IIT Mandi
Proposal for a New Course

Course number : PH607
Course Name : Physics of Ultracold Quantum Gases
Credit Distribution : *3-0-0-3*
Intended for : UG/PG/I-PhD/PhD elective
Prerequisite : PH301/PH513 (Quantum Mechanics), PH522 (Statistical Mechanics), PH524/EP403(Physics of Atoms and Molecules)
Mutual Exclusion : None

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1. Preamble:

With the expanding interest in harnessing quantum science and technology, the main goal of this course is to introduce the basic concepts and fundamentals related to the recent research directions in the field of ultracold atoms, including the ones that investigate fundamental physical problems and those in which highly controllable superfluids are used as quantum simulators of other complex systems.

Students will learn the basic tools and acquire competence to be able to read and understand scientific papers dealing with these topics and in general with the physics of quantum gases and liquids. At the end of the series of lectures, students are expected to have a broad knowledge on many topics that are currently studied worldwide using quantum gases. They will have a hands-on experience of numerically solving Gross-Pitaevskii equation to obtain equilibrium and non-equilibrium solutions, and interpretation of the results.

2. Course Modules with quantitative lecture hours:

(a) The ideal Bose gas **[6 Hours]**

The Bose Einstein condensation in ideal Bose gases, Off-diagonal long-range order, Transition temperature and condensate fraction, velocity distribution, Thermodynamic quantities

(b) Manipulation of atomic internal and external degrees of freedom **[6 Hours]**

Level structure and atomic transitions of alkali-metal atoms, Atom-field interaction, Cooling, trapping and imaging ultracold gases

(c) Atom-atom interaction **[4 Hours]**

Contact interaction, scattering length, Feshbach resonances, Dipolar long-range interactions

(d) Bose-Einstein condensates (BEC) **[12 Hours]**

Condensation and Gross-Pitaevskii equation (GPE) for the macroscopic wave function, BEC dynamics in uniform and trapped configurations; Thomas-Fermi approximation, Hydrodynamic equations, Elementary excitations, BEC as simulator of quantum vacuum effects(Hawking radiation and Casimir effect), collapse and supersolidity with dipolar quantum gases

(e) Atomic mixtures **[7 Hours]**

Coupled GPE, spin waves, phase diagram, Josephson effect and magnetism, Quantum droplets

(f) Lower dimensional systems as solid-state quantum simulators **[7 Hours]**

Phase fluctuations, Mermin-Wagner-Hohenberg theorem, optical lattices, Bose-Hubbard model, Entanglement and correlations.

3. Text books:

1. Atomic Physics; C.J. Foot (Oxford University Press, 2005)
2. Bose-Einstein condensation in dilute gases; C.J. Pethick and H. Smith (Cambridge University Press, 2008)

4. References:

1. M. Ueda, Fundamentals and New Frontiers of Bose-Einstein Condensation, World Scientific Publishing Company 2010.
2. Lev Pitaevskii and Sandro Stringari, Bose-Einstein Condensatio, and Superfluidity, Oxford Science Publication, 2016
3. F. Dalfovo, S. Giorgini, Lev P. Pitaevskii, and S. Stringari, Theory of Bose-Einstein condensation in trapped gases, Rev. Mod. Phys. 71, 463 (1999)

5. Similarity with the existing courses:

(Similarity content is declared as per the number of lecture hours on similar topics)

S. No.	Course Code	Similarity Content	Approx. % of Content
1.	EP403	4 Hours	10%

6. Justification of new course proposal if cumulative similarity content is >30%: NA