Magnetic phase transition and spin fluctuations in the geometrically frustrated antiferromagnetic spinel CdCr$_2$O$_4$:
An experiment using the SPINS cold-neutron triple axis spectrometer

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CdCr$_2$O$_4$: Cr$^{3+}$ (3$d^3$, $S = 3/2$)

Magnetic Cr$^{3+}$ ions form a lattice of corner-sharing tetrahedra
Similar lattices are found in spinel (AB$_2$O$_4$) B-sites or pyrochlores (A$_2$B$_2$O$_7$)

But CdCr$_2$O$_4$ eventually orders at very low temperatures. How?

Magnetic exchange energy between a pair of spins is $H = J_{ij} S_i \cdot S_j$. If $J_{ij} > 0$, then $S_i$ and $S_j$ will become antiparallel to each other.

CdCr$_2$O$_4$  
ZnCr$_2$O$_4$
Magnetic phase transition in \( \text{CdCr}_2\text{O}_4 \)

Magnetic susceptibility

\[ \chi = \frac{dM}{dH} \]

- \( M \): magnetization of the material
- \( H \): applied magnetic field

susceptibility

\[ \Theta_{\text{CW}} = -88 \text{ K} \]

- Indication of the strength of the antiferromagnetic interaction

\[ |\Theta_{\text{CW}}| \approx T_N \]: normal antiferromagnet

\[ |\Theta_{\text{CW}}| \gg T_N \]: strong frustration
SPINS cold neutron triple axis spectrometer

Why SPINS for this study?
Because SPINS
- Precisely access desired Q and $\vec{q}$
- Covers $\vec{q}$ in the range between 0.1 to 10 meV
- Perform diffraction measurement
- Provides a flexible choice of high resolution or high intensity
Looking for the degenerate ground states in the geometrically frustrate phase

Using simulations, we can try to determine the magnetic structure by comparing to the collected data.
Simple calculation of magnetic neutron scattering intensity

Magnetic neutron scattering cross section

\[
\frac{d^2\sigma}{d\Omega d\omega} = r_o^2 \frac{k_f}{k_i} S(Q, \omega)
\]

where,

\[
S(Q, \omega) = \sum_{\alpha, \beta} (\delta_{\alpha\beta} - \tilde{Q}_\alpha \tilde{Q}_\beta) \sum_{\lambda, \lambda'} p_\lambda \sum_{l,d} \sum_{l',d'} f_d^*(Q) f_{d'}(Q) \exp\{iQ \cdot (R_{l'd'} - R_{ld})\}
\]

\[
\times \left\langle \lambda | \hat{S}_{ld}^{\alpha} | \lambda' \right\rangle \left\langle \lambda' | \hat{S}_{l'd'}^{\beta} | \lambda \right\rangle \delta(\hbar\omega + \hbar\omega_{\lambda} - \hbar\omega_{\lambda'})
\]

But if we consider only up and down spins for diffuse quasi-elastic scattering, all we need is the following simple equation:

\[
I(Q) \propto \left| \sum_R f_R(Q) \sigma_R e^{iQ \cdot R} \right|^2
\]

\[f : \text{magnetic form factor}\]

\[\sigma = -1, \text{ or } 1\]
Q-dependence along the (h,0,0) and (0,k,0) crystal configurations

Experimental Data

Theoretical Simulation

$h\omega = 0.6 \text{ meV}$

$T = 15 \text{ K}$

$T = 15 \text{ K}$
Q-dependence along the (h,h,0) and (0,0,l) crystal configurations

Experimental Data

\[ \hbar \omega = 0.6 \text{ meV} \]
\[ T = 10 \text{ K} \]

Theoretical Simulation

\[ T = 10 \text{ K} \]
Temperature Dependence

Low Temperature
Magnon Excitations

T = 1.4 K

High Temperature
Short Range Quasi-elastic Spin Fluctuation

Magnetic Fluctuation
Lifetime ~ 3 ps

T = 10 K
Summary

Using the Triple-Axis Spectrometer, we studied the magnetic phase transitions in CdCr$_2$O$_4$, which is a spinel with antiferromagnetic interactions between Cr$^{3+}$ ions on B sites.

We examined the Q-dependence on different crystal planes.

Using a theoretical simulations, we were able to determine the basic magnetic structure.

Through the use of temperature dependence, we were able to find that the discovered peaks are consistent with magnetic excitations.

The examination of the line width for the quasi-elastic fluctuation shows the lifetime to be on the pico-second scale.
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