

Advanced topics of the physics of ultra-cold gases (SoSe 2015)

I. Bosons in optical lattices

- Optical lattices
- Interference fringes
- Phase fluctuations and number squeezing
- Bose-Hubbard Hamiltonian
- Mott-insulator to superfluid transition
 - Zero-hopping case
 - Superfluid-to-Mott insulator transition
 - Understanding the ground-state phase diagram
 - Bloch's exp., 2002
- Mott shells
 - Local-density approximation: wedding-cake structure
 - Site-resolved detection (Bloch's exp., 2010)
- Parity order (Bloch's exp., 2013).

II. Fermions in optical lattices

- Fermi-Hubbard Hamiltonian: Mott-metal transition (Bloch's exp., 2008)
- Super-exchange: anti-ferromagnetic Heisenberg model
- Super-exchange for bosons: ferromagnetic Heisenberg model
- Super-exchange in two-well experiments (Bloch's exp., 2007)
- Short-range anti-ferromagnetic correlations (Esslinger's exp., 2013)
- Phase diagram as a function of temperature: the entropy problem
- D-wave superconductivity

III. Playing with the lattice potential I

- Lattice shaking
 - Floquet analysis
 - Tuning the hopping rate (Arimondo's exp., 2007)
 - Modifying the lattice dispersion (Chin's exp., 2013)
- Triangular lattices
 - Building a triangular lattice and 2D lattice shaking
 - Classical frustrated anti-ferromagnetism (Sengstock's exp., 2011)
 - Zig-zag lattice
- Other lattice geometries
 - 2D lattice of variable geometry and Dirac cones (Esslinger's exp., 2012)
 - Superlattice techniques (Stamper-Kurn's experiment, 2012)
 - p-band lattices and chiral superfluids (Hemmerich's exp., 2010 and 2015)

IV. Playing with the lattice potential II: Synthetic magnetism

- Photon-assisted hopping (Greiner's experiment, 2011)
- Generation of synthetic magnetism in optical lattices
 - Using lattice shaking (Sengstock's exp., 2012)
 - Using Raman-assisted hopping (Ketterle's and Bloch's exps., 2013)
- Hofstadter Butterfly
- Synthetic magnetism in ladder-like lattices (Bloch's exp. 2014)
- Synthetic dimensions (Fallani's exp., 2015)
- Other more "exotic" scenarios:
 - Non-Abelian gauge fields
 - Modulating interactions

V. Polar lattice gases I

- Magnetic atoms:
 - Cr, Dy, Er
 - Er₂ molecules (Ferlaino's exp., 2014)
- Polar molecules:
 - Molecules in the ro-vibrational ground-state (Zwierlein exp., 2015)
 - Rigid-rotor model
 - Polarization
- Dipole-dipole interaction
- Extended Hubbard model:
 - Derivation
 - Control knobs
- Intersite interactions
 - BEC-Stability experiments (Pfau's exp., 2011)
 - Transport of excitations without transfer of matter
- Quantum phases of the extended Hubbard model
 - Crystals and supersolids
 - Haldane insulator
 - Interlayer superfluids

VI. Polar lattice gases II: Spin models

- Hard-core molecules: XXZ Heisenberg model
- Spin models using polar molecules (Ye/Jin's exp., 2013)
 - Spin-encoding in the rotational states
 - Dipole-induced spin exchange
 - Ramsey spectroscopy: oscillations and damping
- Spin models using magnetic atoms (Laburthe's exp., 2013)
 - Chromium as a spin-3 system: spin changing collisions and spin relaxation
 - Dipole-induced inter-site spin-changing collisions
 - Experimental results
 - Mean-field versus exact spin dynamics
- Controlling the spin-spin interactions using microwaves
- Magnons

VI. Non-equilibrium dynamics

- Absence of dissipation: repulsively bound pairs (Grimm/Denschlag's exp., 2006)
- Relaxation vs integrability: quantum Newton's cradle (Weiss' exp., 2006)
- Transport vs interactions
 - Repulsively-bound pairs for fermions (Esslinger's exp., 2010)
 - Expansion of lattice fermions (Bloch's experiment, 2012)
- Disorder vs transport
 - 3D Anderson localization (Aspect's exp., 2012)
 - Disorder vs interactions (Inguscio/Modugno exp., 2014)
 - Many-body localization (Bloch's exp., 2015)
- Many-body localization without disorder