

# 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

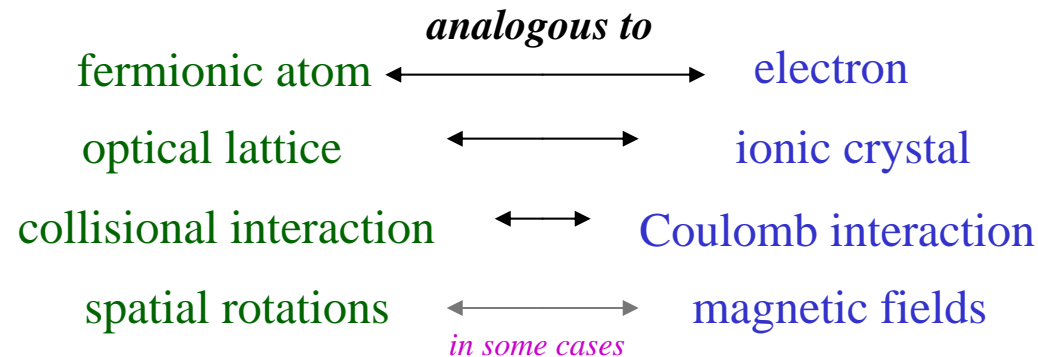
**Goal** : Study the behavior of various model Hamiltonians to determine the essential “ingredients” required in these models to reproduce specific phenomena - examples include

- high-T<sub>c</sub> superconductivity

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

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

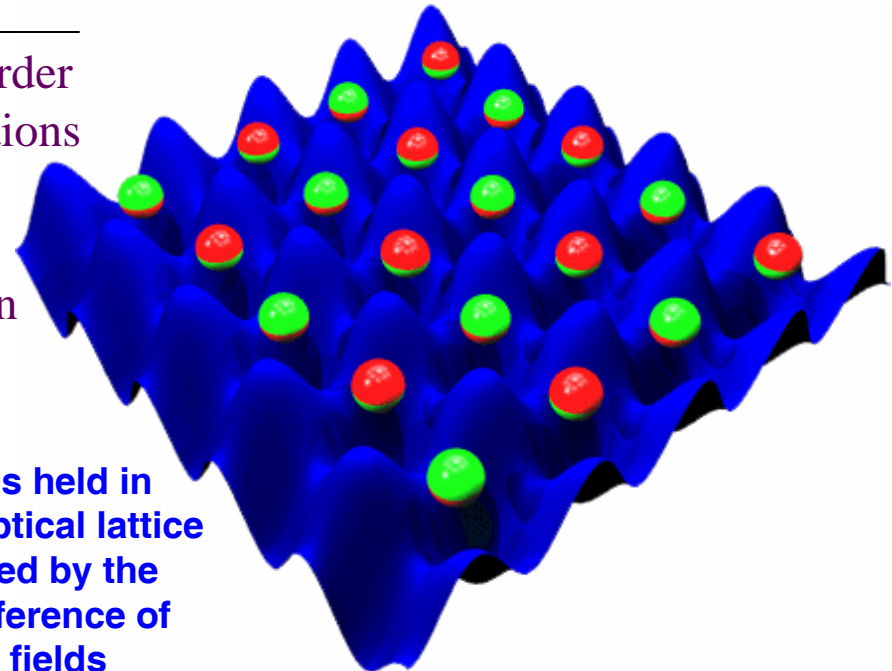
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## Notable differences:

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- 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.



# Recent advances provide proof of relevance and potential

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## *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)