Bose Einstein Condensation in the higher band of a time-dependent double well optical lattice

Saurabh Paul, Eite Tiesinga

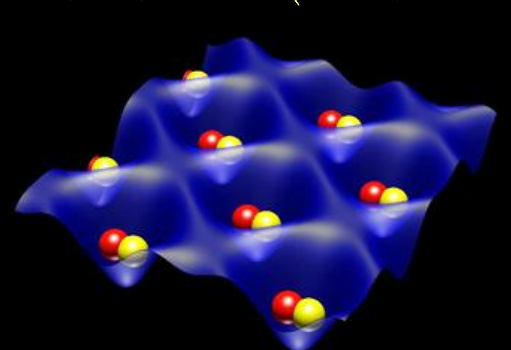
Joint Quantum Institute, National Institute for Standards and Technology and University of Maryland, MD, USA.

Motivation

- Simulations of condensed matter systems with atoms in optical lattice.
- The new thing is, we can modify the lattice and the band structure in real time.
- Doesn't even have to be in the lowest band.
- Bose condensation in different dimensionalities. In particular, we are going from a 1D to a 3D system.
- The lattice we are going to study is inspired by a neat experiment in Germany. *[G. Wirth et al., Nature Physics , doi:10.1038/nphys1857(2010)]*

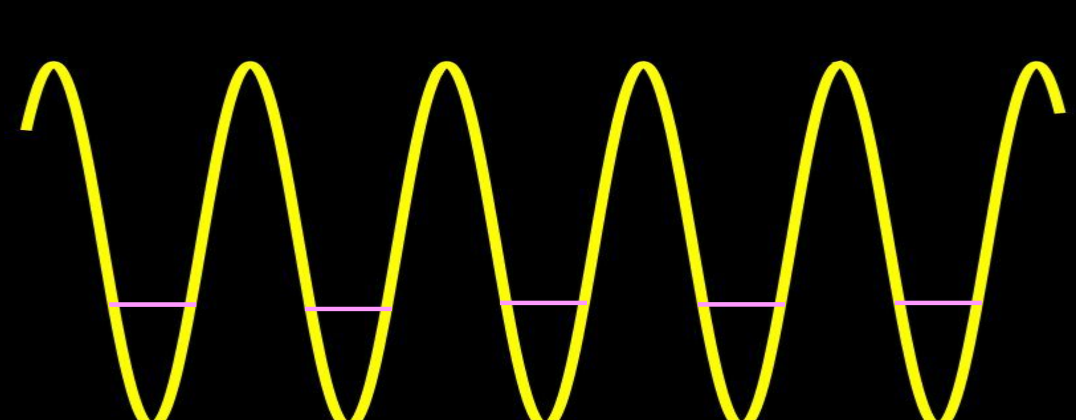
2D Lattice Potential with weak harmonic confinement in the 3rd direction

$$V(x,y) = -|V_0|\left(\cos^2(kx) + \cos^2(ky) + 2\cos\theta\cos(kx)\cos(ky)\right)$$

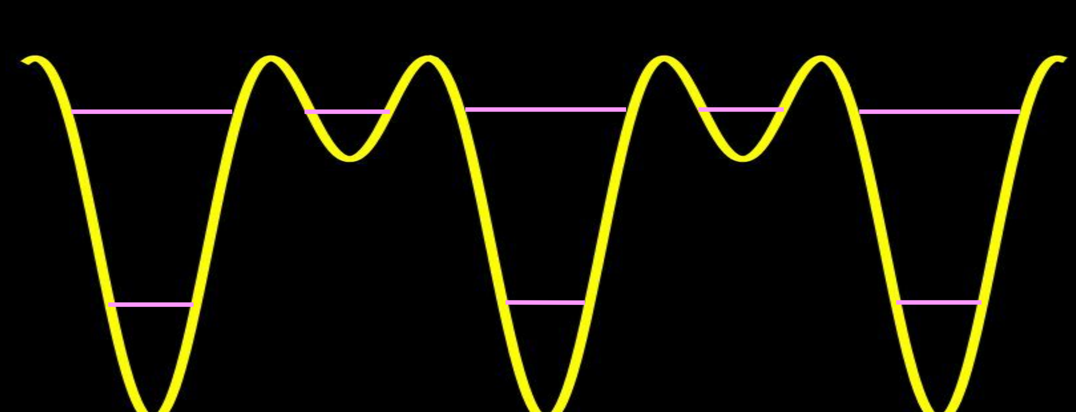


In addition, it is important to note that there is also a weak harmonic trapping potential in the z-direction

