Arc field states, photon statistics probes and quantum lenses: Field evolution and atomic motion in a dispersive interaction model

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Abstract: We study the interaction of a quantized single-mode standing-wave cavity field with a two-level atom de Broglie wave. For the sake of simplicity we consider the field to be far detuned and the atom to be moving in the Raman-Nath regime. We show that the Wigner function of the field is a superposition of the Wigner functions for the coherent states aligned on an arc in phase space. The back action of the measurement of the atomic internal state leads to the modification of the diagonal as well as of the off-diagonal elements of the field density matrix. We investigate the formation of nonclassical field states via atomic deflection and internal-state measurement and show that the coherence of the field and the interference between the constituent coherent states disappear in the limit of large interaction times. The width of the atomic momentum distribution allows us to determine the mean photon number and the width of the photon distribution. We find that, for an appropriate choice of the initial state of the atomic centre-of-mass motion, the form of the atomic momentum distribution is identical to that of the photon distribution. The field near a node or an antinode acts as a focusing or defocusing lens for atoms, depending on the detuning and on the initial internal state of the atom.

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