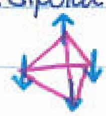
Frustrated Magnets (III) [Balents]

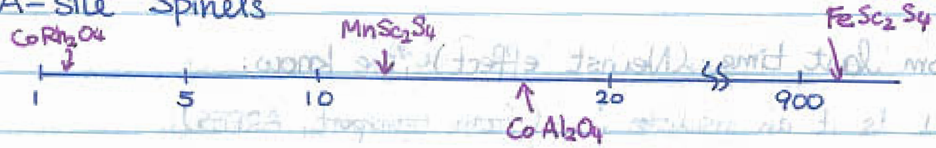
- Frustrated Magnets Hunter Guide:
  (1) Is it an insulator? (from transport, ARPES)
  (2) Is it a magnet? Curie Law (from χ)
  (3) Sign of frustration?
  { $|\Theta_{cw}|$ (from χ) vs. T_N (from transition of χ, C_v, etc.)
  | low-T entropy (C_v) and density of states (from NMR)
  (4) Identify state & compare with theory

- AB_2X_4 spinels
  ▲ Common valence : A^{2+}, B^{3+}, X^{2-}
  ▲ X = O, S, Se
  ▲ A sites form diamond lattice (which is bipartite...)
  ▲ B atoms form pyrochlore — decorate the plaquettes of the diamond lattice
  ▲ EXAMPLE: ACr_2O_4
  ▶ $S = 3/2$ isotropic moments.
  ▶ dominant exchange : antiferro

	$\|\Theta_{cw}\|$	T_N	f
▶ Zn	−390	12	33
Cd	−70	7.8	9
Hg	−32	5.8	6 ∵ lattice expanded

  ▶ Reduced f caused by increasing coupling to lattice distortions.
  ▶ Classical spin liquid — no long-ranged moment; dipolar correlatic
  ▶ Plateaus in magnetization — 3:1 structure 
  ▶ Plateaus caused by spin-lattice coupling, which favours colinearity.

- A-site Spinels

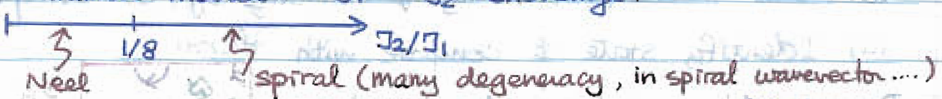


▲ In $FeSc_2S_4$ has $s=2$ but also has $s=2$ orbital degeneracy, which may act as $s=1/2$ pseudospin & increase quantum effects

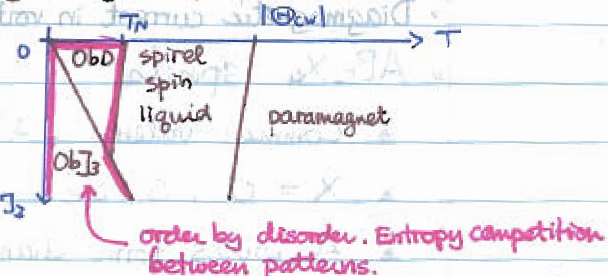
▲ 2^{nd} & 3^{rd} neighbor exchange important.

▸ Minimal model: $J_1 - J_2$ exchange.

▲



▲ Fix J_2/J_1 & introduce J_3

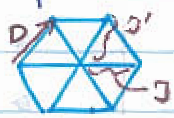


▲ Cs_2CuCl_4 — Cu^{2+} spin-1/2

$$\mathcal{H} = \frac{1}{2}\sum [J_{ij}\, \vec{S}_i \cdot \vec{S}_j - \vec{D}_{ij} \cdot \vec{S}_i \times \vec{S}_j]$$

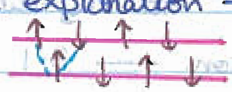
▸ quasi-D. In the 2D plane is spatially anisotropic triangular lattice

$J > J' > D$.



