# High Field ESR on Materials with Magnetic Order

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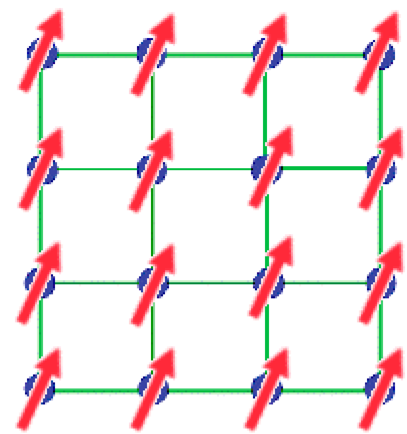
# Ferromagnet, anti□erromagnet in Heisenberg model

$\mathcal{H} = J \sum \boldsymbol{S}_i \boldsymbol{S}_j$

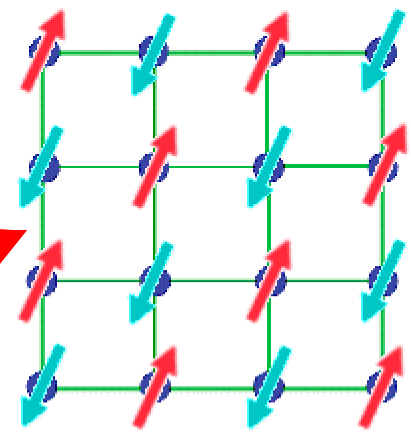


J<0 Ferromagnet□□lassical and □ uantum ground states are the same

$\boldsymbol{S}^{\text{tot}} = \sum \boldsymbol{S} = N \boldsymbol{S}$

$[S_x^{\text{tot}}, S_y^{\text{tot}}] = i\,\hbar S_z^{\text{tot}} \rightarrow [S_x, S_y] = i\,(\hbar/N)\,S_z$

$[\mathcal{H}, S_z^{\text{tot}}] = 0\ ;\ [\mathcal{H}, \boldsymbol{S}^{\text{tot}\,2}] = 0\ ;\quad E = -N\,(z/2)\,(J/4)$



J>0 □nti□erromagnet□N□el state, Sublattice magnetizations

$\boldsymbol{S}^{\text{tot}}{}_A = \sum_A \boldsymbol{S} = (N/2)\,\boldsymbol{S} \quad \boldsymbol{S}^{\text{tot}}{}_B = \sum_B \boldsymbol{S} = (N/2)\,\boldsymbol{S}$

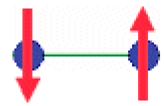
$[H, \boldsymbol{S}^{\text{tot}}{}_A] \neq 0$

$S^z$ is O□□$S^+$, $S^-$ is the problem

N□el state is not a real ground state

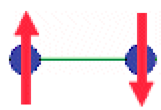
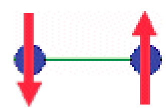
□E□cept □sing model□

# □wo electron ground state

N□el  $E = -\frac{1}{4} J$

□roblems□ no rotational invariance, but $S^{tot}=0$

Better□ singlet

$1/□2($  -  $)$ $E = -\frac{3}{4} J$

□eneralization □or more spins□

□alence bond solid □□BS, Sachdev,Read □□□□□

Resonating valence bond □R□B, □nderson □□□□,□□□□□

# How bad is the N□el state□
# □epends□

Number o□ spin components□ Heisenberg  □□  □sing

Eu□  LiHoF□

Magnitude□ spin S□□□□  S□□  S□□ □□  S□□,  S□□ □□

NaNiO□  Ni□l□  □n□rO□  LaMnO□  □Fe□□OH□□SO□□

□imension o□ lattice□ $d = 0$  $d = 1$  $d = 2$  $d = 3$

Mn□□ □acetate□  □u□eO□  □s□u□l□  LaMnO□

# Stabilty of the Néel state

Magnon excitation spectrum:

