# Physicists seek to quantify macroscopic quantum states

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(PhysOrg.com) -- "Scientists have been interested in generating and observing macroscopic quantum superpositions in order to test quantum mechanics at the macroscopic scale," physicist Hyunseok Jeong of Seoul National University in Seoul, South Korea, told *PhysOrg.com*. "There have been many papers in which the authors claim to have generated mesoscopic or macroscopic superpositions, often called 'Schrodinger cat states.' However, quoting A. J. Leggett in 2002, a question from the theoretical side is ‘What is the correct measure of "Schrodinger's-cattiness"?' It has been considered difficult to answer this question with a general measure, and the answer has remained to be 'very much a matter of personal taste,' quoting Leggett again. Our work now provides scientists with a theoretical tool to quantify and compare different types of quantum superpositions. This can be a step toward rigorous tests of quantum mechanics in a macroscopic limit."

Jeong and his coauthor Chang-Woo Lee, also of Seoul National University, have published their study on the quantification of macroscopic quantum superpositions in a recent issue of Physical Review Letters. Having a way to quantitatively compare different types of states in terms of their size and their degree of quantum coherence will be very useful for theoretical and experimental studies on macroscopic quantum phenomena, generation of nonclassical states, and the decoherence of quantum states within various physical systems.

As the scientists wrote in their study, quantum superposition is often considered the most crucial feature of quantum mechanics. In quantum mechanics, particles can exist in one or more energy levels. When a particle exists in just one energy level, it's in a well-defined energy state. But when a particle exists in two or more different energy levels at once, it's in a superposition of energy states. The most well-known example of superposition is Schrödinger's cat, which is locked in a box with the possibility of being poisoned. Until an observer looks inside the box, the cat is considered to be both dead and alive at the same time, according to quantum mechanics.

Physicists have observed superposition in many experiments with microscopic systems. However, the question of whether a truly macroscopic system – such as a cat – can exist in a quantum superposition is much more complicated.

For the past 10 years or so, physicists have been proposing various ways to define or measure macroscopic quantum superpositions. Many of these proposals start by considering the number of particles or the distance between component states involved in the superposition. Although this approach sounds reasonable, the proposals have run into problems – particularly, they have not been general enough to be applied to different types of states.

The biggest advantage of Lee and Jeong's method of measuring macroscopic quantum superpositions is its generality, which enables it to be applied to many different types of states and allows for direct comparison between them. The method is based on the quantum interference of a given state in phase space, which is the space in which all possible states of a system are represented.

As the scientists explained, a macroscopic quantum superposition has two (or more) well-separated peaks and some oscillating patterns between them in phase space. The scientists showed that the frequency of these interference fringes reflects the size of the superposition, while the magnitude of the interference fringes relates to the degree of genuine superposition. So using this method, the scientists could simultaneously quantify both the size of the system and its degree of quantum coherence. The method also works for superpositions that are fully or partially decoherent, which occurs when macroscopic superpositions lose quantum coherence due to interactions with their environments.

Overall, the method doesn't provide a specific threshold beyond which a superposition is "macroscopic," but instead it provides a continuous scale to compare sizes of different superpositions. The scientists found that the method also agrees with a previous method (Dür, et al.) designed to measure a specific type of state. But with its advantage of being able to measure any state represented in phase space, the new method could be widely useful for future studies on macroscopic quantum systems.

"In [this] paper, the focus was pretty much on continuous-variable states, which mainly relates to light fields," Jeong said. "However, due to the intrinsic generality of our measure, it should be quite straightforward to extend it to various discrete-variable systems such as atomic states. I will then apply this measure (I would call it 'superness,' thanks to Dr. Jonas Neergaard-Nielsen) to various 'claimed' macroscopic superpositions. I believe that such investigations will reveal 'where we are' regarding macroscopic tests of quantum theory."

**More information:** Chang-Woo Lee and Hyunseok Jeong. "Quantification of Macroscopic Quantum Superpositions within Phase Space." *Physical Review Letters* 106, 220401 (2011). DOI: 10.1103/PhysRevLett.106.220401 permission of PhysOrg.com.