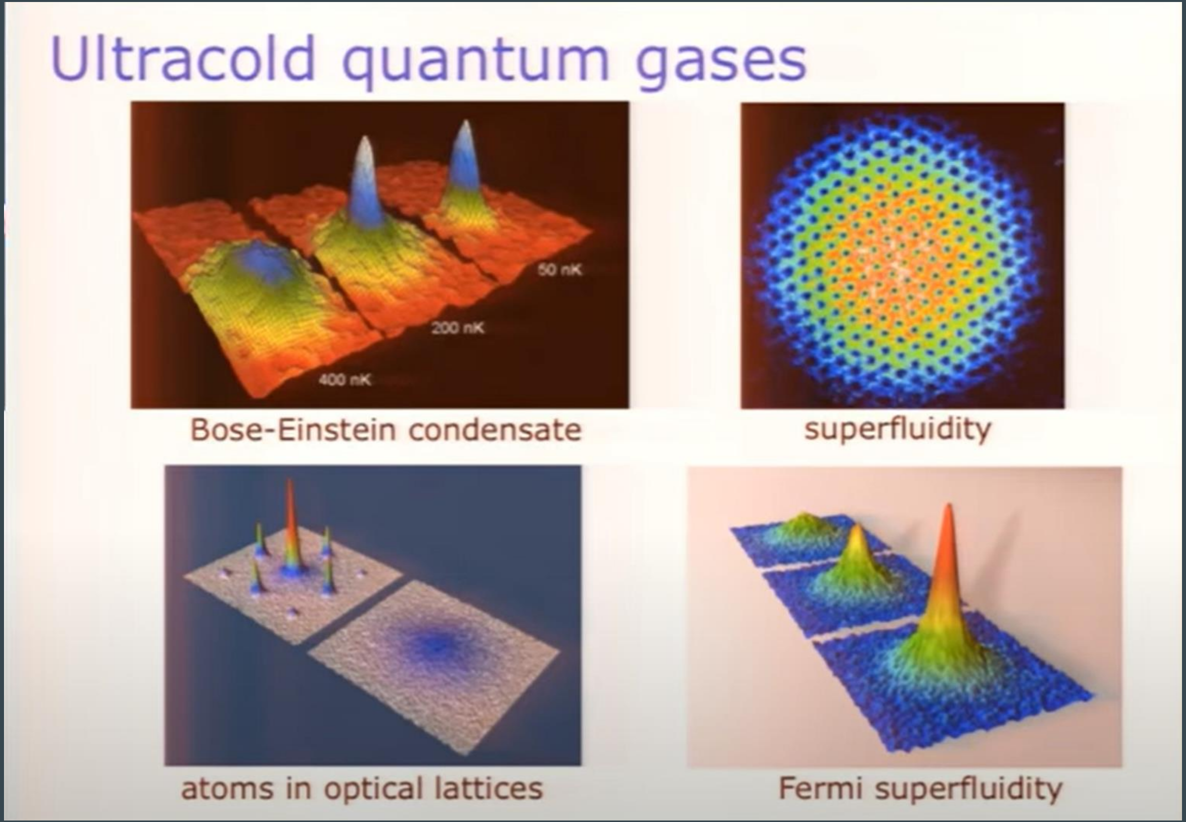
Ultracold atoms

By Sonia Seif

But why should we cool down atoms?



Some applications of ultra cold gases

- # ACCURATE MEASUREMENT

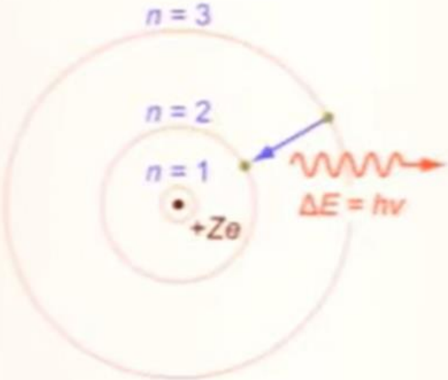
- Measuring energy or frequency levels is DIFFICULT at Finite Temperatures(room temperature)

Technological Applications

- Quantum Sensing:
- Quantum Computers
- Quantum Simulators

Quantum atoms?

