxygen Reduction Effect on the Spatial Spin Density Distribution in T'-$Pr_{1.40}La_{0.60}CuO_{4+y}$

12:30 Lunch & Business meeting: Discussion on future of US-Japan cooperative program@2nd meeting room

Session 7 J-PARC/Crystal growth/Neutron user

13:30 K. Nakajima, J-PARC, Frontier of condensed matter physics at J-PARC

14:00 K. Tomiyasu, Tohoku University, Neutron scattering study of 3D frustrated magnets

14:25 S. Nakatsuji, ISSP University of Tokyo, Large Transverse Responses at Room Temperature in the Weyl Antiferromagnets Mn_3X

14:55 T. Kimura, University of Tokyo, Magnetoelectrics showing non-coplanar magnetic order

15:25 J. D. Reim, Tohoku University, New observations in well-established skyrmion materials Cu_2OSeO_3 and MnSi

15:50 Coffee break

Session 8 Discussions on future of US-Japan cooperative program

16:05 Y. Fujii 10min. talk

16:15 Free discussion

16:35 Closing

POSTER

4th June 13:00 – 14:30

P1 N. Aso, Ryukyu University, Neutron Scattering Study in Single-Crystalline $YbCo_2Zn_{20}$

P2 M. Hagihala, KEK, Magnetic Structure of S=5/2 Spin-dimer compound $Cs_3Fe_2Cl_9$

P3 K. Ikeuchi, CROSS, Phonons and magnetic excitations in Fe-based superconductor $Ca_{10}Pt_4As_8(Fe_{1-x}Pt_xAs)_{10}$

P4 R. Kobayashi, Ryukyu University, Magnetic Interaction Crossover by Rh-doping in a Kondo Semiconductor $CeRu_2Al_{10}$

P5 N. Kurita, Tokyo Institute of Technology, Localized magnetic excitations in the S=1/2 fully frustrated dimer compound $Ba_2CoSi_2O_6Cl_2$

P6 T. Matsumura, Hiroshima University, Magnetic-field-induced charge order in $SmRu_4P_{12}$ studied by polarized neutron diffraction

P7 M. Soda, RIKEN, Neutron Scattering Study in Åkermanite System $Ba_2CoT_2O_7$ (T=Si and Ge)

P8 K. Suzuki, Tohoku University, Step-like Development of magnetism in the electron doped cuprate superconductor $R_{2-x}Ce_xCuO$ (R = Nd, Eu)

P9 D. Ueta, ISSP University of Tokyo, Magnetic Structure of a Non-Centrosymmetric $CePdSi_3$

P10 T. Hawai, KEK, Magnetic excitation of quasi-one dimensional ladder compound $BaFe_2Se_3$

ABSTRACTS

Oral Presentations

O1

Thirty-seven Years Old US-Japan Cooperative Program to be Revitalized

Y. Fujii*

Emeritus Professor of the University of Tokyo

We look back to the 37 year history of this Program and look forward to its possible brighter future.

When the US-Japan Program on Neutron Scattering started in 1981 under the so-called "Non-energy Umbrella Agreement" signed by US President J. Carter and Japanese Primer Minister M. Ohira in 1980, it was an excellent idea for both sides to promote cooperative research by using Japanese neutron instruments newly built at such most advanced US research reactors as HFBR/BNL and HFIR/ORNL capable of producing more than one order of magnitude higher flux than Japanese facilities. Japanese researchers go to the US-based facilities either via ISSP or JAERI (later JAEA) so that the basic mode of operation is "one-way". The discovery of high-Tc superconductors in 1986 excitingly accelerated and enhanced this collaboration.

In 1997, however, we encountered such a critical problem on HFBR as leaks of water containing radioactive tritium from a spent-fuel tank monitored outside the reactor building. By spending two years for careful engineering/environmental investigation as well as political consideration, the US Government finally decided to permanently shut down HFBR in 1999. The inevitable relocation of the ISSP-owned spectrometer from HFBR to HFIR resulted in the present CTAX where the JAEA-owned WAND has been located from the beginning.

Other large change of situations from the early 1980's can be recognized as follows: (US) new large-scale facilities SNS/ORNL, NSLS-II/BNL, (Japan) JRR-3, J-PARC/MLF, MEXT by merger between MONBUSHO and STA. Under these new circumstances on both sides, it may be an appropriate time to freely discuss any opportunity for the future of this Program. It's also known that the US-Japan Program on High Energy Physics under the "Energy Umbrella Agreement" originally signed in 1979, recently switched its mode of operation from "one-" to "two-way". We'll discuss any option, minor or major modification, for our brighter future.

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*Served as a member of Steering Committee for ISSP (1992-2003) and for JAERI/JAEA (2004-2009).

O2

Collective excitations near quantum criticality in the geometrically frustrated antiferromagnet $CsFeCl_3$

Takatsugu Masuda

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Frustrated magnetism and quantum criticality both have been central topics in the condensed matter physics. The frustration prevents conventional magnetic order, leading to complex spin textures [1] or spin liquid states [2]. The enhanced quantum fluctuation at quantum critical point generate nontrivial spin state having scale invariance and universal response function [3], which induces exotic phenomena around the point including Higgs mode in antiferromagnets [4]. Remarkable progresses have been made on these topics separately, and next challenge is to focus on the interplay between them. In this study we demonstrate that novel excitations are induced in the vicinity of the quantum critical point in a frustrated triangular antiferromagnet $CsFeCl_3$ by use of the inelastic neutron scattering technique under high pressure. A well-defined excitation is identified as a non-trivial hybridization of Higgs and transverse modes, which is peculiar to non-collinearity of the magnetic structure. Combination of precise measurements and detailed calculations evidences the existence of the solo Higgs mode in addition to the hybridized mode.

[1] S. Sachdev, Phys. Rev. B **45**, 12377 (1992), S. Mühlbauer *et al*., Science **323**, 915 (2009).

[2] L. Balents, Nature (London) **464**, 199 (2010).

[3] S. Sachdev, Science **288**, 475 (2000).

[4] B. Lake, D. A. Tennant, and S. E. Nagler, Phys. Rev. Lett. **85**, 832 (2000), A. Zheludev *et al*., Phys. Rev. Lett. **89**, 197205 (2002), Ch. Rüegg *et al*., Phys. Rev. Lett. **93**, 257201 (2004), P. Merchant *et al*., Nat. Phys. **10**, 373 (2014). A. Jain *et al*., Nat. Phys. **13**, 633 (2017). T. Hong *et al*., Nat. Phys. **13**, 638 (2017).

O3

High pressure apparatus for neutron diffraction measurements

S.E. Dissanayake[1], M. Matsuda[1], K. Munakata[2], H. Kagi[3], K. Komatsu[3], J. Gouchi[4] and Y. Uwatoko[4]

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[2]*CROSS, Tokai, Ibaraki 319-1106, Japan*
[3]*GRC, Graduate School of Science, The University of Tokyo, Hongo, Tokyo 113-0033, Japan*
[4]*ISSP, The University of Tokyo, Kashiwa, Chiba, 277-8581, Japan*

High-pressure neutron diffraction (HPND) experiments in extended pressure and temperature ranges can provide invaluable information for understanding many pressure-induced emergent phenomena, such as unusual phase transitions and quantum critical behavior involving spin, orbital, charge and structural degrees of freedom, in strongly correlated materials. Many apparatuses for different purposes of HPND experiments have been developed in several laboratories [1]. Under US-JAPAN cooperative program, Onodera et al. was constructed modified McWhan type piston cylinder cell at 1987[2]. Recently, for more high pressure measurements, a clamp-type cubic anvil high pressure cell that can generate pressure over 7 GPa at 3 K was developed for low-temperature HPND measurements [3]. In this talk, characteristics of the clamp-type cubic anvil high pressure cell is presented and its performances are demonstrated by measuring magnetic neutron scattering under pressure on some results [4].

