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"Thermal Spin Valves"

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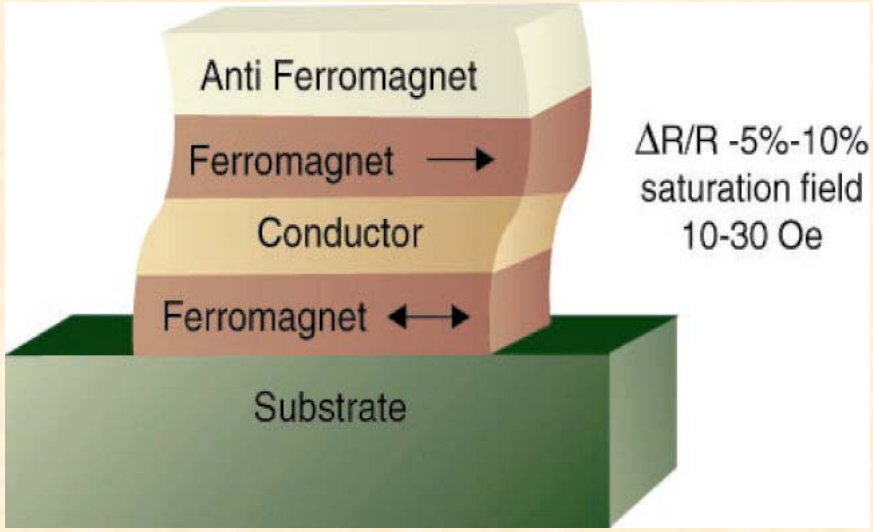
High Density Hard Drives Use Spin Valves



(Left) High Density Hard Drive that uses a spin valve (GMR) read head. Image from IBM press release. (Right) Schematic of Spin Valve

A similar effect can occur in Insulating Low Dimensional Magnetic Systems. A magnetic field is used to change the orientation of the local atomic moments, which in turn can significantly alter the thermal conductivity :

"Thermal Spin Valve"

Three layered antiferromagnetic compounds will be discussed: $K_2V_3O_8$, Nd_2CuO_4 , and Pr_2CuO_4

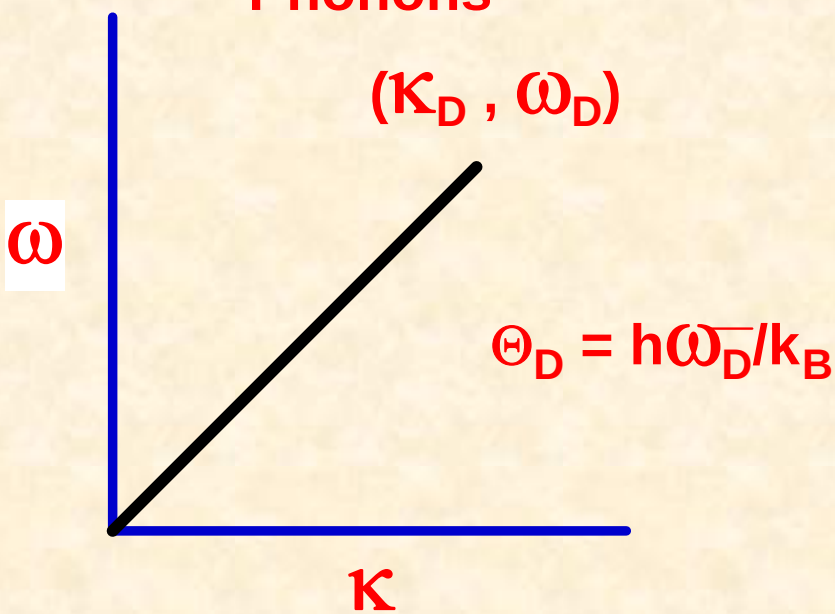
Why Interest in Heat Transport in Low Dimensional Magnetic Systems ?

- In insulating low-d systems would like to use heat current to probe excitations in a fashion analogous to the use of electrical current to study conducting solids
- In an insulating magnetic solid heat is carried by acoustic phonons and magnons (spin waves). Also phonons are scattered by magnons and magnons are scattered by phonons.