The quantum atom



The Bohr model: quantum rules set allowed electron orbits

matter wavelength

$$\lambda_{deBroglie} = \frac{h}{mv}$$

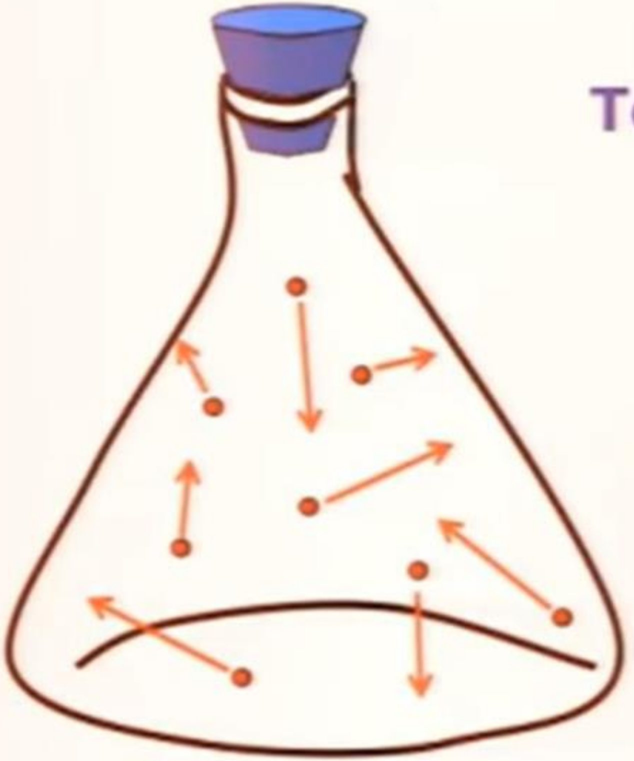
In the quantum atom, the electrons follow quantum rules.

In a quantum gas, the atoms follow quantum rules.

This requires that $\lambda_{deBroglie} \sim d$

where d is the typical distance between identical particles.

