# Optical lattices and quantum simulation

The term phase transition commonly describes change in the physical properties of a thermodynamical system as results of the change of some external condition, such as temperature, pressure or others. Most commonly used example is transitions between solid, liquid and gaseous states of matter, and, in rare cases, plasma. Thermal fluctuations play very important role in these phase transitions. At zero temperatures, however, the thermal fluctuations are absent and a question naturally arises whether phase transitions are possible. The zero temperature quantum states of the matter are known as quantum phases and though the thermal fluctuations are absent, quantum fluctuations exist and therefore can still support phase transitions. As a physical parameter is varied, quantum fluctuations can drive a phase transition between different phases of matter. An example of a canonical quantum phase transition is the well-studied Superconductor-Insulator Transition in disordered thin films which separates two quantum phases having different symmetries. Quantum magnets provide another example of quantum phase transition. The discovery of new quantum phases is a pursuit of many scientists. These phases of matter exhibit properties and symmetries which can potentially be exploited for technological purposes and the benefit of mankind.

Ultra cold atoms in optical lattices have opened up a new realm for condensed matter research to study quantum phase transitions. An optical lattice is artificial crystals of light created by the interference of counter-propagating laser beams. When neutral atoms, which can be Bosons or Fermions, are illuminated with laser beams, the electric field of the laser induces a dipole moment in the atoms which in turn interacts with the electric field, a phenomena known as AC-Stark effect. This interaction modifies the internal energy of the states of the atoms in a way that depends both on the light intensity and on the laser frequency. Resulting interference pattern creates effective periodic potential that may trap neutral atoms if they are sufficiently cooled to the range of nano-Kelvin. Such optical lattice with trapped atoms resembles real crystals where neutral atoms play a role of electrons in real crystal. Yet while in real crystals typical lattice dimensions are tiny, with atoms spaced around nanometre apart, optical lattice has typical dimensions about 1.000 times larger, thus providing enlarged version of real crystal. This analogy makes atoms in optical lattices very intriguing for solid-state physics. Real crystals are incredibly complex with many competing interactions, presence of disorder and lattice vibrations making it very hard to account for various experimentally observed phenomena. On the other hand, optical lattice provides an idealized version of crystal, where interactions can be controlled and finely tuned, thus providing a test bed for solid-state physics, where various theoretical models can be probed to study quantum phase transitions. The most studied phase transition in the optical lattice is Superfluid to Mott insulator transition, which is theoretically predicted and experimentally observed. Bosons in the optical lattice can be modeled by Bose-Hubbard model. We are interested in studying such quantum phase transitions in different type of Bose Hubbard models.

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