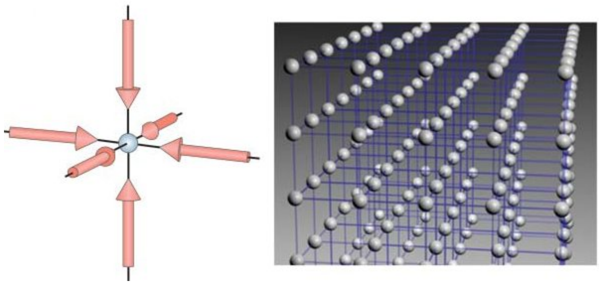
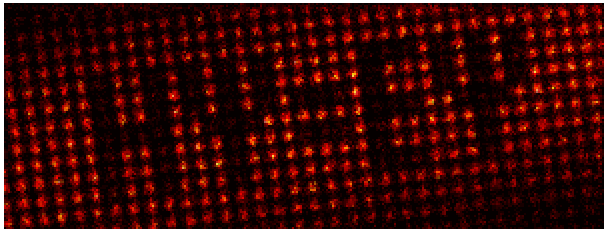
Condensed Matter from Ultracold Atoms: Optical Lattices

- Optical lattices are a laboratory "quantum simulation" of condensed matter systems: they are a combination of overlapping laser beams ("crystal lattice"), which trap ultracold atoms (corresponding to electrons in solids)



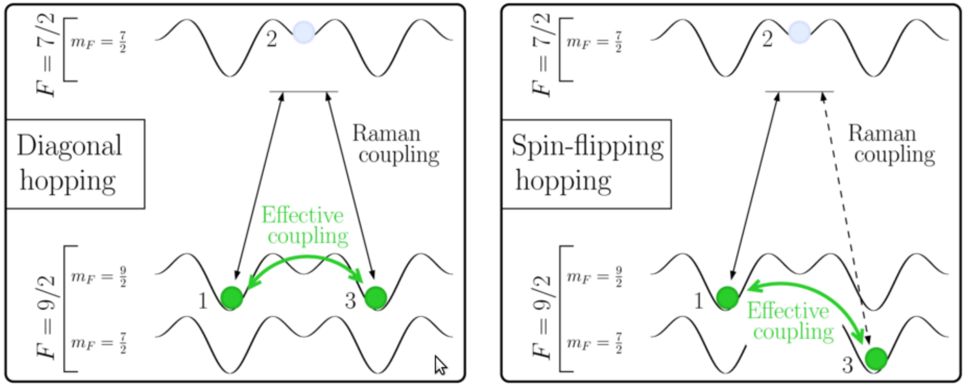
I. Bloch, Nature Phys. 1, 23 (2005)



Würtz et al., Phys. Rev. Lett. 103, 00404 (2009)

Advantages

- Precisely tunable (lattice spacing, depth, interaction, …)
- Highly customizable (lattice geometry: 1D, 2D, 3D, square-like, triangular, …)
- Both bosonic and fermionic realizations are possible (different quantum statistics)



Mazza et al., New J. Phys. 14, 015077 (2012)

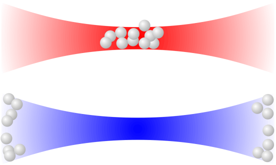
Engineering Spin-changing Hopping

- Work with deep lattices – no unassisted hopping.
- Couple neighboring lattice sites through Raman laser pairs.
- Realize an effective spinful Hamiltonian.

Experimental realizations of (an)isotropic optical lattices

Neutral atoms in the external electromagnetic (laser) field:

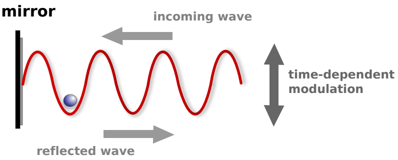
- dipole potential: $V_{dip} = \dfrac{\hbar\Omega_R^2\delta}{\delta^2 + \Gamma_e^2/4}$



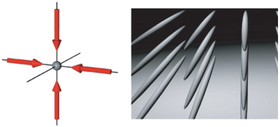
red detuning
$\delta < 0$

blue detuning
$\delta > 0$

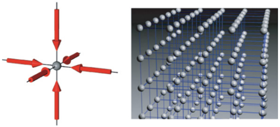
- standing wave (1d lattice):



- 2d lattices:



- 3d lattices:



I. Bloch *et al.*, Rev. Mod. Phys. **80**, 885 (2008) [arXiv link].

- anisotropic lattices:

using different laser intensities in different directions

M. Endres *et al.*, Science 334, 200 (2011) [arXiv link].
J. Krauser *et al.*, preprint (2012) [arXiv link].