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Time-Dependent Dynamics of Fermionic Superfluids: from cold atomic gases, to nuclei and neutron stars

The fascinating dynamics of superfluids, often referred to as quantum coherence revealed at macroscopic scale, has challenged both experimentalists and theorists for more than a century now, starting with electron superconductivity discovered in 1911 by Heike Kamerlingh Onnes. The phenomenological two-fluid model of Tizsa and its final formulation due to Landau, is ultimately a classical approach in which Planck's constant never appears and it is unable to describe the generation and dynamics of the quantized vortices, which are the hallmark characteristics of superfluidity.
Various quantum mechanical phenomenological models have been developed over the years by London, Onsager, Feynman, Ginzburg and Landau, Abrikosov, and many others, but truly microscopic approaches are very scarce. The Gross-Pitaevskii equation was for many years the only example, but it is applicable only to a weakly interacting Bose gas at zero temperature and it has been used to describe the large variety of experiments in cold atomic Bose gases. In the case of fermionic superfluids only a time-dependent mean filed approach existed for a long time, which is known to be quite inaccurate. With the emergence of the Density Functional Theory and its time-dependent extension it became relatively recently possible to have a truly microscopic approach of their dynamics, which proves to be extremely relabel in predicting and describing various experimental results in cold atomic fermionic gases, nuclei and which can be used as well to make predictions about the nature and dynamics of vortices in the neutron star crust. I will describe the time-dependent superfluid local density approximation, which is an adiabatic extension of the density functional theory to superfluid Fermi systems and their real-time dynamics.
This new theoretical framework has been used to describe/predict a range of phenomena in cold atomic gases and nuclear collective motion: excitation of the Higgs modes in strongly interacting Fermi superfluids, generation of quantized vortices, crossing and reconnection of vortices, excitation of the superflow at velocities above the critical velocity, excitation of quantum shock waves, domain walls and vortex rings in superfluid atomic clouds, and excitation

of collective states in nuclei. This approach is the natural framework to describe in a time-dependent framework various low energy nuclear reactions and in particular large amplitude collective motion and nuclear fission and the numerical implementation of this formalism requires the largest supercomputers available to science today.

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