Publications

Division of Condensed Matter Science

Takigawa group

We have been performing nuclear magnetic resonance experiments on various quantum spin systems and strongly correlated electron systems to explore novel quantum phases with exotic ordering and fluctuation phenomena. The major achievements in the year 2018 include: (1) ^{31}P-NMR study on the J_1-J_2 frustrated square lattice antiferromagnet $RbMoOPO_4Cl$ under high pressure, which revealed a first-order transition between low pressure columnar-type to high pressure Neel-type antiferromagnetic structures, (2) discovery of sequential electronic and structurel transitions in the spin-orbit coupled metallic pyrochlore compound $Cd_2Red_2O_7Cd_2$ by ^{111}Cd-NMR measurements, which revealed breaking of inversion and cubic symmetries taking place at slightly different temperatures, (3) ^{51}V-NMR investigation on the spin structure of a Neel-type skyrmion material GaV_4Se_8 and first microscopic observation of the defrmation of spin texture of the skyrmion lattice by oblique magnetic fields.

1. [*]Inelastic Neutron Scattering Study of the Spin Dynamics in the Breathing Pyrochlore System $LiGa_{0.95}In_{0.05}Cr_4O_8$: Y. Tanaka, R. Wawrzynczak, M. D. Le, T. Guidi, Y. Okamoto, T. Yajima, Z. Hiroi, M. Takigawa and G. J. Nilsen, J. Phys. Soc. Jpn. **87** (2018) 073710.

2. [†*]Field-enhanced quantum fluctuation in an S = 1/2 frustrated square lattice: H. Yamaguchi, Y. Sasaki, T. Okubo, M. Yoshida, T. Kida, M. Hagiwara, Y. Kono, S. Kittaka, T. Sakakibara, M. Takigawa, Y. Iwasaki and Y. Hosokoshi, Phys. Rev. B **98** (2018) 094402 (1-6).

3. [*]Universal geometric frustration in pyrochlores: B. A. Trump, S. M. Koohpayeh, K. J. T. Livi, J. -J. Wen, K. E. Arpino, Q. M. Ramasse, R. Brydson, M. Feygenson, H. Takeda, M. Takigawa, K. Kimura, S. Nakatsuji, C. L. Broholm and T. M. McQueen, Nat. Commun. **9** (2018) 2619 (1-10).

Sakakibara group

We study magnetism and superconductivity of materials having low characteristic temperatures. These include heavy-electron systems, quantum spin systems and frustrated spin systems. The followings are some selected achievements in the fiscal year 2018. (1) We studied the superconducting gap symmetry of a candidate triplet superconductor Sr_2RuO_4. We found that the fourfold angular oscillation of the heat capacity under an in-plane rotating magnetic field does not change its sign even at very low temperature of $0.04T_c$. The results can be explained by Doppler-shifted quasiparticles around horizontal line nodes on the Fermi surface, in disagreement with the chiral p-wave scenario. (2) We developed a new technique for measuring the thermodynamic entropy as a function of the magnetic field angle. When the magnetic field is rotated under adiabatic conditions, the sample temperature changes owing to the field-angle variation of its entropy. By investigating this effect, the rotational magnetocaloric effect, the field-angle dependence of the entropy can be determined. (3) We developed an experimental method of low-temperature magnetization measurements with an in-situ two-axis alignment of the sample orientation. The sample alignment can be done within an accuracy of 0.02 deg. using a piezo-stepper-driven goniometer combined with a home-made tilting stage. This technique is useful to study magnetic phase transitions of strongly anisotropic systems.

1. Field-rotational Magnetocaloric Effect: A New Experimental Technique for Accurate Measurement of the Anisotropic Magnetic Entropy: S. Kittaka, S. Nakamura, H. Kadowaki, H. Takatsu and T. Sakakibara, J. Phys. Soc. Jpn. **87** (2018) 073601 (1-5).

2. Giant Hall Resistivity and Magnetoresistance in Cubic Chiral Antiferromagnet EuPtSi: M. Kakihana, D. Aoki, A. Nakamura, F. Honda, M. Nakashima, Y. Amako, S. Nakamura, T. Sakakibara, M. Hedo, T. Nakama and Y. Onuki, J. Phys. Soc. Jpn. **87** (2018) 023701 (1-4).

3. Low-Temperature Magnetization Measurements with Precise Two-Axis Alignment of the Sample Orientation: S. Nakamura, A. Kasahara, S. Kittaka, Y. Kono, Y. Onuki and T. Sakakibara, J. Phys. Soc. Jpn. **87** (2018) 1140018 (1-5).

4. [†*]Magnetic-field-induced Quantum Phase in S = 1/2 Frustrated Trellis Lattice: H. Yamaguchi, D. Yoshizawa, T. Kida, M. Hagiwara, A. Matsuo, Y. Kono, T. Sakakibara, Y. Tamekuni, H. Miyagai and Y. Hosokoshi, J. Phys. Soc. Jpn. **87** (2018) 043701 (1-5).

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[*] Joint research among groups within ISSP.

5. Searching for Gap Zeros in Sr_2RuO_4 via Field-Angle-Dependent Specific-Heat Measurement: S. Kittaka, S. Nakamura, T. Sakakibara, N. Kikugawa, T. Terashima, S. Uji, D. A. Sokolov, A. P. Mackenzie, K. Irie, Y. Tsutsumi, K. Suzuki and K. Machida, J. Phys. Soc. Jpn. **87** (2018) 093703 (1-5).

6. [*]Disorder-sensitive nodelike small gap in FeSe: Y. Sun, S. Kittaka, S. Nakamura, T. Sakakibara, P. Zhang, S. Shin, K. Irie, T. Nomoto, K. Machida, J. Chen and T. Tamegai, Phys. Rev. B **98** (2018) 064505 (1-7).

7. [†*]Field-enhanced quantum fluctuation in an S = 1/2 frustrated square lattice: H. Yamaguchi, Y. Sasaki, T. Okubo, M. Yoshida, T. Kida, M. Hagiwara, Y. Kono, S. Kittaka, T. Sakakibara, M. Takigawa, Y. Iwasaki and Y. Hosokoshi, Phys. Rev. B **98** (2018) 094402 (1-6).

8. [†]Field-induced quantum magnetism in the verdazyl-based charge-transfer salt [o-MePy-V-$(p\text{-Br})_2$]$FeCl_4$: Y. Iwasaki, T. Kida, M. Hagiwara, T. Kawakami, Y. Kono, S. Kittaka, T. Sakakibara, Y. Hosokoshi and H. Yamaguchi, Phys. Rev. B **98** (2018) 224411 (1-8).

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10. Quasi-one-dimensional Bose-Einstein condensation in the spin-1/2 ferromagnetic-leg ladder 3-I-V: Y. Kono, S. Kittaka, H. Yamaguchi, Y. Hosokoshi and T. Sakakibara, Phys. Rev. B **97** (2018) 100406 (1-5).

