Comment on “The Quantum State of a Propagating Laser Field”

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We comment on the theoretical quantum state of a propagating laser field proposed by van Enk and Fuchs [1] and clarify that the multimode description of the propagating laser field does not modify our analysis of continuous variable quantum teleportation [quant-ph/0104036, quant-ph/0111157]. Furthermore we point out that the “complete measurements” discussed by van Enk and Fuchs have not been achieved by existing technology and may not be possible even in principle.

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In critiquing our assertion that continuous variable quantum teleportation (CVQT) cannot be demonstrated with a conventional laser in a linear optical system even with ideal photodetectors and perfect Fock state sources allowed [1], van Enk and Fuchs (vEF) [2] analyze a multimode propagating laser field (MPLF) and claim that a conventional laser suffices. They agree that the intracavity field is correctly described by a mixed state that is diagonal in the Fock state basis, and consequently the coupled–mode analysis they employ yields the MPLF outside the cavity to be a mixed state. However, they go on to demonstrate the attractiveness of expressing the MPLF as an ensemble of multimode coherent states in preference to the many other possible ensembles, with the quantum de Finetti theorem employed in support of their intuitive preference for this particular decomposition of the MPLF density matrix. Specifically, the quantum de Finetti theorem can be used to show that the coherent state ensemble is the only one which conforms with their particular intuition. Such reasoning is clearly open to question however. For example, the mixed state MPLF admits a decomposition that is diagonal in the multimode Fock basis, with each pure state in this ensemble exhibiting manifest photon number entanglement between the modes. This Fock basis ensemble is the only one which requires no violation of conservation of energy to prepare: it is unique with respect to an intuition that many physicists share.

Although we acknowledge the attraction of the coherent state decomposition as a convenient tool for simplifying calculations, designing experiments, and as motivation to strive for vEF’s “complete measurement”, vEF’s approach does not establish a necessary condition for the coherent state decomposition being privileged. In effect they establish an argument which allows for a sufficient understanding of the experiment; however, we believe that claims to demonstrate CVQT must establish that the experiment is necessarily interpreted as such. Our view is that in quantum information processing the use of preferred ensembles can be justified only in scenarios involving retrodiction of preparation procedures, and this retrodictive rationale has no relevance to the topic of CVQT using lasers.

As a justification for favouring coherent states, vEF discuss “complete measurements” that purportedly could be employed to project the MPLF into a true coherent state with known phase; the claim is that inter-modal phase correlation allows such a “complete measurement” on one mode of the MPLF to reduce the mixed state to a pure multimode coherent state. Despite common misconceptions that phase or phase-sensitive measurements have been performed or are possible, no experiment has either been performed or even proposed in principle which would yield an observation that depends in any way upon the relative phase of a superposition of Fock number states within a given mode. The phase of the laser field is just such a phase (it affects the relative phase between superpositions of number states), and the so–called complete measurement would therefore have to be of a completely unconventional type. Measuring all orders of the standard photon correlation functions cannot yield information about this phase.

We do not, however, accept vEF’s premise that some kind of unconventional measurement can in fact measure the phase in a way that necessitates updating the mixed–state description of the MPLF to a pure coherent state. Such a measurement would violate the energy conservation principle. As with any conserved quantity, the description of such a measurement may be constructed by invoking an “effective classical field” approximation, such as employing the classical field description of the local oscillator in homodyne detection, but a rigorous description of the measurement, which does not invoke the mean field approximation and does not yield a coherent superposition of energy states in a specific mode, is always possible and is certainly as valid. Moreover, unless some measurement can be devised, or some operational procedure developed, for which the vEF preferred ensemble may be subjected to empirical tests, we see no reason to prefer their ensemble.
On a separate point, a key criticism by vEF is our alleged claim that there was no entanglement in the experiment [3], hence no CVQT. This was not our claim. Rather we demonstrated that the two-mode squeezed field is not entangled (about which vEF agreed) to demonstrate the danger of the preferred ensemble fallacy (PEF). In Fig. 1 we give yet another simple example of the danger inherent in analyzing CVQT using preferred ensembles.

In summary our objection to the claim that CVQT has been achieved [3] is that its apparent success requires a preferred ensemble. As the quantum teleportation protocol refers to initial states and their subsequent evolution, the multiplicity of differing descriptions for specific data are equally valid. A reconciliation between our objection and the claim of successful CVQT is presumably possible, however, if the CVQT protocol is reconstructed in terms of an initial mixed state. The challenge is then to agree upon a set of genuine operational criteria for “unconditional” CVQT.

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