

論文 / 著書情報  
Article / Book Information

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## 論文要旨

THESIS SUMMARY

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要旨 (英文 800 語程度)

Thesis Summary (approx.800 English Words)

In frustrated magnets, the experimental realization of a quantum disordered ground state (QDGS), especially quantum spin liquid (QSL) ground state, is a central topic in condensed matter physics. Several promising candidates were reported, and a number of QSL-like behavior, such as excitation continuum,  $T$ -linear specific heat, and so on, were observed. However, whether the QSL-like behavior is owing to the synergy between spin frustration and quantum fluctuation or bond randomness effects has not been clarified yet. Several theoretical studies have demonstrated that the synergy effect between the magnetic frustration and the bond randomness suppresses magnetic ordering and induces a QSL-like state. This QSL-like state was proposed to be a random-singlet (RS) state, where not only nearest-neighbor spins but also distant spins form singlet pairs with random coupling energy. Since thermodynamic properties of RS and QSL are predicted to be similar to each other, it is important to elucidate the microscopic nature of randomness-induced QDGSs. However, its experimental verifications are still insufficient due to a lack of model materials.

In this work, I synthesized polycrystalline samples of SrLaCuSbO<sub>6</sub> (SLCSO) and SrLaCuNbO<sub>6</sub> (SLCNO) by a solid-state reaction. Magnetic Cu<sup>2+</sup> ions with  $S = 1/2$  Heisenberg spins form a square lattice with nearest-neighbor ( $J_1$ ) and next-nearest-neighbor ( $J_2$ ) exchange interaction. Thus, SLCSO and SLCNO were magnetically described as quasi-two-dimensional  $S = 1/2$   $J_1$ - $J_2$  square lattice Heisenberg antiferromagnet (SLHAF). The temperature dependence of the magnetic susceptibilities of both compounds shows a broad maximum characteristic of an  $S = 1/2$  SLHAF. However, both compounds undergo magnetic phase transitions at  $T_N = 13.6$  and 15.7 K for SLCSO and SLCNO, respectively, due to weak interlayer interactions. Neutron powder diffraction measurements reveal contrasting spin structures in both compounds. The spin structures of SLCSO and SLCNO below  $T_N$  are Néel antiferromagnetic and collinear antiferromagnetic, respectively. This result demonstrates that the nearest-neighbor interaction is dominant in SLCSO, whereas the next-nearest-neighbor interaction is dominant in SLCNO. The magnitude of the ordered moment was evaluated at 3.5 K to be  $m = 0.39(3) \mu_B$  for SLCSO and  $0.37(1) \mu_B$  for SLCNO, which are significantly reduced from  $1 \mu_B$  expected in the classical spin case. The shrink of the ordered magnetic moment was caused by not only magnetic frustration effects but also bond randomness effects arising from the site disorder of Sr<sup>2+</sup> and La<sup>3+</sup> ions.

Next, I synthesized the mixed system SrLaCuSb<sub>1-x</sub>Nb<sub>x</sub>O<sub>6</sub> with  $0.1 \leq x \leq 0.5$  and performed systematic magnetic susceptibility and specific heat measurements. Because the superexchange paths via Sb<sup>5+</sup> and Nb<sup>5+</sup> make  $J_1$  and  $J_2$  dominant, respectively, the random substitution of Nb<sup>5+</sup> for Sb<sup>5+</sup> produces strong randomness in the magnitude of  $J_1$  and  $J_2$ . Hence, these systems can be magnetically described as  $S = 1/2$  random  $J_1$ - $J_2$  SLHAF. Compared with parent systems SLCSO and SLCNO, the bond randomness effect is more pronounced in SrLaCuSb<sub>1-x</sub>Nb<sub>x</sub>O<sub>6</sub> even for a small amount of Nb substitution. No sign of magnetic ordering was observed in specific heat measurements down to 0.35 K for  $0.1 \leq x \leq 0.5$ . Furthermore,  $\mu$ SR measurements on a sample with  $x = 0.2$  revealed that neither magnetic ordering nor spin freezing occurs. The temperature dependence of the magnetic susceptibility and the specific heat at low temperatures follows the power law, suggesting the realization of a gapless QDGS. LF- $\mu$ SR measurements at 0.035 K showed that muon spin relaxation is still retained even for an applied longitudinal field of 0.3 T, suggesting that spin fluctuation is maintained even at 0.035 K. This is consistent with the emergence of the QDGS.

The QSL-like QDGS is naively considered to be the RS state. However, there are some disagreements between experimental and theoretical results for the temperature dependences of magnetic and thermodynamic quantities.

It was theoretically predicted that the low-temperature magnetic specific heat divided by temperature  $C_{\text{mag}}(T)/T$  and magnetic susceptibility  $\chi(T)$  follow power laws  $\chi \propto T^{-\gamma}$  and  $C_{\text{mag}}(T)/T \propto T^{-\gamma}$  with same exponent  $\gamma$  for the RS state. Although temperature dependence of magnetic susceptibility and specific heat of SrLaCuSb<sub>1-x</sub>Nb<sub>x</sub>O<sub>6</sub> for  $0.1 \leq x \leq 0.5$  follow power laws in the low-temperature region, the exponents  $\gamma$  estimated from  $C_{\text{mag}}(T)/T$  and  $\chi(T)$  do not agree with each other.

備考：論文要旨は、和文 2000 字と英文 300 語を 1 部ずつ提出するか、もしくは英文 800 語を 1 部提出してください。

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