論 文 の 内 容 の 要 旨

論文題目　Dynamical structure in magnetic insulators with orbital degeneracy
（軌道縮退を有する磁性絶縁体における動的構造）

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In the strongly correlated electron systems, physical properties indicated by solids are often elucidated from the viewpoint of charge, spin, orbital, and lattice degrees of freedom. The interplay among multiple degrees of freedom leads to a variety of phenomena such as giant magnetoresistance, magnetoelectric, and magnetostriction effects. So far, the control of the electronic phase in an static ordered state has been extensively studied.

In this thesis, we have studied the system in which the spin, orbital and lattice degrees of freedom are coupled, especially focusing on the dynamical coupling of spin and orbital degrees of freedom. The objective of this thesis is to (i) clarify the dynamical structure from the spin-orbital correlated ground state, motivated by the recent discovery of the electromagnon. Another purpose is (ii) investigating the macroscopic response induced by the spin-orbital coupled fluctuation, motivated by the studies on exotic phenomena around the quantum critical point (QCP). For achieving the purpose (i), we studied magnetic excitations and lattice vibrations in the spinel-type vanadium oxide MnV_2O_4 by using inelastic neutron scattering (INS) and non-resonant inelastic x-ray scattering (NRIXS). Raman scattering and resonant x-ray scattering measurement have been used for observing orbital waves, since these methods provide the direct access to the orbital degree of freedom. However, these methods have some limitations in terms of the accessible region in the momentum space and the energy resolution. Therefore, in the present study, we adopted INS for measuring magnon dispersion and NRIXS for measuring phonon dispersion in wider reciprocal lattice space and with reasonable energy resolution. For achieving the purpose (ii), we investigated the macroscopic mechanical response in $CoNb_2O_6$ which is recently attracted as the realization of the transverse field Ising model. Since the Co^{2+} ion ($3d^7$) has spin-orbital coupled ground state and QCP in $CoNb_2O_6$ is accessible experimentally, we can explore the response induced by the spin-orbital coupled fluctuation at QCP. The major results are summarized as follows.

First, we investigated the magnetic excitations in MnV_2O_4 by INS. In MnV_2O_4, V^{3+} ion has the orbital degree of freedom in t_{2g} orbital, which is expected to have weaker orbital-lattice coupling. In addition, in the spinel vanadium oxides, direct orbital overlap between V sites in the $\{110\}_c$ directions should be expected, which can lead to the strong spin-orbital correlation. In the present study, we newly observed the magnetic scattering in the energy region from 10 to 17 meV, which was not clarified in the previous study. Using the Heisenberg model with magnetic anisotropy term, we optimized the values of magnetic interactions. As a result, we found that the scattering at 22 meV cannot be explained within this model, although the most of the magnetic scattering was reproduced by the spin-wave calculation. Excluding the possibilities of two-magnon scattering, we proposed that this scattering was due to V^{3+} spin-wave mode accompanied by the orbital excitation.

Next, we investigated the phonon dispersions in MnV_2O_4 by NRIXS. We succeeded in clarifying the phonon dispersion below and above T_{OO}. We assigned phonon modes to by the shell model calculations in the cubic phase. Since we found that phonon dispersion was basically independent of orbital ordering, the phonon mode assignment by our calculation should be justified below T_{OO}. We compared the shape of the phonon dispersions around 20 meV with the dispersion obtained by INS. We also found that the calculated INS intensity by phonon cannot explained the experimental intensity of the 22 meV-scattering observed by INS. As a result, we found that 22 meV scattering observed by INS cannot be described by simple phonon. Combining the results by INS and NRIXS, we concluded that the 22 meV scattering observed by INS was spin-orbital-lattice coupled excitations, which was first observed experimentally.

Finally, we investigated the elastic response in $CoNb_2O_6$ by ultrasound measurement. We measured several elastic constants in the function of a transverse magnetic field to the magnetic easy axis. Below magnetic ordered transition temperature, the large elastic anomaly in C_{66} mode was observed in quantum critical region. The magnitude of elastic softening became enhanced in lowering temperature. Comparison between the equivalent C_{66} modes in Faraday and Voigt configurations revealed that this anomaly originated from the lattice rotational components. We discovered the large lattice rotational effect with the magnitude of 10 % in $CoNb_2O_6$, although the magnitude of lattice rotational effect was reported within the magnitude of 0.5 %. These findings demonstrates that the spin-orbital coupled fluctuations plays an important role in the enhancement of mechanical response.

The results in this thesis unveiled the spin-orbital-lattice coupled elementary excitations and the large lattice rotational response induced by the spin-orbital coupled fluctuation, as a consequence of the interplay between spin, orbital and lattice degrees of freedom in the strongly correlated electron systems. The findings in this thesis can lead to the exploitation of physical response by controlling the coupling of the excited state.