A gas of atoms

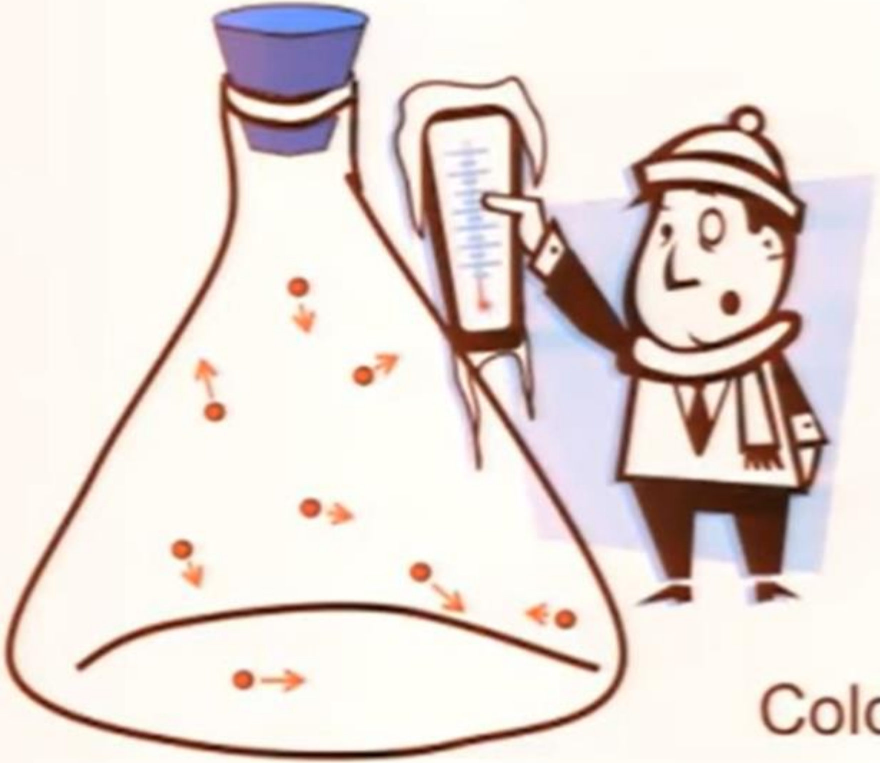


Temperature ⟺ **Kinetic Energy**

$$\frac{1}{2}k_B T = \frac{1}{2}mv^2$$

At T=300 K, $\lambda_{deBroglie} \approx 0.3a_0$

A ultracold gas of atoms



T = 100 nK

Cold atoms move very slowly!

At T=100 nK, $\lambda_{deBroglie} \approx 20{,}000 a_0$

Creating Ultra Cold Gases

Scattering of ultracold atoms

interaction between low-energy (ultracold) atoms and other particles or fields

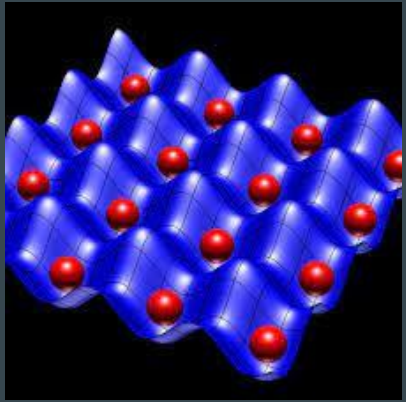
- Elastic and Inelastic