Changing the potential real time



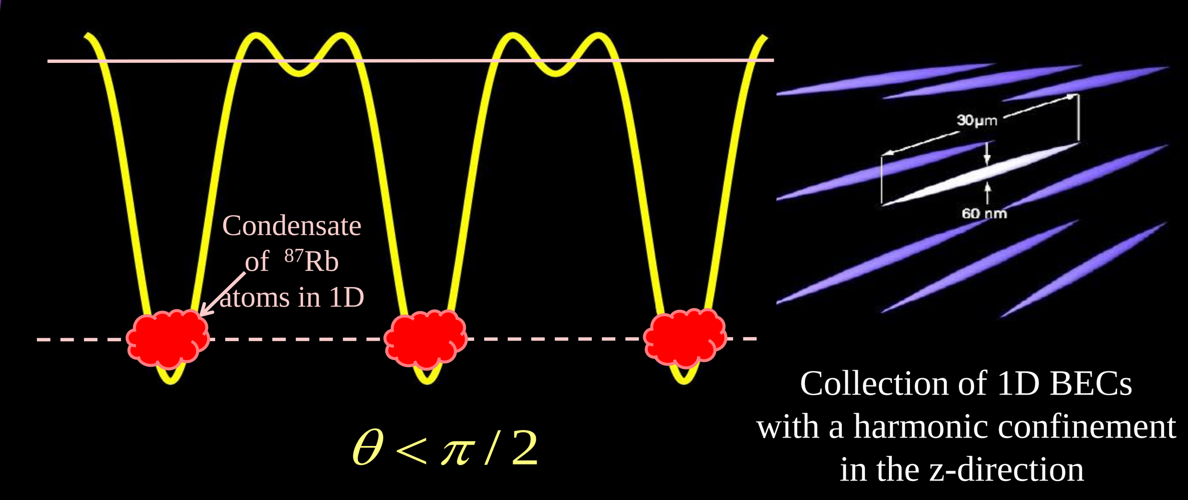
$\theta = \pi/2$



$\theta = \pi/3$

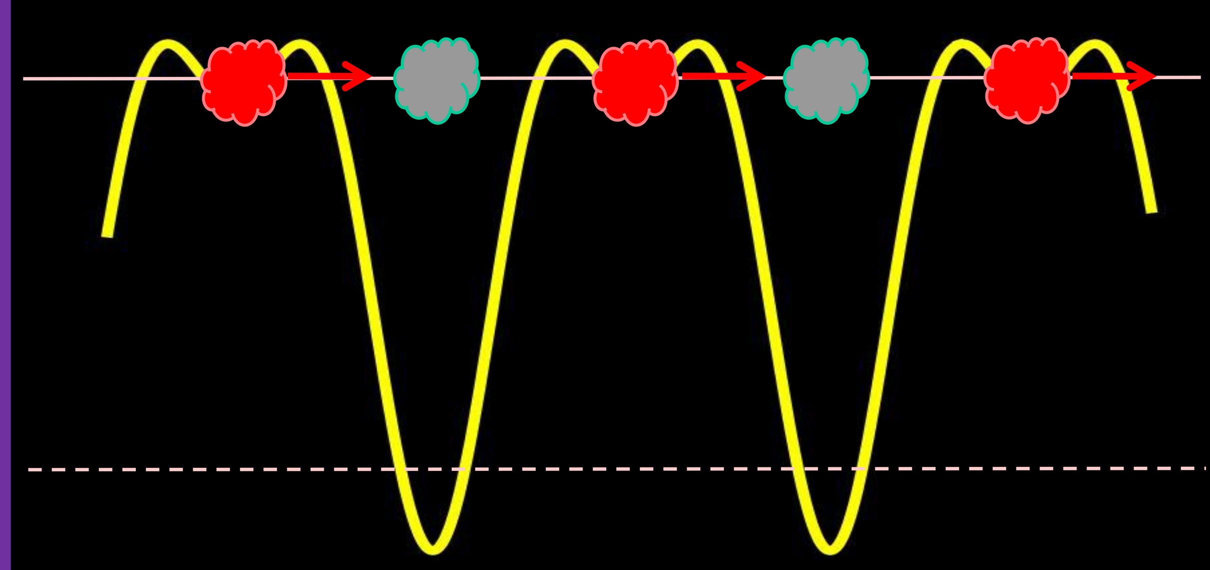
Populating the excited bands