▸ To fit neutron scattering data at 0 field to Heisenberg spin-wave theory, value of J, J' has to be adjusted by 40% in opposite direction (J, J' obtained from high-field measurement)

▸ Physical explanation — dimensional reduction

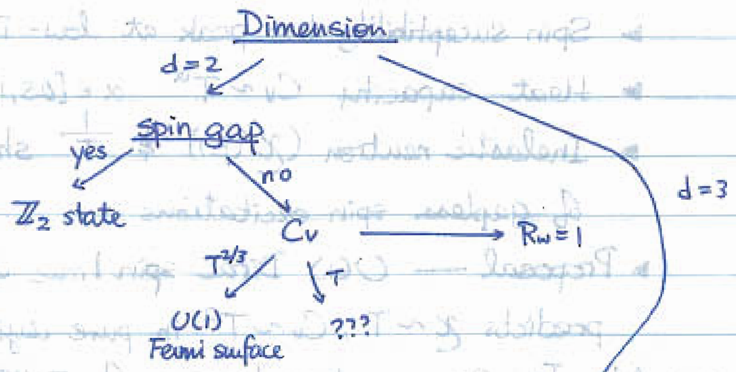


1^{st}-order interchain energy correction vanishes.

Excitations include spin-1/2 spinons (~domain wall)

Spinons cannot hop between chain alone, but can hop in pairs $\Longrightarrow$ spinons tend to stay close to each other

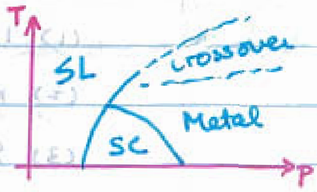
- Quantum Spin Liquids
  - ▲ Quantum fluctuation may prevent ordering at $T=0$.
  - ▲ e.g. RVB states
  - ▲ Quantum Spin Liquid
    - (1) $1/f = 0 \implies$ no ordering
    - (2) no spin freezing (hysteresis, NMR, μSR)
    - (3) Structure of low-energy excitation ($\chi(T)$, $C_v(T)$, $1/T_1$, inelastic neutrons)
  - ▲ Varieties of QSL:
    - (1) $U(1)$ states: (i) spinons unpaired
      - (ii) strong gauge fluctuations
      - (iii) gapless in $d=2$
      - (iv) stable in $d=3$ at $T=0$ only.
    - (2) $\mathbb{Z}_2$ states: (i) spinons paired
      - (ii) weak gauge fluctuations
      - (iii) stable in $d=2$
      - (iv) Ising transitions in $d=3$.
  - ▲



- ▲ QSL candidates

(1) κ-(BEDT-TTF)$_2$Cu$_2$(CN)$_3$

- ▶ Organic
- ▶ $S = 1/2$ triangular lattice, $t'/t \approx 1.06$ (nearly isotropic)



- ▶ suggestion: U(1) spin liquid with spinon Fermi surface
- ▶ { susceptibility ✓
  heat capacity × (too large)
- ▶ Spinon pairing ?

(2) EtMe$_3$Sb[Pd(dmit)$_2$]$_2$

- ▶ Less investigated than κ-(BEDT-TTF)$_2$Cu$_2$(CN)$_3$, but similar to it

(3) ZnCu$_3$(OH)$_6$Cl$_2$ — 2D kagome of Cu^{2+}

- ▶ 2d spin-1/2 antiferromagnetic
- ▶ Problem — invertion between Zn & Cu (5–10%)
- ▶ Spin suceptibility has peak at low-T ⟹ local disorder ?
- ▶ Heat capacity $C_V \sim T^{\alpha}$ $\alpha \in [0.5, 1]$ ⟹ many low-T excitations
- ▶ Inelastic neutron ($\chi''(E)$) & $\frac{1}{T_1}$ show evidence of gapless spin excitations
- ▶ Proposal — U(1) Dirac algebraic spin liquid predicts $\chi \sim T$, $C_V \sim T^2$ in pure system

(4) Na$_4$Ir$_3$O$_8$ — hyperkagome of Ir^{4+}

- ▶ Less disordered than ZnCu$_3$(OH)$_6$Cl$_2$
- ▶ $\Theta_{cw} \approx -650K$
- ▶ Specific heat — broad peak around 30K, power-law (exponent $1 < \alpha < 2$)
- ▶ Transport shows it a Mott insulator but close to Mott transition

▶ Strong spin-orbit coupling ($j = 1/2$ instead of $s = 1/2$)

$\Longrightarrow$ $\chi(T)$ no longer tell low energy excitations.