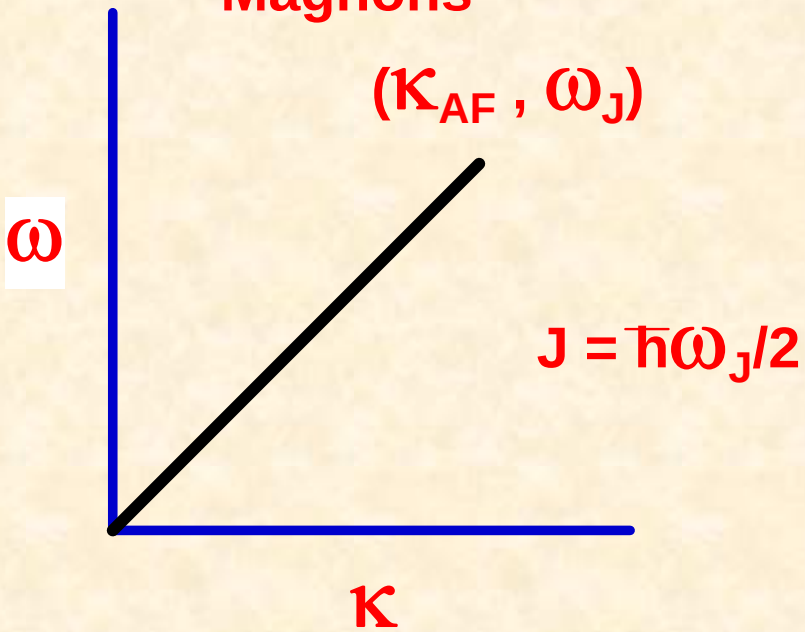
Magnons and Phonons can both Carry Heat

$$\kappa_i - C_i v_i d_i$$

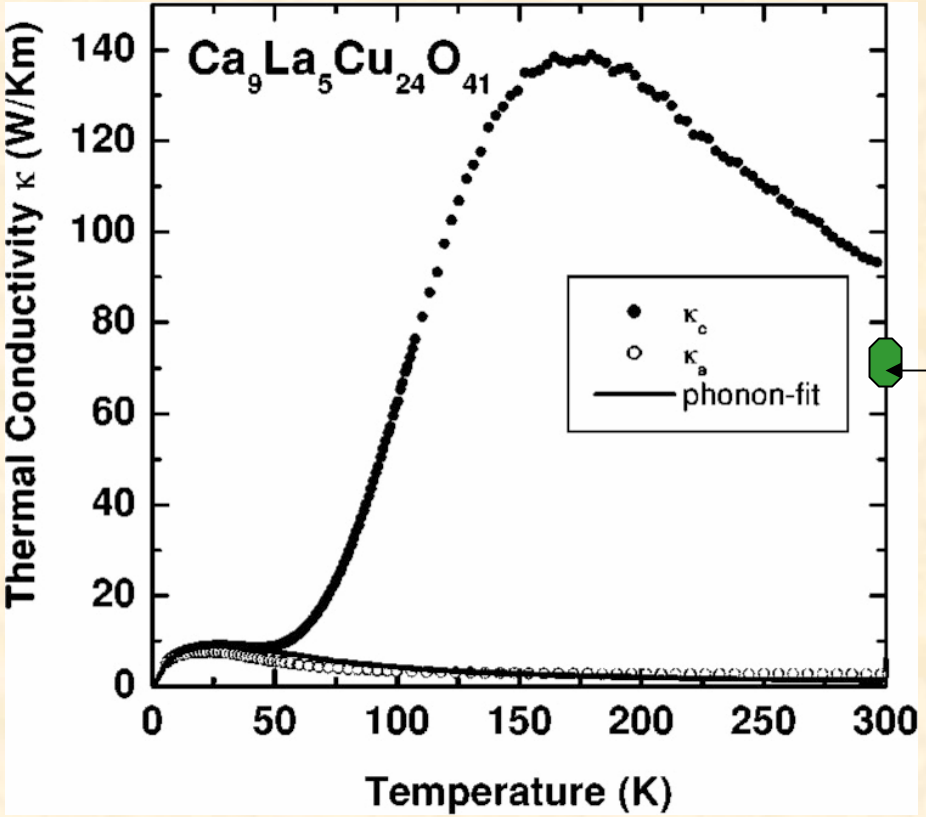
Phonons



Magnons



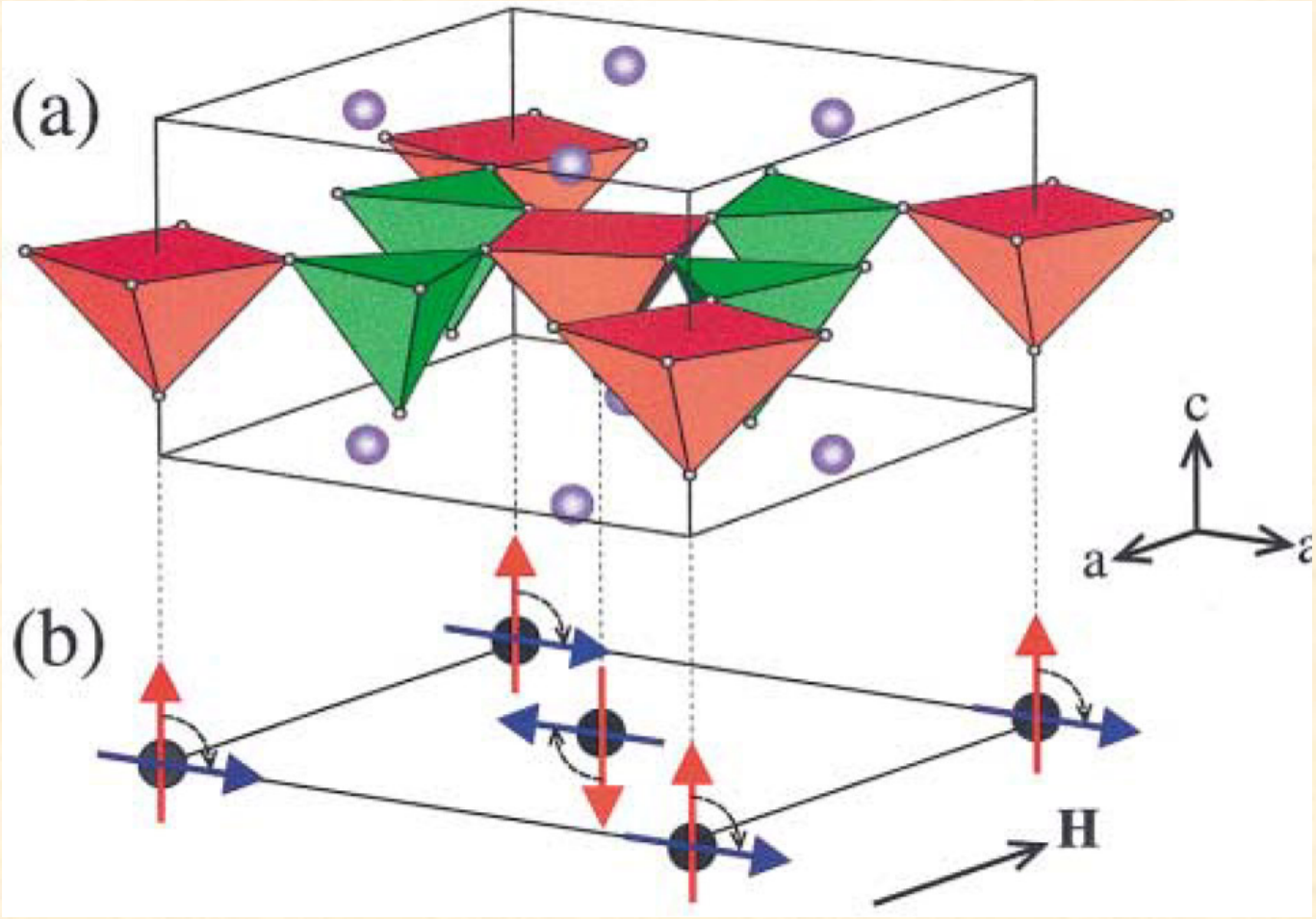
Heat Transport In Low Dimensional Magnetic Compounds
Example: Spin Ladder Compound $Ca_9La_5Cu_{24}O_{41}$
Key Observation: Huge magnon contribution to heat transport- even at room temperature!