11. Fermi surface in the absence of a Fermi liquid in the Kondo insulator SmB_6: M. Hartstein, W. H. Toews, Y. -T. Hsu, B. Zeng, X. Chen, M. Ciomaga Hatnean, Q. R. Zhang, S. Nakamura, A. S. Padgett, G. Rodway-Gant, J. Berk, M. K. Kingston, G. H. Zhang, M. K. Chan, S. Yamashita, T. Sakakibara, Y. Takano, J. -H. Park, L. Balicas, N. Harrison, N. Shitsevalova, G. Balakrishnan, G. G. Lonzarich, R. W. Hill, M. Sutherland and S. E. Sebastian, Nature Phys. **14** (2018) 166-172.

12. Investigation of the tricritical point of the ising ferromagnet URhGe by angle-resolved measurements: S. Nakamura, S. Kittaka, T. Sakakibara, Y. Shimizu, Y. Kono, Y. Haga, J. Pospíšil and E. Yamamoto, AIP Advances **8** (2018) 101305 (1-5).

13. [†]Superconducting symmetries and magnetic responses of uranium heavy-fermion systems UBe_{13} and UPd_2Al_3: Y. Shimizu, S. Kittaka, T. Sakakibara and D. Aoki, Physica B: Condensed Matter **536** (2018) 553-557.

14. [†*]Quantum valence criticality in a correlated metal: K. Kuga, Y. Matsumoto, M. Okawa, S. Suzuki, T. Tomita, K. Sone, Y. Shimura, T. Sakakibara, D. Nishio-Hamane, Y. Karaki, Y. Takata, M. Matsunami, R. Eguchi, M. Taguchi, A. Chainani, S. Shin, K. Tamasaku, Y. Nishino, M. Yabashi, T. Ishikawa and S. Nakatsuji, Sci. Adv. **4** (2018) eaao3547 (1-6).

15. Magnetization study on the ising ferromagnet URhGe with high-precision angle-resolved magnetic field near the hard axis: S. Nakamura, T. Sakakibara, Y. Shimizu, S. Kittaka, Y. Kono, Y. Haga, J. Pospisil and E. Yamamoto, Progress in nuclear science and technology **5** (2018) 123-127.

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17. [†*]S=1/2 ferromagnetic Heisenberg chain in a verdazyl-based complex: N. Uemoto, Y. Kono, S. Kittaka, T. Sakakibara, T. Yajima, Y. Iwasaki, S. Miyamoto, Y. Hosokoshi and H. Yamaguchi, Phys. Rev. B **99** (2019) 094418 (1-6).

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Mori group

We have successfully developed and unveiled unprecedented functional properties for the molecular materials. The major achievements in 2018 are (1) to develop anhydrous organic proton conductors with dicarboxylic acids and imidazoles as an electrolyte of a fuel cell for medium temperatures, (2) to fabricate successfully and characterize the hydrogen-bonded molecular bilayer of catechol-fused TTF and imidazole-terminated alkanethiolate on Au(111), and (3) to estimate the thermoelectric property of the organic conductors, β'-$(BEDT\text{-}TTF)_3(CoCl_4)_{2-x}(GaCl_4)_x$, as thermoelectric materials.

1. Antiferromagnetic Ordering in Organic Conductor λ-$(BEDT\text{-}TTF)_2GaCl_4$ Probed by ^{13}C NMR: Y. Saito, S. Fukuoka, T. Kobayashi, A. Kawamoto and H. Mori, J. Phys. Soc. Jpn. **87** (2018) 013707 (1-4).

[†] Joint research with outside partners.

2. Size effects on supercooling phenomena in strongly correlated electron systems: $IrTe_2$ and θ-(BEDT-TTF)$_2$RbZn(SCN)$_4$: H. Oike, M. Suda, M. Kamitani, A. Ueda, H. Mori, Y. Tokura, H. M. Yamamoto and F. Kagawa, Phys. Rev. B **97** (2018) 085102 (1-7).

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5. The thermoelectric power of band-filling controlled organic conductors, β′-(BEDT-TTF)$_3$($CoCl_4$)$_{2-x}$($GaCl_4$)$_x$: Y. Kiyota, T. Kawamoto, H. Mori and T. Mori, J. Mater. Chem. A **6** (2018) 2004-2010.

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7. Charge Order and Poor Glass-forming Ability of an Anisotropic Triangular-lattice System, θ-(BEDT-TTF)$_2$TlCo(SCN)$_4$, Investigated by NMR: K. Miyagawa, T. Sato, H. Hashimoto, M. Kodama, K. Ohnoh, A. Ueda, H. Mori and K. Kanoda, J. Phys. Soc. Jpn. **88** (2019) 034705.

8. Hysteretic Current–Voltage Characteristics in the Deuterium-Dynamics-Triggered Charge-Ordered Phase of κ-D_3(Cat-EDT-TTF)$_2$: A. Ueda, K. Kishimoto, Y. Sunairi, J. Yoshida, H. Yamakawa, T. Miyamoto, T. Terashige, H. Okamoto and H. Mori, J. Phys. Soc. Jpn. **88** (2019) 034710.

9. *Direct Evidence of Interfacial Hydrogen Bonding in Proton-Electron Concerted 2D Organic Bilayer on Au Substrate: S. Yamamoto, H. S. Kato, A. Ueda, S. Yoshimoto, Y. Hirata, J. Miyawaki, K. Yamamoto, Y. Harada, H. Wadati, H. Mori, J. Yoshinobu and I. Matsuda, e-Journal of Surface Science and Nanotechnology **17** (2019) 49-55.

10. Dynamics of Water Molecules in a 3-Fold Interpenetrated Hydrogen-Bonded Organic Framework Based on Tetrakis (4-pyridyl)methane: D. Inokuchi, Y. Hirao, K. Takahashi, K. Matsumoto, H. Mori and T. Kubo, J. Phys. Chem. C **123** (2019) 6599.

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12. Construction of three-dimensional anionic molecular frameworks based on hydrogen-bonded metal dithiolene complexes and the crystal solvent effect: S. Yokomori, A. Ueda, T. Higashino, R. Kumai, Y. Murakami and H. Mori, CrystEngComm **21** (2019) 2940-2948.

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16. 有機結晶を舞台としたπ電子 - プロトンカップリング物性の新展開：森 初果 , 日本物理学会誌 **74**、**No2** (2019) 82-92.

Osada group

2018 (1) In order to identify the high-magnetic-field insulator phase of graphite, we investigated the phase transition in thin-film graphite samples, which were fabricated on silicon substrate by a mechanical exfoliation technique. The critical magnetic fields of the high-field transition in thin-films shift to higher fields, accompanied by a reduction in temperature dependence. These results can be qualitatively reproduced by the density-wave model with the quantum size effect. Our findings establish the density-wave state standing along the out-of-plane direction. (2) Recently, the small spin-orbit interaction (SOI) gap was proposed as an origin of the anomalous insulating behavior at low temperatures in an organic Dirac fermion system α-(BEDT-TTF)$_2$$I_3$. We built a lattice model with plausible SOI coupling, and indicated that the gapped state is a topological insulator. This model is an organic version of the Kane-Mele model for graphene.

1. Topological Insulator State due to Finite Spin-Orbit Interaction in an Organic Dirac Fermion System: T. Osada, J. Phys. Soc. Jpn. **87** (2018) 075002 (1-2).

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* Joint research among groups within ISSP.

2. Thickness-dependent phase transition in graphite under high magnetic field: T. Taen, K. Uchida and T. Osada, Phys. Rev. B **97** (2018) 115122 (1-7).