References

[1] D.F. Litvin and E.G. Ponyatovskii, 1966 Soviet Phys. 11, 322, D.B. McWhan et al., Rev. Sci. istrum. 1974 45, 643, W. Bao et al., 1995 Rev. Sci. istrum. 66, 1260
[2] A. Onodera et al., 1987 Jpn. J. Appl. Phys. 26 152
[3] Y. Uwatoko et al., 2008 Rev. High Pressure Sci. Technol. 18, 230, S.E. Dissanayake et al., 2017 (AIRAPT26), J.G. Cheng, et al., 2014 Rev. Sci. Instrum. 85 093907
[4] J.G. Cheng, et al., 2015 Phys. Rev. Lett. 114 117001, M. Matsuda, et al., 2016 Phys. Rev. B 93 100405(R), Dissanayake S E et al. (in preparation)

Status of the MANTA project and the future of CTAX

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In this talk I will present the status of the project to design and build a state-of the-art cold neutron triple axis spectrometer that will be located at the CG-1 guide at the HFIR cold neutron guide hall. This instrument will incorporate the latest advancements in neutron optics and will provide capabilities to meet the demands of the US condensed matter and quantum materials communities of the 21st century. These capabilities will include high flux, two orders of magnitude better than CTAX, polarized neutrons, capabilities for ultrahigh-resolution spectroscopy using Wollaston prisms, and a multi-analyzer backend to provide efficient mapping of broad regions of (q, E) space. This instrument will replace the US-Japan triple axis spectrometer CTAX which is currently located at the G-4C guide, and will have two different but interchangeable back ends: one will be a modified version of the current CTAX, the second one will be a multi analyzer backend. The CAMEA concept is being considered for the latter.

O5

Title: Neutron Spectroscopy and Polarization Analysis on HYSPEC.

Igor Zaliznyak[1], Andrei Savici[2], Vasile Garlea[2], Barry Winn[2], Genda Gu[1], John Tranquada[1]

1. Condensed Matter Physics and Materials Science Division, Brookhaven National Laboratory, Upton, NY, USA.

2. Neutron Scattering Division, Oak Ridge National Laboratory, Oak Ridge, TN, USA.

Abstract: HYSPEC is the flagship neutron instrument for spectroscopic studies of magnetic and lattice dynamics in thermal and sub-thermal neutron energy range, with peak incident neutron flux at around 15 meV. With the commissioning of the polarized beam option in 2015, it also provides a unique capability of polarization analysis in thermal and sub-thermal neutron energy range, extending up to energy transfers of approximately 20 meV. HYSPEC experiments provided the first experimental identification of the orbital-selective electron localization in Fe chalcogenide parent material, FeTe [1]. These studies established the concomitant ferro-orbital order, which explains "bicollinear" antiferromagnetism, a metallic state, and a loss of magnetic susceptibility. They also found an unusual forbidden phonon excitation in these materials, which might be a dynamical signature of these electronic behaviors [2]. HYSPEC is also a mainstay for ISSP-BNL collaborative projects. One such recent study provided important contribution to understanding the unusual block type magnetic structure in the iron chalcogenide ladder material, $BaFe_2Se_3$ [3]. More recently, we performed polarized inelastic neutron scattering surveys of the temperature-dependent magnetic dynamics in both parent, $Fe_{1+y}Te$, and the optimally doped superconductor, $FeTe_{0.55}Se_{0.45}$. Using the polarization analysis capability of HYSPEC, which is unique in the field of time-of-flight spectroscopy we are able to clearly separate magnetic dynamics from that of the lattice and thus explore its temperature evolution in the absence of an interference with the strongly T-dependent lattice contribution. Our results thus reveal an unusual, energy- and temperature-dependent orbital composition of the dynamical magnetism in the iron superconductor family materials, which is uniquely identified by the means of polarized time-of-flight inelastic neutron spectroscopy.

References:

[1] I. A. Zaliznyak, Z. Xu, R. Zhong, G. Gu, J. M. Tranquada, L. Harriger, D. Singh, V. O. Garlea, M. Lumsden, B. Winn, Phys. Rev. Lett. 112, 187202 (2014).

[2] D. M. Fobes, I. A. Zaliznyak, Z. Xu, G. Gu, X.-G. He, W. Ku, J. M. Tranquada, Y. Zhao, M. Matsuda, V. O. Garlea, B. Winn, Phys. Rev. B 94, 121103(R) (2016).

[3] T. Hawai, Y. Nambu, K. Ohgushi, B. Winn, V. O. Garlea, M. Graves-Brook, I. A. Zaliznyak, Testuya Y, S. Itoh, T. J. Sato, Phys. Rev. B (in preparation, 2018)

[3] I. Zaliznyak, et. al., unpublished (2018).

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PRESENTATION TYPE: Oral

Category Type: Experimental

The upgraded diffractometer at HFIR, HB-2C: WAND^2

M. D. Frontzek, K. M. Andrews, A. B. Jones, B. C. Chakoumakos, J. Fernandez-Baca

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The Wide Angle Neutron Diffractometer (WAND) at the High Flux Isotope Reactor (HFIR) at the Oak Ridge National Laboratory (ORNL) was built by and continues to be, a joint project between ORNL and the Japan Atomic Energy Agency (JAEA). Its first incarnation dates to the 1980's as part of the US-Japan Cooperative Program. In 2018, the last phase of a long planned upgrade had been completed with the installation of the 120 degree, 2-dimensional position sensitive detector from Brookhaven National Laboratories. The updated instrument has been named WAND^2 and, after it's commissioning in February, had its first general users in May.

WAND^2 is positioned as a thermal, multi-purpose, high throughput powder-/single crystal diffractometer. The instrument can use a large portion of HFIRs sample environment, allowing measurements from mK to 1500 K, magnetic fields up to 6 T and high pressures (~ 10 GPa). The large area coverage of the detector allows efficient collection of powder data in short times which can be used to filter events synchronized to external sample environment parameters.

For single crystal diffraction the instrument's strength is the mapping of a large area in reciprocal space with an excellent noise to background ratio. This allows for instance the search for weak magnetic signals when the propagation vector is unknown and the mapping of diffuse scattering.

In our contribution we review the improvements on WAND^2 implemented during the upgrade and review some of the challenges we encountered. We will review a selection of the first experiments and will be able to gauge the performance of the new instrument, with the hope to continue the success story of this diffractometer as part of the US-Japan Cooperative program and elevate WAND^2 to one of the leading instruments at HFIR.

Charge Ordering Model for Spin and Charge Frustrated System $YbFe_2O_4$

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We have been investigating the charge and spin structure in frustrated triangular mixed valence oxide family RFe_2O_4 (R = Dy - Lu, and Y). This material has attracted a lot of attention, because experimental evidence was reported for a ferroelectricity arising from electron correlations and shows a multiferroic behavior [1]. It also shows very complex charge and magnetic correlations with finite correlation lengths in zero and applied magnetic field [2]. Despite the intensive investigations on charge and magnetic ordering using both synchrotron x-ray and neutrons, the understanding of the physics in $LuFe_2O_4$ is far from complete.