- Scattering Length: he effective range of the interatomic interactions an be positive (attractive interactions), negative (repulsive interactions), or even resonant (strong interactions at specific energies).
- Feshbach Resonances

Feshbach resonances

a phenomenon observed in ultracold atom systems, where the scattering properties of atoms can be dramatically modified by applying an external magnetic or optical field.

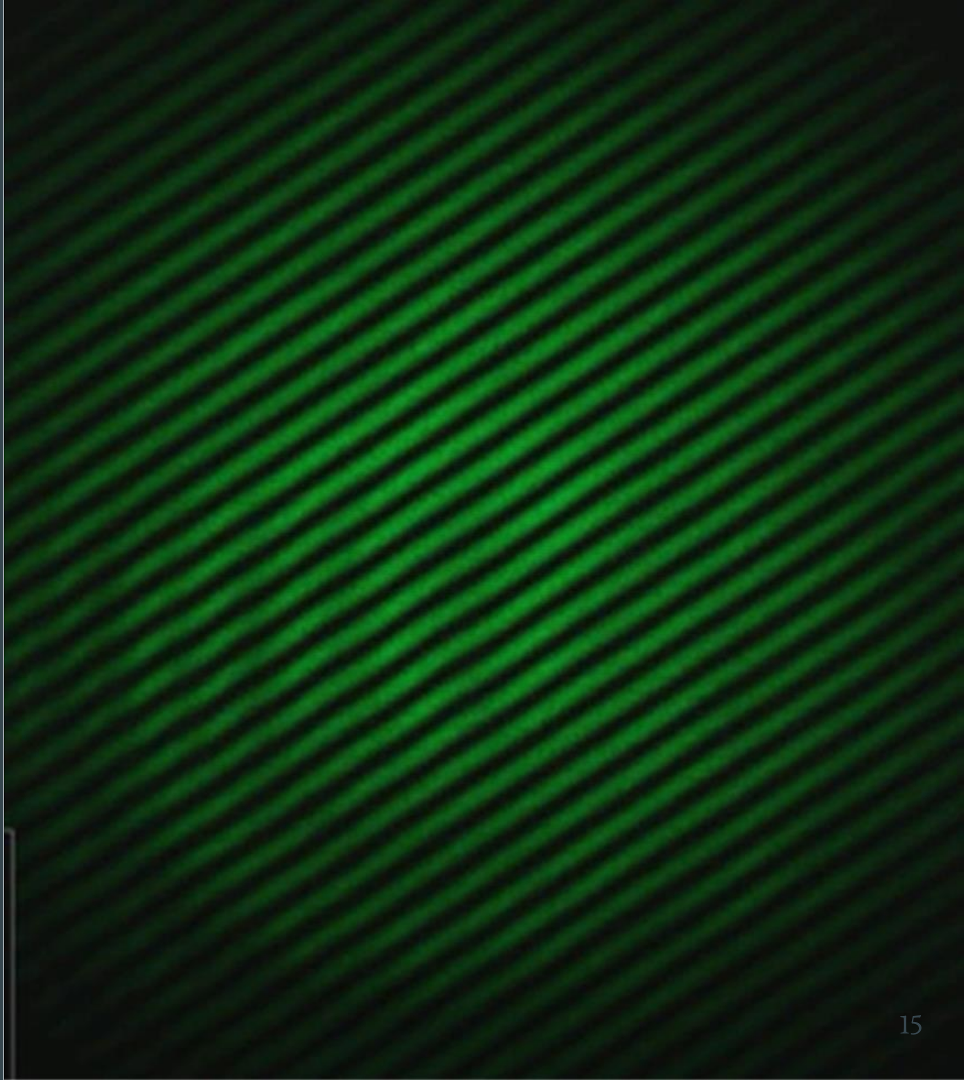
But how to work with them?

