Bose-Einstein condensate - Tunneling

ABSTRACT

Bose-Einstein condensate is a state of matter that is the future of quantum computers. One of the crucial properties of Bose-Einstein condensate is quantum tunneling. In this paper are listed previously achieved results by other authors considering the factors that affect tunneling in Bose-Einstein condensates, such as the form of interaction between particles, the shape of the potential well, and the form and the dimension of the system [1]. According to Meng *et. al.* who studied two-dimensional honeycomb optical lattice, tunneling occurs in an attractive interaction regime if dipole gap solitons are in-phase and in a repulsive interaction regime if dipole gap solitons are out of phase [2]. If the particle experiences a gradual change in potential barrier the probability of the excitation is lower [3]. If the particle experiences a sudden change in the potential barrier, the probability increases [3]. Further study of the factors that affect tunneling in Bose-Einstein condensate may be conducted by exploring different systems and mixtures of the aforementioned condensates.

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INTRODUCTION

Bose-Einstein condensate is a state of matter that is achieved by cooling the gas of bosons up to low temperatures. Consequentially, a large quantity of particles poses the lowest quantum state. The crucial properties of Bose-Einstein condensate are coherence and quantum mechanical tunneling[1]. The whole condensate could be viewed as a wave in analogy with the light wave produced by the laser. Moreover, experiments with Bose-Einstein condensate are similar to those with light waves. In addition, when two condensates overlap, wave interference occurs. The atomic density of condensates does not add up, but the profile of space density is formed with periodical minimums and maximums [2]. Since Bose-Einstein condensate could be viewed as a wave, if the wave function propagates through a potential barrier, quantum tunneling occurs [3]. Part of the condensate can propagate through the barrier which classical particles can not, that part of the condensate tunnels through the barrier. If two macroscopic quantum objects are separated by a barrier that no classical particle goes through but is low enough for part of the condensate to tunnel through, the Josephson effect takes place[4].

OBJECTIVE

The objective of this paper is to list the different factors that affect tunneling in Bose-Einstein condensate and propose further work.

FACTORS THAT INFLUENCE TUNNELING

1. type of particle (bosonic or fermionic)
2. type of interaction between particles
3. the shape of the potential well and lattice
4. dimension of the system [1]

FINDINGS

2D honeycomb optical lattice

Tunneling is limited to these examples:
in-phase dipole gap solitons in the semi-infinite gap, when the interaction regime is attractive
out-of-phase dipole gap solitons - first gap, when interaction regime is repulsive [2]

The shape of potential well

Previously has been mentioned that the shape of the barrier can affect tunneling. If the barrier is asymmetric in shape, asymmetric tunneling may occur. If the particle experiences a gradual change in potential barrier the probability of the excitation is lower. If the particle experiences a sudden change in the potential barrier, the probability increases. [3]