3. Tunable magnetoresistance in thin-film graphite field-effect transistor by gate voltage: T. Taen, K. Uchida, T. Osada and W. Kang, Phys. Rev. B **98** (2018) 155136 (1-7).

4. Double carrier transport in electron doped region in black phosphorus FET: K. Hirose, T. Osada, K. Uchida, T. Taen, K. Watanabe, T. Taniguchi and Y. Akahama, Appl. Phys. Lett. **113** (2018) 193101 (1-4).

5. Anisotropy of Dirac cones and Van Hove singularity in an organic Dirac fermion system: A. Mori, M. Sato, T. Yajima, T. Konoike, K. Uchida and T. Osada, Phys. Rev. B **99** (2019) 035106 (1-5).

Yamashita group

We have been studying (1) quantum criticality in heavy-fermion materials by ultra-low temperature cryostat, (2) thermal-Hall conductivity of exotic excitations in frustrated magnets and (3) a new technique for the study of strongly-correlated electron systems. In this year, we have published our works of (1) dHvA studies of $CeCoIn_5$ at ultralow temperatures, (2) thermal Hall measurements of Ca kapellasite, and (3) thermal Hall measurements of a Kitaev candidate α-$RuCl_3$. We have performed (1) additional measurements of dHvA and Co NMR of $CeCoIn_5$ at ultralow temperatures, (2) thermal Hall measurements of another kagome compound, Cd kapellasite, (3) magnetic torque measurements of organic QSL candidate κ-H_3(Cat-EDT-TTF)$_2$, and (4) thermal transport studies of a chiral magnet $CsCuCl_3$.

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2. *Spin Thermal Hall Conductivity of a Kagome Antiferromagnet: H. Doki, M. Akazawa, H.-Y. Lee, J. H. Han, K. Sugii, M. Shimozawa, N. Kawashima, M. Oda, H. Yoshida and M. Yamashita, Phys. Rev. Lett. **121** (2018) 097203.

3. Unusual Thermal Hall Effect in a Kitaev Spin Liquid Candidate α-$RuCl_3$: Y. Kasahara, K. Sugii, T. Ohnishi, M. Shimozawa, M. Yamashita, N. Kurita, H. Tanaka, J. Nasu, Y. Motome, T. Shibauchi and Y. Matsuda, Phys. Rev. Lett. **120** (2018) 217205.

Division of Condensed Matter Theory

Tsunetsugu group

We have studied topics including harmonic generation in optical response of electron systems and dynamics of charge-density wave order in a planar organic material. We have also investigated spin current generation by light irradiation to a one-dimensional Mott insulator. We have also started a new project about highly out-of-equilibrium electron dynamics and studied the time evolution of the one-dimensional Hubbard model. We have used a two-reservoir quench setup and calculated charge and thermal currents using the generalized hydrodynamic theory based on Bethe ansatz.

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3. Thermalization and prethermalization in isolated quantum systems: a theoretical overview: T. Mori, T. N. Ikeda, E. Kaminishi and M. Ueda, J. Phys. B: At. Mol. Opt. Phys. **51** (2018) 112001.

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5. Floquet-theoretical formulation and analysis of high-order harmonic generation in solids: T. N. Ikeda, K. Chinzei and H. Tsunetsugu, Phys. Rev. A **98** (2019) 063426.

6. Revisiting the Floquet-Bloch theory for an exactly solvable model of one-dimensional crystals in strong laser fields: T. N. Ikeda, Phys. Rev. A **97** (2019) 063413.

7. Photoinduced Dynamics of Commensurate Charge Density Wave in 1T-TaS2 Based on Three-Orbital Hubbard Model: T. N. Ikeda, H. Tsunetsugu and K. Yonemitsu, Appl. Sci. **9** (2019) 70.

† Joint research with outside partners.

Kato group

The main research subject of Kato lab. is theory of non-equilibrium properties in mesoscopic devices. We have studied (1) spin-current noise at the interface between a ferromagnetic insulator and a superconductor, (2) surface plasmon polaritons using Weyl semimetals, (3) domain wall formation in a chiral p-wave superconductor, (4) heat transport via a two-state system, (5) adiabaic electron transport via a quantum dot, and (6) Bell-state correlation in a Kondo quantum dot.

1. DC-Current Induced Domain Wall in a Chiral *p* -Wave Superconductor: T. Jonckheere and T. Kato, J. Phys. Soc. Jpn. **87** (2018) 094705 (1-6).
2. Effect of Interaction on Reservoir-Parameter-Driven Adiabatic Charge Pumping via a Single-Level Quantum Dot System: M. Hasegawa and T. Kato, J. Phys. Soc. Jpn. **87** (2018) 044709 (1-13).
3. Current cross-correlation in the Anderson impurity model with exchange interaction: R. Sakano, A. Oguri, Y. Nishikawa and E. Abe, Phys. Rev. B **97** (2018) 045127 (1-13).
4. Quantum Critical Phenomena in Heat Transport via a Two-State System: T. Yamamoto and T. Kato, Phys. Rev. B **98** (2018) 245412 (1-8).
5. Spin Current Noise of the Spin Seebeck Effect and Spin Pumping: M. Matsuo, Y. Ohnuma, T. Kato and S. Maekawa, Phys. Rev. Lett. **120** (2018) 235120 (1-5).
6. Heat transport via a local two-state system near thermal equilibrium: T. Yamamoto, M. Kato, T. Kato and K. Saito, New J. Phys. **20** (2018) 093014 (1-20).
7. [*]Evolution of Magnetic Double Helix and Quantum Criticality near a Dome of Superconductivity in CrAs: M. Matsuda, F. K. Lin, R. Yu, J.-G. Cheng, W. Wu, J. P. Sun, J. H. Zhang, P. J. Sun, K. Matsubayashi, T. Miyake, T. Kato, J.-Q. Yan, M. B. Stone, Q.-M. Si, J. L. Luo and Y. Uwatoko, Phys. Rev. X **8** (2018) 031017 (1-12).
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13. 非平衡状態にある近藤効果（その 1）非平衡グリーン関数入門：阪野 塁 , 固体物理 **53** (2018) 279-303.

Division of Nanoscale Science

Katsumoto group

Transport properties of double quantum well structures with (n-i-p-i-n)-type modulation doping were studied. For spin-injection, an iron film was deposited on top of the structure. We found peculiar magnetoresistance around zero-field. The lineshape of the magnetoresistance resembles that of anisotropic magnetoresistance. However, the origin is a kind of spin-orbit resonance due to the coexistence of Rashba and Dresselhaus type spin-orbit interactions. The anisotropy of the magnetoresistance on the in-plane angle of the magnetic field exhibited two-fold symmetry of III-V zinc-blende type crystal supporting the interpretation.

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2. [†]Spin–orbit interaction in Pt or Bi_2Te_3 nanoparticle-decorated graphene realized by a nanoneedle method: T. Namba, K. Tamura, K. Hatsuda, T. Nakamura, C. Ohata, S. Katsumoto and J. Haruyama, Appl. Phys. Lett. **113** (2018) 053106.
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[*] Joint research among groups within ISSP.

