Charged-vacuum-induced decoherence of quantum states of light

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Standard quantum optics predicts that a quantum state of the electromagnetic (EM) field prepared in an ideal cavity will not decohere. This is because decoherence requires coupling of the system to an environment, whereas the EM state of an ideal cavity is completely isolated from any external EM modes. But could coupling of the EM cavity modes to other fields induce decoherence, even in an ideal cavity? Specifically, could vacuum fluctuations from the Dirac vacuum cause the EM cavity state to decohere?

We show that the answer is *yes*: even in the absence of environmental noise, quantum-optical states can decohere. Specifically, we demonstrate that a single-mode Schrödinger cat state prepared in an ideal cavity—i.e. a cavity whose internal EM modes are not coupled to any external EM modes—can decohere due to interactions with the vacuum state of a scalar charged field.

Intuition from particle physics does suggest that there should be a fundamental loss of coherence of light due to its interaction with charged fermion field vacua via, for example, vacuum polarization (the Schwinger effect). But we show that this intuition fails to predict the right scales at which this would happen: for short interaction times and small interaction regions, EM field states decohere much earlier than the energy scales for which vacuum polarization happens. Our results therefore imply a fundamental limit on the speed and density of quantum gates inside an optical quantum computer.