Bose-Einstein Condensation with Attractive Interaction: Fate of a False Vacuum

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Among the species that have Bose-condensed, lithium 7 and rubidium 85 form unique condensates in that the interactions between the atoms are predominantly attractive. The emphasis of my talk will be put on some novel features of these new states of matter that are distinguished from those of other species with repulsive interactions.

In a spatially uniform system, bosons with attractive interaction are believed not to undergo Bose-Einstein condensation (BEC) because they tend to collapse upon itself. When they are spatially confined, the zero-point kinetic pressure dynamically stabilizes the gas phase and allows BEC to be formed in a metastable state. However, as the number of condensate bosons N_0 increases, the dynamical barrier decreases and the system becomes absolutely unstable at a certain critical number, N_c. When N_0 is close to but below N_c, the system exhibits the density instability with the collective-mode frequency vanishing according to the one-fourth power law of $1 - N_0/N_c$. When N_0 is in the immediate vicinity of its criticality, the barrier becomes so low that the system may collapse via macroscopic quantum tunneling [1].

When N_0 exceeds N_c, a variational study suggests the collapse of the entire BEC. However, a field-theoretic analysis shows that the collapse occurs only locally inside the region of what we call "black hole" [2]. Inside the "black hole" the density becomes so high that the atoms undergo inelastic collisions and drain out of the trap. In Rice experiments [3], there are abundant above-condensate atoms which replenish the lost atoms. We may therefore expect collapse-and-refill cycles of BEC to occur in the experiments. Macroscopic quantum tunneling and thermal-assisted tunneling also induce the collapse of BEC, and the ensuing refilling of the condensate atoms from the thermal gas again leads to the collapse-and-refill cycles of BEC. It is likely that all of these contribute to the dynamics of this system, which is quite complex and certainly merits further experimental and theoretical study.

Recently, a JILA group has succeeded in making a large ^{85}Rb BEC with repulsive interaction, and then suddenly switching the sign of the interaction to attractive via the Feshbach resonance. Such a large BEC with attractive interaction is shown to exhibit two remarkable collapsing dynamics: intermittent implosion and shell-structure formation in the density distribution of atoms [4].

The attractive interaction also drastically changes the nature of superfluidity and its topology through hybridization of the condensate over different single-particle states. Hybridization destabilizes superfluidity and leads to a modification in their response to rotation, esp. in the quantization of circulation [5].

The alkali BECs have internal degrees of freedom associated with the hyperfine spin. These degrees of freedom are frozen in a magnetic trap, but are liberated in an optical trap, where BEC is formed in a superposition of magnetic sublevels. In the spin-1 BEC of sodium atoms, the repulsive interaction between antiparallel spins is weaker than the repulsive interaction between parallel ones, leading to an effective attractive interaction between the antiparallel spins. The resulting formation of the spin-singlet structure and the hybridization between single-particle spin states will be discussed [6].

References

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