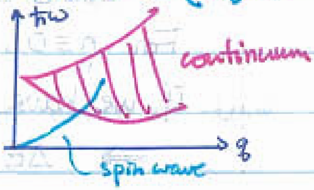
Neutron & X-ray Spectrosopy (II) [Keimer]

- Weak correlation materials
  - e.g. MgB_2 : electron-phonon coupling large ⟹ high T_c.
  - Probe by inelastic neutron scattering.
  - Energy resolution improve by spin-echo (0.1–10 meV ↘ 1–100 μeV)
  - Start with polarized beam, apply pulse to make it rotate so that it is unpolarized at sample, then apply pulse at opposite direction after passing through sample. Analysis polarity of resulting beam.
  - Can now analyse both energy & lifetime of phonon.
  - Find series of linewidth max for $T > T_c$ in Pb (& also Nb). Possible origin from Kohn anomaly.
    - But the peaks not predicted by LDA. And the peak is locked at Δ at $T \sim 0$. Have to include many-body effect for fuller explanations.

- Intermediate correlated materials
  - Inelastic magnetic neutron scattering
    ← encode spin-spin correlation $S^{\alpha\beta}(q,\omega)$
    by fluctuation-dissipation thm related to $\chi(q,\omega)$ spin-flip χ.
  - From RPA, $\chi(q,\omega) = \dfrac{\chi_0(q,\omega)}{1 - J(q)\chi_0(q,\omega)}$



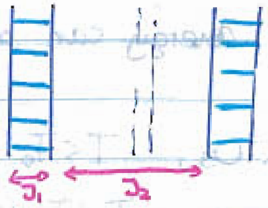
  - Example: Sr_2RuO_4
    - Fermi suface strongly nested ⟹ peaks in susceptibility.
    - Signal explained by "bare" susceptibility ⟹ no apparent role in driving p-wave SC.

- Strongly Correlated Material
  - Example: YBCO (undoped)
    - 2D lattice structure, no orbital degeneracy.
    - Occupation of orbitals detect by X-ray absorption.
    - Antiferro spin alignment in plane & out of plane, detected by inelastic magnetic neutron scattering.
  - Example: YBCO (underdoped)
    - ~Delta peak at (π,π) and has "hourglass" dispersion structure for $T < T_c$, but disappear & become "vertical" as $T > T_c$
      $\Longrightarrow$ evidence of spin dynamics playing role in SC.

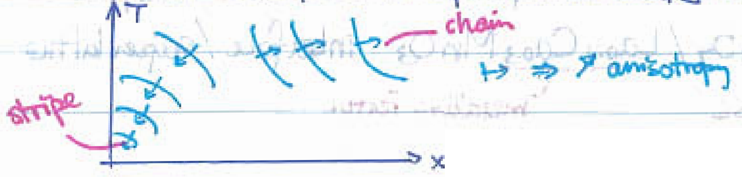
    - Single-particle band structure gives only broad features, disagree with experiment. While RPA agrees quite well.
    - Including perpendicular exchange, we get 2 collective mode instead of 1. (∵ YBCO is bilayer)

      These are spin excitons
    - Alternative proposal is that the state is strip states.

      low-energy: quasi-1D
      high-energy: 1D.



    - generalization: fluctuating stripes (but with too many [~20] parameters), which explains why signal anisotropic at low T & square at high T.
    - From transport, in-plane anisotropy is strong:



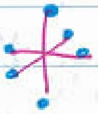
- For magnetic spectrum of $YBCO_{6.45}$ at constant energy cut
  $$\begin{cases} E > 15\text{ meV} \Longrightarrow \text{isotropic} \\ E < 15\text{ meV} \Longrightarrow \text{large anisotropy} \end{cases}$$
- Indicates phase transition at ~150K, where 1D incommensuate modulation appears. Structural in-plane anisotropy selects unique incommensurate domain.
- From muon relaxation, static magnetic order for $T \leq 2K$.
- ~150 K transition may be attributed to isotropic-nematic transition.
- Another proposal (hard to distinguish experimentally) is spiral order.

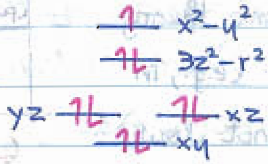
- Orbital Degeracy
  - $LaMnO_3 \longleftrightarrow La_{0.7}Ca_{0.3}MnO_3$
    AF Mott insulator Ferro metal
  - Use elastic neutron scattering (magnetic & non-magnetic)
  - By Jahn-Teller, $|3z^2-r^2\rangle$ has lower energy than $|x^2-y^2\rangle$
  - Splitting of energy can be probe by X-ray linear dichroism.
  - For $LaMnO_3$, $T < T_0 \Longrightarrow$ "Ferro" orbital order
    $T < T_N \ll T_0 \Longrightarrow$ spin order.

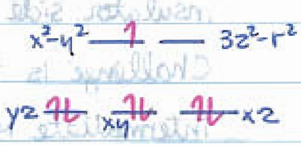
- Oxide hetrostructure
  - Quantum Hall comes from semiconductor interface.
  - $\underbrace{YBa_2Cu_3O_7}_{\text{high-}T_c\text{ SC}} / \underbrace{La_{0.7}Ca_{0.3}}_{\text{metallic Ferro.}}MnO_3$ interface / superlattice

▲ Changes brought by interface:
magnetic enviroment, valence state, crystal field, covalent bond, stoichiometry.

▲ La_2CuO_4 vs. $LaNiO_3$







▲ Substrate strain can induce spliting of orbital in $La_{1-x}Sr_xMnO_3$ thin flim

▲ The $LaNiO_3/LaMnO_3$ superlattice should favor x^2-y^2 orbital $\Longrightarrow$ "cuprate" Hamiltonian ?

▲ Predict even higher T_c than cuprate, but observed insulator.

▲ From soft X-ray reflectivity, "forbidden" (by superlattice symmetry) Bragg peaks appear
$\longrightarrow$ valence state of superlattice $\neq$ atomic valence.