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Demonstration of Quantum Brachistochrones between Distant States of an Atom

Sections I–VIII.

The text is about 27k symbols.

Vocabulary

paradigmatic	характерный	page 1, abstract
advent	пришествие	page 1, par. 2 (left)
conveyor belt	ленточный конвейер	page 2, Fig. 1 caption
conundrum	загадка, парадокс	page 2, par. 2 (right)
trough	впадина, минимум	page 3, par. 1 (left)
crest	гребень, вершина	page 3, par. 1 (left)
recoil	отдача	page 3, par. 1 (left)
swift	быстрый, резкий	page 3, par. 2 (right)
hatched	заштрихованный	page 3, 4th line from the bottom (right)
corroborate	подтверждать	page 3, 4th line from the bottom (right)
ramp	наклонная плоскость	page 4, Fig. 2 caption
render	превратить	page 4, last line (right)
interrogation	извлечение данных	page 5, par. 2 (left)
confine	ограничивать	page 5, par. 2 (right)
conjecture	предположение	page 6, par. 4 (left)

Questions

1. What does the term brachistochrone refer to?
2. How can the Bernoulli's brachistochrone be generalized?
3. For what kind of quantum systems the transition speed limit is long known?
4. What does this limit resemble?
5. Why can't the same logic be applied to other kinds of quantum systems?
6. Why do we need a deep trap potential?
7. Why is the speed limit lower than the adiabatic time?
8. What is the obtained transportation speed limit?
9. How does it depend on the trap potential depth?
10. How can the coherence of the transportation be verified?
11. What is the relation between classical and quantum minimal times of transporting an atomic wave packet?

12. Where does the speed limit come from?

Overview

Since the birth of quantum physics in the early 20th century, there have been discovered many interesting, unusual, and bizarre phenomena. Some of them were then found to be quite useful for applications. The objective of many modern physics experiments is to manage the control of quantum systems to fully exploit their properties. One of such objectives is to transport a quantum system in space. Of course, it's very important to do that coherently, or otherwise the state is distorted and the task of transporting it is failed. So there has to be some natural limit for the duration of coherent transportation. This topic is long understood for simple two-level systems. But those are rare, and we mostly deal with more complex ones. Some would expect complex systems to have some kind of modification of the simpler results, but experiments have shown a difference. So it is interesting both to understand where it comes from and to find a meaningful lower bound for the duration. As a complementary task, it would also be interesting to compare the results with classical physics.

The task of optimizing the path of an object for minimal time was first posed by Bernoulli for a massive object falling under the influence of a uniform gravitational field. The solution is well known and called a brachistochrone curve. This problem can be generalized to finding the shortest time at which a physical system can be changed from its initial state to a desired final state. The shortest time would depend on the amount of energy available and the type of control.

In quantum physics such a speed limit was derived by Mandelstam and Tamm and is reminiscent of Heisenberg's uncertainty principle. It shows that the duration cannot vanish unless one has access to unlimited energy. This limit was experimentally confirmed for two-level systems, however, for complex systems the real limit is much greater, making the existing one meaningless. The problem here is that two-level systems can be converted through a Rabi oscillation, which is fundamentally inapplicable to continuous states like the spatial position.

In this work, a conveyor belt based on optical lattice is used to transport an atomic wave packet on a distance 15 times its size. The trap potential is adjusted to be deep enough to suppress quantum tunneling and also so that the trajectory of the transported system is optimal. The optimal trajectory is obtained from numerical simulations.

The fidelity of the transportation, which is the overlap between the actual and targeted final states, with 1 being the perfect result, is obtained as a function of duration. It is found that the fidelity saturates for durations larger than quasi-harmonious oscillation period of the trap potential (which is also responsible for energy uncertainty of the system to transport). To ensure that the transportation is coherent, the authors prepared a specific superposition as an initial state, then transported part of it to a target state and back, and then extracted the interference constant. The constant was found to be exactly the same as the fidelity measured earlier, proving that the method keeps coherence.

The same measurements and simulations were made for several trap potential depths, and the minimal time is shown to be inversely proportional to the depth. Interestingly, the classical and quantum cases differ only by 25%, which shows that the limit comes mostly from the Hilbertian metric of quantum states.