Dynamics of a few interacting bosons escaping from an open well

Jacek Dobrzyniecki and Tomasz Sowiński

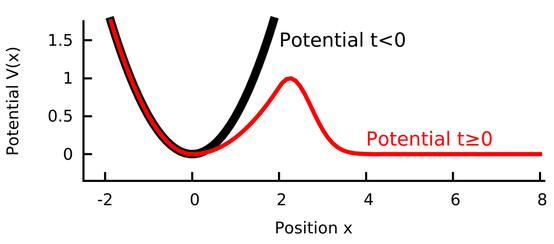
Few-Body Problems Theory Group
Institute of Physics of the Polish Academy of Sciences

Abstract

The dynamics of a few ultracold bosons tunneling from a one-dimensional potential well into an open space is studied. In such a system several decay channels can be distinguished, each corresponding to a different number of bosons escaping simultaneously. We show that as the interparticle interaction strength is changed, the system undergoes transitions between distinct regimes characterized by the dominance of different decay channels. These transitions are reflected in the behavior of the decay rate of the system, which is measurable experimentally. By means of a simple theoretical description, we show that the transitions occur at the points where a new decay channel becomes energetically viable. The results provide insight into the behavior of decaying few-body systems and may have potential interest for experiments.

The model

$$H = \sum_i \left[-\frac{\hbar^2}{2m} \frac{\partial^2}{\partial {x_i}^2} + V(x_i) \right] + g \sum_{i<j} \delta(x_i - x_j)$$

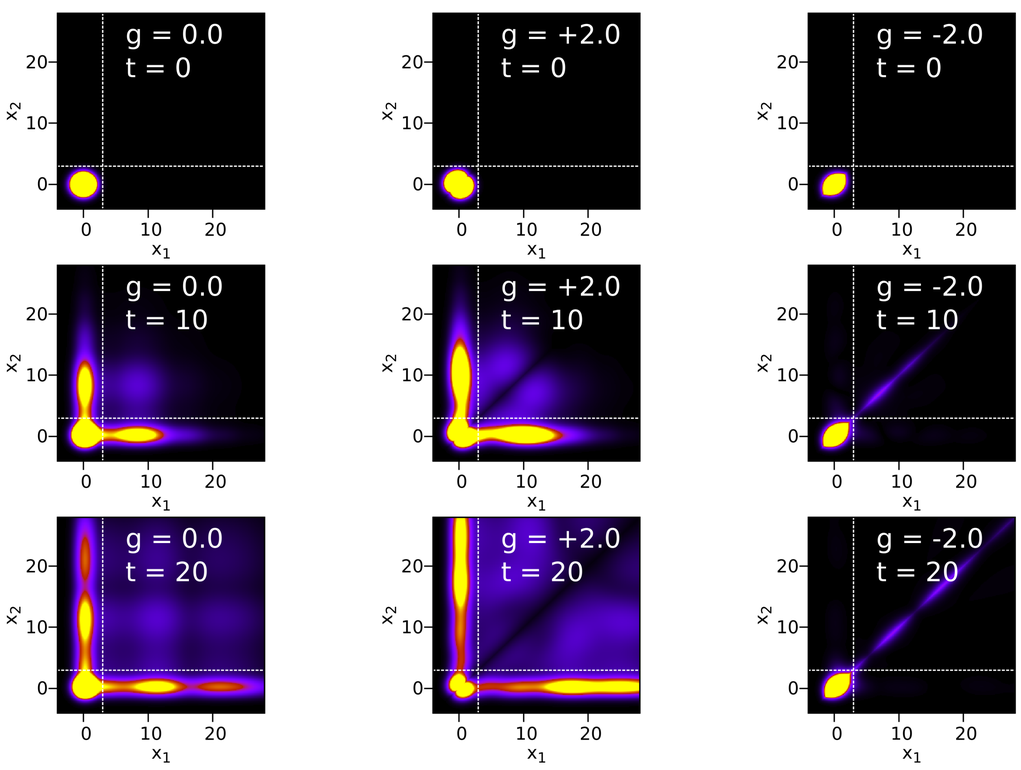


The setup: Initial state is the harmonic oscillator ground state of N interacting bosons