We had performed three-dimensional reciprocal space mapping with wide angle neutron detector in ORNL and ANSTO reactor on newly synthesized iron stoichiometric $YbFe_2O_4$. As shown in the figure, complex incommensurate satellite structures were observed. We made a systematic explanation for these signals. Also we found new results on this material as, 1) the stoichiometric RFe_2O_4 do not show the low temperature spin transition T_{LT}, which indicates the origin of the transition was the pinned effect for the competing short range spins between ferri- and antiferro ordered region. 2) The three-dimensional charge ordering transition of stoichiometric RFe_2O_4 is 390K. 3) Below 300K we had found a partial spin ordered phase where lattice and spin are coupled.

[1] N. Ikeda, *et al.*, *Nature* 436 (2005) 1136.
[2] J. de Groot, *et al.*, *Phys. Rev. Lett.*, 108 (2012) 037206.

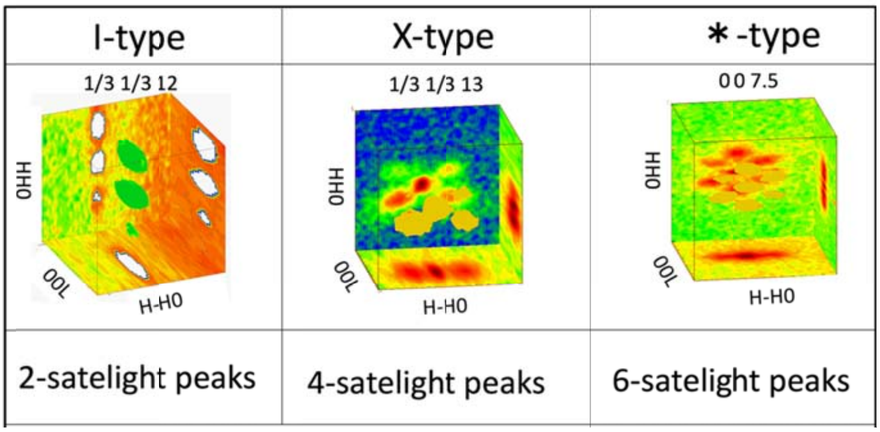

Figure: Three kinds of modulation of super lattice reflection were found in stoichiometric $YbFe_2O_4$.

O8

Magnetic orders and excitations in multiferroic Y-type hexaferrites

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We have investigated magnetic orders and excitations in a Y-type hexaferrite $BaSrCo_2Fe_{11}AlO_{22}$ (BSCoFAO), which exhibits helimagnetic structures with spin-driven ferroelectricity in a wide temperature range [1]. BSCoFAO also shows electromagnon excitations. Shishikura *et al*. observed a strong optical absorption at around 7 meV by means of THz time-domain spectroscopy, and found that the excitation is driven by electric-field component of the incident light [2]. Nevertheless, the peak position and spectral weight of the optical absorption are strongly correlated with the magnetic phase transition, suggesting that the absorption is attributed to electric-field-active magnetic excitation, namely electromagnon. In the present study, we thus performed polarized neutron inelastic scattering experiment on BSCoFAO at the PTAX instrument in HFIR, in order to directly observe the spin part of the excitation. We indeed observed spin-flip inelastic scattering signals at around 7 meV at $(0,0,9+q_m)$ in the reciprocal lattice space, where q_m is the incommensurate magnetic modulation wave vector [3]. By measuring polarized inelastic scattering spectra at several reciprocal lattice points with different directions of neutron spin polarization, we conclude that the spin-wave mode at 7 meV consists of spin components oscillating in a plane perpendicular to the helical axis of the magnetic structure. This phason-like mode can account for the electromagnon in terms of the magnetostriction mechanism. We will also show some preliminary results of neutron diffraction measurements on another Y-type hexaferrite $BaSrCu_2Fe_{11}AlO_{22}$, which shows a field-induced phase transition accompanied by distinct change in electromagnon excitation.

[1] S. Hirose *et al*., Appl. Phys. Lett. **104**, 022907 (2014).
[2] H. Shishikura *et al*. Physical Review Applied **9**, 044033 (2018).
[3] T. Nakajima *et al*. Physical Review B **94**, 195154 (2016).

Systematic neutron scattering study on Eu intermetallics

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Magnetism in rare-earth ions is accompanied by large orbital moment, and therefore, is influenced by single ion anisotropy via crystalline electric field. In contrast, Eu^{2+} and Gd^{3+} have unique state without orbital angular momentum J=S=7/2 with L=0. It provides an ideal opportunity to study the effect of interactions and resulting collective spin behavior without single-ion anisotropy.

On the other hand, limited neutron scattering studies have reported in these compounds due to strong absorption of Gd and Eu. Recently, we started systematic study on Eu compounds using the wide-angle neutron diffractometer WAND. Thanks to a relatively short wavelength neutron of WAND, which helps to suppress substantial neutron absorption, magnetic peaks have been successfully observed even for small crystals. In addition, the large PSD of WAND and recent upgrade to 2-D PSD in $WAND^2$ brings us a further possibility to make an efficient survey of wide reciprocal lattice space.

Recently, interesting variation in the magnetic anisotropy is discovered in orthorhombic isovalent family $EuTIn_4$ with T=Ni, Pd and Pt. Among these compounds, magnetic anisotropy have marked contrast. $EuNiIn_4$ has Ising-type magnetic anisotropy where b is a magnetic easy axis. In contrast, the anisotropy is changes into the a-b planar anisotropy in $EuPdIn_4$, and becomes the a-c planar type in $EuPtIn_4$, which is contrary to $EuNiIn_4$. In order to understand the mechanism of the magnetic anisotropy, single crystal neutron diffraction experiments were carried out. Despite strong neutron absorption of Eu and In, magnetic Bragg peaks were successfully observed. We will discuss the possible origin of the magnetic anisotropy in $EuTIn_4$ based on the magnetic structure, including latest results of $WAND^2$.

O10

Searching for frustrated magnets with the benefit of neutron experiments

Z. Hiroi

ISSP, University of Tokyo

We have been looking for interesting frustrated magnets in nature for many years. The would of frustrated magnets is always complicated essentially owing to competing interactions that cause complex phenomena in the low energy scale and highly degenerate states. In addition, extrinsic effects arising from certain disorder and glassy behavior are unavoidable in actual materials, which tend to mask the intrinsic properties of them. Thus, we should be careful in experiments and interpreting experimental results.

In order to get to a final goal, we should examine a material from wide perspectives. A high-quality sample is to be prepared through fine tuning of preparation methods and conditions, and it is examined by various experimental techniques. However, at the first stage of research, our sample may not be good enough, and we do not know whether our sample is interesting or not from the physics point of view (from the chemistry viewpoint, every material is more or less attracting in certain way). Then, chemists gain motivation to proceed to tune the synthesis when they notice that it would be.

Neutron scattering techniques are obviously key experiments that provide us with detailed information about spins and their dynamics. Here I will introduce a few examples of frustrated magnets and show our efforts for understanding them, which, I hope, will open a new scheme of frustration physics.

O11

Neutron and x-ray scattering studies on semimetal systems $Ce_3\mathit{Tr}_4Sn_{13}$ (*Tr*: transition metal)

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The series of $\mathit{RE}_3\mathit{Tr}_4Sn_{13}$ (*RE*: Ce, La; *Tr*: Co, Rh) have been reported to show various electronic states [1]. The La-based compounds are superconductors below 2-3 K, while the Ce-based compounds behave like semimetals [2]. It has been controversial what are origins of a large value of C_p/T near 1 K considered to be a heavy fermion and electrical-resistivity enhancement below 15 K of $Ce_3\mathit{Tr}_4Sn_{13}$.