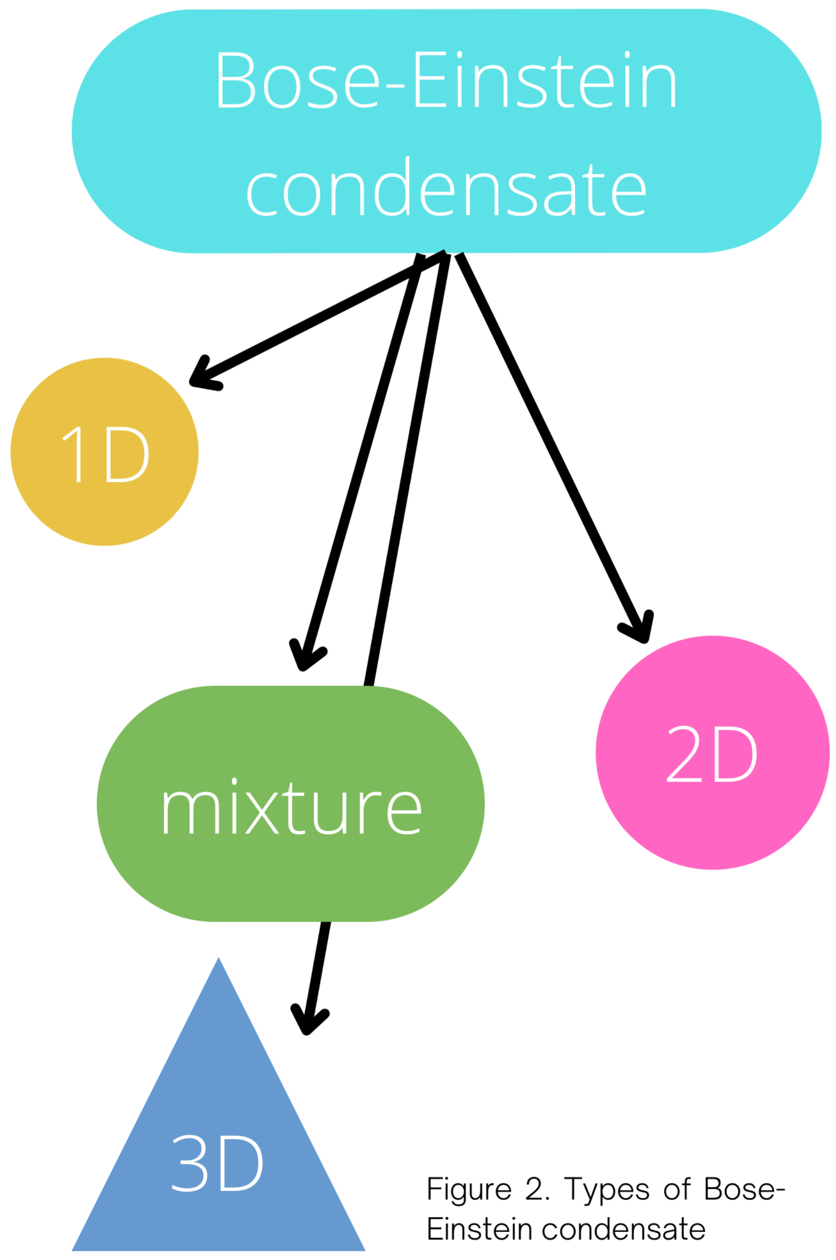

Figure 2. Types of Bose-Einstein condensate

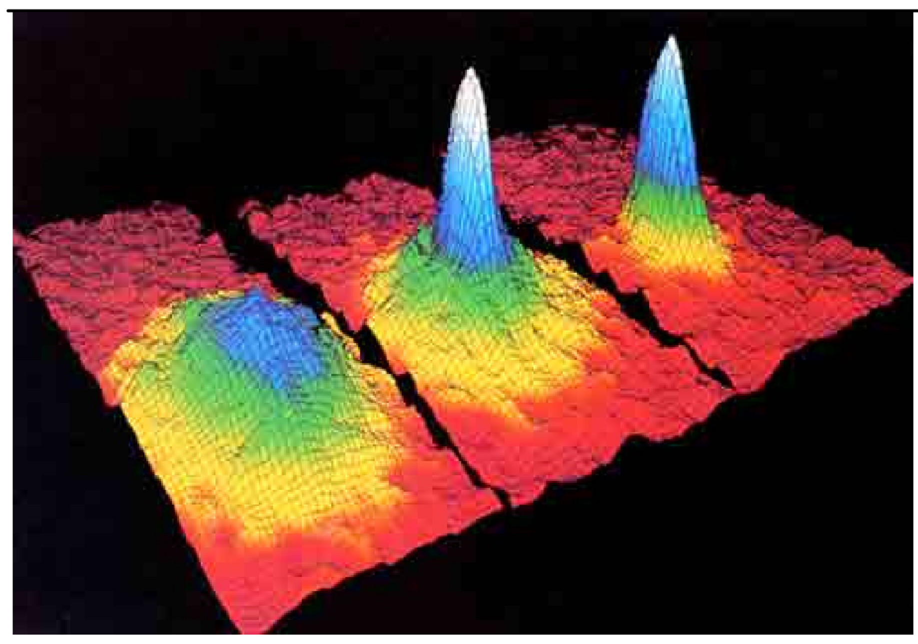

Figure 1. The figure is obtained by Eric A. Cornell, Wolfgang Ketterle, and Carl E. Wieman showing atomic distribution in the different stages of condensation [7]

Interaction-assisted quantum tunneling

Pontis S. *et. al.* conducted an experiment with 87Rb which shows that tunneling rate is correlated with chemical potential. The exponential dependence is present [5].

The mixture of Bose-Einstein condensates

M. Maraj, J. Wang, J. Pan, J., and W. Yi, studied coupled dynamics of the mixture in which one Bose-Einstein condensate is in the double well potential and the other is harmonically trapped. Self-trapping was dominant in the harmonically trapped Bose-Einstein condensate. By adjusting the energy between two condensates and observing the oscillation frequency of the double-well Bose-Einstein condensate they examined shifting between Josephson-like oscillation and self-trapping mode [6].

ANALYSIS

Since Eric A. Cornell, Wolfgang Ketterle and Carl E. Wieman were awarded Nobel Prize in Physics in 2001 there have been numerous both theoretical and experimental research projects [7]. Multidimensional systems have been studied as well as the potentials of different shapes and mixtures of Bose-Einstein condensates. Davletov E. T. *et. al.* optimized the cooling of thulium atoms into Bose-Einstein condensate using machine learning [8].

CONCLUSION

Bose-Einstein condensate is by its nature macroscopic quantum object. It is believed that Bose-Einstein condensate could be used in the future for constructing a qubit, a quantum bit, a unit of quantum information that can hold 0, 1, or their superposition instead of a classical bit that holds only 0 or 1. Therefore Bose-Einstein condensate is key to the future of quantum computing, by using Josephson's effect [9]. The main problem is forming Bose-Einstein condensate in less extreme conditions. Experimenting with different materials and mixtures of condensate is the direction in which further research can go.

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