C. Hess et al., Phys. Rev B. 64 (2001) 184305

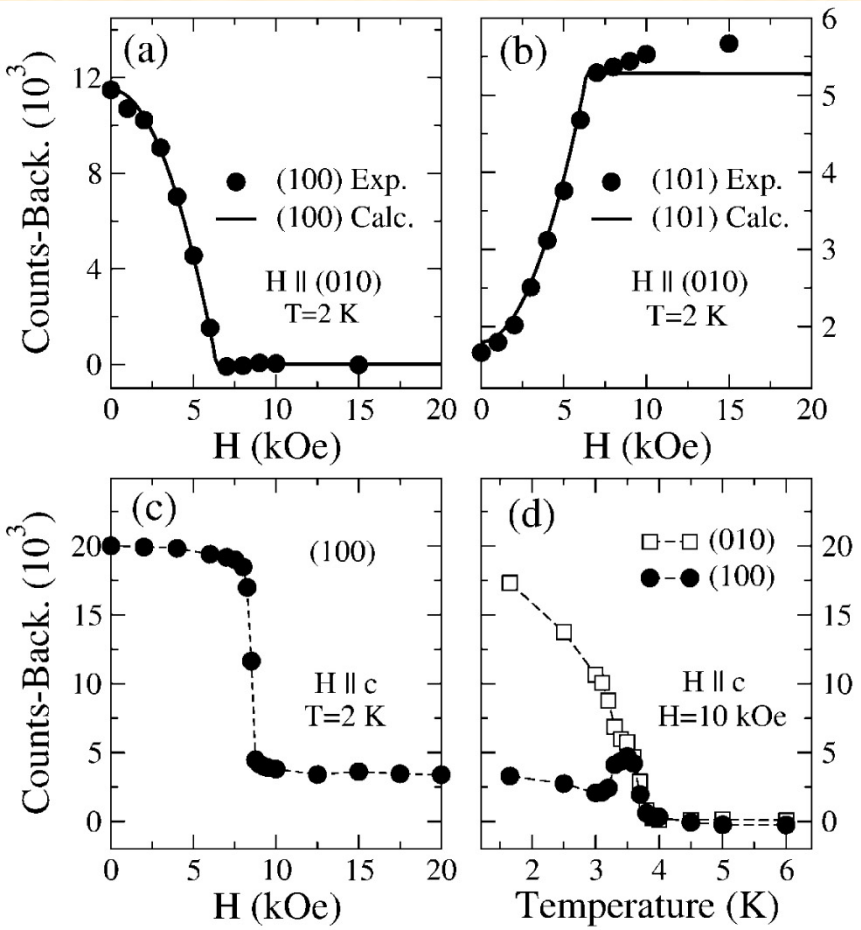
Pt Kappa

Structure of $K_2V_3O_8$

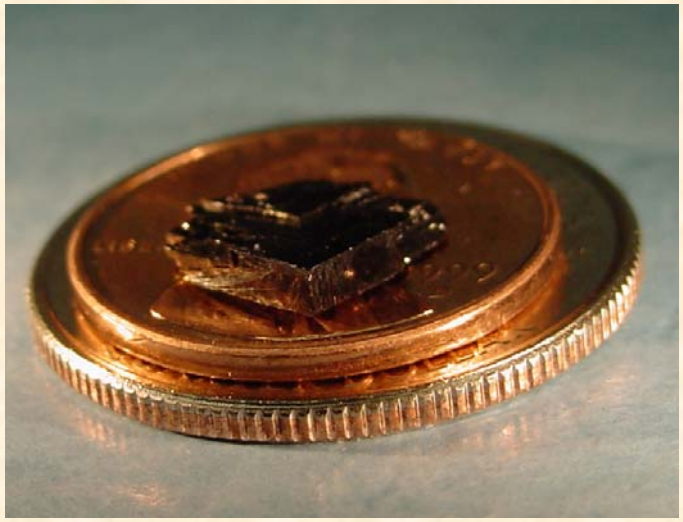


Neutron Data From $K_2V_3O_8$

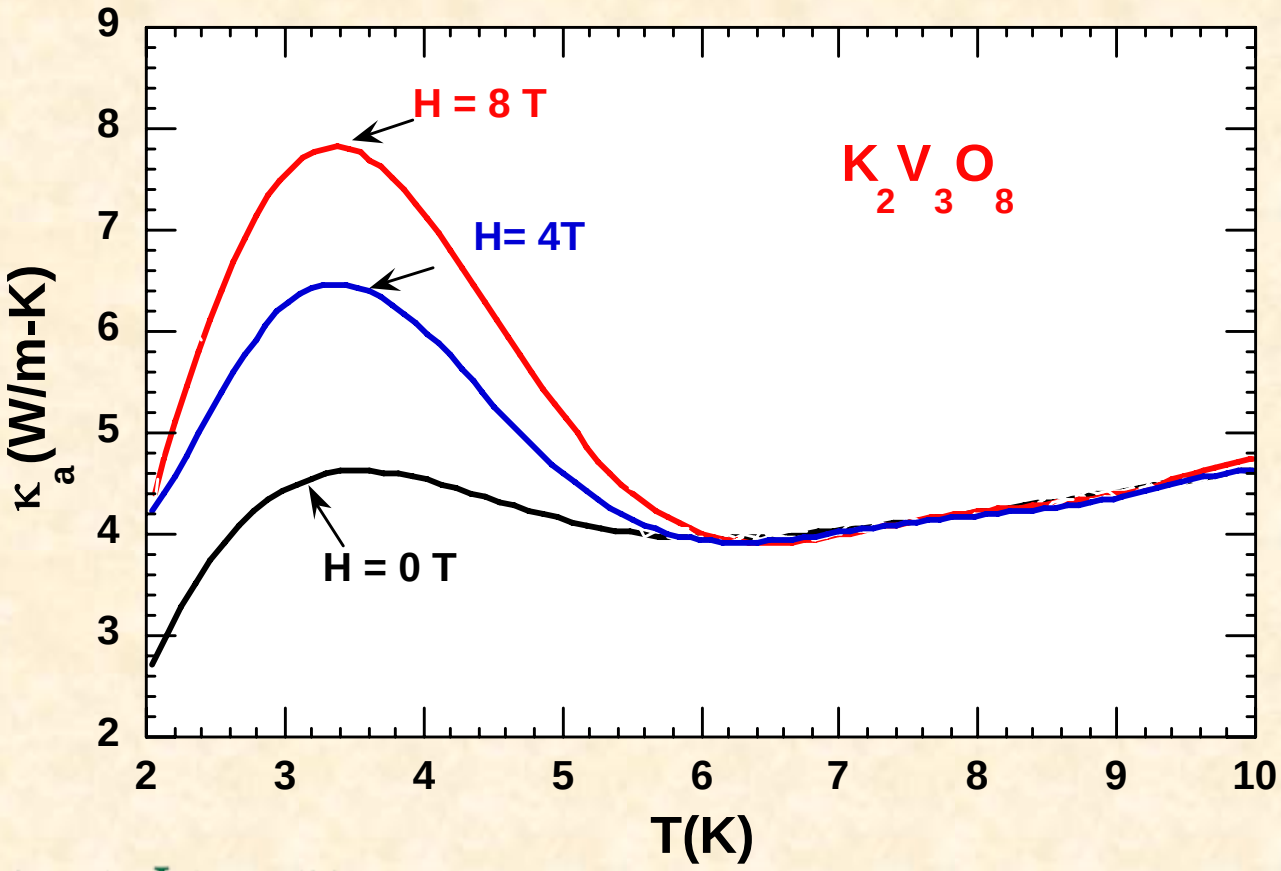
$$H_{12} = 8J\,S_1 \bullet S_2 + 8D_z(S_1 \times S_2)_z + 8E_z S_{1z} S_{2z} - g\mu_B H \bullet (S_1 + S_2)$$