We confirmed that the structures are categorized in the chiral symmetry (space group $I2_13$) below 160 and 350 K of $\mathit{RE}_3Co_4Sn_{13}$ and $\mathit{RE}_3Rh_4Sn_{13}$, respectively [3]. Inelastic neutron scattering experiments revealed crystal-electric-field (CEF) levels of Ce^{3+} $4f^1$-electron state, and striking emergence of spin excitations below 1 meV within the doublet CEF ground state, while no magnetic orderings appear. The spin excitations appear simultaneously with the electrical-resistivity enhancements below 15 K, and are consistent with the specific-heat anomalies at 1 K [4]. The low-temperature semimetal state in $Ce_3\mathit{Tr}_4Sn_{13}$ is dominated by the paramagnetic spin excitations.

[1] A. Ślebarski et al., Phys. Rev. B **88**, 155122 (2013). [2] E. L. Thomas et al., J. Solid State Chem. **179**, 1642 (2006). [3] Y. Otomo et al., Phys. Rev. B **94**, 075109 (2016). [4] K. Iwasa et al., Phys. Rev. B **95**, 195156 (2017).

Opportunities with Inelastic *X-Ray* Scattering

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An increasing number of inelastic scattering experiments are now possible using x-rays, due to improvements in x-ray instrumentation and sources over the last decades. This offers researchers different and, often, complementary probes to investigate material dynamics at finite momentum transfers [1-3]. Non-resonant X-ray methods (using the $\mathbf{A}^2$ or Thompson term of the cross section) are slightly easier to interpret and to instrument with resolution can vary from <1 meV to ~100 meV, while resonant methods (the $\mathbf{A}\bullet\mathbf{p}$ term) can access magnetic excitations, albeit with usually slightly poorer energy resolution.

Method	**Resolution (meV)**	**Q-Range**	**Comment**
Soft X-Ray Resonant "SIXS"	>30 (30 to 70 typ.)	< 10 nm^{-1}	Magnetism Possible
Hard X-Ray Resonant "RIXS"	>10 (~50-200 typ.)	<100 nm^{-1}	Magnetism Possible
Hard X-Ray Non-Resonant "IXS" or "NRIXS"	<1 to >1000	<1 to ~100 nm^{-1}	Atomic and electronic excitations

This talk will discuss opportunities using IXS, focusing primarily on non-resonant methods. After an introduction, I will mention some examples that may include *phonons in superconductors*, measuring *sound speeds in earth's core* conditions [4,5], excitations in *liquid iron for* $Q<1\ nm^{-1}$ [6], the *vibron in liquid hydrogen* at 300K [7], and *d-d excitations* [8].

References:

[1] W. Schülke, *Electron Dynamics by Inelastic X-Ray Scattering* (Oxford University Press, New York, 2007) **[2]** L. J. P. Ament, *et. al*., Rev. Mod. Phys. **83**, 705 (2011). **[3]** A. Q. R. Baron, in *Synchrotron Light Sources Free. Lasers Accel. Physics, Instrum. Sci.*, edited by E. Jaeschke, *et al*., (Springer, Cham, 2016), p. 1643–1757 Also arXiv 1504.01098. **[4]** Y. Nakajima, et al.,, Nat. Commun. **6**, 8942 (2015). **[5]** T. Sakamaki, E. Ohtani, *et al.,* Sci. Adv. **2**, (2016). **[6]** A. Q. R. Baron, M. Inui, D. Ishikawa, Y. Kajihara, Y. Nakajima, K. Matsuda, *et. al*., (in preparation). **[7]** A. Q. R. Baron, D. Ishikawa, H. Fukui, G. Liu, and H.-K. Mao, *et al*., (in preparation). **[8]** D. Ishikawa, *et al*., J. Phys. Soc. Japan, Lett. **86**, 93706 (2017).

O13

Neutron Scattering Research Highlights from ORNL

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ORNL operates two high-flux neutron sources, the High Flux Isotope Reactor (HFIR), a 85-MW continuous source, and the Spallation Neutron Source (SNS), a 1.4 MW pulsed neutron source. HFIR has 12 instruments in the user program and SNS has 19 instruments. The science program supported by these instruments is diverse covering work in quantum materials, soft matter, biology, engineering, imaging and chemistry. Quantum materials has been particularly active and produced several high impact publications recently. An overview will be given of a selection of this work with emphasis on neutron spectroscopy which can provide critical information in quantum magnets. Additionally, some specific technical developments will be highlighted including high pressure capabilities and polarized neutron developments. Finally, the future of neutron scattering at ORNL is centered on the Second Target Station and a brief overview of the unique capabilities of this source will be presented.

Nonreciprocal Magnons in Noncentrosymmetric Magnets

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Magnons attract revived interests recently in a context of realizing spintronic devices utilizing their unique ability to carry spin-wave-spin current. Apparently, controlling propagation direction of magnons is the key element to realize such a device. In this talk, we will introduce two of our recent study related to this unidirectional (or nonreciprocal) propagation of magnons in noncentrosymmetric magnets. The first one is celebrated noncentrosymmetric chiral magnet MnSi [1]. We have shown, by realized small angle inelastic neutron scattering technique at CTAX spectrometer (ORNL), that in its field-polarized ferromagnetic phase, the magnon dispersion relation is asymmetric; magnons propagating parallel and antiparallel to the magnetization direction have different frequency. Furthermore, the dispersion relation can be switched by reversing the external field direction. By using fixed frequency/wavelength excitation, this asymmetry indeed allows one to selectively excite magnons propagating unidirectionally. The second is on the noncentrosymmetric antiferromagnet a-Cu2V2O7 [2]. In the antiferromagnet, there are two circularly polarized states of magnons, which, in the noncentrosymmetric environment, is now confirmed to have different phase velocity for the same frequency. Consequently, the superimposed linearly polarized state has rotating polarization angle, which is analogous to the "circular birefringence" of photons. In other words, the nonreciprocality in this case appears in its phase, and if controlled by external electric field, this would be a magnonic analogy of the optical Faraday effect, which opens a way to realize an intriguing magnonic field effect transistor.

[1] T. J. Sato *et al*. PRB 94, 144420 (2016).
[2] G. Gitgeatpong *et al*. PRL 119, 047201 (2017).

O15

Magnetic Excitations in the Spin-1/2 Triangular-Lattice Heisenberg Antiferromagnet $Ba_3CoSb_2O_9$

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An S=1/2 triangular-lattice Heisenberg antiferromagnet (TLHAF) is a prototypical frustrated quantum magnet, which exhibits remarkable quantum many-body effects arising from spin frustration and quantum fluctuation. The ground-state properties of an S=1/2 TLHAF are theoretically well understood. The most remarkable static quantum effect is the magnetization plateau at one-third of the saturation magnetization. This macroscopic quantum phenomenon was verified by experiments on $Ba_3CoSb_2O_9$, which is considered to be the best experimental realization of the spin-1/2 TLHAF [1]. However, magnetic excitations are less well understood and the theoretical consensus is limited. The experimental study of the magnetic excitations in S=1/2 TLHAFs has also been limited [2]. In this presentation, we show the whole picture of magnetic excitations in $Ba_3CoSb_2O_9$ investigated by inelastic neutron scattering [3]. The excitation spectra have a three-stage energy structure. The lowest first stage is composed of dispersion branches of single-magnon excitations. The second and third stages are dispersive continua. The excitation continuum extends above 10 meV, which is six times larger than the exchange interaction J=1.67 meV. This result strongly suggests that the excitation continuum in the S=1/2 TLHAF is composed of multiple excitations of fractionalized spin excitations. At present, no theory describes the structure of the excitation continua observed in this experiment, and thus, a new theoretical framework is required.

