Thermal equilibrium states into superpositions of macroscopically distinct states

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We present a simple method for converting thermal equilibrium states into superpositions of macroscopically distinct states. Thermal equilibrium states, Gibbs states, are the most common states to human beings. By contrast, superpositions of macroscopically distinct states, hereafter generalized cat states, are recognized as the states not very accessible to humans, as the Schrödinger's paradox suggests. However, we find that the former can be converted into the latter through only two procedures: For N spin systems with $S = 1/2$, for example, prepare an equilibrium state in the presence of heat bath and magnetic field parallel to the x-axis. Then, measure the z-component of the magnetization. We show that the post-measurement state is a generalized cat state for the cases when spins do not interact with each other and when spins interact in the XYZ model manner. The mechanism of the conversion owes to the noncommutativity between M_z and the Hamiltonian in the presence of the magnetic field.
We find that the post-measurement state is a mixture of an exponentially large number of states. It is due to two factors: The pre-measurement state is a mixture of an exponentially large number of states, and the measurement operator projects onto an exponentially large subspace. This should be contrasted to the superposition states that were previously realized experimentally in systems at extremely low temperature, such as with SQUID [1], or with small degrees of freedom, such as with single-mode photons [2].
We note that there is a trade off between the resolution of the measurement and the probability of obtaining a generalized cat state. For the above calculation, we assumed that the measurement operator is a projection onto $M_- \leq M_z \leq M_+$ subspace. When $M_+ - M_-$, resolution, is $O(1)$, the post-measurement state is a generalized cat state with almost 100% probability. When $M_+ - M_-$ is larger, the success probability becomes exponentially small.
Lastly, we show that our method is feasible enough in experiments. With NV centers [3,4], that have a long coherence time, and SERF magnetometers [5], that have high sensitivity, we estimated that the obtained generalized cat state survives for about 7μs when $N = 100$. Expecting experimental realizations, we also discuss how to verify the success of the creation of generalized cat states.

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