New Journal of Physics
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Second sound and the density response function in uniform superfluid atomic gases

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New Journal of Physics **12** (2010) 043040 (24pp)
Received 7 January 2010
Published 22 April 2010
Online at http://www.njp.org/
doi:10.1088/1367-2630/12/4/043040

Abstract. Recently, there has been renewed interest in second sound in superfluid Bose and Fermi gases. By using two-fluid hydrodynamic theory, we review the density response $\chi_{nn}(\mathbf{q}, \omega)$ of these systems as a tool to identify second sound in experiments based on density probes. Our work generalizes the well-known studies of the dynamic structure factor $S(\mathbf{q}, \omega)$ in superfluid ^{4}He in the critical region. We show that, in the unitary limit of uniform superfluid Fermi gases, the relative weight of second versus first sound in the compressibility sum rule is given by the Landau–Placzek ratio $\epsilon_{\rm LP} \equiv (\bar{c}_p - \bar{c}_v)/\bar{c}_v$ for all temperatures below T_c. In contrast to superfluid ^{4}He, $\epsilon_{\rm LP}$ is much larger in strongly interacting Fermi gases, being already of order unity for $T \sim 0.8T_c$, thereby providing promising opportunities to excite second sound with density probes. The relative weights of first and second sound are quite different in $S(\mathbf{q}, \omega)$ (measured in pulse propagation studies) as compared with $\mathrm{Im}\chi_{nn}(\mathbf{q}, \omega)$ (measured in two-photon Bragg scattering). We show that first and second sound in $S(\mathbf{q}, \omega)$ in a strongly interacting Bose-condensed gas are similar to those in a Fermi gas at

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