[1] Y. Shirata et al., PRL **108**, 057205, T. Susuki et al., PRL **110**, 267201 (2013).
[2] J. Ma et al., PRL **116**, 087201 (2016).
[3] S. Ito et al. Nat. Commun. **8**, 235 (2017).

O16

Magnetic excitations in antiferromagnetic alternating spin-3/2 chain compounds $RCrGeO_5$

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Spins on Cr^{3+} ions (S = 3/2) are expected to form antiferromagnetic (AF) alternating chains in $RCrGeO_5$ (R = Y or rare earth) [1]. We performed inelastic neutron scattering measurements on $RCrGeO_5$ (R = Y, Ho, ^{166}Er, ^{154}Sm or Nd) powder using the High Resolution Chopper (HRC) spectrometer at BL 12 in J-PARC [2]. We observed magnetic excitations of Cr spins. We evaluated the dispersion relation parallel to the chain for the Y and Sm compounds using the Tomiyasu method [3]. The dispersion relations are consistent with the calculated ones of the AF alternating spin-3/2 chain. $RCrGeO_5$ are the first spin-3/2 chain compounds having a spin-singlet ground state with a spin gap. We evaluated two exchange interactions to be J_1 = 16.0 and J_2 = 2.3 meV (J_1 = 20.9 and J_2 = 1.1 meV) for the Y (Sm) compounds. From the alternation ratio J_2/J_1, the ground state is the strongly dimerized state [4]. The main origin of the spin gap is the bond alternation. We speculate, however, that the spin gap values are enlarged by the frustration between nearest-neighbor and next-nearest-neighbor exchange interactions in the chains. The magnetic excitations exist between 10 and 24 meV in the Y, Ho, and Er compounds, and between 18 and 24 meV in the Sm and Nd compounds. The two nearest neighbor Cr-Cr distances are almost the same in the former three compounds and in the latter two compounds. This result is consistent with that the value of the exchange interaction is determined mainly by the Cr-Cr distance.

[1] R. V. Shpanchenko et al., J. Solid State Chem. 181, 2433 (2008).
[2] M. Hase et al., Phys. Rev. B 90, 024416 (2014).
[3] K. Tomiyasu et al., Appl. Phys. Lett. 94, 092502 (2009).
[4] M. Yajima and M. Takahashi, J. Phys. Soc. Jpn. 65, 39 (1996).

The role of neutron science in solid state chemistry

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Mixed anion compounds, which contain several different anions, began to draw attention as game-changing inorganic materials. Since, compared with conventional inorganic compounds such as oxides, mixed-anion compounds may exhibit unique coordination and resultant extended structures, from which fundamentally different chemical and physical property may emerge [1]. My talk mainly discusses our recent works on oxyhydride and oxynitride perovskites to demonstrate how neutron diffraction contributes to the structural determination. Finally, I will show a failed synthesis of oxyhydride perovskite that eventually leads to the discovery of unprecedented rattling behavior.

[1] H. Kageyama *et al*., *Nat. Commun*. 9, 772 (2018)

O18

Development of thermoelectric materials using rattling and lone pairs

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Thermoelectric generation is expected to contribute to energy conservation through the generation of electricity from waste heat. To realize the technology, further improvement in thermoelectric property is required. The efficiency of thermoelectric materials is determined by the dimensionless figure of merit $ZT = S^2T/\rho\kappa$, where S is the Seebeck coefficient, ρ is the electrical resistivity, and κ is the thermal conductivity. Lowering electrical resistivity and thermal conductivity simultaneously is essential to achieve high thermoelectric performance. That is, heat flow must be scattered without scattering electricity. To solve the problem, large vibration of atoms, so called rattling, were proposed that it can provide an ideal scattering mechanism. In addition, lone pairs are also considered to be a key factor, because they can be the origin of anharmonicity of interatomic potentials.

Recently, we found several new thermoelectric materials that contain lone pairs and rattling atoms. LaOBiSSe exhibit extremely low lattice thermal conductivity (κ_L) of ~0.5 W/mK with ZT = 0.36 at 650 K [1]. In the compound, Bi rattle with lone pairs. Tetrahedrites $Cu_{12-x}Tr_xSb_4S_{13}$ (Tr = Mn, Fe, Co, Ni, Zn) also exhibit extremely low κ_L ~ 0.5 W/mK with ZT = 0.5-1.0 at 673 K [2]. In the compounds, Cu atoms rattle toward lone pairs of Sb atoms. We also found As-based 122 Zintl compounds, (Ba,K)(Zn,Cd)2As2, exhibiting κ_L lower than 1 W/mK with ZT = 0.81 at T = 762 K [3,4]. In the workshop, we will present results on inelastic neutron scattering of those materials and propose a new strategy for developing high performance thermoelectric materials using rattling and lone pairs.

[1] A. Nishida et al., Applied Physics Express 8, 111801 (2015). [2] K.Suekuni, et al., J. Appl. Phys. 113, 043712 (2013). [3] K. Kihou et al., Inorg. Chem. 56, 3709 (2017). [4] H. Kunioka et al., (submitted).

J-PARC, Frontier of condensed matter physics at J-PARC

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Materials & Life Science Experimental Facility (MLF) at J-PARC provides the world's highest class of neutron and muon beams as one of the most modern facilities in the world. MLF started its user program in 2008. Currently, 20 neutron instruments are opened to users and one is under commissioning. For these almost 10 years, our instruments have been providing unique opportunities in the broad range of research fields from fundamental physics to industrial applications as well as condensed matter physics [1].

In this presentation, with touching overview of our instruments and possible scientific opportunities served by them, I will review recent out comes especially in the field of condensed matter physics.

[1] K. Nakajima *et. al.*, Quantum Beam Sci. **1**, 9 (2017).

Fig. 1 Neutron scattering instruments in the (2nd) experimental hall of MLF.

O21

Neutron scattering study of 3D frustrated magnets

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Determination of magnetic structure is indispensable to develop a broad range of science. Its prime tool is the neutron diffraction technique. In this talk, we will introduce our advanced mathematical method to analyze the data. Furthermore, by taking the magnetic structure described by $\boldsymbol{k}_{\mathrm{mag}} = (0, 0, 0)$ in pyrochlore $Nd_2Ir_2O_7$ for example, we will demonstrate the prescription by using measured polarized neutron data. $Nd_2Ir_2O_7$ is expected to exhibit the so-called all-in all-out magnetic structure as the proximate state of three-dimensional Weyl semimetal and a constituent of spintronics device owing to the frustration and 5*d*-electron's novelty [1–3]. Thus far, within the scope of unpolarized neutron experiments and conventional analysis, this magnetic structure was found [4] and the refinement was performed [5].

The neutron experiments were performed on the thermal neutron three-axis spectrometer HB1A, installed at the HFIR of the ORNL. The travel fee was supported by Japan-US program administrated by ISSP at University of Tokyo. This study was also financially supported by the MEXT and JSPS KAKENHI (JP18K03503, JP17H06137, JP15H03692), the PREST (JPMJPR14E6) and by the FRIS Program for the creation of interdisciplinary research at Tohoku University.