Step#1



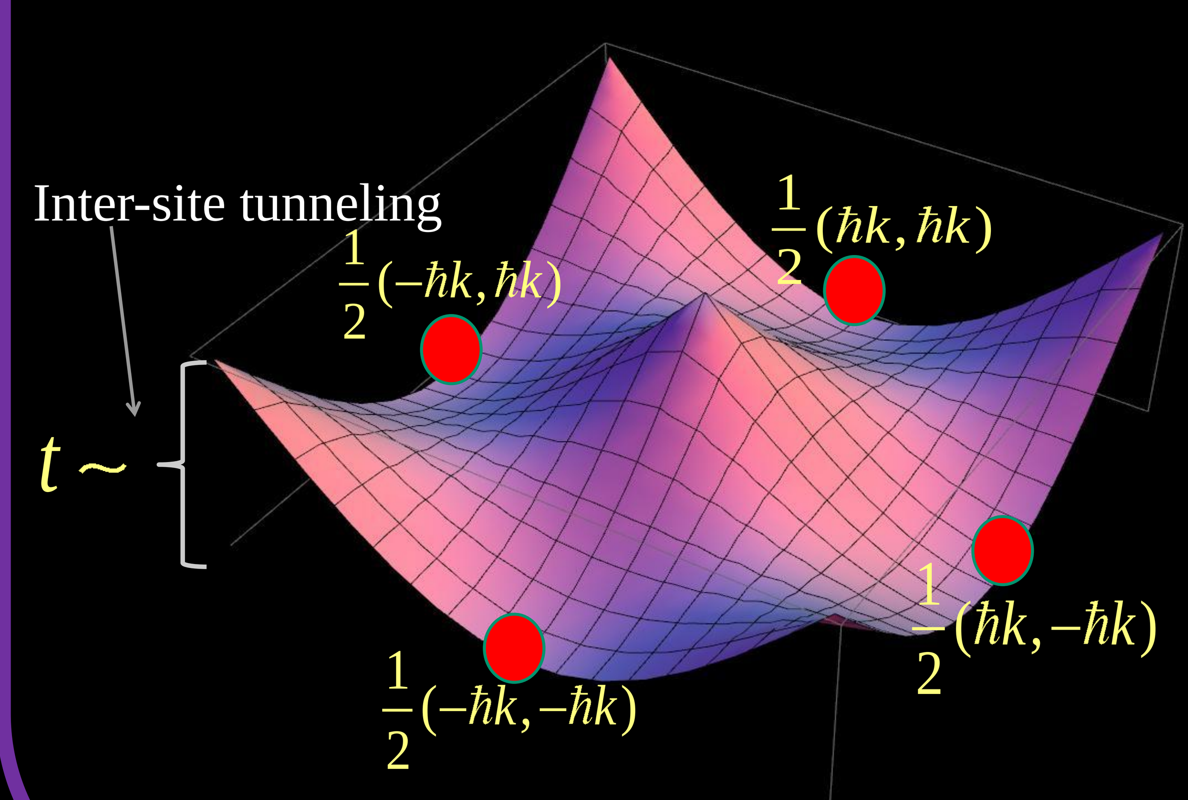
Step#2

Tunneling and collisions re-distribute the atoms among all sites

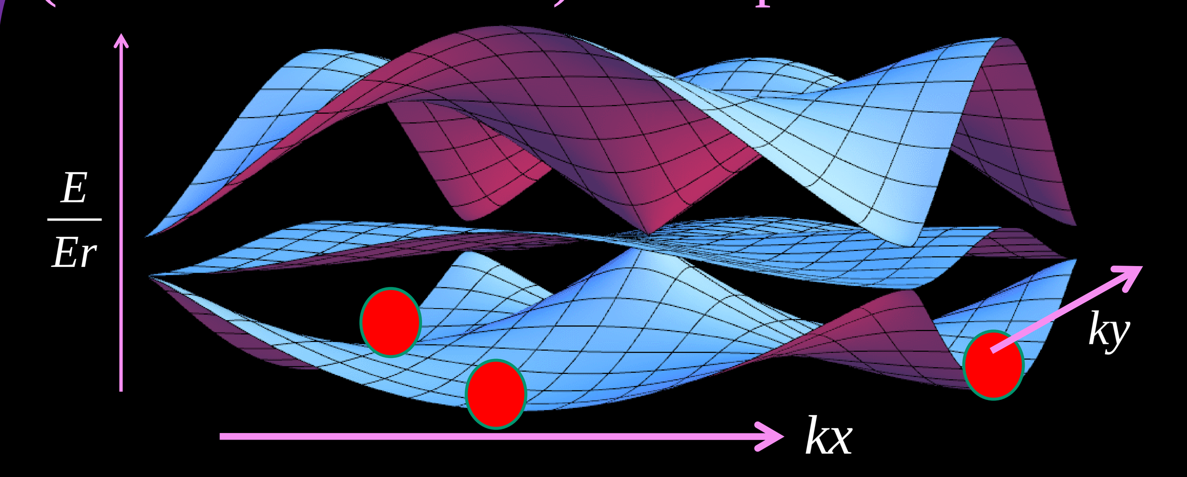


