Lectures on *Quantum Gas in Optical Lattices & in Continuum*

Learning objective:
In this course, we will give an in-depth view of many-body quantum simulation with atomic and molecular systems. We will place particular emphasis on developing intuition for the physical phenomena and equipping the students with the tools necessary for working in the field of quantum simulations.

Prerequisites: Atomic Physics, Non-relativistic Quantum Mechanics, Classical & Quantum Statistical Mechanics.

Lecture Plan for Optical Lattices (Taught by Mehedi Hasan)

Lecture – 1: Optical Lattices

Review: Bloch's Theorem

Main Topic: Experimental realization of different types of optical lattices, band structure, Wannier states, Hubbard model (for Boson & Fermion), first-principal calculation of the parameters in the Hubbard model (e.g., hopping matrix elements, on-site energies, density-induced hopping, etc.) and their significances.

Lecture – 2: Quantum Phases of Atoms and Molecules in Optical Lattices

Review: Landau-Ginzburg Phase transition criterion, Density matrix & correlation functions, Feshbach resonances

Main Topic: Thermodynamics in optical Lattice. Quantum phases of matter in optical lattice for Bose-Hubbard & Fermi-Hubbard models, extended Hubbard model (eHM) for molecule and various phases in eHM. Momentum-space probing (time-of-flight) of quantum phases. Real-space probing (quantum gas microscope) of quantum phases. Measurement of the Hubbard model parameters.

Lecture – 3: Artificial Gauge Fields and Lattice Gauge Theory in Optical Lattices

Review: Landau levels, Quantum Hall effects, Hofstadter model

Main Topic: Realization of $\mathrm{U}(1), \mathrm{SU}(2), \text{and } \mathrm{SU}(3)$ artificial gauge field with neutral particles (static gauge field), fractional quantum Hall effect in optical lattices, density-dependent gauge field (dynamic gauge field) in optical lattices, toy models of lattice gauge theory with optical lattices.

Lecture – 4: Metrology with Optical lattices

Review: Doppler broadening, Dynamic polarizability & hyperpolarizability, operation of an optical clock

Main Topic: Metrological advantages in optical lattices, neutral-atom and molecular optical clocks in optical lattice, spectroscopic measurement of dynamic polarizability & hyperpolarizability, atom interferometry with optical lattices.

Notes: This is a draft plan of four two-hour lectures.