$\omega(q) = JS\sqrt{(1-\cos 2(qa))} \sim q$ for small $q$

Quantum fluctuations destroy sublattice magnetization $S_A^{tot}/N = \frac{1}{2}(S - \delta S)$

$$\delta S \approx \frac{1}{2S}\frac{1}{N}\sum_{\mathbf{R}}\left\langle S_{\mathbf{R}}^{-}S_{\mathbf{R}}^{+}\right\rangle = \frac{1}{2S}\int\frac{d^3\mathbf{Q}}{v_{BZ}}\frac{g^{-+}(\mathbf{Q})}{\hbar\omega(\mathbf{Q})} \sim \int g(q)/\omega(q)\, d^D q$$

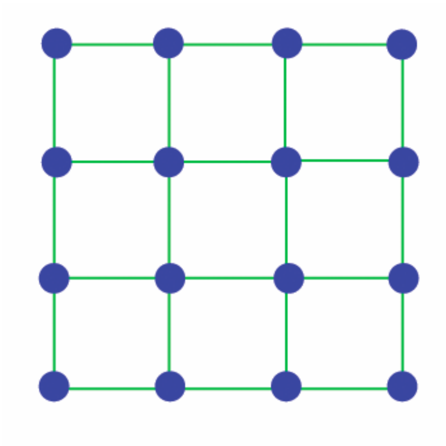
Divergent in one dimension!

Must know excitation spectrum (neutron). Gap helps to stabilize the classical solution. **ESR measures gap at q=0.**

# Connectivity of Lattice

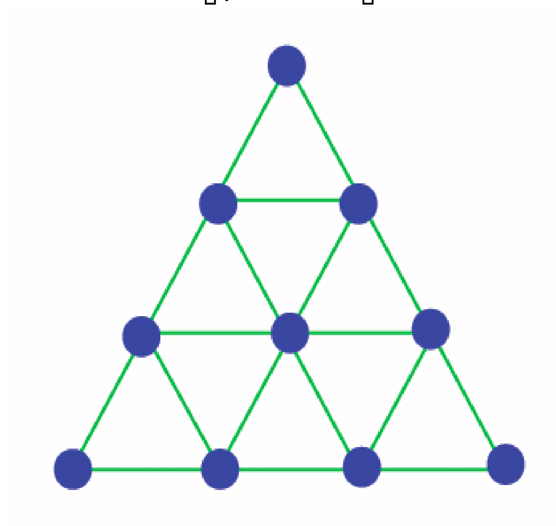
Square lattice

$La_2CuO_4$



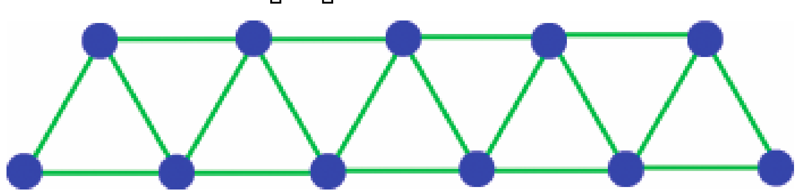
Triangular lattice

$CsCoCl_3$, $LiNiO_2$

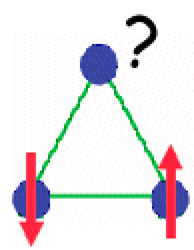


zig-zag chain

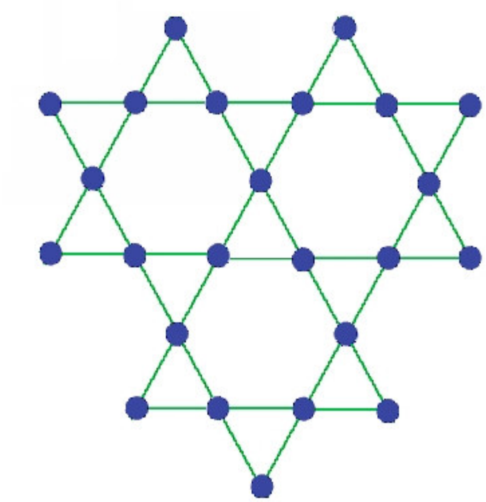
$LiCu_2O_2$



Frustration: One of three spins is unhappy



# Connectivity of Lattice



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