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5. †Evidence for a quantum spin Hall phase in graphene decorated with Bi_2Te_3 nanoparticles: K. Hatsuda, H. Mine, T. Nakamura, J. Li, R. Wu, S. Katsumoto and J. Haruyama, Sci. Adv. **4** (2018) eaau6915.

6. Quantum Hall Edge States Probed by Plasmon Excitations: A. Endo and S. Katsumoto, AAPPS Bulletin **28** (2018) No.5 28 - 30.

7. Evidence for Spin-Triplet Electron Pairing in the Proximity-Induced Superconducting State of an Fe-Doped InAs Semiconductor: T. Nakamura, L. D. Anh, Y. Hashimoto, S. Ohya, M. Tanaka and S. Katsumoto, Phys. Rev. Lett. **122** (2019) 107001.

8. Spin Filtering Magnetoresistance in Double-Well Resonant Structures: T. Nakamura, Y. Hashimoto, T. Ke and S. Katsumoto, Phys. Status Solidi B **256** (2019) 1800560.

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10. Spatial distribution of thermoelectric voltages in a Hall-bar shaped two-dimensional electron system under a magnetic field: A. Endo, K. Fujita, S. Katsumoto and Y. Iye, J. Phys. Commun. **3** (2019) 055005 (1-19).

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Otani group

We have studied the following topics this year; spin conversion behaviors in the bulk, the interfaces and the surfaces, magnetization dynamics in ferromagnetic nanostructures, and magneto-thermoelectric properties. In the first topic, our international collaboration with the Spanish group revealed the mechanism of the spin Hall effect in tantalum. We also succeeded in inducing the inverse Edelstein effect by decorating a copper surface with a lead phthalocyanine molecule. Furthermore, we have discovered that nonmagnetic metal/indium-tin-oxide interfaces can act as an efficient spin current source. In terms of magnetization dynamics, we have studied in collaboration with the Suemoto Group at ISSP on macroscopic magnetization control by symmetry breaking of photoinduced spin reorientation with intense terahertz magnetic near field. Apart from the above, we have also established a spin current generation by using magnon-phonon coupling.

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2. Inverse Edelstein effect induced by magnon-phonon coupling: M. Xu, J. Puebla, F. Auvray, B. Rana, K. Kondou and Y. Otani, Phys. Rev. B **97** (2018) 180301.

3. Unveiling the mechanisms of the spin Hall effect in Ta: E. Sagasta, Y. Omori, S. Vélez, R. Llopis, C. Tollan, A. Chuvilin, L. E. Hueso, M. Gradhand, Y. Otani and F. Casanova, Phys. Rev. B **98** (2018) 060410.

4. Direct current modulation of spin-Hall-induced spin torque ferromagnetic resonance in platinum/permalloy bilayer thin films: S. Hirayama, S. Mitani, Y. Otani and S. Kasai, Jpn. J. Appl. Phys. **57** (2018) 060301.

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9. Active Control of Mode Crossover and Mode Hopping of Spin Waves in a Ferromagnetic Antidot Lattice: S. Choudhury, S. Majumder, S. Barman, Y. Otani and A. Barman, Phys. Rev. Applied **10** (2018) 064044.

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† Joint research with outside partners.

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Komori group

Changes in the magnetism of epitaxially grown fcc Fe films on Cu(001) induced by single-crystal Mn overlayer are studied by scanning tunneling microscopy/spectroscopy and soft X-ray magnetic circular dichroism. Element specific magnetization curves of the Fe layer exhibit a two-step spin reorientation transition from out-of-plane to in-plane direction by increasing the Mn coverage. The atomic-scale characterizations of structural and electronic properties and the first-principles calculations successfully unravel the roles of the interface alloys and clarify the driving forces of the transition. Spin-resolved band L-gap surface bands on the noble metal (111) surfaces are quantitatively studied by spin- and angle-resolved photoelectron spectroscopy with a vacuum-ultraviolet laser. The surface-state wave function is found to be predominantly of even mirror symmetry with negligible odd contribution by SARPES using a linearly polarized light.

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* Joint research among groups within ISSP.

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8. *Discovery of 2D Anisotropic Dirac Cones: B. Feng, J. Zhang, S. Ito, M. Arita, C. Cheng, L. Chen, K. Wu, F. Komori, O. Sugino, K. Miyamoto, T. Okuda, S. Meng and I. Matsuda, Adv. Mater. **30** (2018) 1704025 (1-6).

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15. †*Coexistence of Two Types of Spin Splitting Originating from Different Symmetries: K. Yaji, A. Visikovskiy, T. Iimori, K. Kuroda, S. Hayashi, T. Kajiwara, S. Tanaka, F. Komori and S. Shin, Phys. Rev. Lett. **122** (2019) 126403.

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Hasegawa group

We performed scanning tunneling potentiometry; STM-based microscopy that enables us to obtain spatial mapping of electrochemical potential over the sample surface, on the Si(111)7x7 surface. Since the surface has the metallic surface states, electrical current flows through the surface layer created on an almost insulating low-doped substrate. We observed potential drops at the step edges and the domain boundaries of the superstructure, indicating the presence of electrical resistance there. It is found that the resistance at the step edge is rather large and thus the net conductivity of the reconstructed surface is basically determined by the step density or miscut angle of the substrate. This answers the long-standing question why the conductivity measured in macroscopic methods has dispersed so much. Our study demonstrates the importance of microscopic characterization for precise understanding of the conductivity in the two-dimensional metallic states. In the case of metallic surface states, because of the presence of the substrate, inversion symmetry is naturally broken. Therefore, superconductivity realized on the states cannot hold conventional s-wave Cooper pairing. In collaboration with Professor Shuji Hasegawa's group, Department of Physics, Univ. Tokyo, we investigated the superconductivity of a Tl-Pb monolayer formed on a Si(111) substrate by using low-temperature STM. Since previous angle-resolved photoemission spectra (ARPES) had revealed Rashba splitting in the metallic states, p-wave triplet or other unconventional pairings was expected. Our tunneling spectra clearly showed superconducting gaps on the surface whose spectrum shape cannot be explained with the BCS function. Vortices were also observed under magnetic fields. Curiously, however, even when the vortices cover the whole surface, the gaps still remain. In order to remove the gaps higher magnetic field has to be applied, which is quite unusual compared with the case of conventional s-wave superconductors. Whereas the reason of the peculiar gap behaviors is not revealed yet, the results demonstrate the possibility of unique and unconventional superconducting states on two-dimensional metallic surface states.

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3. SPM 特集号『プローブ顕微鏡によるナノサイエンスの最前線』企画趣旨：長谷川 幸雄，表面と真空 **61** (2018) 630-631.

† Joint research with outside partners.

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Lippmaa group

Noble metal doping can be an effective way of controlling the band gap width of titanate semiconductors like $SrTiO_3$. The special feature of noble metal dopants is that they form impurity states close to the valence band top of the crystal, thereby reducing the band gap without affecting the electronic structure at the conduction band bottom. For this reason, Ir, Pt, Pd, and Rh doping in $SrTiO_3$ has been studied in the area of solar-driven photocatalysis. In our recent work, we look at the microscopic mechanism of oxide doping with noble metals and self-organized nanoscale metal segregation. We find that during thin film growth of a noble-metal-doped $SrTiO_3$ film, the metal can migrate rapidly on the film surface and aggregate in a nanoscale cluster. This cluster formation, cluster size, and areal density can be controlled by the noble metal doping level. We use transmission electron microscopy and x-ray photoelectron spectroscopy to analyze the metal nanocluster formation and growth.

