1. General remarks.

Many-body physics course not AMO

Traditional many-body physics is driven by experimental puzzles and discoveries.
In this course the driving force will be experiments in cold atoms (unlike solids)

Prerequisites

Quantum mechanics (second quantization)
Statistical mechanics (bosons vs. fermions)
A little bit of electrodynamics.

Seminar course. Urge questions and discussions.

Requirements

Homeworks. A presentation in the second part of the semester on some advanced topic not covered in class.
AMO and Many-Body Physics

Developments:

1924 Bose - statistics of photons
1925 Einstein - excitation to massive particles - Bose-Einstein condensation

1938
• Kapitza + Allen and Hilsen -
  - observation of superfluidity in He³

• London suggested there is a connection with superfluidity and Bose-Einstein condensation

1941 Tisza & then Landau:
  Two fluid model for superfluidity

1946 N. Bopoliubov - quantitative theory for weakly interacting Bose gas. Explained a lot of phenomenology by Landau

1972 Superfluidity in He³, Orrin Lee Richardson

1985 Chu, Phillips and Cohen-Tannoudji
  Laser cooling technique. "Euuu.

http://www.colorado.edu/physics/2000/bec/lascool1.html

1986 Evaporative cooling: Kleppner,
  Greiner, HESS (applied to hydrogen)

http://www.colorado.edu/physics/2000/bec/evap_cool.html
Cold atoms vs. conventional condensed matter systems: similarities & differences

1) Cold atoms are isolated (or almost isolated) from environment. This means that their dynamic & static properties are entirely governed by Hamiltonians with only internal degrees of freedom.
In conventional systems there are always other degrees of freedom (e.g. phonons), which are hard to take into account.

Despite the seeming simplicity of these systems, they yield lots of interesting and complicated phenomena.

"More is different"  P.W. Anderson

Two-particle problems are well studied and well understood.

Three-particle problems cannot be generally solved and require very elaborated methods to be dealt with.

Many-particle problems—new approaches and methods are required.
2) Microscopic Hamiltonians for cold atoms are very well known (usually). This means that one does not need, generally, any fitting parameters to compare theory & experiment. 

3) The cold atoms systems are usually tunable. One can change the ratio of interaction and kinetic energies by orders of magnitudes during a single experiment. To achieve a similar effect in solid state systems one often has to prepare a different (but not always same) sample.

4) The cold atoms systems are usually disorder free, there are no defects. It is quite challenging and not always possible to have very clean solid state systems (though there are some exceptions: 2DEG semiconducting graphene).

Shortcomings:
1) Measurements are very limited in variety and usually destructive. Every new measurement is a new experiment.

2) These systems are in the metastable regime (the true equilibrium state will be a solid), hence they have only a finite life time.

In many occasions the advantages overcome these limitations and open new and exciting ways to explore many-particle phenomena.

Alkali atoms: easy to cool by laser cooling technique.
Total number of fermions (protons, neutrons and electrons) is \( A + Z \)
\( Z \) is always odd =)

= 1: A odd = particles are bosons &
A even = particles are fermions.

\([\text{8}^8\text{Be}, \text{2}^{23}\text{Na}, \text{7}^7\text{Li}] \) - Bosons
\([\text{6}^{6}\text{C}, \text{6}^6\text{Li}] \) - Fermions
Need to go to very low densities $n \sim 10^{15} / \text{cm}^3$ (solids $\sim 10^{20} / \text{cm}^3$) in order to avoid triple collisions and to very low temperature.

Criterion for condensation:

De Broglie wave length should be comparable to the particle separation,

$$\lambda \sim \frac{\hbar}{\sqrt{2mE}} \sim n^{-1/3}$$

Take $E \sim kT$

$$\lambda \sim \frac{\hbar}{\sqrt{m kT}} \sim n^{-1/3} \sim \frac{\hbar}{m k}$$

Take $R \approx 87$ atoms

$$T \sim \frac{10^{-55}}{10^7} \cdot \frac{10^7}{10^{-27} \cdot 10^3 \cdot 10^2 \cdot 10^{-16}} \sim 10^{-7} \text{ K} \sim 100 \text{ mK}$$

These are the typical temperatures required to observe condensation.

Problems 1.2 & 1.3 from Bechhoefer and Smith.