[1] a) K. Matsuhira *et al.*, J. Phys. Soc. Jpn. **76**, 043706 (2007); b) **80**, 094701 (2011).

[2] a) D. Pesin and L. Balents, Nat. Phys. **6**, 376 (2010); b) X. Wan, A. M. Turner, A. Vishwanath, and S. Y. Savrasov, PRB **83**, 205101 (2011); c) Y. Yamaji and M. Imada, PRX **4**, 021035 (2014).

[3] Z. Tian, Y. Kohama, T. Tomita, H. Ishizuka, T. H. Hsieh, J. J. Ishikawa, K. Kindo, L. Balents, and S. Nakatsuji, Nat. Phys. **12**, 134 (2015).

[4] K. Tomiyasu, K. Matsuhira, K. Iwasa, M. Watahiki, S. Takagi, M. Wakeshima, Y. Hinatsu, M. Yokoyama, K. Ohoyama, and K. Yamada, J. Phys. Soc. Jpn. **81**, 034709 (2012).

[5] H. Guo, C. Ritter, and A. C. Komarek, Phys. Rev. B **94**, 161102(R) (2016).

O22

Large Transverse Responses at Room Temperature in the Weyl Antiferromagnets Mn_3X

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Recent observations of large anomalous Hall effects in the non-collinear antiferromagnets Mn_3X have opened new venues to study the effects of Berry curvature and their potential applications at room temperature. Our detailed experiments on the anomalous Hall and Nernst effects have clarified that large Berry curvature exists nearby the Fermi energy in the momentum space. Besides, our measurements of ARPES, magnetoresistance, and their comparison with theory have provided strong evidence for the magnetic Weyl fermions in the ferro-ordered state of magnetic octupoles in Mn_3Sn. In addition, we find that this Weyl antiferromagnet exhibits an anomalous type of spin Hall effect (magnetic spin Hall effect). If time permits, interesting subjects for future neutron experiments will be also discussed. This presentation is based on the collaboration with Takahiro Tomita, Tomoya Higo, Muhammad, Ikhlas, YoshiChika Otani, Motoi Kimata, Kouta Kondo, Kenta Kuroda, Takeshi Kondo, Shik Shin, Pallab Goswami, Hua Chen, Allan MacDonald, Ryotaro Arita, Michito Suzuki, Takashi Koretsune.

O23

Magnetoelectrics showing non-coplanar magnetic order

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In this study, we deal with magnetoelectric multiferroics in which non-coplanar magnetic orders develop. Such ordered states can break either time-reversal and/or space-inversion symmetries, and induce magnetoelectric activity. An example of the ordered states is a transverse conical phase where both time-reversal and space-inversion symmetries are broken, and resulting spontaneous magnetization and electric polarization appear. To fully understand the magnetoelectric activity in non-coplanar multiferroics, detailed information of their magnetic structure and its response to applied fields is necessarily required. To date, our group has fabricated several non-coplanar multiferroics such as olivine-type Mn_2GeO_4 with a transverse conical structure, Y-type hexaferrite $Ba_{1.3}Sr_{0.7}CoZnFe_{11}AlO_{22}$ with the so-called alternating longitudinal conical structure, and $A(TiO)Cu_4(PO_4)_4$ (A = Ba, Sr, and Pb) showing a quadrupole ordered structure. In this presentation, we introduce our collaboration work with neutron scattering experts for understanding magnetoelectric activity of these non-coplanar multiferroics [1].

[1] J. S. White *et al.*, Phys. Rev. B 94, 024439 (2016).

[2] T. Honda *et al.*, Nat. Commun. 8, 15457 (2017).

[2] H. Ueda *et al.*, Appl. Phys. Lett. 109, 182902 (2016).

[3] K. Kimura *et al.*, Nat. Commun. 7, 13039 (2016).

[4] P. Babkevich *et al.*, Phys. Rev. B 96, 214436 (2017).

[5] K. Kimura *et al.*, Phys. Rev. B 97, 134418 (2018).

O24

New observations in well-established skyrmion materials Cu_2OSeO_3 and MnSi

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Topological spin textures have attracted growing interest in the condensed matter physics community. One representative example of such spin textures is the skyrmion in chiral magnets - a spin swirling carrying a topological quantum number [1,2]. The magnetic skyrmion was first observed in MnSi using small angle neutron scattering (SANS) [3]. Since then, skyrmion lattice phases have been reported in various compounds. Among these, Cu_2OSeO_3 [4,5] has attracted particular interest because of its multiferroic properties [6].

Previously, the skyrmion lattice in MnSi was observed to rotate under application of electric current [7]. However, using a confined neutron beam we discovered the rotation of the skyrmion lattice to vary perpendicular to the current with opposite senses of rotation at the sample edges. In Cu_2OSeO_3, following up on our phase diagram study [8], we found a new phase pocket at low temperatures for $H \| (100)$. Also using polarized neutron scattering we found a nuclear-magnetic interference in the skyrmion phase indicating a magnetic impact on the crystallographic lattice.

[1] A. N. Bogdanov and D. A. Yablonskii. Sov. Phys. LETP, 68 101, (1989).
[2] N. Nagaosa and Y. Tokura. Nature Nanotechnol., 8 899, (2013).
[3] S. Mühlbauer et al. Science, 323 915, (2009).
[4] S. Seki et al. Phys. Rev. B, 85 220406, (2012).
[5] T. Adams et al. Phys. Rev. Lett., 108 237204, (2012).
[6] S. Seki et al. Science, 336 198–201, (2012).
[7] F. Jonietz et al. Science, 330 1648-1651, (2010).
[8] K. Makino et al. Physical Review B, 95 134412, (2017).

ABSTRACTS

Poster Presentations

P1

Neutron Scattering Study in Single-Crystalline $YbCo_2Zn_{20}$

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Inelastic neutron scattering experiments on a heavy fermion Yb compound $YbCo_2Zn_{20}$ were performed to investigate a nature of its magnetic excitations. We succeeded in observing wavevector *k*-dependent magnetic excitations using a large “single” crystal. Crystal-field excitation centered around 0.7 meV has *k*-dependent intensities with little k-dependent excitation energies, implying none-existence of the magnetic correlation characterized by the wave vector $\tau = (0\ 0\ 1)$, which corresponds to the wave vector of the pressure-induced antiferromagnetic phase. No distinct 2.0 meV crystal-field excitation observed in this work. Quasi-elastic magnetic peaks has also *k*-dependent intensities, which probably indicating that the moments fluctuate with polarization along the a-axis.

