

## Orbital Ordering and Excitation in Correlated Electron Systems

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It is widely accepted that the orbital degree of freedom is one of the essential ingredients to reveal the complex and dramatic phenomena observed in several transition metal oxides and other compounds with strong electron correlation. This degree of freedom is recognized to be the third degree of freedom in addition to the spin and charge degrees of freedom of an electron. The long ranged orbital ordering is realized in several insulating compounds and is recently observed by resonant x-ray scattering experiments. In the vicinity of the metal-insulator transition, orbital fluctuation is expected to be one of the origin of the anomalous metallic properties.

In the above viewpoint, we theoretically study the orbital ordering/fluctuation in transition metal oxides; 1) The collective orbital excitation in orbital ordered state termed orbital wave is studied in  $\text{LaMnO}_3$ . The dispersion relation of the orbital wave is calculated in several spin structures. A possible scattering process for Raman scattering from the orbital wave is proposed. The scattering cross section is obtained in the several polarization configurations of light and the selection rule is derived by the group theoretical analyses. The calculated results are in good agreement with the recent experimental results observed in  $\text{LaMnO}_3$ . 2) The orbital state in  $\text{RTiO}_3$ , where R indicate a rare earth ion, is investigated. The effective Hamiltonian for spin and orbital states is derived with taking into account the electron correlation and triply degenerate  $t_{2g}$  orbitals. The orbital and magnetic phase diagram is obtained using mean field approximation. It is shown that the stable orbital state is largely degenerate in comparison with the  $e_g$  systems. The polarization dependence of the resonant x-ray scattering intensity is also formulated.