Macroscopic Entanglement between a Superconducting Loop and a Bose Einstein Condensate

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Quantum entanglement is one of the most fundamental and intriguing phenomena in quantum mechanics. We propose an experiment to realise a macroscopic entanglement. A magnetic trap containing a BEC when adiabatically moved close to a superconducting loop existing in quantum superposition of two different flux states [1, 2], can perturb the confining potential of the magnetic trap leading to a macroscopic entanglement [3]. The macroscopic variables correspond to the spatial distribution of the BEC in the trap, the chemical potential and the flux state of the superconducting loop. A schematic of the superconducting loop coupled to a magnetic trap is shown in Fig. 1. In addition we also explore the effect of a sudden turn on of the coupling between the superconducting loop and the magnetic trap.

The Hamiltonian of the superconducting loop coupled with the magnetic trap can be written as

$$H(t) = E_0|0\rangle\langle 0| + E_0|1\rangle\langle 1| + \mu_0 \hat{a}_0^\dagger \hat{a}_0|0\rangle\langle 0| + \mu_1 \hat{a}_1^\dagger \hat{a}_1|1\rangle\langle 1| \tag{1}$$

where $|0\rangle$ and $|1\rangle$ corresponds to the flux state of the loop, $\hat{a}_0$ ($\hat{a}_1$) is the bosonic annihilation operator when the trap potential is perturbed by the state $|0\rangle$ ($|1\rangle$).

Considering the initial state $|\Psi, t=0\rangle = \frac{1}{\sqrt{2}}(|0\rangle + |1\rangle)|N, \phi(r, t=0)\rangle$, where $|N, \phi(r, t=0)\rangle$ is the state representing N atoms in the ground state of the trap when the perturbation caused by the loop is zero. At time t the state evolves to an macroscopic entangled state

$$|\Psi, t\rangle = \frac{1}{\sqrt{2}}(|0\rangle|N, \phi_0(r,t)\rangle + e^{i\Phi(t)}|1\rangle|N, \phi_1(r,t)\rangle) \tag{2}$$

where $|N, \phi_0(r,t)\rangle$ and $|N, \phi_1(r,t)\rangle$ correspond to N atoms in the ground state of two different perturbed potentials introduced by the loop.

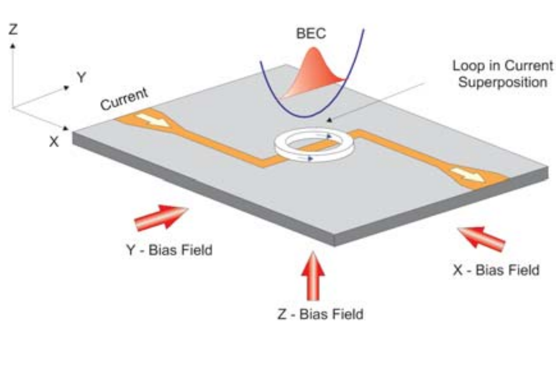

Fig. 1: Schematic of an atom chip containing the superconducting loop.

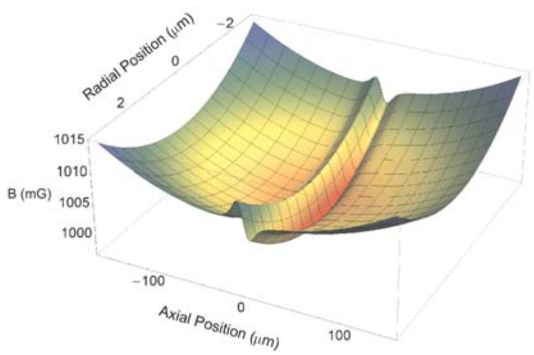

Fig. 2: Perturbation induced in the magnetic trap by the loop in state $|0\rangle$.

References

[1] C. H. van der Wal et al., Science **209**, 773 (2000).
[2] J. R. Friedman et al., Nature **406**, 43 (2000)
[3] M. Singh, PhD Thesis, Swinburne University of Technology, Australia (2008).