Excitations in Bose-Einstein condensates revisited

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We report new theoretical predictions for an interacting single-component Bose-Einstein condensate, which may change standard viewpoints on the system substantially.

Widely accepted results for the system may be summarized as follows. (i) Single-particle excitations can be described by the Bogoliubov mode with a linear dispersion and infinite lifetime at low energies; (ii) the Bogoliubov mode is also identical with the sound wave in the two-particle channel; (iii) it is the Nambu-Goldstone mode of broken $U(1)$ symmetry. On the other hand, there has been no reliable approximation schemes for the system that satisfies Goldstone's theorem and conservation laws simultaneously.

Recently, we have established a definite procedure to construct such approximations systematically to express the thermodynamic potential in a unique Luttinger-Ward form. According to this theory, each of the above statements should be modified as follows.[1] (i) The excitation in the single-particle channel is *not* the Bogoliubov mode *but* a bubbling mode with a finite lifetime even at low energies; (ii) the poles of the two-particle Green's function are *not* shared with those of the single-particle one, i.e., the two modes are different in character; (iii) the two distinct modes in the single- and two-particle Green's functions correspond to two different proofs of Goldstone's theorem by Goldstone *et al.* These qualitative changes originate from a new class of Feynman diagrams for the self-energy that has been overlooked so far, which is shown to modify the Lee-Huang-Yang correction for the ground-state energy.

[1]T. Kita, Phys. Rev. B **80**, 214502 (2009); *ibid.* **81**, 214513 (2010); J. Phys. Soc. Jpn. **80**, 084606 (2011).

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