Quantum materials research with ultra-cold atomic gases

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Theme : An ensemble of ultra-cold atoms held in optical potentials can be used to experimentally realize and study certain model Hamiltonians

Directions : Realize N-body quantum systems of fundamental interest to condensed matter physics - low dimensional and/or strongly correlated systems - examples include

- 1-D chains - *(Luttinger liquids and Tonks gas)*
- 2-D and 3-D Hubbard (lattice) models with bosons and/or fermions

Goal : Study the behavior of various model Hamiltonians to determine the essential "ingredients" required in these models to reproduce specific phenomena - examples include

- high-Tc superconductivity

What is its connection (if any) to the Fermi-Hubbard model?

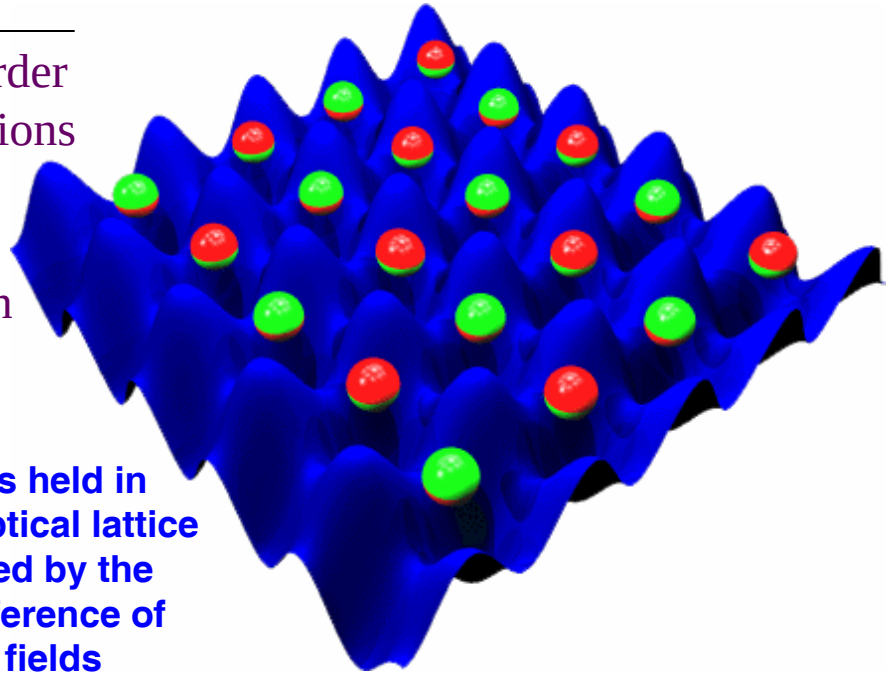
The connections to electronic condensed matter systems provides a kernel for synergy

	analogous to	
fermionic atom	⟷	electron
optical lattice	⟷	ionic crystal
collisional interaction	⟷	Coulomb interaction
spatial rotations	⟷	magnetic fields
	in some cases	

Notable differences:

- optical lattices possess (almost) perfect crystal order
  no phonons, no impurities, no dislocations
  but "imperfections" can be added in...

- mixtures of fermionic and bosonic particles can be realized and studied.



atoms held in an optical lattice formed by the Interference of laser fields

Recent advances provide proof of relevance and potential

Recent experimental realizations of the Bose-Hubbard model and BCS fermionic pairing

"*Quantum phase transition from a superfluid to a Mott insulator in a gas of ultracold atoms*", Nature **415**, 39 (2002)

"*Probing the excitation spectrum of a Fermi gas in the BCS-BEC crossover regime*," Phys. Rev. Lett. **94**, 070403 (2005))

"*Condensation of Pairs of Fermionic Atoms near a Feshbach Resonance*," Phys. Rev. Lett. **92**, 120403 (2004)

Proposals to observe related effects with cold atoms abound

"*High-Temperature Superfluidity of Fermionic Atoms in Optical Lattices*", Phys. Rev. Lett. 89, 220407 (2002).

"*Atomic Bose and Anderson Glasses in Optical Lattices*," Phys. Rev. Lett. **91**, 080403 (2003).

"*Controlling ultracold atoms in multi-band optical lattices for simulation of Kondo physics*" Euro. Phys. Lett. **67** (5): 721-727 (2004).

"*Atomic Quantum Simulator for Lattice Gauge Theories and Ring Exchange Models*,"Phys. Rev. Lett. **95**, 040402 (2005)