Rotons in a Bose-Einstein condensate

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One of the most striking features of the prototypical superfluid, helium II, is the peculiar 'roton' minimum in its excitation spectrum [1]. Feynman's [2] celebrated formula for the excitation spectrum $\mathcal{E}(k)$ of a quantum fluid

$$\mathcal{E}(k) = \frac{\hbar^2 k^2}{2mS(k)}$$

interprets this minimum as arising from a *peak* in $S(k)$, the static structure factor. $S(k)$ is a second order correlation function containing information about the degree of atom-atom correlation in the fluid. Thus, the roton minimum tells us that there is a high degree of correlation in superfluid helium. It is this large atom-atom correlation which is responsible for its distinctive superfluid properties.

Gaseous Bose-Einstein condensates (BECs) on the other hand are very weakly correlated because they are so dilute with respect to the range of the interatomic interactions (the s-wave scattering length). A roton minimum is therefore absent from the excitation spectrum of a conventional BEC [3].

However, it is possible to enhance the interactions in a BEC using external electromagnetic fields. We consider the effects of slightly polarising an atomic BEC using a far off-resonant laser. The resulting retarded dipole-dipole interaction can be very long-range (with terms decaying only as 1/r)—in contrast to the usual very short range van der Waals type interactions found in the BECs which have been realised in the laboratory thus far. We predict that these retarded dipole-dipole interactions are capable of introducing strong correlations between the atoms in a gaseous BEC and suggest a scheme by which a roton minimum might be realised in these systems—allowing one to effectively tune (e.g. via laser intensity) an atomic BEC between being a weakly correlated quantum gas and a strongly correlated quantum fluid.

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