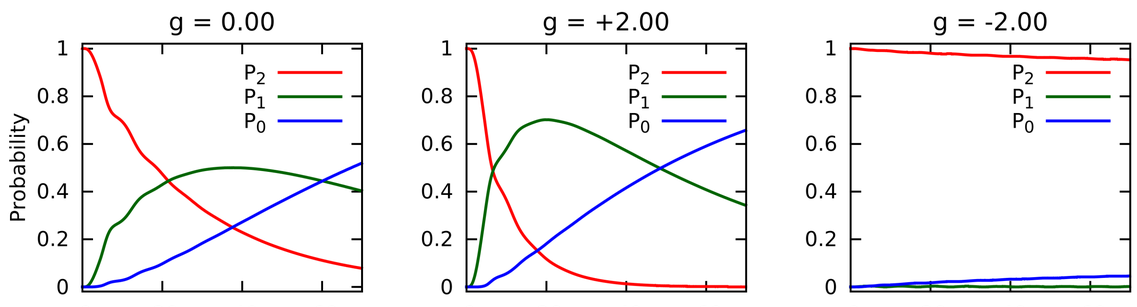
At $t = 0$ the trap is suddenly opened and the particles can tunnel into open space

Two-boson dynamics

Probability density: Probability of finding the two bosons at positions x_1, x_2 at time t



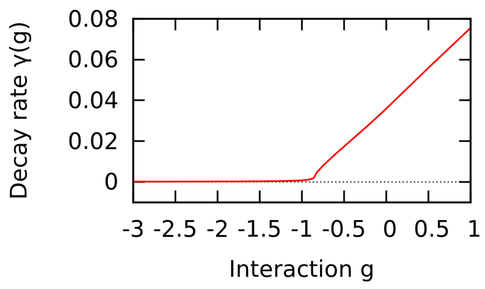
Probability $P_n(t)$: Probability of finding exactly n bosons in the trap at time t



Depending on g, the dominant tunneling mechanism is different: bosons tunnel one by one (sequentially), or in pairs

Exponential decay: For all g, $P_2(t)$ displays exponential decay with a specific decay rate γ: $P_2(t) \sim \exp[-\gamma t]$

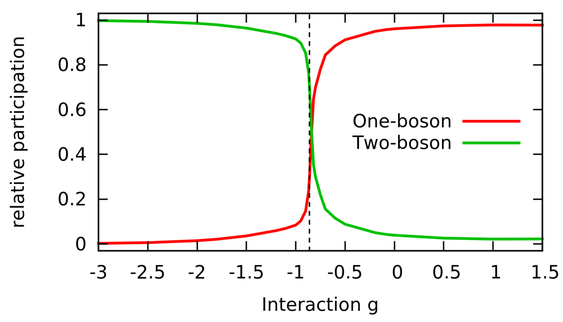
The decay rate of $P_2(t)$ shows a qualitative change around $g = -0.9$



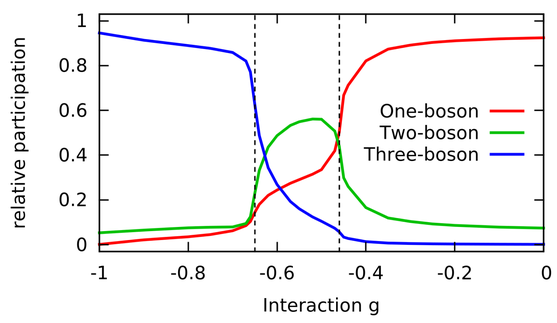
Long-time dynamics

Relative participation of different processes: We separate the outward probability flux from the well into one-, two- and three-boson decay. Several regimes can be distinguished, with different processes dominating. Transitions between the regimes are sharp and clear

