Bose Einstein Condensates

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Outline of Talk

- Motivation
- Derivation
- Exploration
  - Production
  - Uses

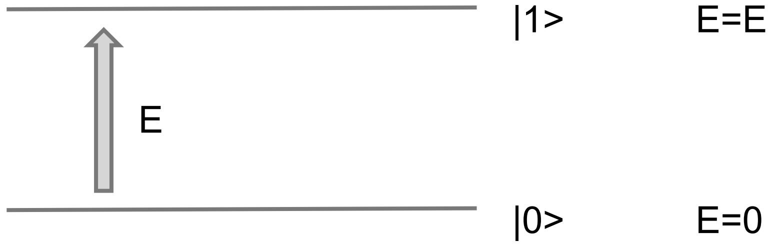
Motivation

- Unique macroscopic physical state dominated by quantum mechanics

- Experimental usefulness
  - probing quantum phenomena
  - High-accuracy measurements of fine structure constant

Overview of Derivation

- N non-interacting gas of bosons
- 2 level system: states |0> , |1> for each boson
- Assume energy of |0> is less than |1>



Overview of Derivation

Distinguishable Particles: 2^N possibilities
Indistinguishable Particles: N+1 possibilities

K bosons in state |1> implies N-K in |0>

Overview of Derivation

Each K is a quantum state with unique energy, so it is associated with a boltzmann probability

$$P(K) = Ce^{-EK/T} = C\left(e^{-E/T}\right)^{K} = Cr^{k}$$

Overview of Derivation

$$1 = \sum_{K=0}^{N} C r^k \rightarrow C^{-1} = \sum_{0}^{N} r^k \rightarrow C = (1-r)$$

$$< n(K) > = \sum_{K=0}^{N} (1-r) K r^k \rightarrow \sum_{K=0}^{N=\infty} (1-r) K r^k = \frac{r}{1-r}$$