optical lattices



optical lattices

1D



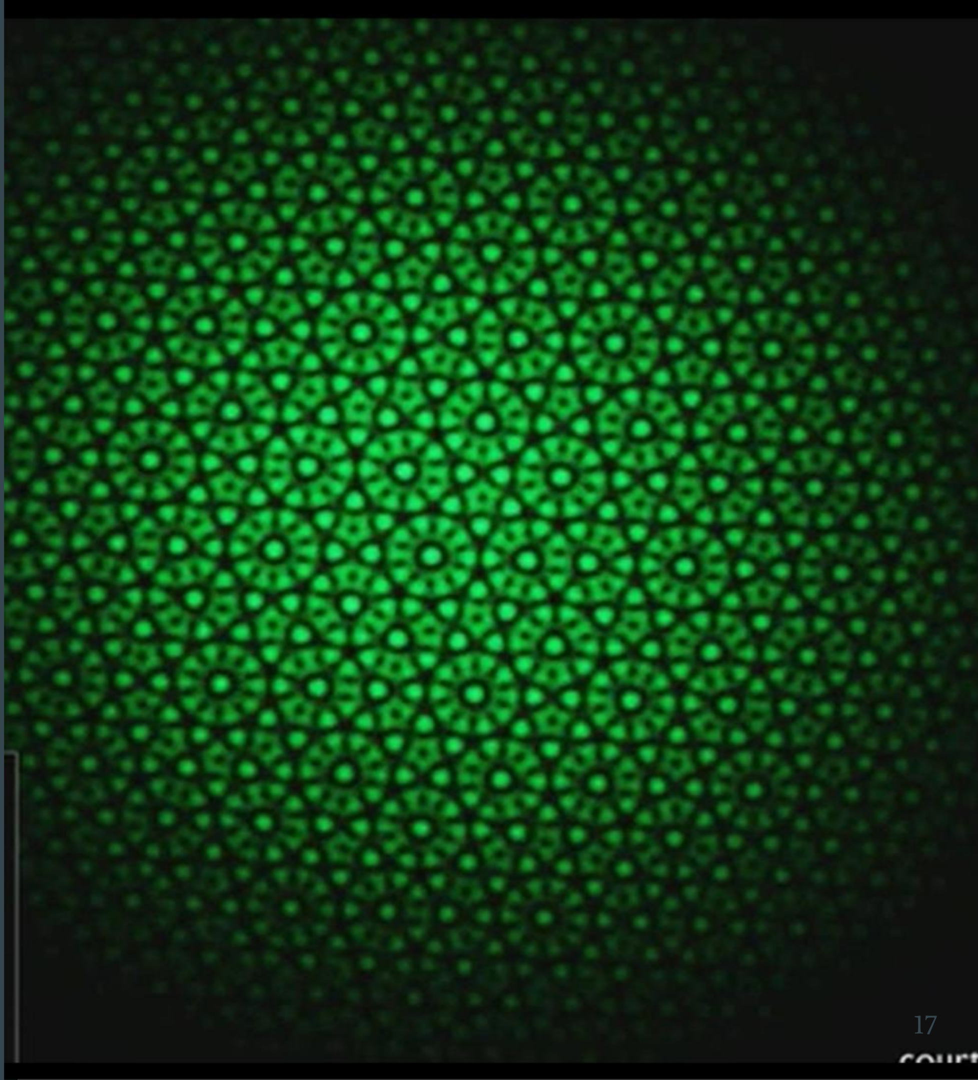
optical lattices

3D

optical lattices

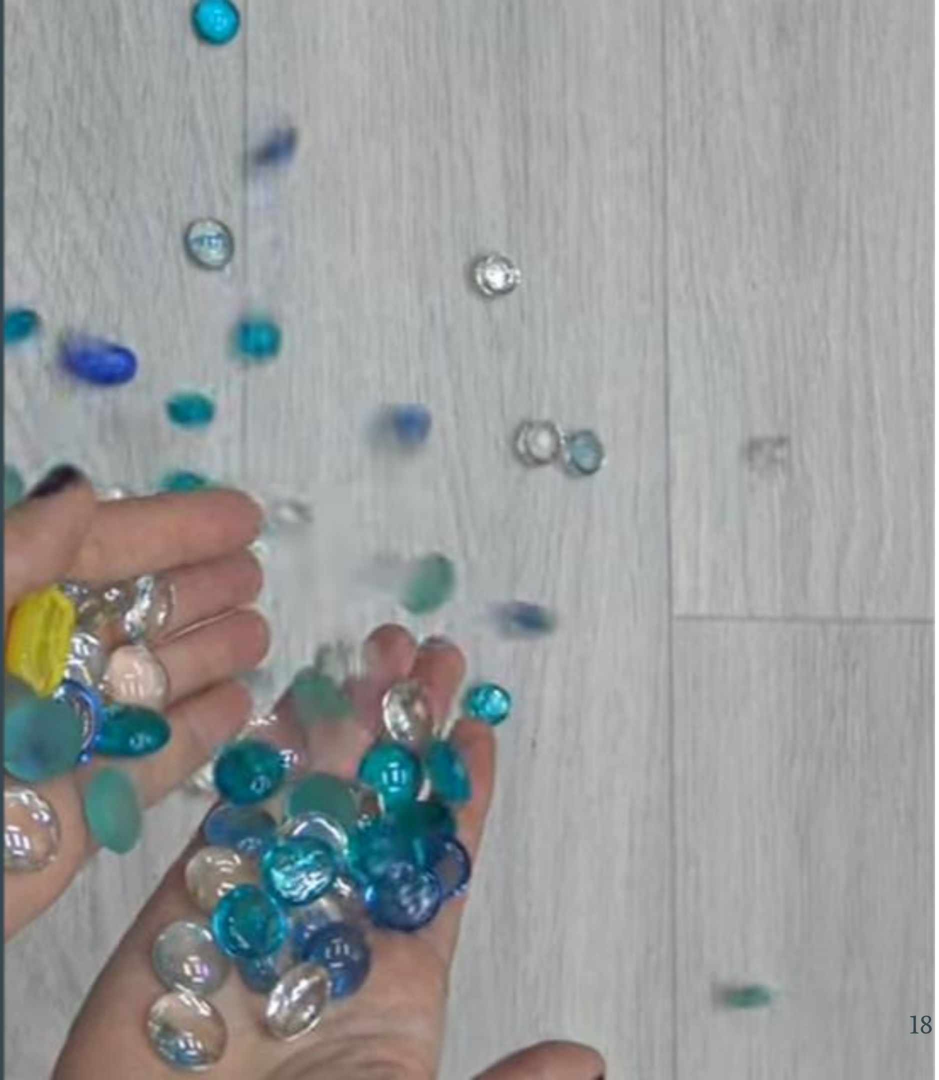
5D

interference of counter-propagating laser beams, creating a spatially periodic polarization pattern.