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2. Pyroelectric detection of ferroelectric polarization in magnetic thin films: R. Takahashi and M. Lippmaa, Jpn. J. Appl. Phys. **57** (2018) 0902A1.

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7. *Strain-induced spontaneous Hall effect in an epitaxial thin film of a Luttinger semimetal: T. Ohtsuki, Z. Tian, A. Endo, M. Halim, S. Katsumoto, Y. Kohama, K. Kindo, M. Lippmaa and S. Nakatsuji, Proc. Natl. Acad. Sci. USA **116** (2019) 8803-8808.

8. Gradient Carrier Doping as a Method for Maximizing the Photon-to-Current Efficiency of a $SrTiO_3$ Water Splitting Photoanode: S. Kawasaki, R. Takahashi and M. Lippmaa, J. Phys. Chem. C (2019), accepted for publication.

9. 酸化物半導体中に自己組織化した金属ナノピラーによる高効率･水分解光電極反応 : 川崎 聖治 , 高橋 竜太 , リップマー ミック , 応用物理 **87** (2018) 366-369.

Functional Materials Group

Yoshinobu group

We conducted several research projects in the fiscal year 2018: (1) Systematic study of the activation and hydrogenation of CO_2 on Zn/Cu model catalysts by AP-XPS, IRAS, and TPD. (2) The surface chemistry of formic acid on Zn/Cu model catalysts studied by SR-PES, IRAS, and TPD. (3) Spectroscopic characterization of Hydrogen adsorption and absorption on Pd-Cu and

* Joint research among groups within ISSP.

Pd-Ag surfaces by XPS. (4) LT-STM study of Zn on Cu(997). (5) The surface chemistry of hydrogen and formic acid on Pd/Cu model catalysts studied by SR-PES, IRAS, and TPD. (6) Observation of CVD processes of graphene formation on a Cu surface.

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2. *Atomic Structure and Local Electronic States of Single Pt Atoms Dispersed on Graphene: K. Yamazaki, Y. Maehara, C.-C. Lee, J. Yoshinobu, T. Ozaki and K. Gohara, J. Phys. Chem. C **122** (2018) 27292.

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7. *Hydrogen adsorption and absorption on a Pd-Ag alloy surface studied using in-situ X-ray photoelectron spectroscopy under ultrahigh vacuum and ambient pressure: J. Tang, S. Yamamoto, T. Koitaya, Y. Yoshikura, K. Mukai, S. Yoshimoto, I. Matsuda and J. Yoshinobu, Applied Surface Science **463** (2019) 1161-1167.

8. *Mass transport in the PdCu phase structures during hydrogen adsorption and absorption studied by XPS under hydrogen atmosphere: J. Tang, S. Yamamoto, T. Koitaya, A. Yoshigoe, T. Tokunaga, K. Mukai, I. Matsuda and J. Yoshinobu, Applied Surface Science **480** (2019) 419-426.

9. *CO_2 Activation and Reaction on Zn-Deposited Cu Surfaces Studied by Ambient-Pressure X-ray Photoelectron Spectroscopy: T. Koitaya, S. Yamamoto, Y. Shiozawa, Y. Yoshikura, M. Hasegawa, J. Tang, K. Takeuchi, K. Mukai, S. Yoshimoto, I. Matsuda and J. Yoshinobu, ACS Catal. **9** (2019) 4539-4550.

Akiyama group

In 2018, we fabricated and characterized 1035nm InGaAs laser diodes for short and intense pulse generation via gain switching (NEDO project). We studied single- and multi-junction solar cells for absolute electroluminescence-efficiency standard. We made femto-sectond time-resolved laser photo-emission spectroscopy for solar cell systems (LASOR collaboration), and analyzed their results in comparison with model calculations and time-resolved PL spectroscopy, We made computational studies with quantum-chemistry and molecular-dynamics calculations on oxyluciferins and caged-luciferins, and corresponding experiments.

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9. Intrinsic and extrinsic drops in open-circuit voltage and conversion efficiency in solar cells with quantum dots embedded in host materials: L. Zhu, H. Akiyama and Y. Kanemitsu, Scientific Report **8** (2018) 11704.

10. Synthesis and quantitative characterization of coumarin-caged D-luciferin: M. Kurata, M. Hiyama, T. Narimatsu, Y. Hazama, T. Ito, Y. Hayamizu, X. Qiu, F. M. Winnik and H. Akiyama, Journal of Photochemistry and Photobiology B: Biology **189** (2018) 81.

11. *Nonlinear propagation effects in high harmonic generation in reflection and transmission from gallium arsenide: P. Xia, C. Kim, F. Lu, T. Kanai, H. Akiyama, J. Itatani and N. Ishii, Optics Express **26** (2018) 29393-29400.

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Sugino group

In this fiscal year, we have developed a novel first-principles simulation method for defects in a material and excitons in a molecule and, in addition, have applied an advanced simulation method to a surface. The first topic is a replica exchange Monte Carlo sampling of defects in a solid, which has not been tried previously in the literature but has proven to be unexpectedly efficient. The second topic is on our progress in improving the efficiency of the Green's functional approach, which makes it possible to simulate up to 200 atoms exceeding most of our target systems. The third topic is on the problem of resolving the hydrogen adsorption on Pt(111) surface. By using an advanced exchange-correlation functional, it was finally revealed how strongly and at which site hydrogen atoms are adsorbed on the surface. This is an important step for true understanding the water splitting and fuel cell reactions.

1. * 物質科学、この 1 年「ボロフェンにおけるディラックフェルミオン」：松田 巌 , パリティ **33** (2018) 36-38.

2. Optical properties of six isomers of three dimensionally delocalizedπ-conjugated carbon nanocage: Y. Noguchi, D. Hirose and O. Sugino, Eur. Phys. J. B **91** (2018) 125.

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Inoue group

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Quantum Materials Group

Oshikawa group

We studied a variety of problems in quantum condensed matter physics, statistical mechanics, and field theory. In particular, we studied the electronic structure of α-$ZrCl_3$. Under the ligand field splitting and a strong spin-orbit interaction, each Zr^{3+} has one electron each in the J=3/2 quartet states. The strong anisotropy of d-orbitals leads to highly orbital- and direction-dependent hoppings. Nevertheless, we found that, after an appropriate gauge transformation, the effective model has a global SU(4) symmetry which corresponds to the simultaneous complex rotation of the quartet states. In the presence of a strong Coulomb repulsion, the system would be described by the SU(4) antiferromagnetic "Heisenberg" model on a honeycomb lattice, which is predicted to have a gapless spin liquid state. This suggests an intriguing possibility of realizing a SU(4) spin-orbital liquid, in which spin and orbital degrees of freedom of a magnetic material are intertwined.