P2

Magnetic structure of S=5/2 spin-dimer compound $Cs_3Fe_2Cl_9$

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$Cs_3M_2X_9$ (M : 3d metal, X : halogen ion) is well known dimer system. The ground state of $Cs_3Cr_2Cl_9$ ($\boldsymbol{S}$ = 3/2) is spin singlet [1] and the magnetization curve shows three steps related to dimer's total spin states [2]. On the other hand, $Cs_3Fe_2Cl_9$ ($\boldsymbol{S}$ = 5/2) shows antiferromagnetic transition at T_N = 5.3 K together with large anomaly of heat capacity, which suggests that structural transition occurs simultaneously. Below T_N, magnetic susceptibility is proportional to temperature toward T = 0 [3]. By fitting the magnetic susceptibility with dimer model, the intra-dimer exchange interaction is estimated to be antiferromagnetic. Moreover, magnetization process at T = 2 K is very complicated; there are seven magnetic phases including 1/2 magnetic plateau [4]. The main exchange interaction of this system is dimer coupling, the second and third nearest neighbor coupling compose honeycomb and triangular lattice, respectively. It is assumed that relatively weak dimer coupling caused by d^5 orbital, competition of intra- and inter-dimer couplings and anisotropic effect cause such a variability of the spin states. To reveal the origin of complicated magnetism, we carried out magnetic structure analysis. Neutron diffraction measurement using single crystal was performed at four-circle spectroscopy HB3A installed research reactor HFIR, ORNL. The magnetic peaks of $\boldsymbol{k}$ = (1/2 0 0) was observed below T_N. It is revealed that magnetic structure is ferromagnetic on the dimer, and stripe type order on the honeycomb lattice. In addition, according to study of similar magnetic structure compound Ba_2NiTeO_6 [5], anisotropic effect plays an important role in determining the spin arrangement.

[1] B. Leuenberger *et al.*, Inog. Chem. **24**, 1035-1038 (1985).

[2] Y. Ajiro *et al.*, J. Phys. Soc. Jpn. **58**, 1021-1026 (1989).

[3] Y. Ishi *et al.*, 71th JPS meeting, 19aPS-75 (2016).

[4] Y. Ishi *et al.*, JPS autumn meeting 2016, 13pAA-7 (2016).

[5] S. Asai *et al.*, Phys. Rev. B **93**, 024412 (2016).

P3

Phonons and magnetic excitations in Fe-based superconductor $Ca_{10}Pt_4As_8(Fe_{1-x}Pt_xAs)_{10}$

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Fe-based superconducting systems are superconducting systems having orbital degree of freedom defined the electron occupancy between the $3d_{yz}$ and $3d_{zx}$ orbitals (bands). Not only for the superconductivity but also for a nematic state, which is assigned by appealing the breakdown of the four-fold symmetry of transport and other static quantities in high temperature region above the tetragonal-orthorhombic structural transition temperature, the orbital degree of freedom may play a direct role to realize the phase diagram of these systems.

To study this issue in detail, we performed inelastic neutron scattering experiments on superconducting $Ca_{10}Pt_4As_8(Fe_{1-x}Pt_xAs)_{10}$ with the transition temperature T_c = 38 K. to observe phonons, combined with orbitals directly. These experiments were carried out with HB-3 at ORNL and 2T1, 4F2 at LLB. Finally, we obtained the softening of an in-plane transverse acoustic mode and the enhancement of spectral weight of optic phonons, occurring from rather high temperature region above T_c. In addition to a temperature dependence of the spectral weight of the magnetic fluctuations, obtained by these experiments, these phonon behaviors are useful for studying possible role of the orbital fluctuations in the pairing mechanism [1].

[1] K. Ikeuchi et al., J. Phys.: Condens. Matter, **27** (2015) 465701.

Magnetic Interaction Crossover by Rh-doping in a Kondo Semiconductor $CeRu_2Al_{10}$

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We have studied doping evolution of the neutron diffraction patterns using single crystals of $Ce(Ru_{1-x}Rh_x)_2Al_{10}$. Previously, non-doped $CeRu_2Al_{10}$ (x = 0) has been reported to show magnetic peaks below T_0 = 27 K with a propagation vector $\boldsymbol{k_0}$ = (0, 1, 0). This $\boldsymbol{k}_0$ is well known as that of spin density wave (SDW) origin [1]. However, in x = 0.34 sample, we discovered new propagation vector $\boldsymbol{k_1}$ = (0, 0.765, 0) below T_1 = 7.1 K, in addition to $\boldsymbol{k}_0$ below T_0 = 13 K. Furthermore, in x = 0.34 sample, $\boldsymbol{k}_0$ disappeared and we only observed $\boldsymbol{k_1}$ below 6.1 K.

We argue that the value of $\boldsymbol{k_1}$ is close to that of $SmRu_2Al_{10}$ and $GdRu_2Al_{10}$ which show antiferromagnetic (AFM) order driven by Ruderman Kittel Kasuya Yosida (RKKY) interaction [2,3]. Therefore, our results indicate that Rh-doping induces the RKKY-type AFM order (characterized by $\boldsymbol{k}_1$) and suppresses nesting-type SDW order (characterized by $\boldsymbol{k}_0$) due to the reconstruction of density of state by extra 5*d*-electron of dopant. This is the first experimental demonstration showing the crossover of two different mechanisms of AFM order in one magnetic site.

[1] H. Kato, *et al*. J. Phys. Soc. Jpn. **80,** 073701 (2011).

[2] S. Takai, *et al*. Physical Review B **92**, 174427 (2015).

[3] T. Matsumura, *et al*. J. Phys. Soc. Jpn. **86**, 094709 (2017).

Localized magnetic excitations in the S = 1/2 fully frustrated dimer compound $Ba_2CoSi_2O_6Cl_2$

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$Ba_2CoSi_2O_6Cl_2$ is a coupled spin dimer compound in which the low-temperature magnetic properties can be described by an S = 1/2 XXZ model with strong XY anisotropy [1]. A previous high-field magnetization study has revealed that $Ba_2CoSi_2O_6Cl_2$ exhibits a stepwise magnetization process with a plateau at one half of the saturation magnetization [1]. This indicates that the frustration for the interdimer exchange interactions is almost perfect and hence, above the critical field, triplet excitations form a periodic array. For directly probing the magnetic excitations of $Ba_2CoSi_2O_6Cl_2$, we have performed inelastic neutron scattering measurements at 4 K using a cold-neutron double-chopper spectrometer AMATERAS installed at MLF, J-PARC, Japan. Figure 1 shows an energy-momentum map of the scattering intensity along Q_a measured at 4 K with the incident neutron energy E_i = 7.7 meV. Dispersionless and resolution-limited excitations were observed at 4.8, 5.8, and 6.8 meV. Interestingly, intensities of these excitations show different Q-dependences. In the presentation, we will discuss the origin of the observed excitations.

[1] H. Tanaka et al., J. Phys. Soc. Jpn. **83**, 103701 (2014).

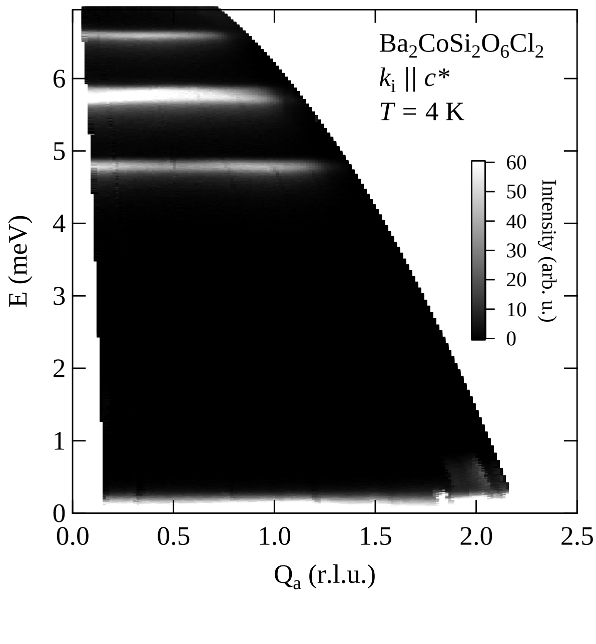

Fig. 1 Energy-momentum map of the scattering intensity along Q_a in $Ba_2CoSi_2O_6Cl_2$ measured at T = 4 K with E_i = 7.7 meV. The wave vector k_i of the incident neutron was set to be parallel to the c^* axis

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Magnetic-field-induced charge order in $SmRu_4P_{12}$ studied by polarized neutron diffraction

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A filled-skutterudite SmRu4P12 is an antiferromagnet with TN=16.5 K. What is anomalous is that there exists another transition at T*~14 K and the intermediate phase is enhanced by applying magnetic fields, which has long been unresolved [1,2]. From the recent theoretical and experimental studies, it has been clarified that a CDW is induced by the field through the p-f mixing effect. Staggered ordering of the crystal-field levels, atomic displacements, an antiferromagnetic component parallel to the field, which is not preferable in normal states, is also induced.