$$= \frac{e^{-E/T}}{1-e^{-E/T}} < \infty$$

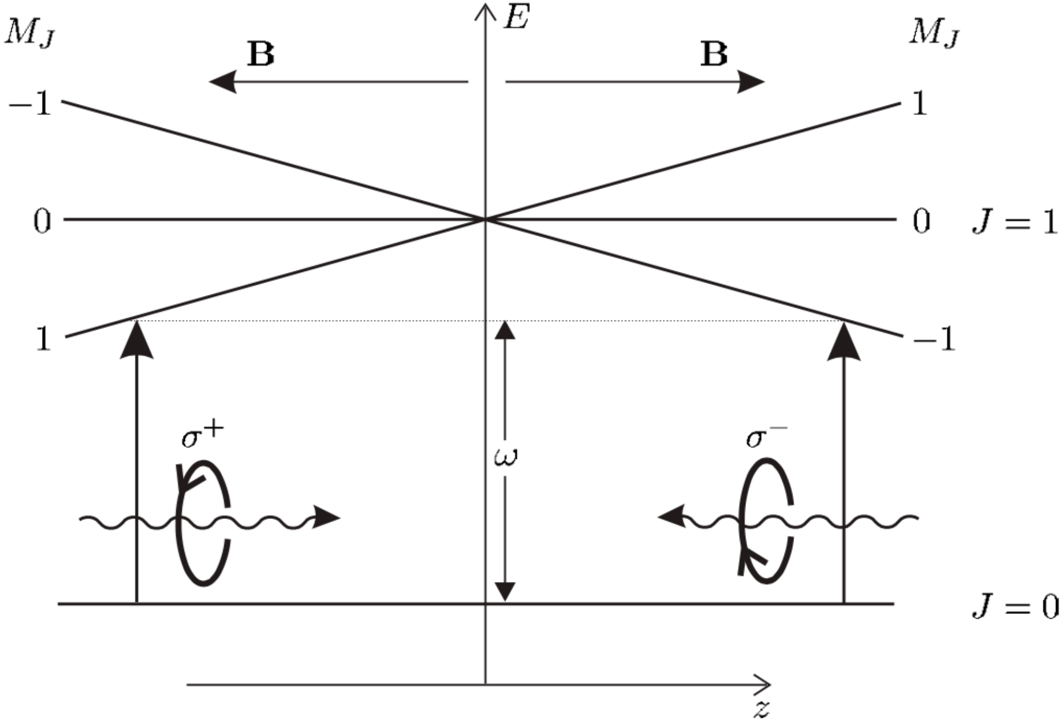
Physical intuition

Thermal deBroglie Wavelength

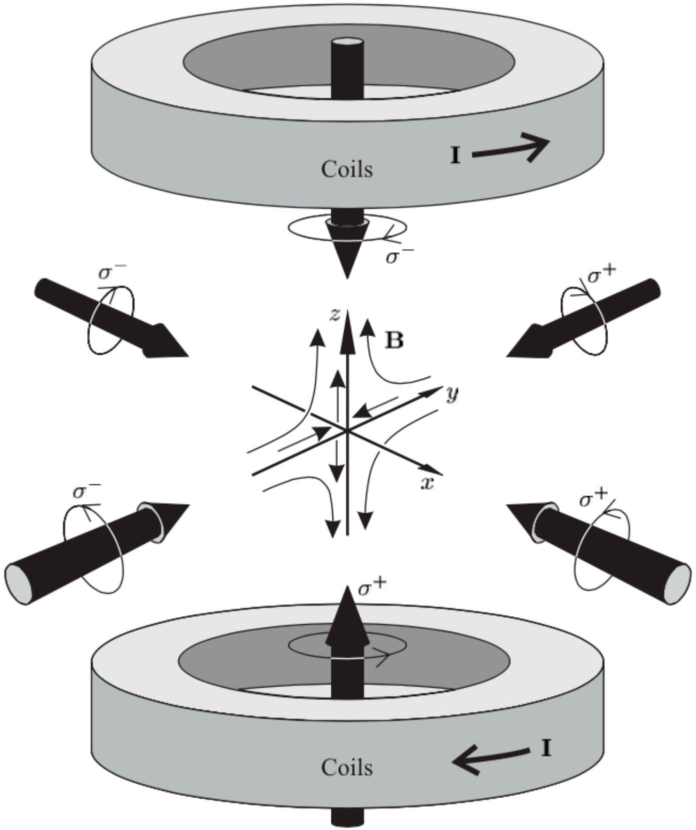
$$\lambda = \left(\frac{2\pi\hbar^2}{mk_bT}\right)^{1/2}$$

Condensation occurs approximately when the wavelength is longer than the mean free path. In reality this is in the nK.

