Macroscopic Realism and a Retrocausal Model for Reality

M D Reid[1], M Thenabadu[1], and P Drummond[1]

[1] *Centre for Quantum Technology Theory, Swinburne University of Technology, 4, John St., Melbourne, Australia.*
Contact Phone: +61412597948
Contact Email: mdreid@swin.edu.au

We begin by considering Bell violations with macroscopic qubits formed from cat states, which are superpositions of macroscopically distinct coherent states with amplitudes α and $^{-}\alpha$ (for α large). Here the unitary rotations equivalent to polarisers in the Bell experiment are achieved via a nonlinear interaction, the interaction time determining the measurement setting. We confirm the prediction of violation of macroscopic Bell inequalities in this macroscopic regime where all necessary measurements need only distinguish between the positive and negative amplitudes of the coherent states [1-3]. This constitutes a Leggett-Garg test of macrorealism [4], where the noninvasiveness of the measurement is justified by locality at the macroscopic level.

The violation of the macroscopic Bell inequalities confirms the failure of deterministic macroscopic (local) realism [1-3]. This is where there is assumed a predetermined value for the measurement, for both measurement settings, prior to the unitary rotation that determines the measurement setting. We also show how a delayed-choice Wheeler-Chaves-Lemos-Pienaar experiment [5] can be performed with cat states, implying failure of all two-dimensional non-retrocausal macroscopic models.

We point out that the macroscopic Bell-Leggett-Garg and delayed-choice violations can be viewed consistently with a weaker form of macroscopic realism (weak macroscopic realism), for which there is a predetermination of the outcome of the macroscopic measurement once the system is prepared after the unitary rotation with respect to the pointer basis. Yet, assuming the validity of weak macroscopic realism leads to an Einstein-Podolsky-Rosen-type paradox, demonstrating an inconsistency between weak macroscopic realism and the completeness of quantum mechanics [2,3].

Interestingly, we may resolve this paradox by considering an objective model for reality-based on generalisations of the Q function, in which there is a microscopic level of retrocausality [6]. The microscopic retrocausality explains Bell nonlocality. We find that when considering a superposition of eigenstates (or cat states), trajectories for amplitudes in the model support the hypothesis of weak macroscopic realism.

References

[1] M Thenabadu, G-L Cheng, T L H Pham, L V Drummond, L Rosales-Zárate and M D Reid, Phys. Rev. A **102**, 022202 (2020)

[2] M Thenabadu and M D Reid, arXiv:2012.14997 (2020)

[3] M D Reid and M Thenabadu, arXiv:2101.09476 (2021)

[4] A Leggett and A Garg, Phys. Rev. Lett. **54**, 857 (1985)

[5] R Chaves, G B Lemos and J Pienaar, Phys. Rev. Lett. **120**, 190401 (2018)

[6] P D Drummond and M D Reid, Phys. Rev. Res. **2**, 033266 (2020)