Spin-Orbit Coupling

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That’s an extremely general title.....

Spin-orbit coupling in a condensed-matter context, where it is of somewhat current interest.

Topics

- Topological Insulators *et al.* (see also: Last year’s seminar.)
- Topological-defect states
  - Skyrmions
  - Domain walls
  - Surfaces/interfaces
  - Vortices
- Multiferroics
- Spin-Orbit coupling of light
- Spin-orbit coupling in cold-atom systems and topological stuff
- Correlations and spin-orbit coupling
Immensely successful band theory

- Atoms come close together: energy bands
- Available energy levels almost say it all

Wave function hardly discussed $\Rightarrow$ topology

Topologically nontrivial states:
- Description uses concept from field of topology (winding numbers, genus of a surface, ...)
- Property of the wave function, not just eigenenergies relevant
- Expected to be robust
Replaces Magnetic field

- Quantum Hall effect: Magnetic field breaks time-reversal invariance
- **Quantum “Anomalous” Hall States:** TRI broken by other means
  

- Quantum Spin Hall: TRI not broken

  M. Hasan and C. Kane, RMP 82, 3045 (2010)
Lifshitz invariants allow ‘particles’

- Lifshitz invariants \((\mu \partial_\gamma \nu - \nu \partial_\gamma \mu)\) needed for ‘particles’
- Non-centrosymmetric systems
  - **Multiferroics**
  - **Helimagnets**: \(DM \times \nabla M \Rightarrow\) skyrmions
  - **Chiral liquid crystals \(\Rightarrow\) blue phases**
    D. Wright and N. Mermin, RMP **61**, 385 (1989)
- **Here**: Hamiltonian inversion symmetric, \(120^\circ\) order breaks inversion symmetry

Spin-orbit coupling + correlations: iridates

G. Jackeli and G. Khaliullin, PRL 102, 017205 (2009)

- Three $t_{2g}$ orbitals, two spins
- Spin-orbit coupling: $j = \frac{1}{2}$ and $j = \frac{3}{2}$ quartet
- Doublet has one hole

B. Kim et al., PRL 101, 076402 (2008)
Many 3D and 2D lattices

- **Pyrochlore**: $A_2Ir_2O_7$, topological Mott insulator possible?

- **Hyper-kagome**: 3D spin liquid?

- **Honeycomb**: $A_2IrO_3$, zig-zag, 2D spin liquid possible?

- **Triangular, made of dimers**: $Ba_3IrTi_2O_9$
  T. Dey, PRB **86**, 140405 (2012)

- **Square**:
  - single-layer $Sr_2IrO_4$: like high-$T_C$ cuprates?
  - bi-layer $Sr_3Ir_2O_7$: 3D perovskite: metal
2D square: like cuprates

Spin-orbit order:

Magnetic order:

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Spin-orbit coupling and superconductivity

- Iridates and other systems
- Total angular momentum $j$ vs. “singlet-triplet mixing”
- Topological superconductivity
- Majorana Fermions