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Nakatsuji group

Our group explores ground state properties and spintronic functions of novel quantum phases and phase transitions in rare-earth and transition-metal based compounds. The followings are some relevant results obtained in 2018. (1) We found one order magnitude higher anomalous Nernst effect in Co_2MnGa, in comparison with the previously reported value for ferromagnets, ascribable to the quantum Lifshitz transition between type-I and type-II Weyl fermions (2) We have succeeded in growing a high-quality thin film of magnetic Weyl semimetal Mn_3Sn that exhibits anomalous Hall effect by a sputtering method. (3) our recent study on Mn_3Sn has revealed a new type of spin Hall effect, whose sign and magnitude can be controlled by magnetization for the first time (4) We found a spin ice state with significant quantum fluctuations, namely, a quantum spin ice state in $Pr_2Zr_2O_7$. (5) We established the thin film growth method of the Luttinger semimetal state of $Pr_2Ir_2O_7$ and reported strain-induced Weyl semimetal state in using the thin films.

† Joint research with outside partners.

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Miwa group

We have studied following topics in this year: (1) Voltage-controlled magnetic anisotropy using interface-controlled tunnel junction, (2) Spin-to-charge conversion using metal/organic interface, and (3) Reservoir computing using spintronics devices. In the topic (1), we have performed experiments using interface-controlled devices. For instance, we studied FeCoPtPd/MgO junction with various composition ratio of the Co, Pt and Pd. Specifically, we performed tunnel spectroscopy to characterize the correlation between interface electronic states and the voltage-controlled magnetic anisotropy. As a result, we find that interface resonant state enhances the voltage effect. We have also published a review paper on this topic. In the topic (2), we find that it is feasible to obtain efficient inverse Rashba-Edelstein effect at an interface between copper and lead-phthalocyanine in collaboration with Otani group. In the topic (3), we performed both experimental and theoretical study to evaluate the figure-of-merit of physical reservoir computing using spintronics devices.

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Materials Design and Characterization Laboratory

Hiroi group

We revisit the superconducting pyrochlore oxide $Cd_2Re_2O_7$ with a particular emphasis on the sample-quality issue. The compound has drawn attention as the only superconductor (Tc = 1.0 K) that has been found in the family of α-pyrochlore oxides since its discovery in 2001. Moreover, it exhibits two characteristic structural transitions from the cubic pyrochlore structure, with the inversion symmetry broken at the first one at 200 K. Recently, it has attracted increasing attention as a candidate spin–orbit coupled metal (SOCM), in which specific Fermi liquid instability is expected to lead to an odd-parity order with spontaneous inversion-symmetry breaking and parity-mixing superconductivity. We show that a synthetic copper mineral, Cd-kapellasite, which comprises a kagomé lattice consisting of corner-sharing triangles of spin-1/2 Cu2+ ions, exhibits an unprecedented

† Joint research with outside partners.

series of fractional magnetization plateaus in ultrahigh magnetic fields of up to 160 T. We propose that these quantum states can be interpreted as crystallizations of emergent magnons localized on the hexagon of the kagomé lattice.

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Kawashima group

We have been investigating quantum spin/boson systems and frustrated systems by means of large-scale numerical simulation. We also develop new numerical techniques. Our group's activities of 2018 include: (1) tensor-network study of frustrated quantum spin systes, such as S=1 bilinear-biquadratic model and kagome antiferromagnet, and comparison with experimental results, (2) efficient implementation of real-space renormalization group in tensor-network representation, (3) molecular-dynamics simulation of complex fluids, and (4) Monte Carlo simulation study classical statistical mechanical models.

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Uwatoko group

We report a high-pressure study on the heavily electron doped $Li_{0.36}(NH_3)_yFe_2Se_2$ single crystal by using a cubic anvil cell apparatus. The superconducting transition temperature Tc≈44K at ambient pressure is first suppressed to below 20 K upon increasing pressure to Pc≈2GPa, above which the pressure dependence of Tc(P) reverses and Tc increases steadily to ca. 55 K at 11 GPa. These results thus evidence a pressure-induced second high-Tc superconducting (SC-II) phase in $Li_{0.36}(NH_3)_yFe_2Se_2$ with the highest Tmaxc≈55K among the FeSe-based bulk materials. We report two distinct superconducting states with different crystal structures and a crossover from a type-II to a type-I superconductor (SC) in (Ba,Sr)Bi_3. The superconducting parameters are revealed to classify two SCs: $BaBi_3$ is in the weak-coupling limit on the basis of $\Delta C/\gamma nTc$~0.67 and $2\Delta/kBTc$~3.28 while $SrBi_3$ is a strong-coupling SC with $\Delta C/\gamma nTc$~2.41 and $2\Delta/kBTc$~6.09. With increasing the pressure, the Tc of BaBi3 decreases linearly at first, and then shows an abrupt increase up to 6.2 K at 0.88 GPa. Tc of $SrBi_3$ is suppressed monotonously by pressure. Possible physical mechanisms are proposed. The coexistence of superconductivity (SC) and charge density waves (CDWs) was investigated for pure and Se-doped 1T−TaS_2 via electrical resistivity under hydrostatic pressure. A pressure-induced superconducting state coexists with various CDWs, then bulk SC emerges along with the complete collapse of various CDWs. The superconducting transition temperature increases monotonously up to ~7.3K at 15 GPa without a domelike shape. The results clarify that the superconducting Cooper pairing is associated with the CDWs' instability near Pc(x). The electrical resistivity and magnetization of a single crystal of $Ce_2Ni_3Ge_5$ heavy fermion compound were performed under pressure. On applying pressure, the two antiferromagnetic transitions merged at 1 GPa. At higher pressures, the antiferromagnetic transition temperature decreases, and disappears. It is suggesting that the critical pressure of $Ce_2Ni_3Ge_5$ was 4.1 GPa. Polarized neutron analyses on MnP were applied to two different helical magnetic structures (helical-c and helical-b). Helicity was observed in the both structures. The two helical domain ratio becomes more unbalanced in the helical-b structure at a higher pressure, suggesting that the Dzyaloshinskii-Moriya interaction, which is enhanced by a local structural strain, could be related with the helical structures.

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Ozaki group

In collaboration with experimental groups, we have investigated novel three kinds of surface structures and its electronic states by means of first-principles electronic structure methods based on density functional theory (DFT). (i) We identified detailed structures of two energetically competing root-13 x root-13 R13.9°silicene on Ag (111) surface which were recently revealed by scanning tunneling microscopy (STM) and atomic force microscopy (AFM). Simulations of AFM suggested that attractive interaction with the tip pulls up buckled down Si atoms which causes local flips of the buckled structures, leading to an understanding of the mechanism of experimental high-resolution AFM imaging. (ii) In single-atom catalysis, the atomic structure and local electronic states of single atoms on a supporting material remain a fundamental question. We experimentally and theoretically solved these problems for single Pt atoms dispersed on freestanding graphene using plasma sputtering. First-principles calculations elucidated that the Pt 5dxy-orbital in the step edge plays a crucial role in the formation of chemical bonds to C atoms and in the considerable charge transfer from Pt to C atoms, resulting in the large binding energy shift of the Pt 4f state. (iii) We showed that the B atoms deployed at the centers of honeycombs in boron sheets, borophene, behave as nearly perfect electron donors for filling the graphiticσbonding states without forming additional in-plane bonds by first-principles calculations. It was confirmed from our the XPS binding energy calculations that the unusual energy sequence of core electrons in the borophene, verified by our high-resolution core-level photoelectron spectroscopy measurements, is originated by the hidden honeycomb bonding structure.