Tight binding calculation of the band structure using local s and p orbitals

Second energy band as a function of 2D quasi momenta

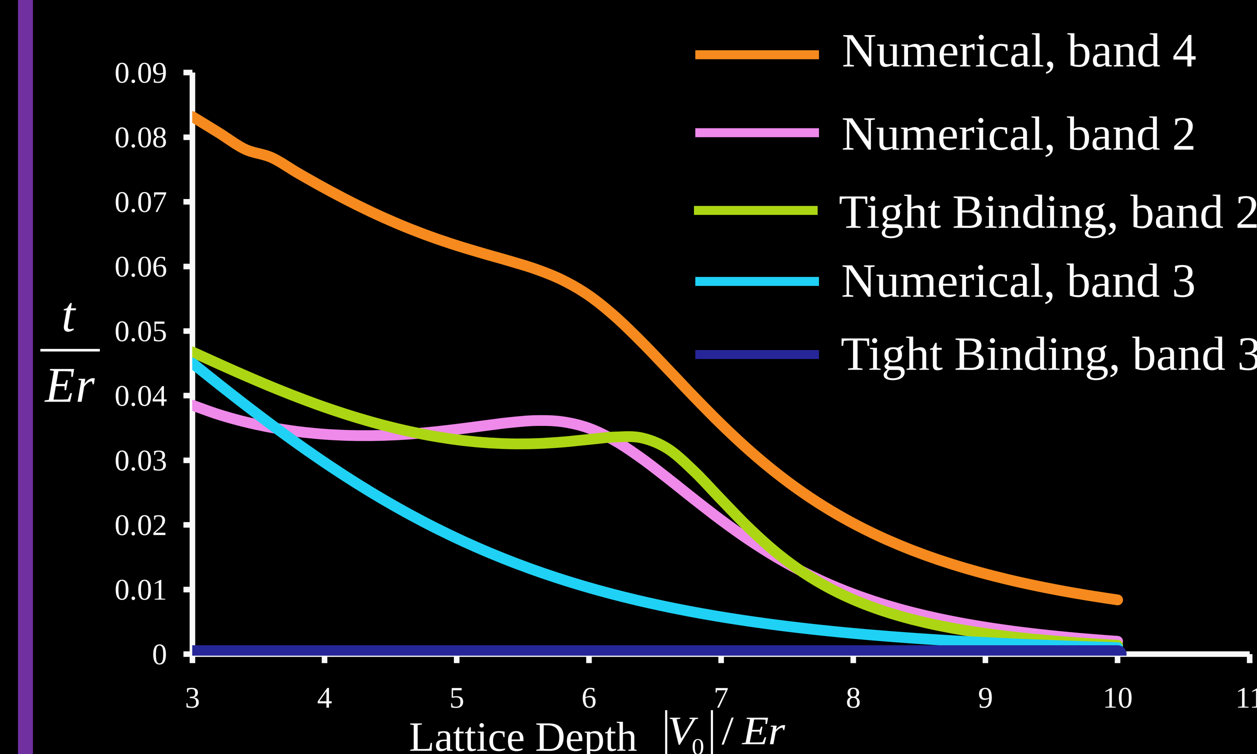