optical lattices

Simplified



Two important factor when dealing with optical lattices

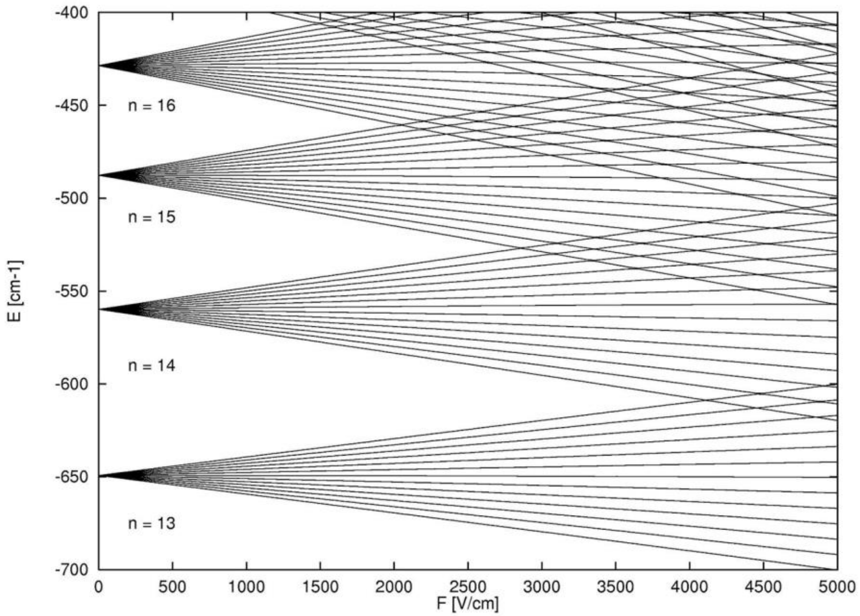
- potential well depth
- periodicity.

Dipole force

$$\mathbf{F} = \frac{1}{2}\alpha(\omega_L)\,\nabla\left[|\mathbf{E}(\mathbf{r})|^2\right]$$

- polarizability
- time-averaged intensity

=Stark shift + light field



Atoms are thus attracted to the nodes or to the antinodes of the laser intensity

A spatially dependent intensity profile I(r), therefore, creates a trapping potential for neutral atoms.

$$V_{\mathrm{dip}}(\mathbf{r}) = \frac{3\pi c^2}{2\omega_0^3}\frac{\Gamma}{\Delta}I(\mathbf{r}),$$

$$V_{\mathrm{dip}}(r,z) \approx -V_{\mathrm{trap}}[1 - 2(r/w_0)^2 - (z/z_R)^2].$$

Potential well depth

$$V(r,z) \simeq -V_0 e^{-2r^2/w^2(z)} \sin^2(kz), \qquad (35)$$

where $k=2\pi/\lambda$ is the wave vector of the laser light and V_0 is the maximum depth of the lattice potential. Note

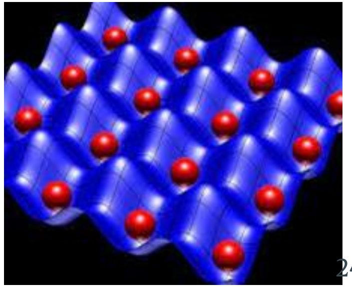
- The depth of an optical lattice potential well refers to the energy difference between the bottom of the potential well and the surrounding potential barrier
- determines the strength of the trapping potential
- depth of an optical lattice potential well can range from a fraction of a microkelvin to a few millikelvin in terms of energy

periodicity

$$V(r,z) \simeq -V_0 e^{-2r^2/w^2(z)} \sin^2(kz), \qquad (35)$$

where $k=2\pi/\lambda$ is the wave vector of the laser light and V_0 is the maximum depth of the lattice potential. Note

- can be described by the lattice spacing
- lattice spacing is typically on the order of the wavelength of the laser light used to create the lattice
- depends on the specific geometry and configuration of the lattice



Potential of well
Vs
Atoms energy

- Conductor
- Insulator(Mott insulator phase)
- antiferromagnetic(fermionic atoms)