Production



M_J
E
M_J
B
B
-1
1
0
0
$J = 1$
1
-1
σ^+
ω
σ^-
$J = 0$
z



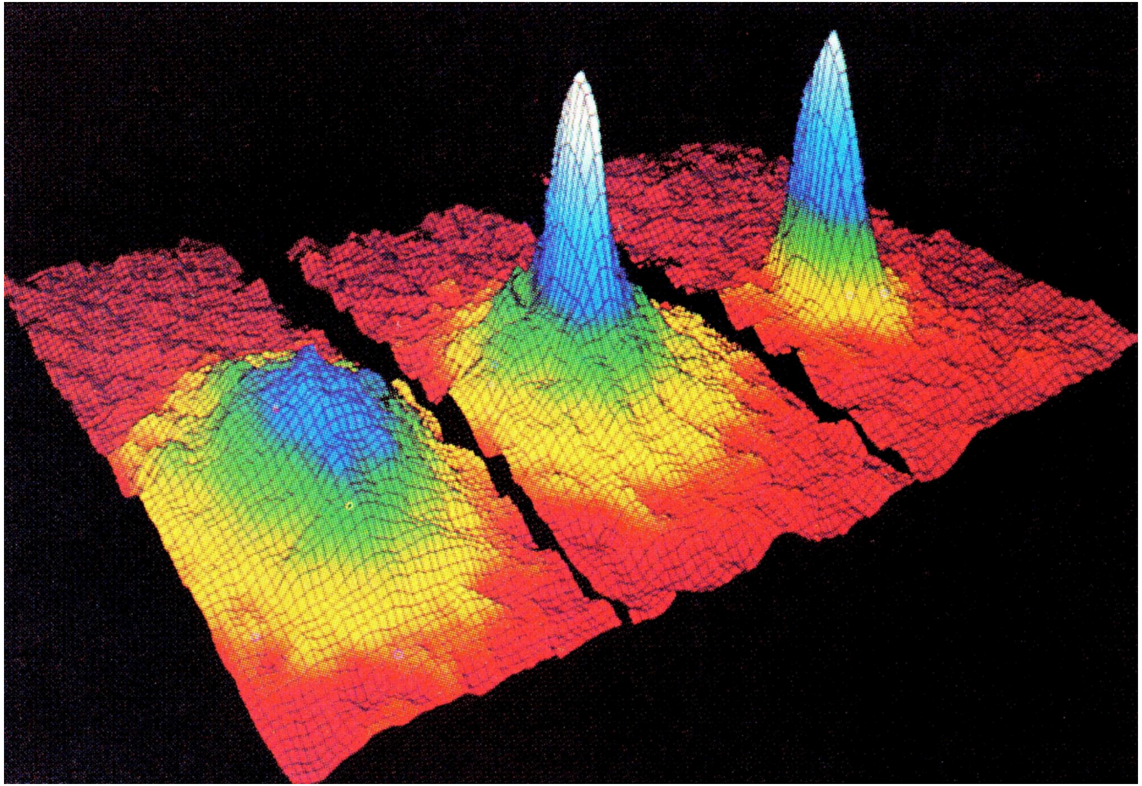
Coils
I
σ^-
σ^-
σ^+
z
B
y
x
σ^-
σ^+
σ^+
Coils
I