Estimate of the band structure (in units of E-recoil) in the plane-wave basis



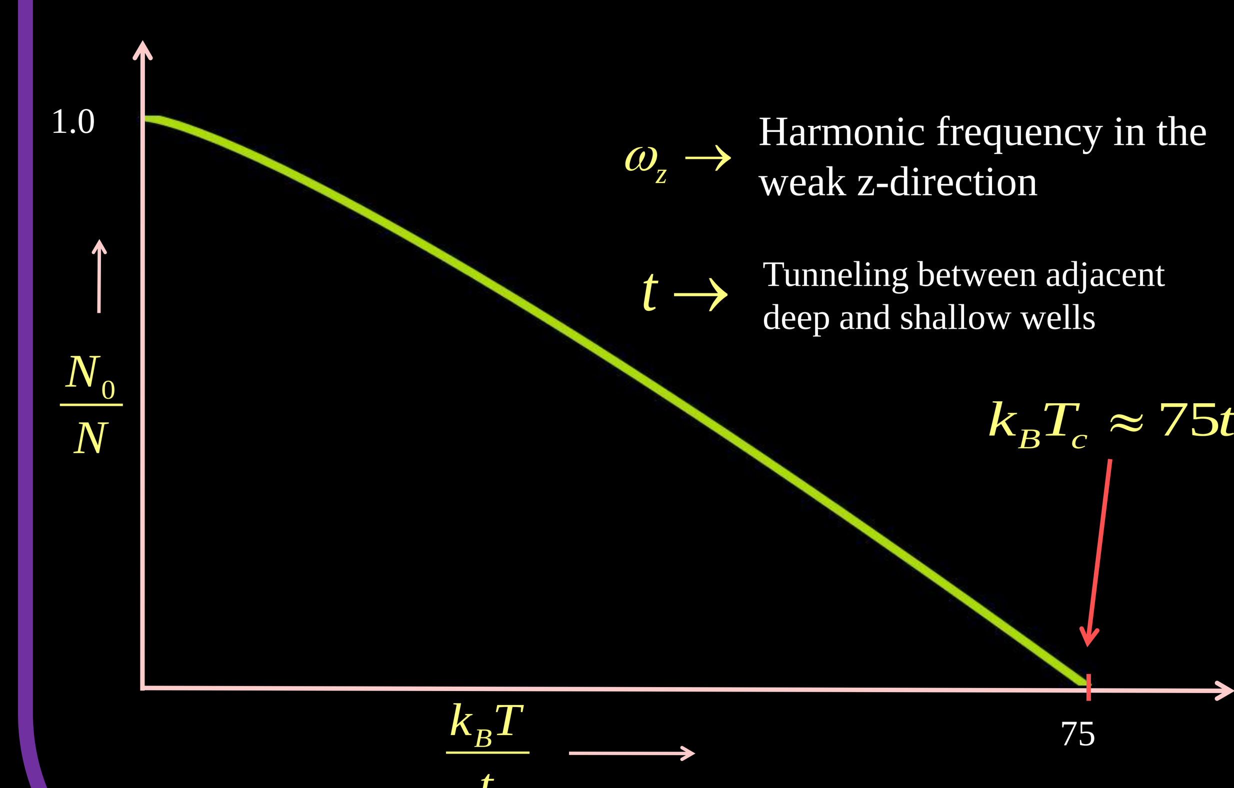
Second, third and fourth energy bands as a function of the 2D quasi-momenta