To study the relationship between the atomic displacement (expansion and shrink of the Ru lattice) and the antiferromagnetic component (long or short), which is of crucial importance in the relationship with the p-f mixing theory, we have performed a polarized neutron diffraction experiment at the HB-1 spectrometer at HFIR, ORNL. By measuring the difference in intensity between $|F_{\mathrm{lattice}}+F_{\mathrm{mag}}|^2$ and $|F_{\mathrm{lattice}}-F_{\mathrm{mag}}|^2$, both arises at the CDW wavevector (1, 0, 0), we aimed to clarify the relation between the atomic displacement and the change in the antiferromagnetic moment. The result shows that the magnetic moment of Sm is shortened (elongated) around which the Ru lattice expands (shrinks). This result will be compared with that of resonant x-ray scattering in magnetic fields.

[1] K. Matsuhira et al., J. Phys. Soc. Jpn. 71, Suppl. 237 (2002).
[2] C. H. Lee et al., J. Phys. Soc. Jpn. 81, 063702 (2012).
[3] R. Shiina, J. Phys. Soc. Jpn. 82, 083713 (2013).
[4] T. Matsumura et al., Phys. Rev. B 94, 184425 (2016).
[5] T. Matsumura et al., Phys. Rev. B 89, 161116 (2014).

Neutron Scattering Study in Åkermanite System $Ba_2CoT_2O_7$ (T=Si and Ge)

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$Ba_2CoGe_2O_7$ has a two-dimensional layer composed of the network of CoO_4 and GeO_4 tetrahedra. Co^{2+} ions form a square lattice. $Ba_2CoGe_2O_7$ shows an antiferromagnetic order below T_N=6.7 K, and the ferroelectric polarization is observed under the magnetic field. Furthermore, the 4 meV excitation, which is an electric-active mode through the coupling between spin and electric-dipole, was observed in the electromagnetic wave absorption. In the present study, the neutron scattering measurements were carried out in $Ba_2CoGe_2O_7$. We found one acoustic and two optical modes, which are reasonably reproduced by the extended spin wave theory. Furthermore, our result indicates that the anisotropy of the magnetic moments also connects with the multiferroic property of $Ba_2CoGe_2O_7$.

$Ba_2CoSi_2O_7$ has the similar network of CoO_4 and SiO_4 tetrahedral. However, the square lattice formed by Co^{2+} ions is distorted. The magnetic susceptibility shows Neel order at T_N~6 K. In contrast to $Ba_2CoGe_2O_7$, the anomaly of the dielectric constant in $Ba_2CoSi_2O_7$ was hardly observed at the transition temperature. The neutron scattering measurements were also carried out in $Ba_2CoSi_2O_7$. We found the dispersionless magnetic excitation. Our results of the magnetization and the neutron scattering suggest that $Ba_2CoSi_2O_7$ is the one-dimensional Ising antiferromagnet.

[1] M. Soda *et al.*, Phys. Rev. Lett. **112** (2014) 127205.
[2] M. Soda *et al.*, Phys. Rev. B **94** (2016) 094418.

Step-like Development of magnetism in the electron doped cuprate superconductor $R_{2-x}Ce_xCuO$ (R = Nd, Eu)

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In high-T_c copper-oxide superconductors, the superconductivity appears with hole or electron doping into an antiferromagnetic Mott insulator. The electron-hole asymmetry in physical properties is a basis for understanding of the microscopic mechanism of superconductivity. The parent compounds of prototypical electron- and hole-doped systems are T'-structured R_2CuO_4 (R = Pr, Nd, Sm, Eu) and T-structured La_2CuO_4. They have been recognized to have qualitatively the same electronic and magnetic properties.[1,2] However, the appearance of superconductivity in R_2CuO_4 for thin film samples was reported.[3] This result sheds new light on understanding mechanisms of superconductivity in the T'-structured systems.

Recently, we have performed muon spin rotation (μSR) measurements on T'-structured Eu_2CuO_4. Intriguingly, a distinct magnetic phase with dynamical nature exists in a wide temperature region between a static magnetic ordered state below T_{N2} = 110 K and a paramagnetic state above T_{N1} = 265 K. Further μSR studies on Nd_2CuO_4 show qualitatively the same trend as Eu_2CuO_4, indicating that the dynamical magnetic phase exists universally for the T'-R_2CuO_4 system. Neutron diffraction measurements performed using SENJU in MLF, J-PARC for Nd_2CuO_4 failed to detect the anomalous temperature dependence. This may be due to the incident energy of a few meV is too high to sense slow dynamics. Another finding is that the magnetic order below T_{N2} is quite insensitive to reduction annealing, type of rare earth ions and electron doping through Ce substitution while the high temperature magnetic phase becomes unstable with these treatments. The present results suggest a different nature in magnetism of hole-dopes and electron-doped copper oxide superconductors.

[1] G. Shirane *et al.*, Phys. Rev. Lett. **59**, 1613 (1987). [2] Y. Endoh *et al.*, Phys. Rev. B **40**, 7023 (1989). [3] M. Naito *et al.*, Physica C **523**, 28 (2016).

Magnetic Structure of a Non-Centrosymmetric $CePdSi_3$

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Since the discovery of the first heavy electron superconductor $CePt_3Si$ [1] with a non-centrosymmetric crystal structure, the effect of the antisymmetric spin-orbit interaction (ASOI) on superconductivity and magnetism in correlated *f* electron physics has attracted much attention. Particularly, the $CeTX_3$ (T = transition metal, X = Si and Ge) system is an excellent test bench to examine the influence of the ASOI to the magnetic and transport properties. Here we focus on the non-centrosymmetric $BaNiSn_3$-type compound $CePdSi_3$. It exhibits successive magnetic transitions, weak ferromagnetism, and unusually complex metamagnetic transitions [2]. Since this crystal structure does not cause geometric frustration such as a triangular lattice, influence of ASOI may drive multiple metamagnetic transitions.

As the first step of further understanding of the ASOI effect, we examine the magnetic structure of $CePdSi_3$. By the neutron diffraction experiments using a single crystalline sample, we observed magnetic reflections at $\tau_1 = (0.32, 0, 0)$ in the phase I, and at $\tau_2 = (0.32, 0, 1)$ in addition to $\tau_1 = (0.32, 0, 0)$ in the phase III. We found that the magnetic structure of $CePdSi_3$ is a longitudinal spin density wave similar to those in $CeRhSi_3$ and $CeIrSi_3$.

[1] E. Bauer *et al*., Phys. Rev. Lett., **92**, 027003 (2004)
[2] D. Ueta, Y, Ikeda and H. Yoshizawa, J. Phys. Soc. Jpn., **85**, 1014703 (2016)

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