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SPIN WAVE DESCRIPTION OF ULTRACOLD 2D PARAMAGNETIC CRYSTAL

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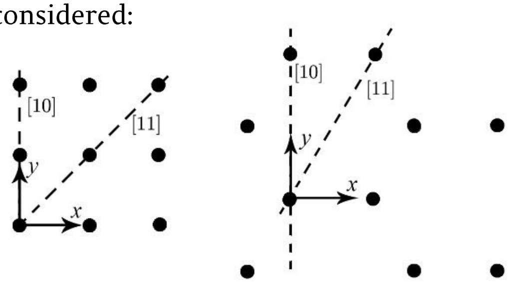
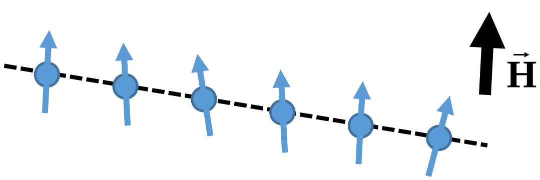
INTRODUCTION

- The spin-wave approach is applied to the macroscopic properties calculation of the 2D paramagnetic is under low temperature and strong external magnetic field.
- The square and honeycomb lattices are considered:

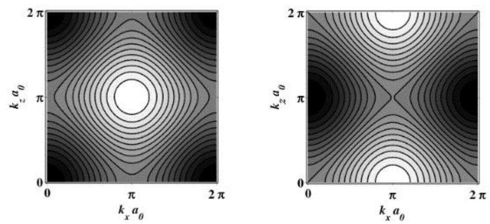


- The external field is perpendicular the lattice or parallel the crystal axes [10] or [11].
- The node spins deviates from the field direction and form the **spin waves** due to **dipole pair interaction**:



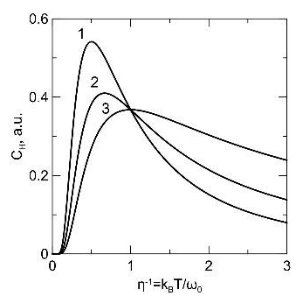
SPIN WAVES DISPERSION

- The spin-waves energy surfaces for the cases when the field is orthogonal to the lattice (left) and parallel to it (along [10]-axis, right). Energy rises from black to white:



MACROSCOPIC PROPERTIES

- The specific heat C_{SW} (curves 2, 3) is calculated:



$$C_{SH} = \left(\frac{\hbar\omega_L}{k_B T}\right)^2 \exp\left(-\frac{\hbar\omega_L}{k_B T}\right)$$

$$C_{SW}^{2D} = \frac{\hbar\omega_L}{k_B T} \exp\left(-\frac{\hbar\omega_L}{k_B T}\right)$$

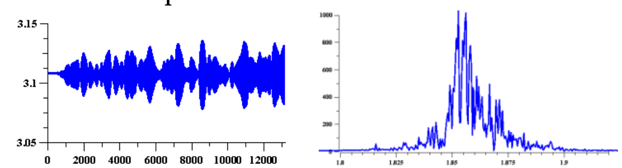
$$C_{SW}^{3D} = \left(\frac{\hbar\omega_L}{k_B T}\right)^{3/2} \exp\left(-\frac{\hbar\omega_L}{k_B T}\right)$$

- It differs from the Schottky law C_{SH} (curve 1) and can be found at temperatures <0.01 K.

ω_L is the Larmor frequency;

SPIN DYNAMICS SIMULATION

- The spin-wave model is checked by direct numerical simulation of the 2D spin system under orthogonal magnetic field.
- The dipolar energy time dependence and its' Fourier spectrum:



- Average dipolar energy, its' deviation and spin wave spectrum interval:

$$E_d \approx 3.2NS^2 p_d, \quad \Delta E_d \approx 6.4Sp_d\langle n\rangle,$$

$$E_{SW} \in \left[\hbar\omega_L\left(1-\frac{3}{2}Sp_d\right), \hbar\omega_L\left(1-\frac{1}{2}Sp_d\right)\right].$$

N is total spin number in lattice, $\langle n\rangle$ is average number of spin deviations per node, and p_d = dipolar pair energy / $\hbar\omega_L$

- The analytics matches the simulation data.

CONCLUSION

- The spin-wave approach is applicable in pure paramagnetic crystals.
- The external field direction permits to control material properties.