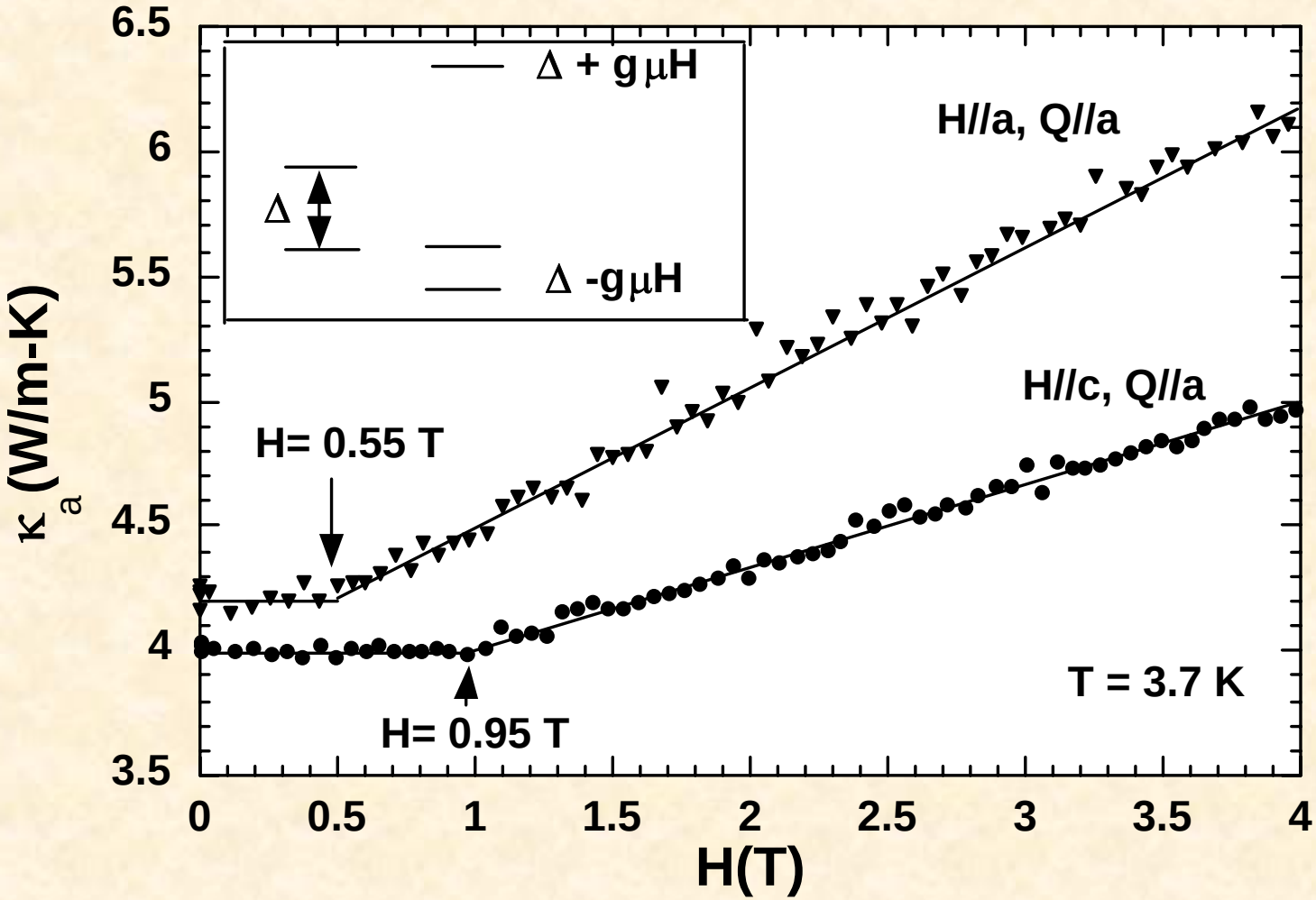
Lumsden et al.
PRL 86 (2001) 159



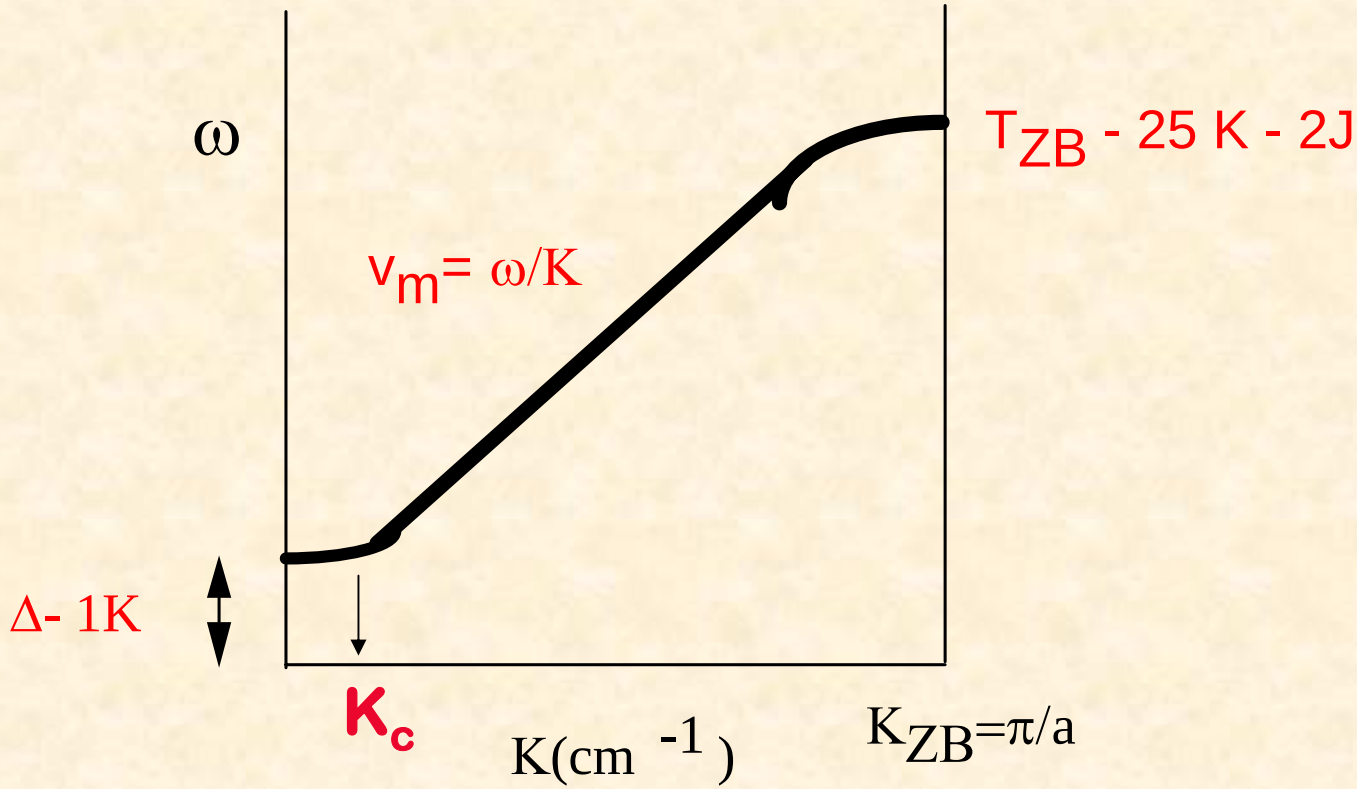
Kappa vs T,H Linear Scale



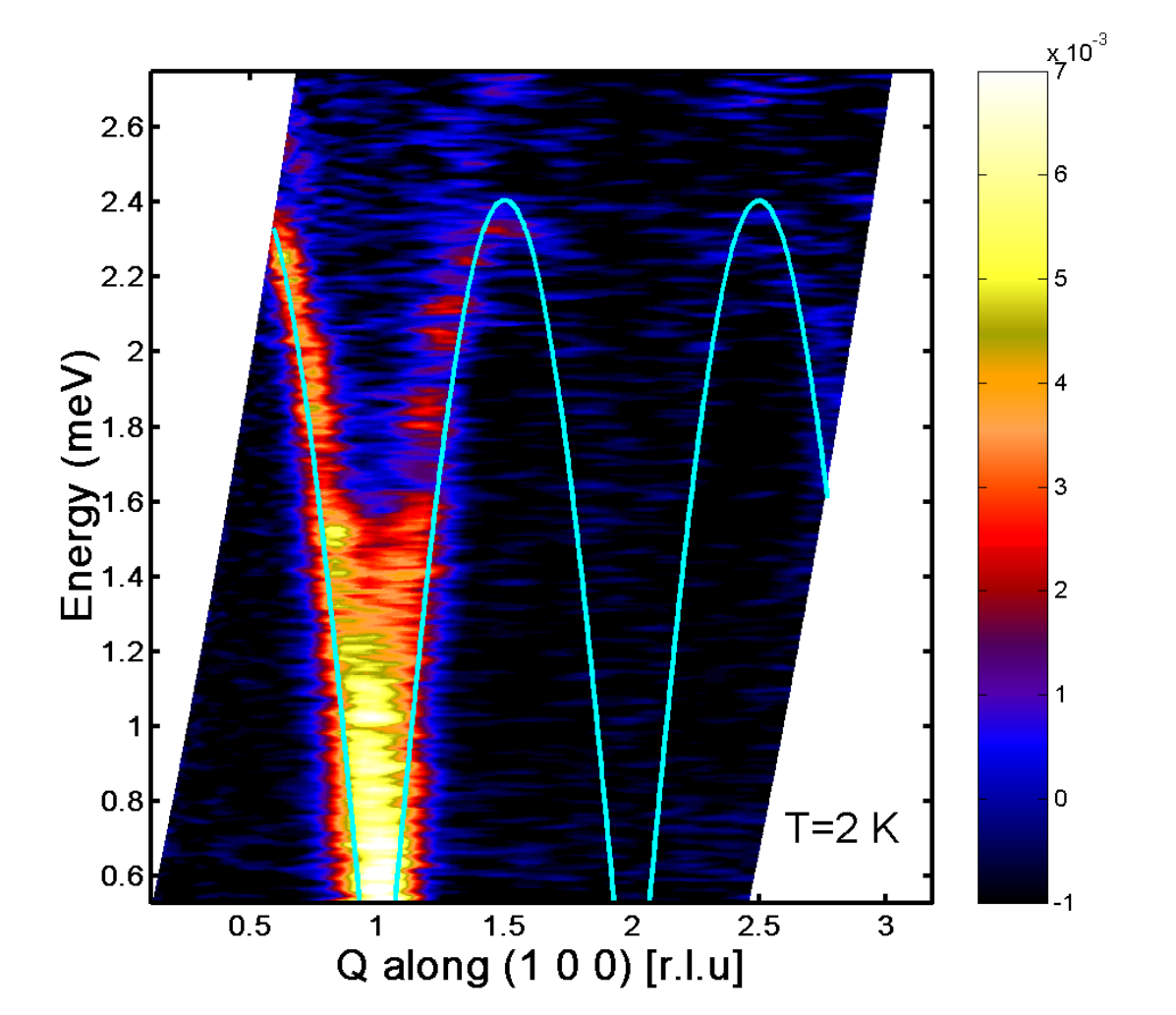
Kappa vs Field , T = 3.7 K, H//a, H//c



Schematic Magnon Spectra for $K_2V_3O_8$



Measured Magnon Spectra: $K_2V_3O_8$

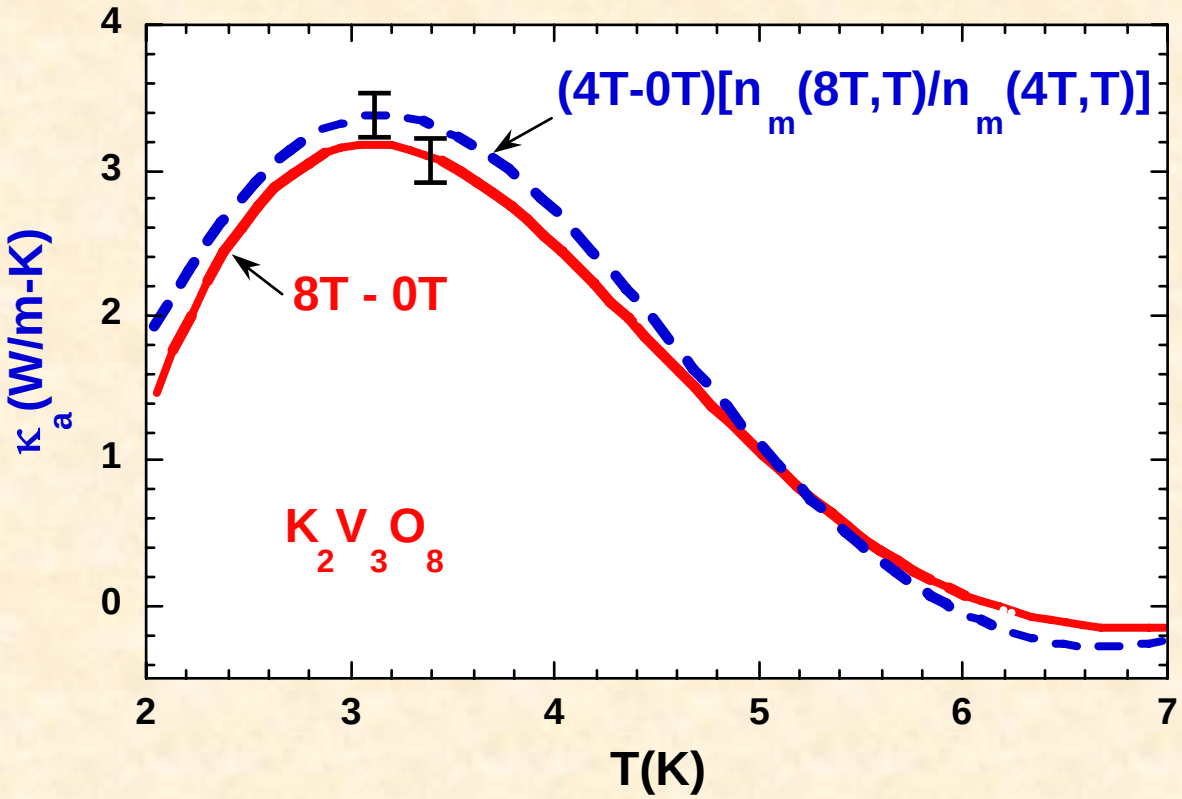


Experimental Data suggests that the functional form of the excess heat transported is described by:

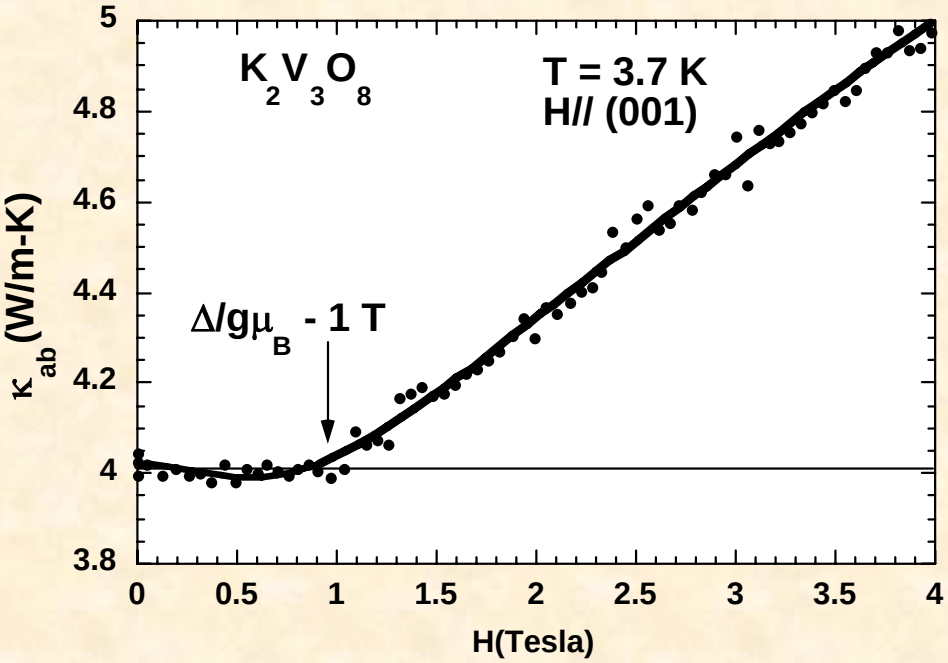
