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Genesis of a density functional with no free parameter for nuclei and cold atoms: From unitary gas to neutron matter

A density functional theory is proposed for strongly interacting fermions with arbitrary large negative scattering length. The functional is firstly designed to reproduce the universal properties of unitary gas: the so-called "Bertsch parameter" ξ_0 and a parameter η_e related to the possible influence of the effective range r_e at infinite scattering length a. Using most recent quantum Monte-Carlo (QMC) estimates of these two parameters, it is shown that the functional properly reproduces the experimental measurements of interacting Fermi systems not only at unitarity but also away from this limit over a wide range of $(ak_F)^{-1}$ values. The new functional is applied to obtain an expression of the Tan's contact parameter including the effect of r_e. Application is finally made to neutron matter. The functional is shown to be predictive up to densities ~ 0.01 fm^{-3} and reproduces well states of the art QMC results. Starting from the functional, density–dependent scales are introduced. It is shown that the scales associated to the bare interaction are strongly renormalized by medium effects. As a consequence, some of the scales at play around saturation are dominated by the unitary gas properties and not directly to low-energy constants. For instance, we show that the scale in the s-wave channel around saturation is proportional to the so-called Bertsch parameter ξ_0 and becomes independent of a_s. At saturation density, these scales are of the same order of magnitude than those empirically obtained in the Skyrme energy density functional. Illustration of application to the study of thermodynamic and dynamic of quantum Fermi liquids will be given.

[1] D. Lacroix, Phys. Rev. A 94, 043614 (2016)
[2] D. Lacroix, A. Boulet, M. Grasso, & C.-J. Yang, Phys. Rev. C 95, 054306 (2017)
[3] M. Grasso, D. Lacroix, & C. J. Yang, Phys. Rev. C 95, 054327 (2017)

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