Non-perturbative magnetic field effects on solid states by ultrahigh fields of 1000 T

(Session1, Oral)

Yasuhiro H. Matsuda,[1] Yuto Ishii,[1] Akihiko Ikeda,[2] Xu-Guang Zhou,[1] Polin Chiu,[1] and Shiyue Peng[1]

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

2 Department of Engineering Science, University of Electro-Communications, Chofu, Japan

Recent developments in the research on the 1000 T material science will be introduced. After showing developments of the measurement techniques, recent results on spin systems and oxides are introduced.

It has never well been explored how a strong magnetic field exceeding 100 T changes the properties of matter because of the technical difficulties for producing such high magnetic fields. The success of the 1200 T generation with a high controllability [1] opens a research discipline on non-perturbative magnetic field effects in matter. The spin Zeeman splitting of a free electron at 1000 T is as large as the thermal energy of 1350 K which nearly corresponds to the melting temperature of copper, imagining a considerable impact on the electronic state in matter.

Experimental technique is one of the keys for development of the ultrahigh magnetic field science. Magnetoresistance can be measured through the impedance change with a high-frequency modulation technique [2]. The fiber Bragg grating (FBG) allows us to know a change in a crystal lattice induced by ultrahigh magnetic fields over 100 T [3]. Moreover, a mobile 100 T generator has been on the way of development for the experiment using an x-ray free electron laser [4].

Strongly correlated electrons exhibit fascinating quantum phenomena such as insulator-metal transition and high-temperature superconductivity. Ultrahigh magnetic fields have been found to alter the ground state and induce phase transitions in some strongly correlated materials. Insulator-to-metal phase transitions have been observed in $V_{1-x}W_xO_2$ [5], FeSi [6], and SmB_6 [7] in a magnetic field range of up to 500 T. In $LaCoO_3$, a quantum condensation of the magnetic exciton occurs in magnetic fields of up to 600 T [8]. Although a clear microscopic interpretation of the field-induced quantum phase transitions has never been obtained, it is likely that the Zeeman splitting overcomes the energy gaps between the ground and exited states through many-body effects. We also present recent experimental results on $RuCl_3$, $Na_2Co_2TeO_6$, VO_2, V_2O_3 and YBCO, which show the variety of phase transitions and quantum phenomena in magnetic fields of up to 600 T. A challenge to quest a magnetic field control of ferroelectricity in $BaTiO_3$ is also presented.

[1] D. Nakamura *et al.*, Rev. Sci. Instrum. **89**, 095106, (2018)
[2] S. Peng *et al.*, arXiv:2401.00389, (2024)
[3] A. Ikeda *et al.*, Rev. Sci. Instrum. **88,** 083906, (2017)
[4] A. Ikeda *et al.*, Appl. Phys. Lett., **120**, 142403, (2022).
[5] Y. H. Matsuda *et al.*, Nat. Commun. **11**, 3591, (2020)
[6] D. Nakamura *et al.*, Phys. Rev. Lett. **127**, 156601, (2021)
[7] D. Nakamura *et al.*, Phys. Rev. B **105**, L241105, (2022)
[8] A. Ikeda *et al.*, Nat. Commun. **14**, 1744, (2023)