Relaxation of phonons in a one-dimensional integrable bosonic system

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Ultracold bosonic atoms trapped on atom chips in the effective one-dimensional (1D) geometry offer an experimental realization of the celebrated quantum integrable Lieb-Liniger model, or, from the macroscopic point of view, its classical analog, the 1D non-linear Schrödinger equation. We demonstrate that the further relaxation of a prethermalized state established after a coherent splitting of a quasicondensate of \textsuperscript{87}Rb atoms and subsequent dephasing of elementary excitations [1] is consistent with the theory [2] that assumes only non-linear interactions in a classical-field integrable model and does not require any integrability-breaking effects. The physical reason for thermalization of phononic degrees of freedom in such a system is that the occupation numbers of the phonon modes are not the integrals of motion (the non-trivial integrals of motion being hardly experimentally measurable).

We show that the time dependence of the temperature $T(t)$ of the antisymmetric mode measured in the course of the relaxation from the prethermalized state to the thermal equilibrium is consistent with the theoretical expression:

$$\frac{T(t)}{T(\infty)} = \left\{ \left[ \frac{T(\infty)}{T(0)} \right] \exp \left[ -\frac{t}{\tau_T} \right] + 1 - \exp \left[ -\frac{t}{\tau_T} \right] \right\}^{-1},$$

where the scaling time

$$\tau_T = \kappa \hbar^3 n_{1D}^2 / \left( m [k_B T(\infty)]^2 \right)$$

does not depend on the speed of sound and depends on the equilibrium temperature $T(\infty)$ and the 1D number density $n_{1D}$ of atoms of the mass $m$; the numerical coefficient $\kappa \approx 0.72$ is not a fitting parameter, but is calculated \textit{ab initio}.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{figure1.png}
\caption{Relaxation time fitted using Eq. (1) from the experimental data (points) and its value predicted by Eq. (2) (dashed line) on the log-log scale. The shadowed area corresponds to the uncertainty of the number density $n_{1D} = (43\pm7) \text{ \mu m}^{-1}$.}
\end{figure}

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