INTRODUCTION

Ultracold quantum gases are a promising platform for studying fundamental phenomena in quantum many-body physics, as they are easily described and highly controllable. This requires atoms in a quantum degenerate state, a state which can only be achieved by cooling them to nanokelvins. Optical lattices (generated by interfering laser beams) offer a way of subjecting quantum degenerate gases to periodic potential landscapes analogous to the crystalline structure of a solid.

In this project, several possible beam configurations have been analyzed and their band structure calculated. Moreover, an experimental test setup for generating optical lattices has been designed and constructed, with the required stabilization systems (intensity and phase).

QUANTUM SIMULATION

Ultracold atoms in an optical lattice can simulate condensed-matter phenomena.

\[ H = -t \sum_{<ij>} C_{ij} \delta_{ij} + U \sum_{i=1}^{N} n_i \delta_{ii} \]

A condensed matter problem can be mapped on a more controllable system.

EXPERIMENTAL SETUP

QUANTUM DEGENERATE GAS

COOLING TECHNIQUES

Laser cooling Evaporative cooling

APPARATUS

1) Ion pump
2) Atomic source
3) 2D magneto-optical trap
4) Differential pumping tube
5) Magnetic field coil
6) Science chamber
7) Non-evaporable getter pumps

OPTICAL LATTICES

Optical lattices offer a way of creating periodic potential landscapes in an ultracold quantum gas experiment.

DESIGNING OPTICAL POTENTIALS

RUNNING-WAVE LATTICES

Triangular lattice Hexagonal lattice

RETRO-REFLECTED LATTICES

Triangular lattice Dimers lattice Brick wall lattice 1D chains lattice

EXPERIMENTAL IMPLEMENTATION

PHASE STABILIZATION SYSTEM

Heterodyne interferometer and phase-locked loop

INTENSITY CONTROL AND STABILIZATION SYSTEM

PID controller

RUNNING-WAVE AND RETRO-REFLECTED CONFIGURATIONS

CONCLUSIONS

- Designed and developed an optical lattice test setup that will be used to subject quantum degenerate gases to periodic potential landscapes.
- Analyzed several lattice structures that can be created with the constraints of the experiment, derived their expressions and computed their band structure.
- Built and tested three active phase stabilization setups (with improvements introduced in each new scheme) and an intensity control and stabilization system.