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<td>Chien, CC; Guo, H; Levin, K</td>
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Comment on “Density and Spin Response of a Strongly Interacting Fermi Gas in the Attractive and Quasirepulsive Regime”

In Ref. [1], the authors summarize a linear response theory for Fermi gases undergoing Bardeen-Cooper-Schrieffer (BCS) to Bose-Einstein condensation (BEC) crossover. Invoking Popov theory, they include a rather complex set of diagrams on the basis of avoiding a divergence in the density response associated with noninteracting bosons. We wish to point out that repairing this divergence as they do above $T_c$ leads to violations of Ward identities or conservation principles. The essence of the Ward identity in question is the verification that the diamagnetic and paramagnetic contributions cancel to avoid an unphysical normal-state Meissner effect. Indeed, their previous work [2] implied that consistency was not yet established in their Popov-based approach; the authors indicated that in the last step of the program they would need to “modify the number equation to be consistent with the above approximation” for their self-energy diagrams. Although they did not specify the precise form of the self-energy $\Sigma_p$, the Supplemental Material in Ref. [1] suggested that there were no incompatibilities between the linear response vertex $\Lambda$ and $\Sigma_p$. Here we prove that this is not the case.

We confine our attention in this Comment to the attractive interaction regime which was considered by us in earlier work [3–7] to address a systematic theory of spin and charge interaction regime which was considered by us in earlier papers. As pointed out in textbooks [8], it is difficult using approximate methods to obtain the same answer for the compressibility from the static correlation function and the thermodynamic derivative. Although qualitative agreement with experiments is reported in Ref. [1], the theoretical inconsistencies addressed in this Comment should not be overlooked.

Chih-Chun Chien, Hao Guo, and K. Levin

1Theoretical Division
Los Alamos National Laboratory
MS B213, Los Alamos, New Mexico 87545, USA
2University of Hong Kong
Hong Kong 999077, China
3James Frank Institute and Department of Physics
University of Chicago
Chicago, Illinois 60637, USA

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The reason that this Ward identity cannot be respected is because the repeated AL diagrams will introduce factors of $2^n$ in the response vertex due to the two possible ways of connecting the two fermion propagators inside. In order to find consistency, it is essential to include diagrams of the MT or mixed MT and AL forms and thereby cancel these factors of $2^n$ which do not appear naturally in self-energy diagrams.

The consistency with a Ward identity is a crucial check of the gauge invariance of a theory. The reliability of any theory of transport in a many-body system needs to be built on this level of consistency. When there is such a violation, $f$ sum rules will not be satisfied. Moreover, an unphysical normal-state Meissner effect ensues, which implies a finite superfluid density above $T_c$. This Comment is intended to emphasize the key role played by sum rules and other conservation constraints in transport and scattering theories of Fermi gases, as we have repeatedly stressed in our papers [3–7]. As pointed out in textbooks [8], it is difficult using approximate methods to obtain the same answer for the compressibility from the static correlation function and the thermodynamic derivative. Although quantitative agreement with experiments is reported in Ref. [1], the theoretical inconsistencies addressed in this Comment should not be overlooked.
