Macroscopic superpositions, entanglement and the EPR Paradox

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The aim of this project is to provide strategies for detecting mesoscopic/macroscopic quantum superpositions and Einstein-Podolsky-Rosen paradoxes in mixed states that accurately represent the output of physical systems used to generate squeezing and entanglement. The paradox of macroscopic entanglement occurs where we have a quantum superposition of two macroscopically distinguishable states. A paradox arises because the system cannot be interpreted as being in one state or the other, prior to measurement. This is a fundamental scientific question in both quantum and atom optics, and the experimental groups in the ACQAO Centre are competitively placed to investigate these issues, with world-class squeezing and entanglement.

Experiments in quantum optics are at the forefront in experimentally confirming quantum entanglement. These involve measurements performed on fields generated by parametric amplification, which can have macroscopic output intensities. An article summarising the criteria used to detect the entanglement of the EPR paradox has been published [1] and a review incorporating experimental achievement has been written by invitation and submitted to Reviews of Modern Physics[2]. As part of this review, the criteria have been extended to incorporate Bohm's spin version of the EPR paradox. We have conducted an analysis that reveals the detection efficiencies required if this version of the paradox is to be realised. Closely linked with this work is the effort to propose a feasible experimental arrangement for the violation of Bell inequalities for continuous variable measurements. The quantum theory of such experiments predicts a decoherence-insensitive amplification of the quantum superpositions to enable an interesting version[3] of a Schrodinger cat paradox. Other work in this area includes the relationship between entanglement and fundamental conservations laws and symmetries in quantum electrodynamics [4], as well as work on methods to violate new types of multipartite Bell inequalities.

The challenge to generate and detect *macroscopic* quantum superpositions and entanglement still remains. We have derived criteria[5] for the detection of mesoscopic/macroscopic quantum superpositions that are based on the measurable variances of output probability distributions. To do this, we define the concept of the generalised S-scopic superposition. The criteria are applicable to both discrete and continuous variable measurements, and to entangled states that are of current interest experimentally, namely the squeezed state and the higher-spin and atomic squeezed states. We have shown how these new signatures would allow a macroscopic version of the Einstein-Podolsky-Rosen paradox and a Schrdinger's cat paradox, by enabling confirmation of failure of certain macroscopic quantum mixtures[6]. More recently, we have pointed out that the measure of squeezing of fluctuations in an observable will imply a minimum quantum indeterminacy in the complementary observable, so that large detected squeezing in a particle's momentum is confirmation that the particle's position cannot be thought of as constrained to any microscopic region, prior to measurement. Currently, this work is being extended to a proposal for a macroscopic EPR experiment.

References

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