COMPOSITE PARTICLES IN MEDIUM — EFFECTS OF SUBSTRUCTURE*

Simon Liebing

Institute of Theoretical Physics, TU Bergakademie Freiberg, Freiberg, Germany

David Blaschke

Institute of Theoretical Physics, University of Wrocław, Wrocław, Poland
and
Bogoliubov Laboratory of Theoretical Physics, JINR, Dubna, Russia
and
National Research Nuclear University (MEPhI), Moscow, Russia

(Received April 26, 2017)

The role of phase-space occupation effects for the formation of two- and three-particle bound states in a dense medium is investigated for systems with short-range interactions. While for two-fermion bound states due to the Pauli blocking in a dense medium the binding energy is reduced and vanishes at a critical density (Mott effect), for three-fermion bound states, it is shown to be nonzero and positive. Therefore, beyond the Mott density of the two-fermion bound state, three-fermion bound states can exist in a medium and, therefore, be denoted as the in-medium Borromean states.

DOI:10.5506/APhysPolBSupp.10.921

In strongly coupled systems where the interaction saturates at short distances, the effects of phase-space occupation (Pauli blocking and Bose enhancement) are dominating medium effects. They can be nicely discussed in the algebraic Lipkin model [1] by generalising it for fermion–boson pairs (composite fermions) as compared to boson–boson pairs [2]. The problem of stability of three-particle bound states in dense matter is interesting for applications like the dissociation of baryons in dense quark/nuclear matter [3–6] and to fermionic atoms in traps [7].

---

* Presented at the "Critical Point and Onset of Deconfinement" Conference, Wrocław, Poland, May 30–June 4, 2016.

In the present note, we discuss the case of composite fermions in medium by considering the phase-space occupation factor that results from the Matsubara summation in the intermediate propagation in the N-particle T-matrix approach. The N-particle T-matrix in ladder approximation fulfils the Bethe–Goldstone equation

$$T_N = V_N + V_N G_N^0 T_N = V_N \left(1 - V_N G_N^0\right)^{-1} , \qquad (1)$$

were V_N is the interaction potential and G_N^0 is the free N-particle Greens function in which the phase-space occupation effects become apparent. Let us examine the case of 2-particle and 3-particle states. The free two-fermion propagator in medium depends on the bosonic Matsubara frequency $\Omega_{12} = \omega_1 + \omega_2$ and is obtained by performing the Matsubara summation over ω_1

$$G_2^0(\Omega, e_1, e_2) = \sum_{\omega_1} \frac{1}{\omega_1 - e_1} \frac{1}{\Omega_{12} - \omega_1 - e_2} = \frac{Q_{12}}{\Omega_{12} - e_{12}} . \qquad (2)$$

The energy denominator has a pole at $\Omega_{12} = e_{12} = e_1 + e_2$ and in the numerator occurs the phase-space occupation (Pauli blocking) factor $Q_{12} = 1 - f_1 - f_2$ with the Fermi functions $f_i = [\exp(e_i/T) + 1]^{-1}$. The free three-particle propagator is obtained by considering a pair of fermion and (composite) boson with the fermionic Matsubara frequency $\Omega_{123} = \Omega_{12} + \omega_3$

$$\begin{aligned} G_3^0(\Omega, e_1, e_2, e_3) &= \sum_{\omega_3} \frac{1}{\omega_3 - e_3} \frac{Q_{12}}{\Omega_{123} - \omega_3 - e_{12}} = \frac{(1 - f_3 + g_{12}) Q_{12}}{\Omega - e_{12} - e_3} \\ &= \frac{Q_{123}}{\Omega_{123} - e_1 - e_2 - e_3} , \end{aligned} \qquad (3)$$

where $Q_{123} = 1 - f_1 - f_2 - f_3 + f_1 f_2 + f_1 f_3 + f_2 f_3$ is the three-particle phase-space occupation factor and we have used the identity $g_{12}(1 - f_1 - f_2) = f_1 f_2$.

The in-medium Borromean property of three-fermion states can be seen in the simple example when $f_1 = f_2 = 0.5$, leading to a blocking of the two-particle state, $Q_{12} = 0$ (Mott effect). The three-particle state, however, has for the same case only a reduction of the effective coupling since $Q_{123} = 0.25 \neq 0$ [6], but can still be bound. In a next step, for a liquid of composite fermions such as nucleons, one obtains a weakly attractive boson exchange interaction that leads to fermonic superfluidity, as in nuclear matter [7].

This work was supported by the COST Action MP1304 "NewCompStar" and by the National Science Centre, Poland (NCN) under grant UMO-2011/02/A/ST2/00306. D.B. was supported in part by the MEPhI Academic Excellence Project under contract No. 02.a03.21.0005.

REFERENCES

[1] H.J. Lipkin, *Quantum Mechanics: New Approaches to Selected Topics*, North Holland, Amsterdam 1973.

[2] S. Liebing, D. Blaschke, *Phys. Part. Nucl.* **46**, 794 (2015).

[3] G. Röpke, D. Blaschke, H. Schulz, *Phys. Rev. D* **34**, 3499 (1986).

[4] M. Beyer, S. Mattiello, T. Frederico, H. Weber, *Phys. Lett. B* **521**, 33 (2001).

[5] E. Blanquier, *J. Phys. G* **38**, 105003 (2011).

[6] D. Blaschke, A. Dubinin, D. Zablocki, *PoS* **BaldinISHEPPXXII**, 083 (2015).

[7] K. Maeda, *Ann. Phys.* **326**, 1032 (2011).