$$p_m(T,H) = \frac{e^{-(\Delta - g\mu H)/k_B T}}{e^{-(\Delta - g\mu H)/k_B T} + e^{-(\Delta + g\mu H)/k_B T}} - \frac{1}{1 + e^{-2\Delta/k_B T}}$$

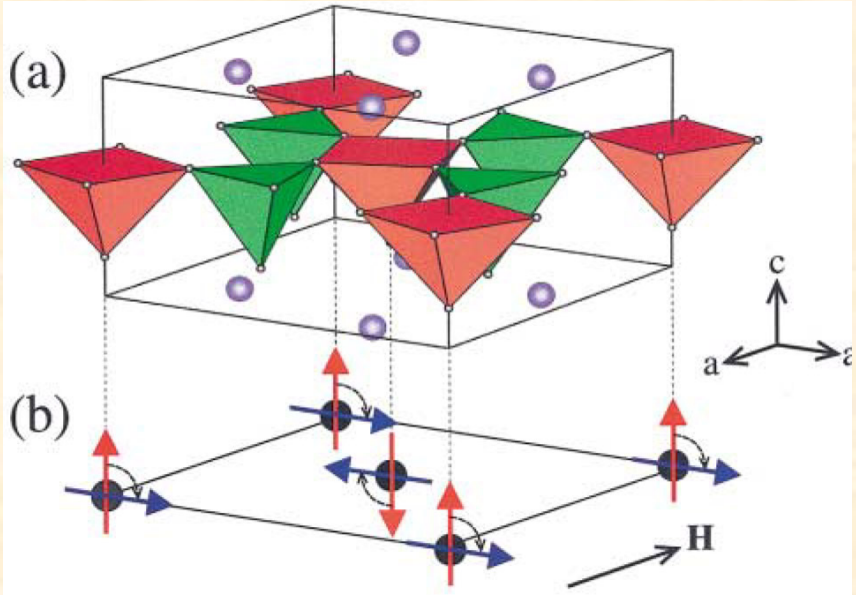
Note: When $H > H_c$ a new magnetic ground state is formed

Kappa Scaled with $n_m(H,T)$ (no adjustable parameters)



Spin-Flop Transition at ≈ 1 T in quasi-2d Heisenberg Compound $K_2V_3O_8$ results in Closure of Gap in Magnon Spectra and Additional Channel For Heat Conduction. Is this a general phenomenon?



