Temperature Dependent Bilayer Ferromagnetism in $Sr_3Ru_2O_7$

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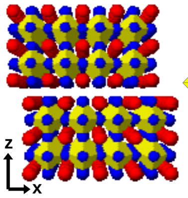
Introduction

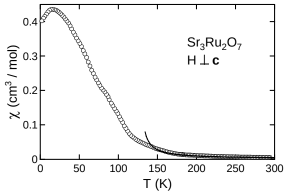
The Ruthenium based perovskites exhibit a wide range of behavior, including exotic superconductivity, metal insulator transitions, and strong quantum fluctuations. Exciting magnetic phenomena have been identified in several ruthenates, but a clear understanding of the underlying magnetic excitation spectrum in these layered perovskites is far from complete. We present results of detailed inelastic neutron scattering measurements of $Sr_3Ru_2O_7$ performed at the HFIR neutron scattering facility. Measurements were performed using the HB1 triple-axis spectrometer to probe the ferromagnetic fluctuations of the bilayer structure as a function of temperature. We find that the ferromagnetic correlations extend to large temperatures relative to their energy scales.

Structure, Magnetization and Transport

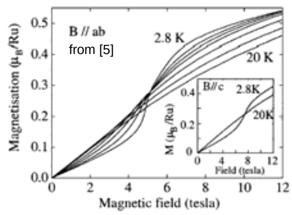


- layered-perovskite 4d transition metal oxide.
- Ru^{4+} octahedral coordinated ions form isolated square lattice bilayers, with Ru-Ru distance = 3.877 Å. Intra-bilayer distance ≈ 4.1 Å [1,2].
- Floating zone growth able to produce m ≈ 4 g single crystals.

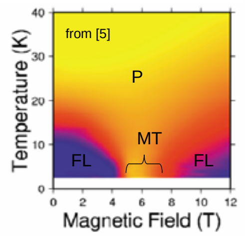
- Magnetization as a function of temperature indicates high temperature paramagnetic behavior with a Curie-Weiss temperature Θ_{CW} = -126(1)K and effective moment 2.50(5) μ_B/Ru.
- Curie-Weiss parameters and location of rounded maximum at $T \approx 17$ K are consistent with previous results [3,4] indicating sample quality.



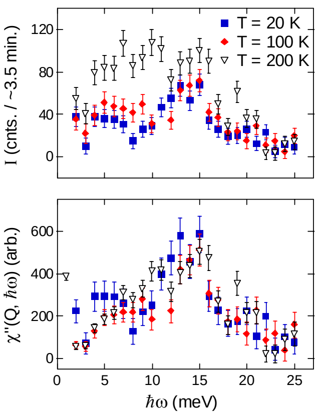
- Magnetization as a function of magnetic field from Ref. 5 indicates low temperature metamagnetic behavior in the vicinity of H = 5 Tesla.
- Thermodynamic and transport measurements describe $Sr_3Ru_2O_7$ as a paramagnetic quasi-two-dimensional metal near a ferromagnetic transition [6].



- Magnetic field and temperature dependent electrical transport measurements in Ref. 5 reveal regions of behavior including disordered paramagnetic behavior (P), Fermi liquid behavior (FL), and a range of magnetic fields associated with the metamagnetic transition (MT).

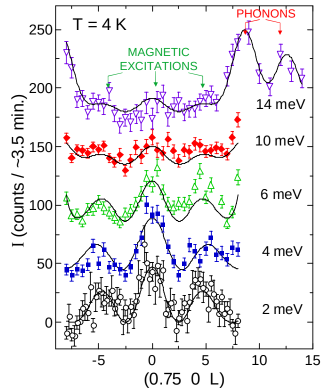


Lattice Excitations



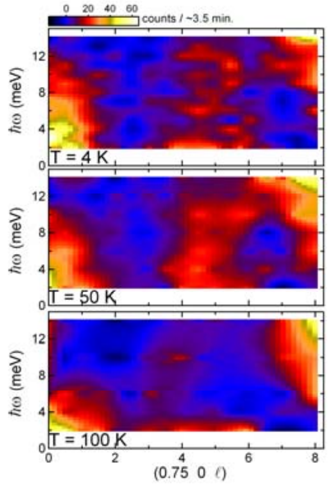
- Constant wave-vector scans measured at (0.75 0 8.5) at T = 20 K, 100 K and 200 K plotted as scattering intensity (top) and dynamic susceptibility (bottom) reveal a phonon excitation at $\hbar\omega \approx$ 14.5 meV in agreement with Raman scattering measurements.
- Due to the quantity of atoms in the unit cell, spectral measurements of the magnetic fluctuations in $Sr_3Ru_2O_7$ are susceptible to contamination by phonon scattering

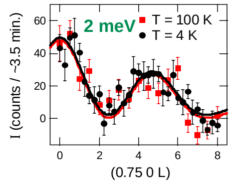
Magnetic Excitations

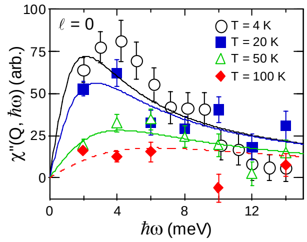


- Constant energy scans along the (0.75 0 L) direction.
- Phonon scattering at large Q and energy transfer
- Ferromagnetic bilayer structure factor seen up to $\hbar\omega$ = 14 meV. 2z = bilayer separation, $F(Q)$ = magnetic form factor
$$I = A|F(Q)|^2 \cos^2(2\pi Lz/c)$$
- Bilayer separation:
  2z = 4.2 ± 0.2 Å (fit)
  2z = 4.056 (from structure)

- Intensity contour made up of constant energy scans performed along (0.75 0 L) at several temperatures.
- Ferromagnetic bilayer structure factor still clearly seen at T = 50 K up to ≈ 10 meV.
- T = 100 K measurement still retains the ferromagnetic bilayer structure factor for smaller values of energy transfer. (right and below)







- Dynamic susceptibility, $\chi''(\mathbf{Q}, \hbar\omega)$ also indicates characteristic ferromagnetic bilayer excitations up to T = 100 K especially at (0.75 0 0).
- A single relaxor model with the form of an asymmetric Lorentzian, where Γ describes a characteristic energy of the response yields a linearly increasing value of Γ as temperature is increased.

Conclusions

We performed measurements of the ferromagnetic fluctuations associated with the bilayer structure in $Sr_3Ru_2O_7$. The persistence of the bilayer response at temperatures large compared to the energy transfer, $\hbar\omega$ = 2 meV at T = 100 K, is surprising. At these temperatures, thermal fluctuations should populate the lower energy excitations typically resulting in a strong damping of the excitation spectrum at lower values of energy transfer. However, we find the opposite to be true in $Sr_3Ru_2O_7$ for measurements of the bilayer excitations at $\hbar\omega$ = 2 meV and T = 100 K. Although the higher energy bilayer excitations are substantially damped with temperature, the low-energy ferromagnetic fluctuations persist. A potential explanation of this behavior includes invoking a coupling between the higher energy phonon modes and the magnetic excitations. The presence of ferromagnetic fluctuations at higher temperature for smaller values of energy transfer may be an additional measure of the ability to enhance the magnetic behavior in $Sr_3Ru_2O_7$ via external perturbations and the vicinity of the system to a ferromagnetic/metamagnetic transition.

References

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