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Noguchi group

We have studied nonequilibrium dynamics of polymer solutions and bilayer membranes. We investigated Karman vortex in polymer solution using molecular dynamics simulation. The polymer induces a reduction in the vortex shedding frequency and broadening of the lift coefficient spectrum. We also investigated the shape transformation of vesicles induced by chemical reactions. We revealed that the dynamics can be altered by the viscosity change in the membrane compared to the surrounding fluids.

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Materials Synthesis and Characterization group

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Neutron Science Laboratory

Shibayama group

Shibayama group has been exploring the structure and dynamics of soft matter, especially polymer gels, micelles, thermo-responsive polymers, and thermosets, utilizing a combination of small-angle neutron scattering (SANS), small-angle X-ray scattering (SAXS), and dynamic light scattering (DLS). The objectives are to elucidate the relationship between the structure and variety of novel properties/functions of polymer gels/resins. The highlights of 2018 include investigations of (1) probe diffusion of sol-gel transition in isorefractive indexed solvents, (2) microscopic structure of module-assembled thermoresponsive conetwork hydrogels, (3) diffusion behavior of methanol molecules confined in cross-linked phenolic resins, (4) structure-mechanical property relationships in crosslinked phenolic resin, and (5) dynamics of thermoresponsive conetwork gels, and so on.

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Yamamuro group

Our laboratory is studying chemical physics of complex condensed matters by using neutron scattering, X-ray diffraction, calorimetric, dielectric, and viscoelastic techniques. Our target materials are glasses, liquids, and various disordered systems. In this year, the synchrotron X-ray diffraction of glassy and liquid toluene ($C_6H_5CH_3$) was measured following the previous works on carbon disulfide (CS_2), propane ($CH_3CH_2CH_3$) and propene (CH_3CHCH_2). By means of the Reverse Monte Carlo (RMC) method combining the molecular dynamics (MD) simulations, we found that the orientational correlation between neighboring molecules steeply increased on cooling below the melting temperature and was frozen at the glass transition temperature. Another topic is the inelastic neutron scattering of vapor-deposited glassy carbon tetrachloride (CCl_4). We observed the

* Joint research among groups within ISSP.

Q-dependence of the boson peak intensity and the dispersion-like phenomenon of acoustic phonons as observed in SiO_2 glass, which is a typical covalent-bond network glass. Other than the above topics, we have conducted neutron diffraction experiment of the PdRu alloy nanoparticles supported on CZ (CeO_2-ZrO_2). This is a high-performance catalytic system for removing CO and NOx gases. The pdf (pair-distribution function) analysis is now going on to investigate the atomic scale miscibility and local structure of the alloy.

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Masuda group

The goal of our research is to discover a new quantum phenomenon and to reveal the mechanism of it. In this fiscal year we studied the following topics; magnetic order in the rare-earth ferroborate $CeFe_3(BO_3)_4$, magnetic state selected by magnetic dipole interaction in the kagome antiferromagnet NaBa2Mn3F11, polarization analysis of magnetic excitation in multiferroic $Ba_2CoGe_2O_7$, pressure-induced quantum phase transition in the quantum antiferromagnet $CsFeCl_3$, neutron spin resonance in the 112-type iron-based superconductor, crystal structure of magnetoelectric $Ba_2MnGe_2O_7$ at room and low temperatures by neutron diffraction.

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2. f-Electron States in $PrPd_5Al_2$: N. Metoki, H. Yamauchi, H. S. Suzuki, H. Kitazawa, M. Hagihara, T. Masuda, A. A. Aczel, S. Chi, T. Hong, M. Matsuda, D. Pajerowski and J. A. Fernandez-Baca, J. Phys. Soc. Jpn. **87** (2018) 094704 (1-8).

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International MegaGauss Science Laboratory

Takeyama group

1000 T-class megagauss generator system has been accomplished to be used for the electro-magnetic flux compression. The system is comprised of 5 MJ and 2 MJ condenser modules, respectively, for a primary coil and 2 MJ condenser modules for the seed-magnetic field generation to be compressed. This project has started in 2010 supported by a budget from the MEXT. After long-standing struggles over 10 years with serious difficulties in the construction processes, the instruments have been finally accomplished. We could break the world record of high-magnetic fields, 1200 T, of which value was successfully recorded by the optical Faraday rotation technique with high precision and reliability.

1. †*Ultrahigh-Magnetic-Field Magnetization of Multi-Kagome-Strip (MKS) Lattice Spin-Frustrated Magnet $K_2Mn_3(OH)_2(VO_4)_2$: D. Otsuka, H. Sato, A. Matsuo, K. Kindo, D. Nakamura and S. Takeyama, J. Phys. Soc. Jpn. **87** (2018) 124701 (1-7).

2. Note: An approach to 1000 T using the electro-magnetic flux compression: D. Nakamura, H. Sawabe and S. Takeyama, Rev. Sci. Instrum. **89** (2018) 016106 (1-3).

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Kindo group

We have succeeded in examination of various Cu-Ag strong wire. A stronger wire can suppress the deformation of the magnet after generation of high magnetic field but has a short-life frequently. We have examined the wire which has a tensile strength below 1.1 GPa. As a result, the magnet obtained long-life. Next step is to elucidate threshold between long and short life.

1. †*Magnetic and Structural Properties of A-Site Ordered Chromium Spinel Sulfides: Alternating Antiferromagnetic and Ferromagnetic Interactions in the Breathing Pyrochlore Lattice: Y. Okamoto, M. Mori, N. Katayama, A. Miyake, M. Tokunaga, A. Matsuo, K. Kindo and K. Takenaka, J. Phys. Soc. Jpn. **87** (2018) 034709 (1-8).

* Joint research among groups within ISSP.

2. †*Magnetic-field-induced Quantum Phase in S = 1/2 Frustrated Trellis Lattice: H. Yamaguchi, D. Yoshizawa, T. Kida, M. Hagiwara, A. Matsuo, Y. Kono, T. Sakakibara, Y. Tamekuni, H. Miyagai and Y. Hosokoshi, J. Phys. Soc. Jpn. **87** (2018) 043701 (1-5).

3. †Magnetism and High-magnetic Field Magnetization in Alkali Superoxide CsO_2: M. Miyajima, F. Astuti, T. Kakuto, A. Matsuo, D. P. Sari, R. Asih, K. Okunishi, T. Nakano, Y. Nozue, K. Kindo, I. Watanabe and T. Kambe, J. Phys. Soc. Jpn. **87** (2018) 063704 (1-5).

4. Superconducting Phase Diagram of the Organic Superconductor κ-(BEDT-TTF)$_2$ Cu[N(CN)$_2$]Br above 30 T: S. Imajo, Y. Nakazawa and K. Kindo, J. Phys. Soc. Jpn. **87** (2018) 123704 (5).

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7. *Frustrated magnetism of the maple-leaf-lattice antiferromagnet $MgMn_3O_7{\cdot}3H_2O$: Y. Haraguchi, A. Matsuo, K. Kindo and Z. Hiroi, Phys. Rev. B **98** (2018) 064412 (1-7).