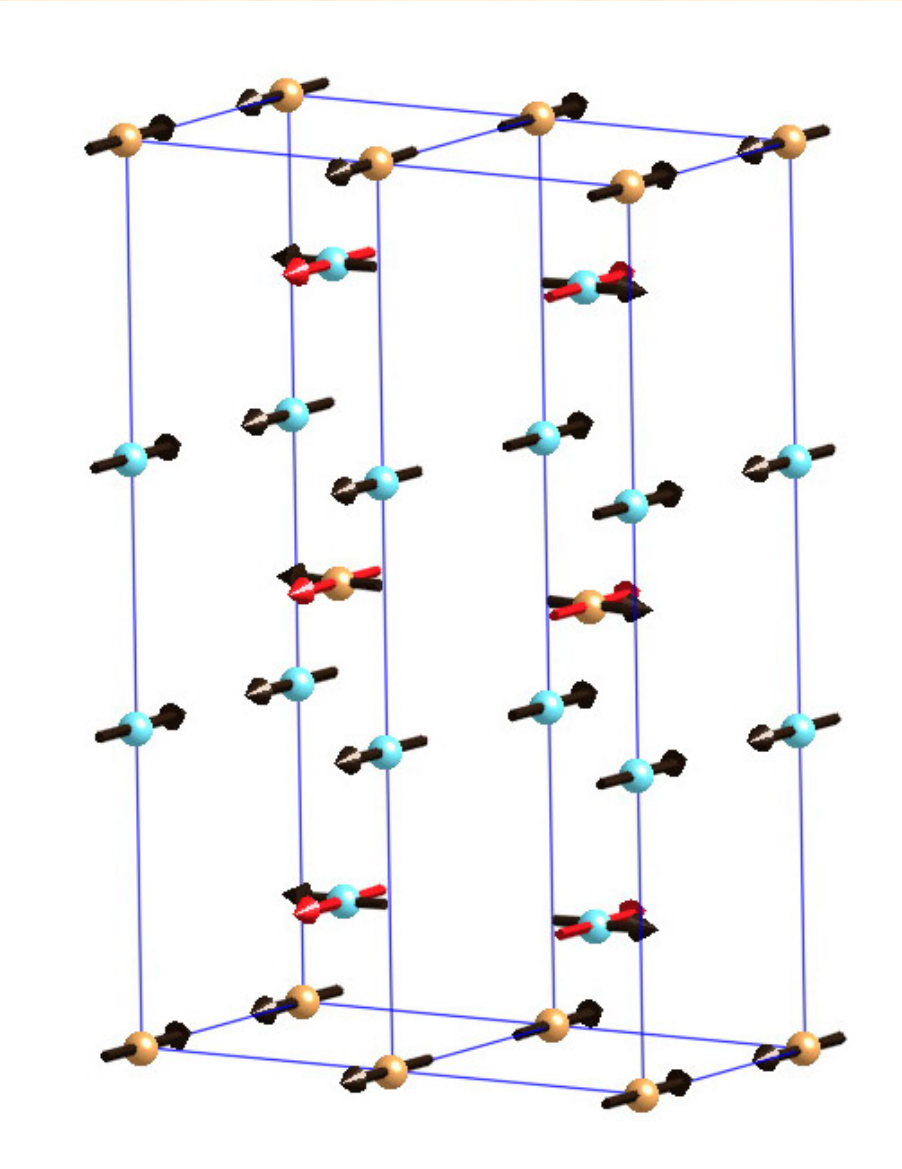


Magnetic Structure of Nd_2CuO_4 Below 30 K

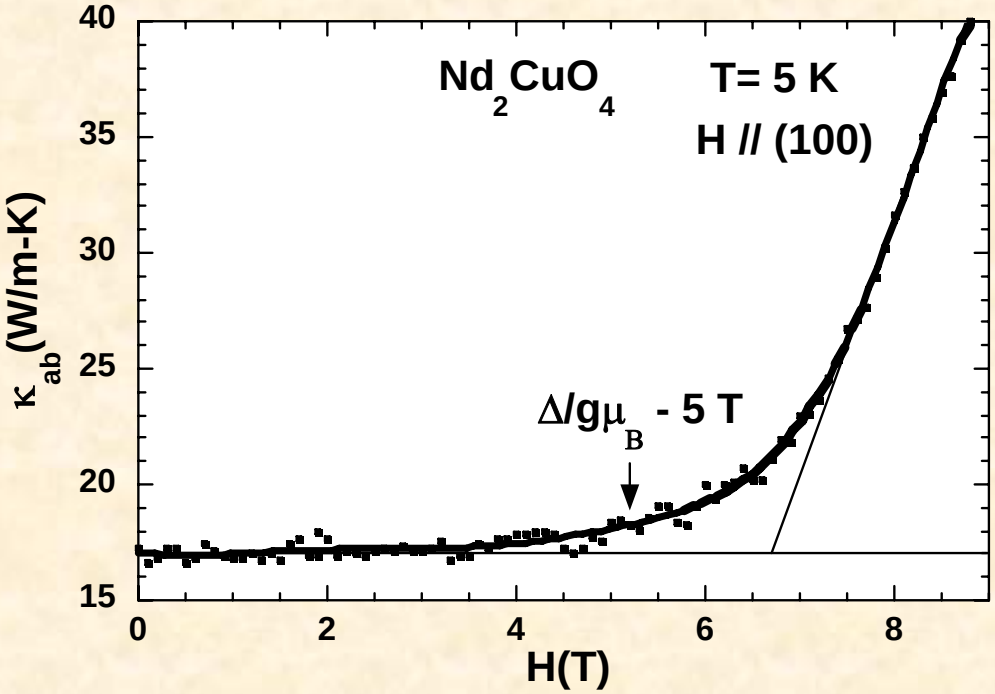
Noncollinear spin arrangement for
H < 4.5 T (all black spins)

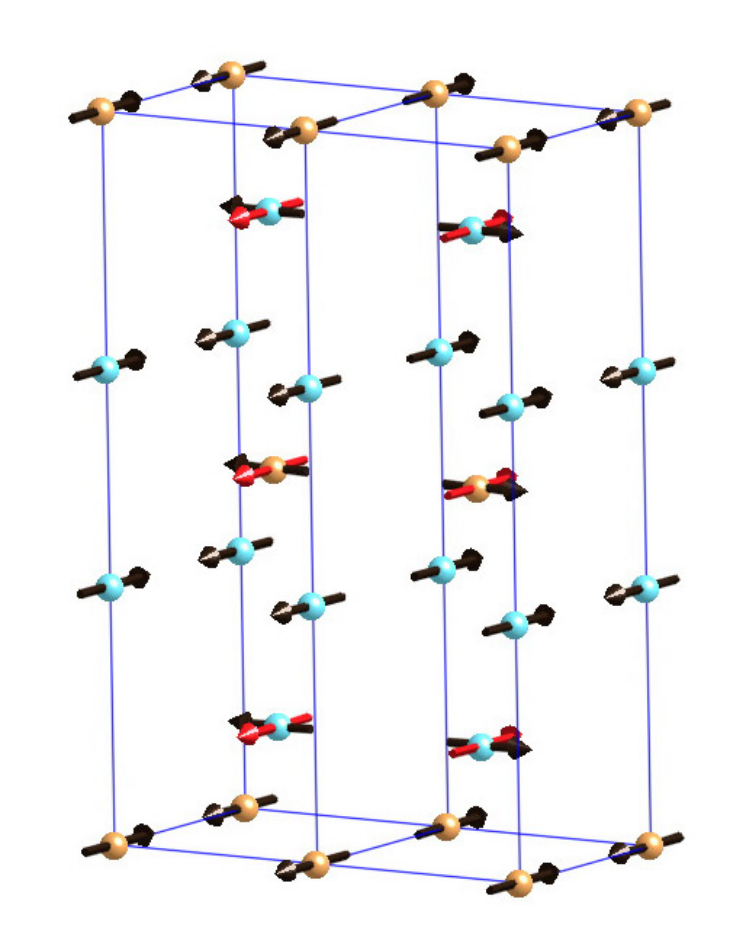
First order transition to Collinear spin structure when H ≈ 4.5 T and H// (100)
Spins along (100) direction rotate by about 90 degrees to remain perpendicular to direction of applied field

