Physics 452 – Quantum Optics and Quantum Gases

Class information: https://ultracold.uchicago.edu/phys_courses

Chin Lab at the University of Chicago

Ultracold atomic and molecular physics

Home » Courses/Outreach » Physics Courses

Autumn 2017 P452

Physics 45200 Quantum Optics and Quantum Gases

Time: MW 09:00 -10:20 am

Office hour: TuTh 11am–12pm
Classroom: KPTC 105
Lecturer: Cheng Chin, echin@uchicago.edu
Website: http://ultracold.uchicago.edu

Quantum Gases

Wk01 09/25 M 9.00~10.20 The holy grail – Bose-Einstein condensation
Wk01 09/27 W 9.00~10.20 Quantum gas vs. normal gas HW1
Wk02 10/02 M 9.00~10.20 Atomic s-wave interactions
Wk02 10/04 W 9.00~10.20 Weakly interacting BEC: Gross-Pitaevski equation HW2
Wk03 10/09 M 9.00~10.20 Bogoliubov transformation
Quantum Gases
Wk01 09/25 M 9:00~10:20 The holy grail – Bose-Einstein condensation
Wk01 09/27 W 9:00~10:20 Quantum gas vs. normal gas HW1
Wk02 10/02 M 9:00~10:20 Atomic s-wave interactions
Wk02 10/04 W 9:00~10:20 Weakly interacting BEC: Gross-Pitaevski equation HW2
Wk03 10/09 M 9:00~10:20 Weakly interacting BEC: Bogoliubov transformation
Wk03 10/11 W 9:00~10:20 Cold collisions and Feshbach resonances HW3
Wk04 10/16 M 9:00~10:20 Strongly interacting gas: Bosons vs. Fermions
Wk04 10/18 W 9:00~10:20 Lab Tour
Wk04 10/23 M 9:00~10:20 Ultracold molecules
Wk05 10/25 W 9:00~10:20 Optical lattices HW4
Wk06 10/30 M 9:00~10:20 Presentations 1 + Midterm
**Physics 452 – Quantum Optics and Quantum Gases**

**Quantum Optics**
- Wk06 11/01 W 9:00~10:20 Inelastic and elastic (Rayleigh) scattering HW5
- Wk07 11/06 M 9:00~10:20 Light shifts and dressed atom picture
- Wk07 11/08 W 9:00~10:20 Precision measurements HW6
- Wk07 11/10 F 9:00~10:20 Coherent states and squeezed states
- Wk08 11/13 M 9:00~10:20 Photon entanglement HW7
- Wk08 11/15 W 9:00~10:20 **No Class**
- Wk08 11/20 M 9:00~10:20 Quantum teleportation
- Wk09 11/22 M 9:00~10:20 Cavity QED
- Wk09 11/27 M 9:00~10:20 Quantum computation HW8
- Wk09 11/29 W 9:00~10:20 Presentations 2 + Final

**Evaluation**
- Problem sets 40%
- Midterm 20%
- Final 20%
- Final paper/presentation 30%
Presentations

Quantum gas
- Creation of a Bose-condensed gas by laser cooling: arXive: 1705.03421

Quantum optics
Supporting texts

**Quantum gases:**
- Bose-Einstein Condensation in Dilute Gases by C. J. Pethick and H. Smith
- Bose-Einstein Condensation by L. Pitaevskii, S. Stringari

**Review papers:**
- Theory of Bose-Einstein condensation in trapped gases, RMP 71 463 (1999)
- Theory of ultracold atomic Fermi gases, RMP 80 1215 (2008)
- Many-body physics with ultracold gases, RMP 80 885 (2008)
- Feshbach resonances in ultracold gases, RMP 82 1225 (2010)

**Quantum optics:**
- Quantum Optics by M. Scully and S. Zubairy
- Mesoscopic Quantum Optics by Y. Yamamoto and A. Imamoglu
- Quantum Optics by D. F. Walls and G. J. Milburn
- Electromagnetic Noise and Quantum Optical Measurements by Hermann A. Haus

**Review papers:**
- Continuous-variable optical quantum-state tomography: RMP 81 299 (2009)
- Linear optical quantum computing with photonic qubits: RMP 79 135 (2007)
Phase space density

Classical mechanics:
# of particle in a unit phase space

\[ \phi = NP(E_0) = n\lambda_{dB}^3 \sim Ne^{-H(x,p)/kT}(dx dp / \hbar)^3 \]

Quantum Mechanics:
# of particle in the ground state

High Temperature T:
- Thermal velocity \( v \)
- Density \( d^{-3} \)
- "Billiard balls"

Low Temperature T:
- De Broglie wavelength \( \lambda_{dB}=h/mv \propto T^{-1/2} \)
- "Wave packets"

\( T=T_C: \)
- BEC
  - \( \lambda_{dB} \approx d \) 
  - "Matter wave overlap"

\( T=0: \)
- Pure Bose condensate
  - "Giant matter wave"
Which experiment really prove Bose-Einstein condensation?
Non-interacting BEC and Fermi gas
Interacting gas

Many-body approach

\[ H(x_1, x_2...x_N, p_1, p_2...p_N)\psi(x_1, x_2...x_N) = E\psi(x_1, x_2...x_N) \]

\[ H = \sum_i \frac{\hat{p}_i^2}{2m} + \hat{V}(x_i) + \sum_{i<j} V(|x_i - x_j|) \]

Mean field approach: introduce one more particle in the system

\[ H(x, p)\phi(x) = \mu\phi(x) \]

\[ H = \frac{p^2}{2m} + \hat{V}(x) + g \frac{N}{V} \]

\[ \psi(x) = \sqrt{N}\phi(x) \]

\[ \mu = \frac{\partial E}{\partial N} \quad g : \text{coupling constant} \]

Gross-Pitaevskii Equation:

\[ \left( \frac{p^2}{2m} + \hat{V}(x) + g |\psi|^2 \right)\psi = \mu\psi \]