Nearest Neighbor Hopping (in units of recoil energy)

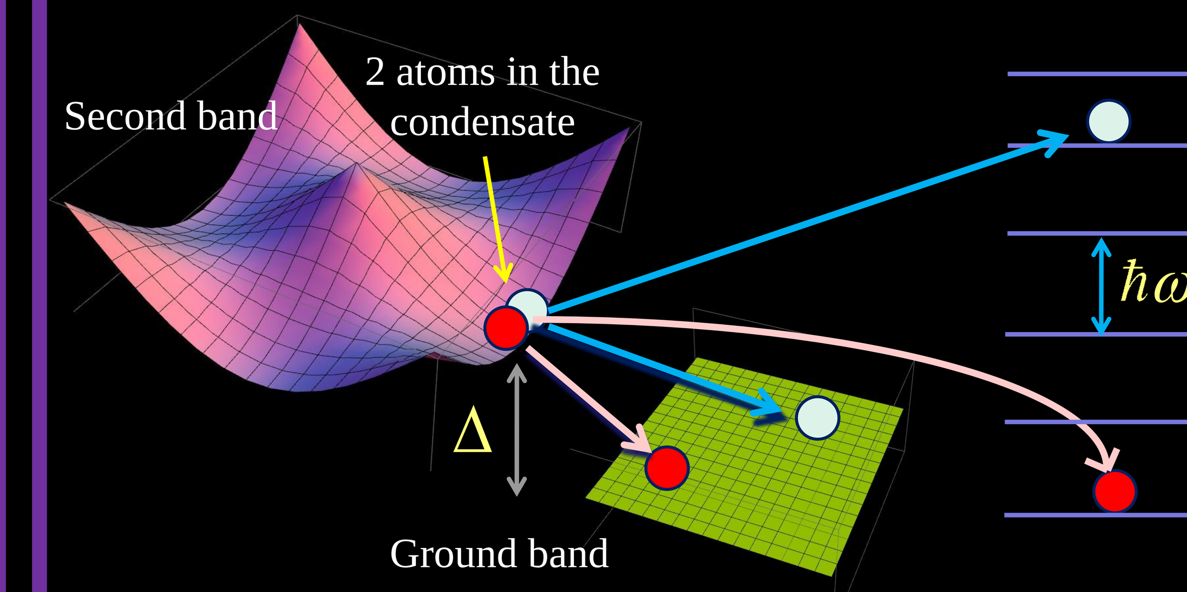


Thermodynamics of the non-interacting gas in the first excited band

We determined the fraction of atoms in condensate vs temperature:



Lifetime of the condensate- decay to the ground band due to collisions



The dominant term

Lifetime of the condensate

Here we present our estimate for the decay rate Γ

$$\Gamma = \frac{\pi^{3/2}}{4}\frac{|V_0|}{\hbar}\left(\frac{a_s}{a}\right)^2 n^2 \frac{1}{\sqrt{\Delta/\hbar\omega_z}} \ll t/\hbar$$

Scattering length; # of atoms per lattice site; Lattice depth; Lattice constant; Band gap; Harmonic frequency in the weak z-direction

For typical numbers:

$n = 200, \Delta/\hbar\omega_z = 10{,}000, |V_0| = 6Er$

$\&\ a_s/a = 1/100$, $1/\Gamma \approx 280ms$

Summary

- Theoretically analyzed the formation of BEC in the excited state of a double well optical lattice, at the edge of the first and second BZ.
- One of the dominant decay process involves collision between atoms to the lower band and the decay rate is smaller than the intersite hopping rate.