The meaning of superfluidity for polariton condensates

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Since its first discovery in 1937 in liquid 4-Helium, several definitions have been proposed to summarize in simple but precise terms the ever surprising phenomenon of superfluidity [1]. Among the most important definitions, one can mention the absence of drag force onto a slowly moving object through the fluid, the gyroscopic rigidity in the fixed stars frame (the so-called Hess-Fairbank effect), the metastability of supercurrents, and the absence of response to a transverse gauge field.

Remarkably, for most systems at (or close to) thermal equilibrium such as liquid Helium and ultracold atoms, all these criteria agree in defining whether a specific system is superfluid or not, and superfluidity appears to be linked in a quite tight way to Bose-Einstein condensation. The situation is completely different for intrinsecally non-equilibrium objects such as exciton-polariton condensates: in this case, no complete consensus exists so far between the different definitions, and the concept of superfluidity still remains very elusive.

In our contribution we shall try to illustrate recent progress in the theoretical analysis of the different aspects of polariton superfluidity, and we shall try to summarize which issues can be considered in our opinion as understood and which ones are still open.

Most of our discussion will be focussed on the so-called Landau criterion, which defines superfluidity in terms of the perturbation created in the fluid by a weak and uniformly moving defect: in traditional systems at equilibrium, no drag force appears if the speed of the object is lower than the speed of sound.

The consequences of such a criterion on resonantly pumped polariton systems have been investigated in [2], and the results seem to quite agree with the physical expectations: regimes of well-developed superfluidity have been identified, as well as regimes where peculiar Čerenkov patterns can be observed in both the near- and the far-field emission patterns. New results for realistic finite-spot geometries will be presented and the prospects towards experimental observations discussed.

The situation seems more complicate when non-resonantly pumped condensates are considered: the diffusive nature of the BEC Goldstone mode [3–5] fixes the Landau critical velocity to zero, still the drag force suddenly drops to almost zero when the speed of the defect drops below a non-vanishing critical value [6]. We shall show how a suitable generalization of the Landau criterion is able to solve this apparent contradiction.

We shall conclude by reviewing the directions we plan to explore in the next future and the prospects towards a unified theory of non-equilibrium superfluidity.

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