At least one branch of magnon spectra becomes gapless at spin-flop transition

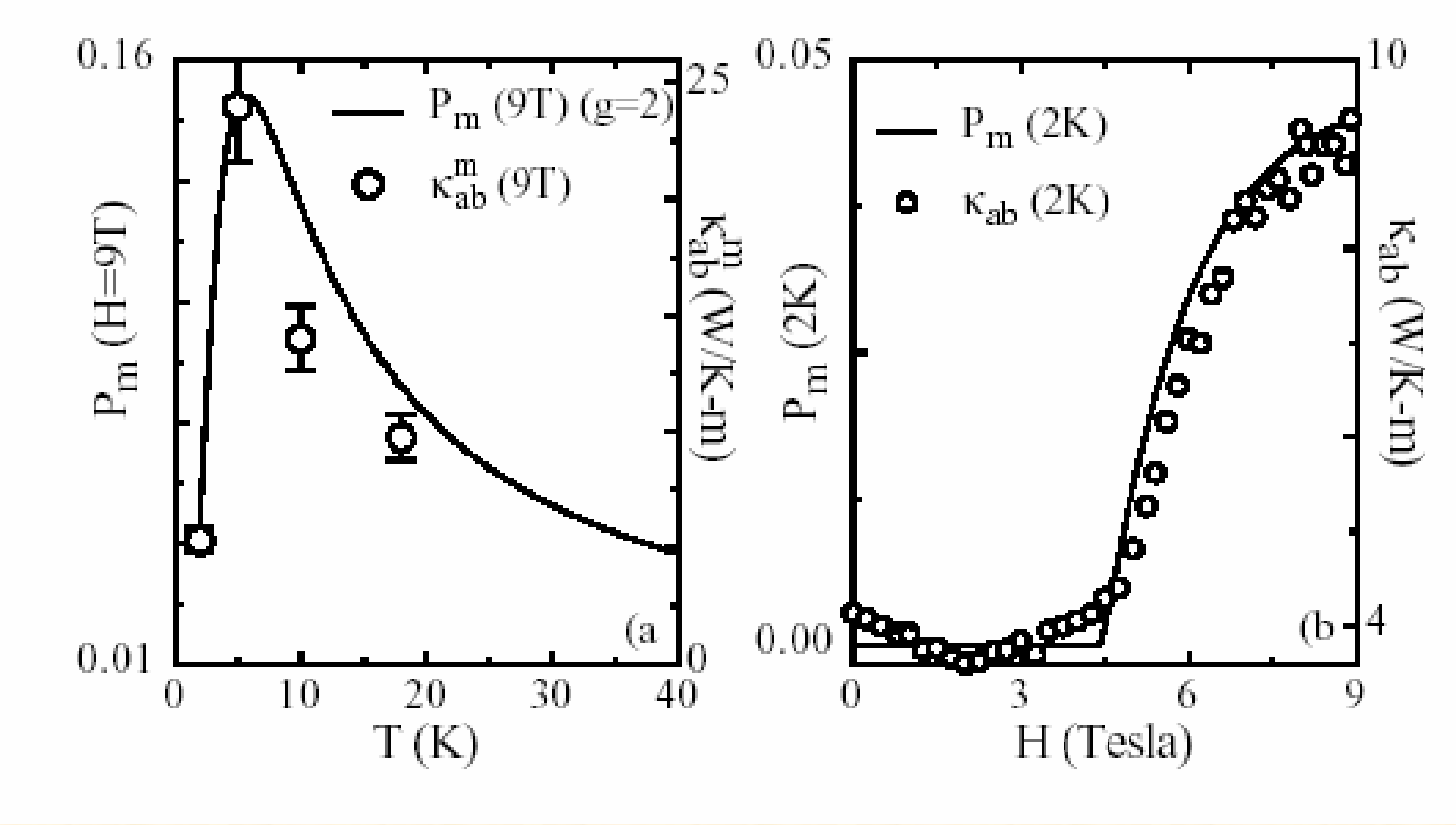


Spin-Flop Transition at ≈ 5 T in quasi-2d Heisenberg Compound Nd_2CuO_4 results in Closure of Gap in Magnon Spectra and Additional Channel For Heat Conduction

