BEC superpositions in twin wells

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The idea of a macroscopic entity simultaneously existing in two distinct possible states was introduced by Erwin Schrödinger in 1935, as a Gedanken experimental demonstration of the absurdity of quantum mechanics [1]. Since then, evidence has mounted that reality is as absurd as quantum mechanics suggests, with persistent currents (of a few μA) of opposite circulation having been detected in SQUIDS [2]. The fact that Bose-Einstein condensates are mesoscopic quantum entities which can be trapped in tunnel-coupled double wells seems to make them an attractive candidate for the demonstration of mesoscopic superpositions.

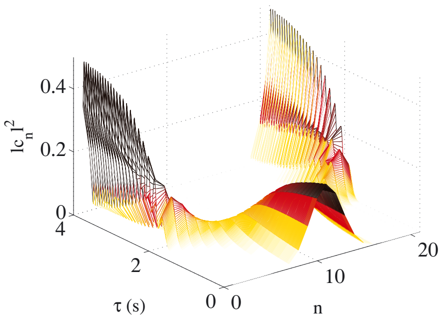

Figure 1: Evolution into a mesoscopic superposition caused by a linear decrease in interaction strength from $U = 1s^{-1}$ to $-3s^{-1}$ in $4s$.

This work investigated methods to manufacture superpositions of two states where all the atoms are localised in one of the wells and investigated how the existence of such a Schrödinger cat state might be proven by realistic measurements [3]. Such states, known as N00N states, promise to be extremely useful in quantum information applications and precision measurement, allowing for a precision beyond the standard quantum limit.

We found that an almost perfect superposition may be possible to make by slowly changing the atomic interactions from positive (repulsive) to negative (attractive). If the process were perfectly adiabatic, the atoms would go from their repulsive ground state, which is a binomial distribution in the two wells, to their attractive ground state, which is a perfect superposition. The development of the occupation probabilities in one of the wells for this process is shown Fig. 1, where we see that the two main probabilities are for either zero or full occupation. As both these exist simultaneously, we have a superposition.

We also investigated how such a superposition could be distinguished from a statistical mixture, investigating various measurement techniques. The standard Ramsay interferometry as used with, for example, two level atoms, only works for a single atom.

We did find a promising candidate in the parity, defined as $P = \sum_n (-1)^n |c_n|^2$, which is an oscillatory function of the accumulated relative phase between the wells while the superposition exists. After creating the superposition, the tunneling (κ) and interaction (U) strengths are set to zero and the system evolves for a time δt with an energy difference δE between the wells. The well symmetry is then restored and tunneling switched on for a time $\pi/4\kappa$. For superpositions, the parity is an oscillatory function of the accumulated phase, whereas for statistical mixtures it always has an expectation value of zero. For the imperfect superpositions which are more likely to be manufactured, the parity remains oscillatory but is a more complicated function.

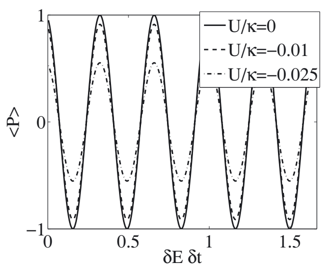

Figure 2: Expectation values of the parity for an ideal superposition, with different ratios of the collisional to the tunnelling interaction strengths.

References

[1] E. Schrödinger, Translation by J. D. Trimmer, Proc. Am. Philos. Soc. **124**, 323 (1980).
[2] J. R. Friedman *et al.*, Nature **406**, 43 (2000).
[3] T. J. Haigh, A. J. Ferris, and M. K. Olsen, Opt. Commun. **283**, 3540 (2010).