Experimental Evidence/Discovery

1995: Rb 87

Nobel Prize

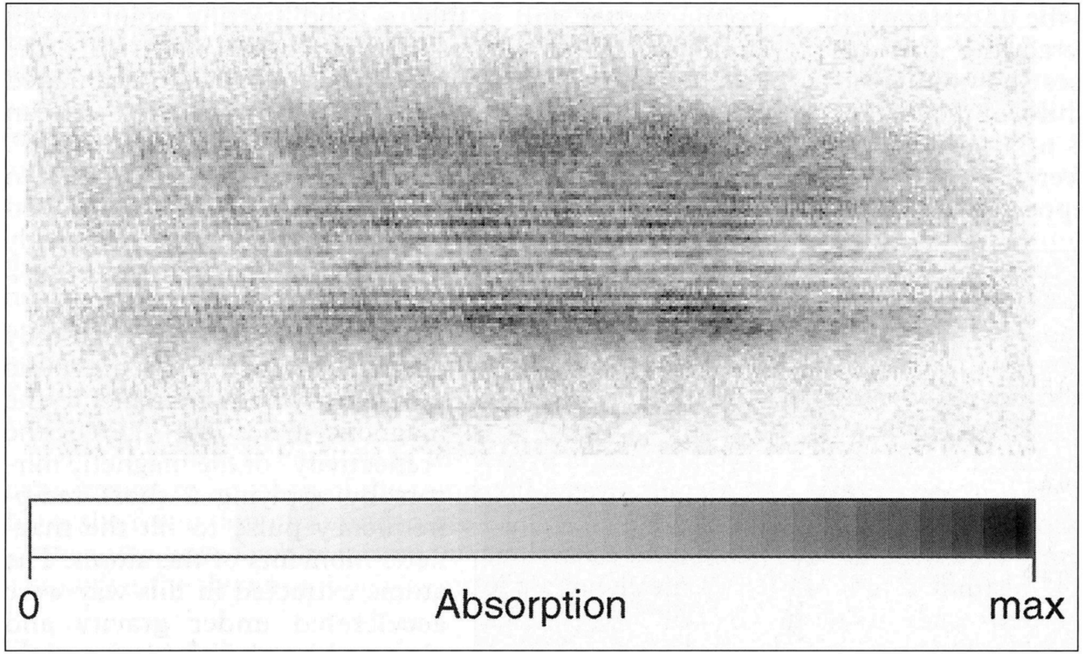
Ground state
is x=y=0



Matter interferometry

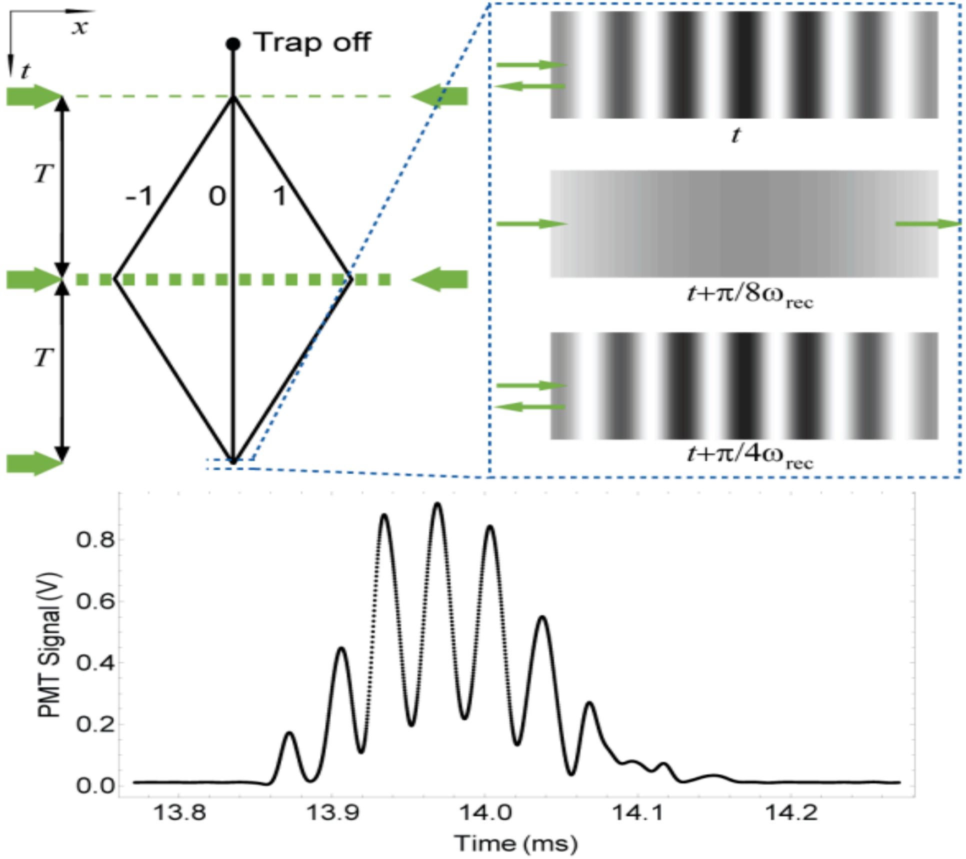
Two colliding BEC’s with a large phase difference

Shadows capture the interference patterns



Current Work Here!

Ytterbium gas interferometry



Matter interferometry

- Wavelength of interference pattern related to the fine structure constant.
- Resolution high enough to compete with current measurements, aiding in experimental verification of QED

Other Phenomena

- Quantum Vortices can be sustained, Quantum Hydrodynamics/Turbulence can have experimental verification/falsification outside of superfluid helium

- Lattice of BEC’s with optical trap, useful in condensed matter research
  - “negative temperature” material

- Quantum information

Citations

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