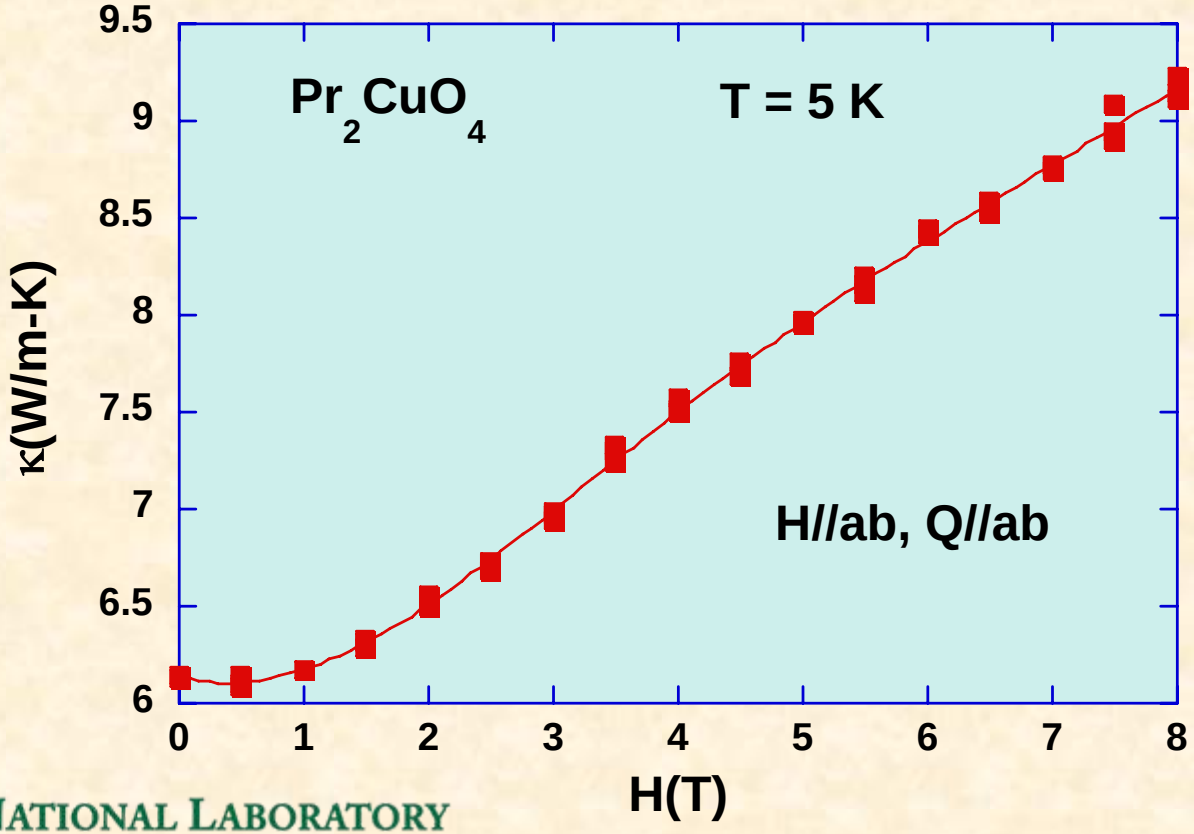




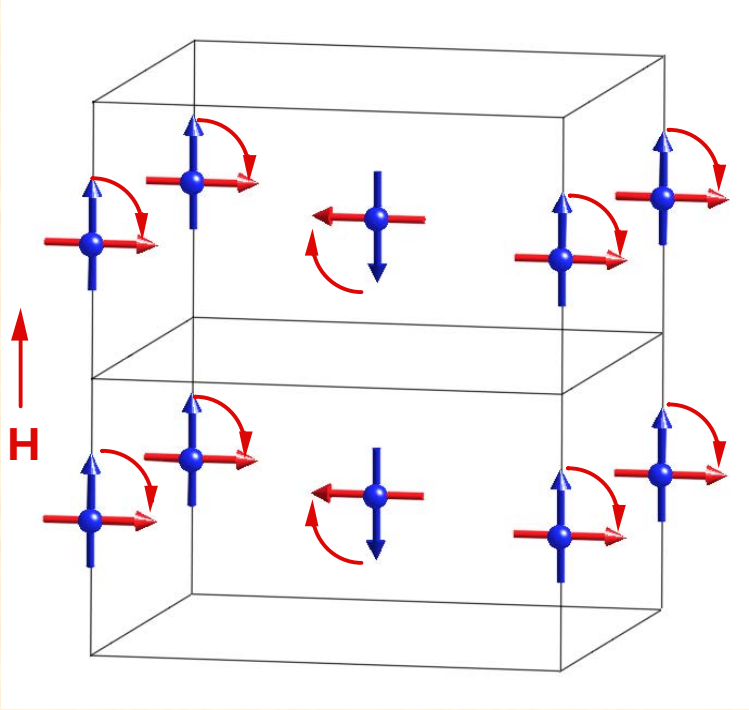
Comparison of Nd_2CuO_4 Data and Phenomenological Model

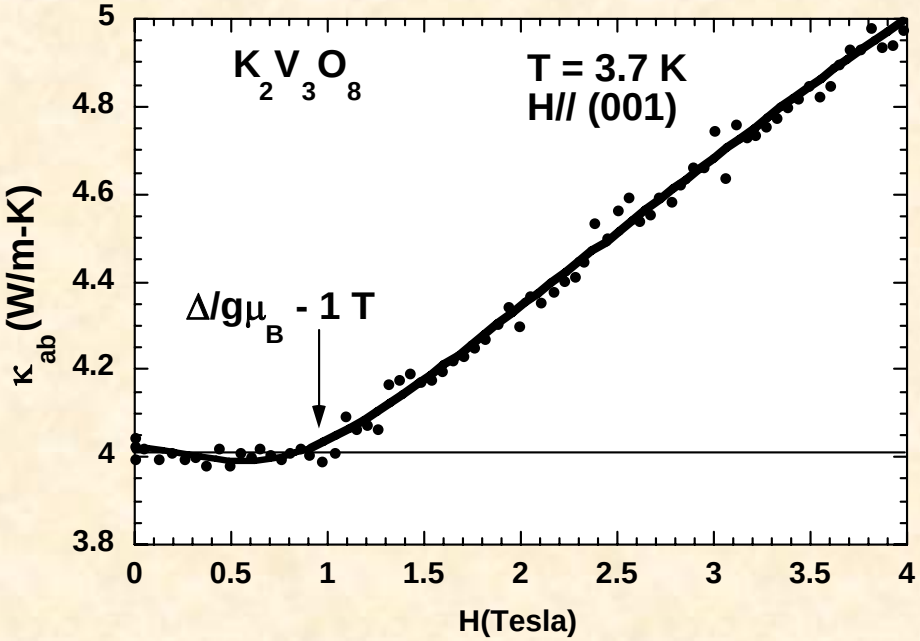


Similar Effect Occurs for Pr_2CuO_4 -*But Onset Field Much Smaller* than expected from Neutron Scattering Data



Key Observation: Additional heat transport occurs when anisotropy gap is closed with a magnetic field. Reorientation of spin directions changes Kappa for $K_2V_3O_8$, Nd_2CuO_4, and Pr_2CuO_4





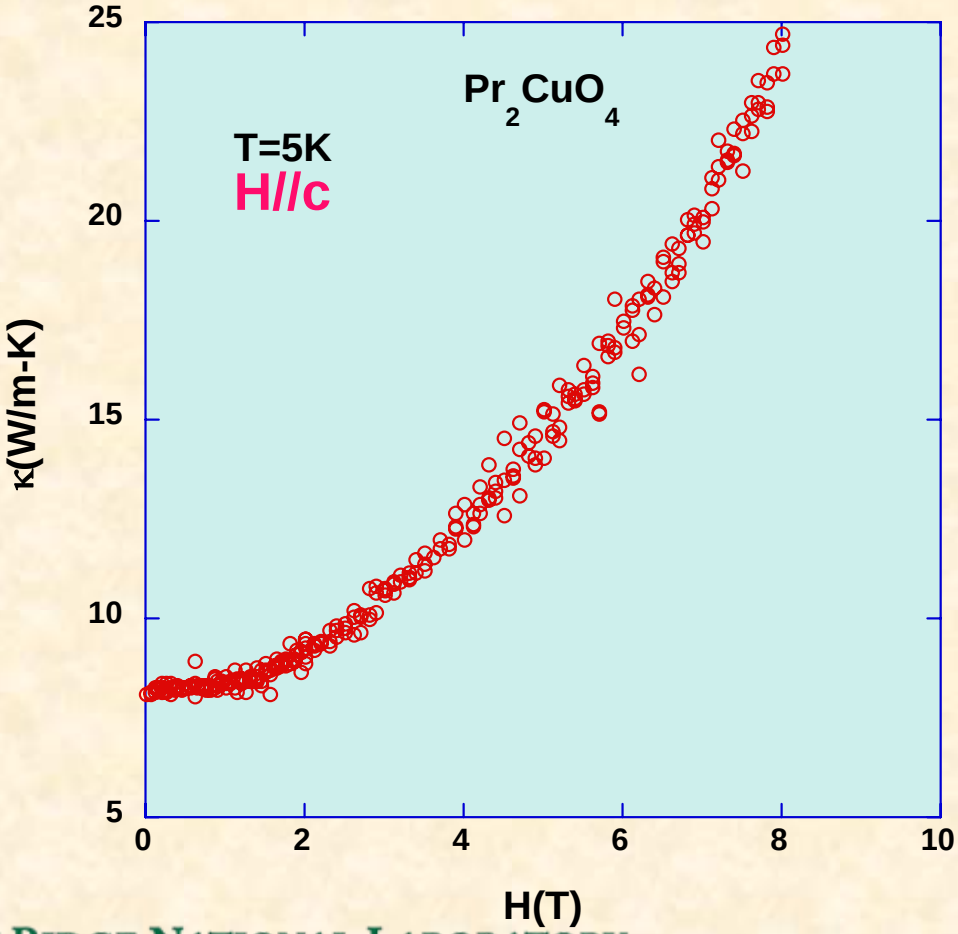
Major Problem: How to decide what part of heat conduction is due to phonons and what part is due to magnons.

- $K_2V_3O_8$ is a relatively simple layered magnetic material.
- A reasonable spin Hamiltonian has been determined from the neutron scattering and magnetic measurements
- The detailed effects of magnetic field on the magnon spectra can be calculated (Sasha Chernyshev)

CONCLUSIONS:

- In three layered quasi-2D magnetic materials, closure of a magnon gap with a magnetic field results in a new magnetic ground state.
- New ground state is characterized by the rotation of local magnetic spins and a higher thermal conductivity - **"Thermal Spin Valve"**
- For $K_2V_3O_8$, theory suggests that additional heat current is due to reduction in scattering of phonons by magnons.
- Situation Not Clear for Nd_2CuO_4, and Pr_2CuO_4

In Pr_2CuO_4 -large change in κ for H//c ! No spin flop for H//c. Magnetic Excitons ?



Important Implication :
Claim of violation of Wiedemann-Franz Law and Fermi Liquid Theory in $Pr_{1.85}Ce_{0.15}CuO_4$ at low temperatures not correct.
R. W. Hill et al. *Nature*, 414, 711 (2001)