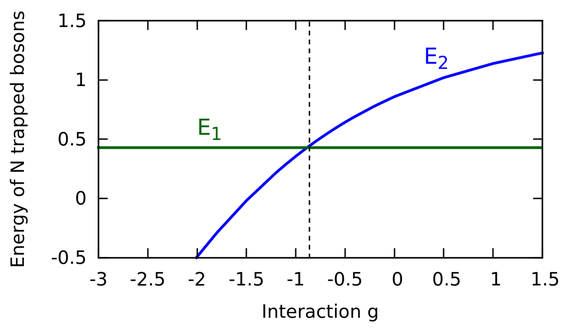
Two bosons

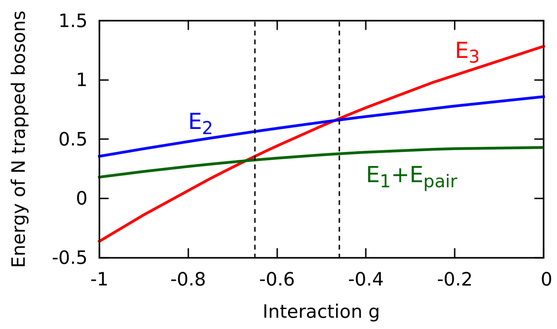


Three bosons

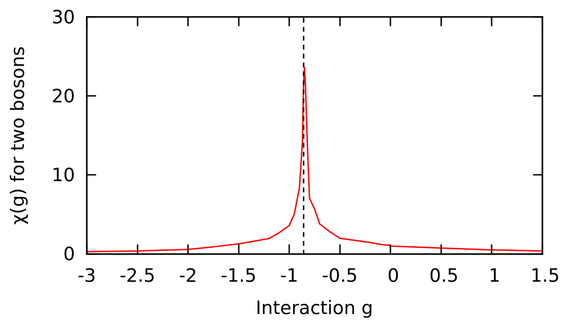


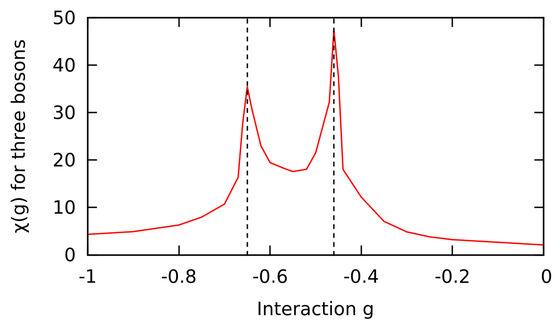
Simplified explanation through energy conditions: A transition between regimes occurs when different decay channels become energetically viable





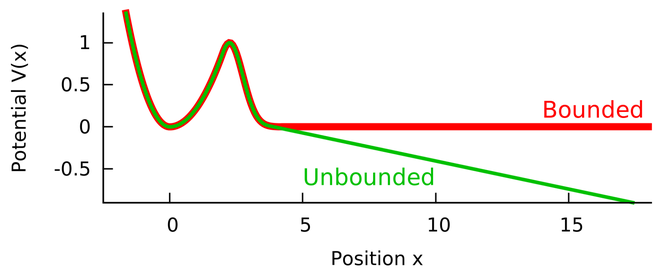
Connection to decay rate: The transitions between the different regimes are accompanied by sharp peaks in the decay rate susceptibility $\chi(g) = (d\gamma/dg)/\gamma$, which is detectable experimentally

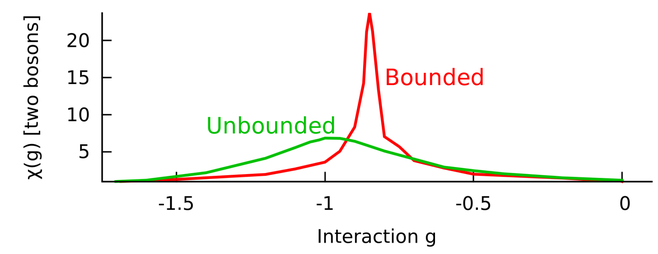




Role of the potential shape

The case of an unbounded potential: If the potential is not bounded from below outside the well (no lower energy bound for escaped particles), the boundary between the regimes is much more indistinct





Summary

- The decaying few-body system can be described in terms of transitions between distinct regimes, characterized by the dominance of different decay channels
- The transitions occur at specific interaction strengths, such that a new decay channel becomes energetically viable
- The transitions can be detected by analysing the decay rate

More details:

Phys. Rev. A **98**, 013634 (2018)
arXiv:1902.03069 (2019)