Quantum Thermalization and the Expansion of Atomic Clouds

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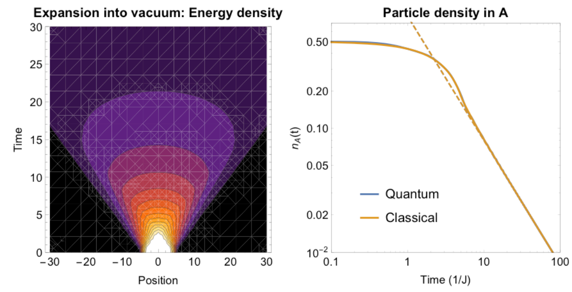
Reference: arXiv:1703.02489.

I. Expansion of an Atomic Cloud: Classical or Quantum?

Motivation: In the cold atomic 'time-of-flight' measurements, one suddenly releases the confining potential and the atomic cloud expands. Typically, it has been assumed that this expansion is governed by a purely classical Newtonian or wave kinematics. Naively, it is not at all obvious why this works. After all, before releasing the trapping potential, one may be in a quantum regime with Bose condensation or Fermi-degeneracy. How can these atoms suddenly behave like classical canon balls?

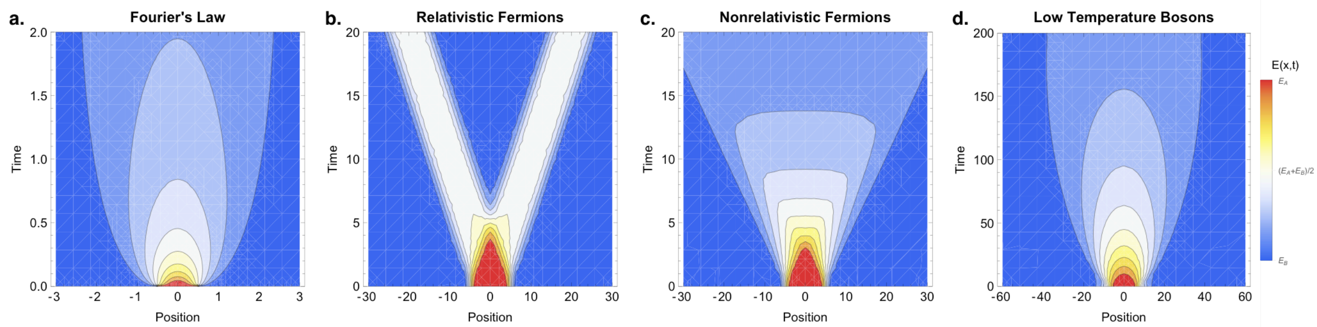
Main question: ***Are there instances where the quantum time evolution of a macroscopic system is qualitatively different from the equivalent classical system?***

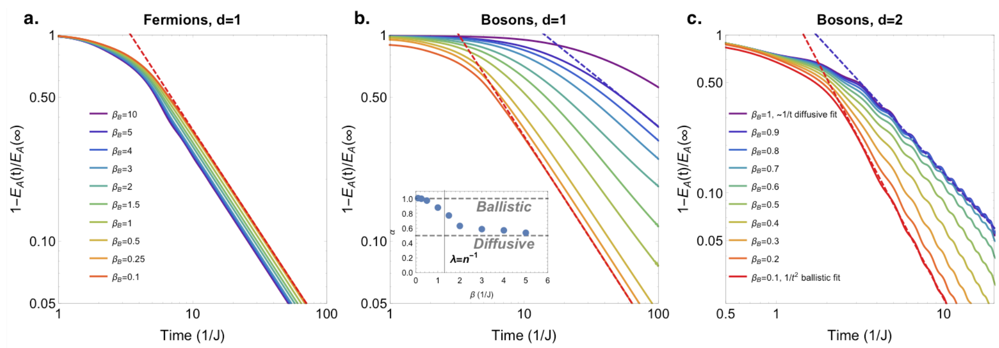
II. Expansion into the vacuum



The expansion of an atomic cloud into vacuum is the same when computed fully quantum-mechanically or classically!

III. Expansion into a cold bath





We start with a hot subsystem A in a cold bath. **How will A thermalize?**

Classical thermalization is diffusive, $\partial_t T = \mathcal{D}\nabla^2 T$ so $\Delta T \sim t^{-d/2}$.

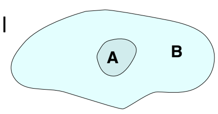
Relativistic fermions thermalize instantaneously.

Nonrelativistic fermions thermalize ballistically, $\Delta E \sim t^{-d}$.

But **bosons** show a crossover from ballistic behavior, at high bath temperatures, to **diffusive** at **low bath temperatures!**

IV. Method of Modular Hamiltonian

Separate a system into two parts ***A*** and a bath ***B***. The initial density matrix is a product of a thermal state in A and a thermal state in B.



$$\rho_0 = \frac{1}{Z_A Z_B} e^{-\beta_A \mathcal{H}_A} \otimes e^{-\beta_B \mathcal{H}_B}$$

It's easier to compute the modular Hamiltonian: $\mathcal{M} = -\log \rho$

For noninteracting particles, the time evolution is simply:

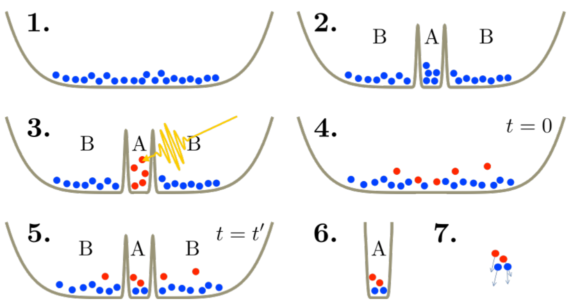
$$\mathcal{M}(t) = \sum_{kk'} m_{kk'} e^{-i(\xi_k - \xi_{k'})t} \, c_k^\dagger c_{k'} + \log Z$$

The modular matrix decays as a ***ballistic*** powerlaw,

$$\Delta m_{j,j+1}(t \gg 1) = 2\Delta\beta(0)\left(\frac{L_A - 1}{2\pi J t}\right)^d \sim \frac{V_A}{t^d}$$

though the Greens function (and the energy) can have different time-dependence, since $\hat{G}(t) = \left[e^{\hat{m}(t)} - \eta\right]^{-1}$.

V. Experimental realization



1. Trap an atom cloud
2. `Build a wall' between A and B
3. Heat up system A
4. At t=0, remove wall
5. At later time, build wall
6. Remove all atoms in B
7. Measure kinetic energy in A using Time-Of-Flight