

# Study of condensed matter physics with non-perturbative ultrahigh magnetic fields

## 非摂動超強磁場による物性研究



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A magnetic field modifies electronic states of matter through control of magnetic moments and orbital motion of electrons, which leads to various intriguing phenomena such as magnetization plateaus in frustrated magnets [1], quantum oscillations in Dirac semimetals [2], emergence of field-induced superconducting phases in heavy fermion systems [3], and metamagnetic transitions and shape memory effects in Heusler alloys [4]. Although these studies are extremely intriguing, most of them utilize a magnetic field effect as a perturbation, i.e., the intriguing ground state of matter is elucidated through field-induced phenomena. On the other hand, when we look at the nature of the outside of the earth, a super-strong magnetic field of  $10^5$ – $10^{11}$  T exists on neutron stars in the universe, where even covalent chemical bonds are collapsed through the Pauli exclusion principle [5]. The world-highest indoor magnetic field is 1200 T, which was achieved in 2018 [6] at the Institute for Solid State Physics, the University of Tokyo, paving the way to explore the non-perturbative magnetic field effects by which the state of a chemical bonding is significantly influenced, resulting in a potential new crystal structure appearing as the ground state in the ultrahigh magnetic fields. The magnetic field-induced  $\alpha$ - $\theta$  phase transition in solid oxygen around 120 T [7] and the potential collapse of the molecular orbital of V-V dimers in W-doped  $\text{VO}_2$  at approximately 500 T [8] are archetypes of the non-perturbative magnetic field effect. In this colloquium, in addition to the recent research progress of W-doped  $\text{VO}_2$  and solid oxygen, the current status of the study using the non-perturbative magnetic fields will be introduced, such as insulator metal transition in correlated conductors, ultrahigh-field magnetic quantum phases in frustrated magnets, and possible field-control of ferroelectricity in nonmagnetic insulators.

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[3] S. Ran, I-L. Liu, Y. S. Eo, *et al.*, Nat. Phys. **15**, 1250 (2019).

[4] T. Kihara, T. Roy, X. Xu *et al.*, Phys. Rev. Materials **5**, 034416 (2021).

[5] M. Date, Aust. J. Phys. **48**, 187 (1995).

[6] D. Nakamura, A. Ikeda, H. Sawabe *et al.*, Rev. Sci. Instrum. **89**, 095106 (2018).

[7] T. Nomura, Y. H. Matsuda, S. Takeyama *et al.*, Phys. Rev. Lett. **112**, 247201 (2014).

[8] Y. H. Matsuda, D. Nakamura, A. Ikeda, *et al.*, Nat. Commun. **11**, 3591 (2020).