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COMMENTS AND REPLIES

Reply to 'Comment on 'Single-mode excited entangled coherent states''

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Abstract
We agree with the correction made by Yuan and Hu (Comment on 'Single-mode excited entangled coherent states') on entanglement analysis of single-mode excited entangled coherent states proposed in our previous paper (Xu and Kuang 2006 *J. Phys. A: Math. Gen.* **39** L191). We re-examine the numerical computation of the concurrence in our paper.

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In our original paper [1] we introduced single-mode excited entangled coherent states (SMEECSs), studied mathematical properties and entanglement characteristics of the SMEECSs and investigated the influence of photon excitations on quantum entanglement. It was shown that the SMEECSs form a type of cyclic representation of the Heisenberg–Weyl algebra. It was found that the photon excitations affect seriously entanglement character of the SMEECSs. We also showed how such states can be produced by using cavity QED and quantum measurements. Because of a change of the matrix element $\langle\alpha|\hat{a}^m\hat{a}^{\dagger m}|-\alpha\rangle$ in equation (6) as pointed out by Yuan and Hu [2], an error was created. $L_m(|\alpha|^2)$ in equations (4) and (6) should be replaced by $\mathrm{e}^{-2|\alpha|^2}L_m(|\alpha|^2)$. And the correct form of the concurrence (23) and (24) is

$$\mathcal{C}_-(\alpha, m) = \frac{\left[(1-\mathrm{e}^{-4|\alpha|^2})\left(L_m^2(-|\alpha|^2) - \mathrm{e}^{-4|\alpha|^2}L_m^2(|\alpha|^2)\right)\right]^{1/2}}{L_m(-|\alpha|^2) - \mathrm{e}^{-4|\alpha|^2}L_m(|\alpha|^2)}, \tag{1}$$

$$\mathcal{C}_+(\alpha, m) = \frac{\left[(1-\mathrm{e}^{-4|\alpha|^2})\left(L_m^2(-|\alpha|^2) - \mathrm{e}^{-4|\alpha|^2}L_m^2(|\alpha|^2)\right)\right]^{1/2}}{L_m(-|\alpha|^2) + \mathrm{e}^{-4|\alpha|^2}L_m(|\alpha|^2)}, \tag{2}$$

respectively.

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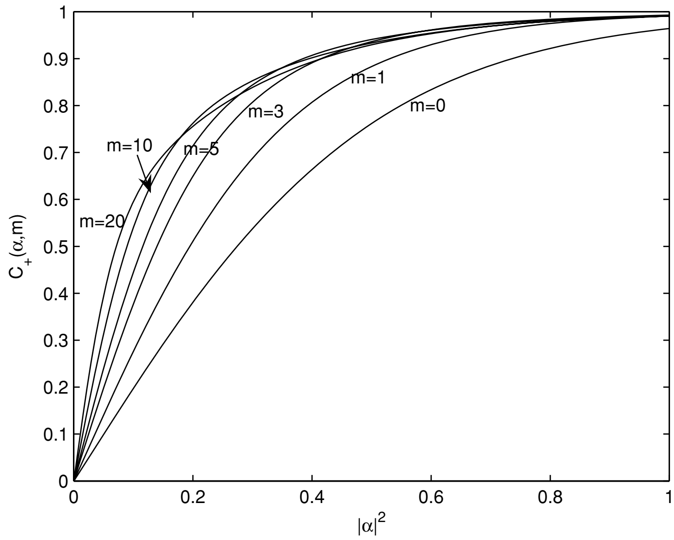

Figure 1. The concurrence of the SMEECS $|\Psi_+(\alpha, m)\rangle$ versus $|\alpha|^2$ for the different photon excitations with $m = 0, 1, 3, 5, 10$ and 20, respectively.

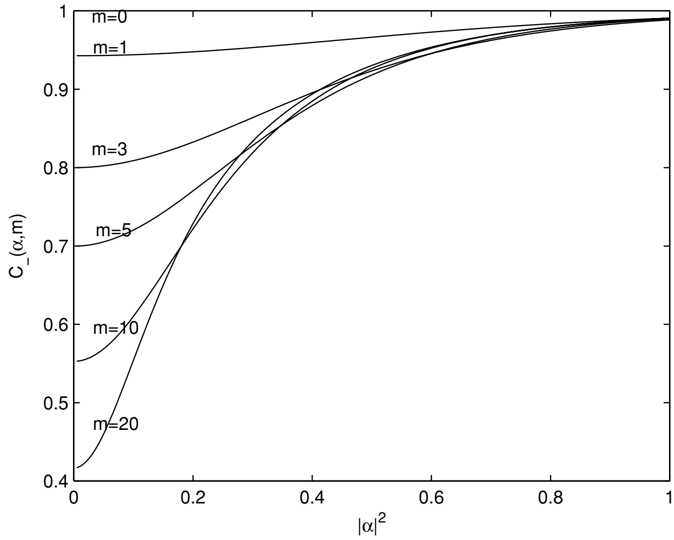

Figure 2. The concurrence of the SMEECS $|\Psi_-(\alpha, m)\rangle$ versus $|\alpha|^2$ for the different photon excitations with $m = 0, 1, 3, 5, 10$ and 20, respectively.

In the weak field regime of $|\alpha|^2 \ll 1$, we have $L_m(|\alpha|^2) \approx 1 - m|\alpha|^2$. Then, from equations (1) and (2) we have

$$\mathcal{C}_+(\alpha, m) \approx \sqrt{1+m}|\alpha|^2, \qquad \mathcal{C}_-(\alpha, m) \approx \frac{\sqrt{1+m}}{2+m}, \tag{3}$$

which indicate that in the weak field regime of $|\alpha|^2 \ll 1$, $\mathcal{C}_+(\alpha, m)$ increases with the photon excitation number m while $\mathcal{C}_-(\alpha, m)$ decreases with the photon excitation number m. This implies that in the strong field regime the photon excitations enhance the entanglement amount for the SMEECS $|\Psi_+(\alpha, m)\rangle$ while the photon excitations suppress the entanglement amount for the SMEECS $|\Psi_-(\alpha, m)\rangle$.

In the strong field regime of $|\alpha|^2 \gg 1$, since $e^{-2|\alpha|^2} L_m(|\alpha|^2) \approx 0$, from equations (1) and (2) we find $\mathcal{C}_\pm(\alpha, m) \approx 1$. This implies that in the weak field regime the photon excitations do not affect the entanglement amount for the SMEECSs $|\Psi_\pm(\alpha, m)\rangle$.

In the intermediate field regime, entanglement character of the SMEECSs $|\Psi_\pm(\alpha, m)\rangle$ is more complex than that in other regimes. We plot the concurrence $\mathcal{C}_\pm(\alpha, m)$ with respect to $|\alpha|^2$ for different values of the photon excitations in figures 1 and 2, respectively.

Acknowledgments

We wish to thank Hong-chun Yuan and Li-yun Hu for pointing the error out to us.

References

[1] Xu L and Kuang L M 2006 *J. Phys. A: Math. Gen.* **39** L191

[2] Yuan H C and Hu L Y 2010 Comment on 'Single-mode excited entangled coherent states' *J. Phys A: Math. Theor.* **43** 018001