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Brief Survey of Strongly-Interacting Electron Systems

Most complete review to date: M. Imada, A. Fujimori, and Y. Tokura, "Metal Insulator Transitions", "Rev. Mod. Phys. 70, 1039 (1998), which reviews theory and experiment on correlated-electron systems, especially transition metal oxides.

See also E. Dagotto, "Correlated Electrons in High Temperature Superconductors", Rev. Mod. Phys. 66, 763 (1994).

A. Damascelli and Z. Hussain and Z-X. Shen,"Angle-resolved photoemission studies of the cuprate superconductors", Rev. Mod. Phys. 75, 463 (2003).

Collosal Magnetoresistance: M. B. Salamon and M. Jaime, "The physics of manganites: Structure and transport",Rev. Mod. Phys. 73, 583 (2001).

1. Zaanen-Allen-Sawatzky classification scheme

Discussed in Imada, et al.

A. Example that was believed to be the realization of a Mott-Hubbard insulator: V_2O_3

- The only states near E_F are 3d states
- Hubbard model with 10 3d states
- Metal-insulator transition believed to be mainly a property of the interacting electrons in the Hubbard model for the 3d states
- Other states (Oxygen 2p, 4s, etc.) are either strongly bound below the Fermi energy or well above - not involved crucially in the transition
- See figures from Imada review

B. Charge Transfer Insulators

- NiO - nominally d^8 antiferromagnetic insulator with Gap $\approx 4eV$
- Photoemission shows $d^8 \rightarrow d^7$ is far below E_F by about 10 eV.
- $d^8 \rightarrow d^9$ lowest empty states
- Oxygen 2p states (band-like "Ligand" states highest occupied states
- Very different from band calculations, which find states at Fermi energy to be mainly 3d like a Mott-Hubbard system
- Comparison of Cu_2O ("Ordinary" Band Insulator with filled d shell) and CuO (one hole per Cu, which leads to correlated antiferromagnetic insulator)

2. Cu Oxide planar systems: Antiferromagnetic Insulators to High-Tc superconductors

- Gross Features of Bands: Simple nondegenerate Hubbard model with one band (mainly Oxygen 2p in character) crossing E_F

- Undoped systems (e.g. $CaCuO_2$; La_2CuO_4 (La214); YBa_2CuO_3 (YBa123); (Bi,Tl)Ca 221; (Bi,Tl)BaCa2212; etc. all have similar CuO_2 square layers - counting gives a half-filled nondegenerate Hubbard model
- Would be a metal except that interactions lead to correlated antiferromagnetic insulator
- Doping with holes (e.g., $(La_{1-x}Sr_x)_2CuO_4$) leads to metal and superconductor for "optimal range of doping"
- States for added holes are mainly O p states - leads to idea of "O metal" - "t-J" model for holes on O that interact with spins on the Cu (spin 1/2 on each Cu)

$$H = t \sum_{<ij>\sigma} c^{\dagger}_{i\sigma} c_{j\sigma} + J_1 \sum_i \sigma_{\mathbf{i}} \cdot \mathbf{S}_i + J_2 \sum_{<ij>} \mathbf{S}_i \cdot \mathbf{S}_j, \tag{1}$$

  where $< ij >$ denotes nearest neighbor pairs.
  The last term involving J_2 leads to antiferromagnetic order, and the holes tend to promote ferromagnetism - i.e., a competition or frustration.
- Gross Features of Photoemission from metallic systems
- Very weak features near E_F in the doped materials are the metallic bands that lead to superconductivity
- Angle Resolved Photoemission (ARPES) - See review by Domacelli, et al. Many examples that show the Fermi surface - anomalous behavior of spectra that are non-Fermi-liquid-like as a function of $E - E_F$
  - Examples from the High-Tc materials - recent very high precision experiments - Figures from Lect. 1
  - d-wave symmetry gap
  - "Pseudogap" in underdoped materials - depression in spectra near E_F - similar to the superconducting gap, but above T_c.

3. "Colossal Magneto-Resistance" (CMR) materials

- Cubic perovskite structure $La_{1-x}Sr_xMnO_3$ (with some Jahn-Teller distortion)
- $LaMnO_3$ is a ferromagnetic insulator
- Can be understood in terms of a type of band picture: Mn d states form large local 3/2 spins - modelled as classical spins - plus additional itenerant electrons that move in a field of the spins - double exchange mechanism (Zener, 1951) - the quantum version is a variant of the "t-J" model where J_2 is small so that one finds ferromagnetism
- Doped system (each Sr subtracts one electron) has metal-insulator (M-I) transition
- Leads to large coiupling of conductivity and magnetism "Colossal Magneto-Resistance" near the phase transition

- What happens at M-I transition - matter of controversy:
  - Just disorder in spins (C. M. Varma, PRB 54, 7328 (1996)
  - Disorder in spins plus Jahn-Teller distortions (Millis, et al. PRL 74, 5144 (1995) - in this model the dynamic J-T effect makes resistivity very large in metallic phase

4. Stripes Formation of inhomogeneities or ”stripes” or ”pasta phases” - seen in some materials - theories by Zaanen and by Emery and Kivelson