

Electronic and magnetic ground state of $4d^3$ double perovskite ruthenates : A_2LaRuO_6 ($A = Ca, Sr, Ba$) and Ca_2ScRuO_6

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$4d$ transition metal oxides (*TMOs*) lie at the crossover regime of strong spin orbit interaction (*SOC*) and strong electron-electron correlation (*U*). An exotic array of quantum phases emerge from these interactions which are relevant to spintronic and quantum technologies[1]. Double perovskites (DP) TMOs with a single $4d$ transition metal is an ideal platform to systematically investigate these interactions and ground states, owing to their site-tunability. Often $4d^3/5d^3$ are overlooked due to an expected total quenching of orbital angular momentum. But the recent theoretical reports on $4d^3/5d^3$ systems show that they lie at the intermediate regime of *LS* and *JJ* coupling, where the effects of *SOC* are unpredictable[2]. Recent works on $4d^3$ DP ruthenates with a single magnetic ion have shown unconventional multi polar ordering in Ba_2YRuO_6 , superconductivity in Cu-doped Sr_2YRuO_6 , making these systems an ideal platform for the investigating the effects of *SOC*. In this work, we have explored the electronic and magnetic ground state of the less investigated $4d^3$ DP ruthenates A_2LaRuO_6 ($A = Ca, Ba$) and A_2ScRuO_6 and the effects of *SOC* in them[3,4].

Single phase polycrystalline A_2LaRuO_6 ($A = Ca, Ba$) and A_2ScRuO_6 ($A = Ca$) was successfully synthesized by the conventional solid-state synthesis route. The bulk magnetic, specific heat measurements of A_2LaRuO_6 indicate a spin-only Mott insulating ground state ($S = 3/2$) for these materials with a weak *SOC*. Magnetization measurements show that both materials, Ba_2LaRuO_6 and Ca_2LaRuO_6 shows anti-ferromagnetic ordering with a high degree of magnetic frustration ($f \approx 13-15$). Our results also highlight the reason for the non-existence of Sr_2LaRuO_6 . On the other hand, Ca_2ScRuO_6 shows a Mott insulating long range antiferromagnetic ground state with a reduced magnetic moment along with small magnetic clusters which give rise to an unusual ferrimagnetic like behavior. Interestingly, a near T^2 behavior is observed in low-temperature magnetic heat capacity measurement for all these systems indicating the presence of low-dimensional spin-wave excitation and magnetic frustration in both materials.

References:

- [1] W. Witczak-Krempa and G. Chen, Y., *Annu. Rev. Condens. Matter Phys.*, 5 (2014) 57–82.
- [2] H. Matsuura and K. Miyake, *Journal of the Physical Society of Japan*, 82 (2013) 073703.
- [3] A. A. Abraham and R. Roy, *Journal of Physics: Condensed Matter*, 37 (2025)355602.
- [4] A. A. Abraham and A. Kumari, arXiv preprint(2025), 2601.00085.