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10. †*Magnetic field induced ferroelectricity and half magnetization plateau in polycrystalline $R_2V_2O_7$ (R = Ni, Co): R. Chen, J. F. Wang, Z. W. Ouyang, Z. Z. He, S. M. Wang, L. Lin, J. M. Liu, C. L. Lu, Y. Liu, C. Dong, C. B. Liu, Z. C. Xia, A. Matsuo, Y. Kohama and K. Kindo, Phys. Rev. B **98** (2018) 184404 (1-7).

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Tokunaga group

In this year, we have mainly studied magnetotransport properties on several kinds of topological semimetals. As one of the important achievements in our group, we demonstrated an experimental method to evaluate the degree of similarity between one system and ideal Dirac fermion system, "Diracness", in a narrow-gap semiconductor PbTe through systematic studies of quantum oscillations up to the quantum limit state. We also developed international collaborations on various subjects, e.g. multiferroics, heavy fermion compounds, and topological materials.

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Y. Matsuda group

Ultrahigh magnetic fields of up to 1200 T has been generated by the electromagnetic flux compression technique using a new 5 MJ condenser bank system installed in ISSP rather recently. It is the indoor world record of magnetic field. Several measurements such as Faraday rotation, optical transmission, magnetization, and electrical resistivity have already been done using multi-megagauss magnetic fields. Development of the technique for measuring magnetostriction has been conducted and the one using so-called Fiber Bragg Grating (FBG) was improved. The field-induced linear magnetostriction corresponding to the magnetization plateau behavior of a deformed Kagome lattice has been clearly observed. In addition, thermal properties in the Kondo insulator YbB_{12} was studied in pulsed high fields of up to 60 T, and the field-induced metallic phase has been found to be a heavy fermion metal.

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Kohama group

We have investigated various high-field properties by means of specific heat, magnetooptics and resistivity measurement techniques. In $Ni_3V_2O_8$, YbB_{12} and UIrGe, the field-induced phase transitions have been detected, where the field dependence of entropy have been unveiled. We also have started to construct a new type of capacitor bank for the generation of pulsed magnetic fields with the second order timescale.

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Laser and Synchrotron Research Center

Shin group

We studied high Tc Fe-pnictide superconductors using 7-eV laser. High resolution photoemission study with polarization dependence is very powerful for the study of the superconducting mechanism. Orbital fluctuation mechanism is also important in addition to the spin fluctuation mechanism.

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I. Matsuda group

In 2018, we extended our experimental technique, developed at SPring-8 BL07LSU, to the next generation light sources. Using an X-ray free electron laser, we successfully observed the second harmonic generation of soft X-ray in a non-linear crystal of $GaFeO_3$. The signal was enhanced by the core-level resonance effect and, thus, it contained the element specific information. This fact indicates that the non-linear soft X-ray spectroscopy becomes an experimental probe for material science. We also designed new beamlines and experimental stations for ultimately high-brilliant soft X-ray synchrotron radiation, motivated by announcement on the next-generation facility by the Minister of Education, Culture, Sports, Science and Technology. Concerning the material science, we synthesized novel atomic layers. For examples, we fabricated a free-standing layer of borophane and also a monolayer of the Cat-TTF derivative that form interface hydrogen bonding with the self-assembled monolayer. We also examined their electronic properties and carrier dynamics by synchrotron radiation and laser.

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Kobayashi group

We are studying the state-of-the-art laser system including ultrashort-pulse lasers and deep-ultraviolet lasers. We aim to know "How and Why materials are broken by light?" utilizing experiment of light-matter interaction and deep-learning technology.

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Itatani group

We developed a high harmonic beamline for soft X-ray spectroscopy in the water window. Using a few-cycle CEP-stable intense IR source (optical parametric chirped pulse amplifier; OPCPA), attosecond pulses were produced in helium with a high pressure gas cell, resulting in broadband soft X-ray spectra that cover the entire water window (280-530 eV). We also developed an intense MIR source with a multi-plate pulse compression technique. Sub-two-cycle pulses at at 3.5-μm with a stable carrier-envelope phase were successfully produced. The maximum field amplitude at the focus was estimated to be 280 MV/cm. Using intense MIR sources, we carried out several experiments on high harmonic generation in solids. With a crystalline GaSe, we observed nontrivial polarization behavior, which was reproduced by the first-principle simulation and an intra-band current model. We also produced high harmonics in GaSe with circularly polarized pulses, and experimentally confirmed a selection rule. Collaboration with Shin and Okazaki groups was continued on time-resolved ARPES experiments.

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Harada group

Advanced use of Resonant Inelastic X-ray Scattering is not limited to solid state physics or solution chemistry but now extending to biochemistry. Before entering real biosystems which contain extremely complex and inhomogeneous local structure and multi-elements we analyzed functional part of biosystems using model complexes like iron complexes, iron–sulfur complexes and cobalt containing polyoxometalate complexes. Charge transfer dynamics among metal sites of those complexes mediated by anionic ligands are essential to function biomaterials through catalysis, molecular binding, electron transfer and so on. We have established novel methods to obtain intact spectra of those fragile complexes to X-rays without radiation damage and published three papers this year. We have performed 13 collaborative works at BL07LSU HORNET end-station. They are well balanced in scientific topics; five of which are studies on the behavior of water at various circumstances (including international collaborations with researchers in MAX IV and Stockholm University in Sweden), four are batteries and the remaining four are solid state physics. Using beamtimes for beamline tuning we accepted some test experiments on samples from companies for future collaborations.

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Wadati group

We succeeded in the observation of tensile-strain dependent spin states in epitaxial $LaCoO_3$ thin films by using soft x-ray RIXS in SPring-8 BL07LSU. We also started to use SACLA soft x-ray beam line and obtained second-harmonic generation of $GaFeO_3$.

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Kondo group

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Matsunaga group

Matsunaga group investigated light-matter interactions and light-induced nonequilibrium phenomena by utilizing terahertz (THz) wave, infrared, and visible light sources based on ultrafast pulsed laser technology. Polarization-sensitive THz time-domain spectroscopy system was developed with precision of several tens of micro rad between 0.5 and 2.0 THz frequency. By using this system, terahertz anomalous Hall effect in quantum materials were investigated. High-frequency THz pulge generation technique was also developed using Yb:KGW laser with 250 femtosecond pulse width. Novel pulse compression technique using a series of quartz plates were developed and evaluated, and broadband THz generation up to several tens of THz frequency with remarkable stability of carrier-envelope phase were realized.

Okazaki group

We have investigated superconducting-gap structures of unconventional superconductors by a low-temperature and high-resolution laser ARPES apparatus and transient electronic structures in photo-excited non-equilibrium states by a time-resolved ARPES apparatus using EUV and SX lasers. In the fiscal year 2018, we have investigated the systematic S substitution dependence of the electronic structure of $FeSe_{1-x}S_x$ in the superconducting state, and found strong evidence that this system is located in the BCS-BEC crossover regime. In addition, we have obtained strong evidence that Ta_2NiSe_5 is an excitonic insulator from its dynamical behavior to photo-excitation, and found a photo-induced transition from an excitonic insulating state to an exotic non-equilibrium semimetallic state in this material.

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[†] Joint research with outside partners.
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