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Comments on "Objectification of classical properties induced by quantum vacuum fluctuations"

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Abstract

We argue that in standard quantum electrodynamics radiative corrections do not lead to decoherence of unexcited atomic systems. The proposal of Santos relies upon deliberately switching on and off the vacuum interactions.

In his recent Letter [1], Santos claims to show that "there exists a *fundamental* mechanism producing decoherence of macroscopic bodies, without any departure from quantum theory". This fundamental mechanism is provided, as the Letter states, by the coupling of charged constituents with the electromagnetic quantum vacuum.

We agree with the general part of the Letter's argument. Quantized electromagnetic vacuum is, in many respects, similar to ordinary reservoirs influencing the given quantum system and destroying its coherence permanently [2,3]. There is a particular difference, however. The influence of vacuum must not lead to any decoherence if the system is in an unexcited state. We note that, for the evolution of bare excited states, decoherence is a well-known effect. The electromagnetic vacuum-fluctuations make the excited state of an H atom decay; the reduced density matrix of the atom will be a mixture of the excited state and of the various ground states corresponding to various recoils exerted by the emitted photon (for an exact relativistic evolution equation of the reduced atomic density operator see Ref. [4]). The naive idea that decoherence would occur for bare *ground* states as well fails definitely. We think that the effect calculated by Santos is due to the suddenly switching on of the vacuum influence at $t = 0$. Had we chosen the usual adiabatic switching on we would get no decoherence at all.

We consider the suddenly switching on at time $t = 0$ unphysical. In particular, it would excite ground state atoms and would make them radiate after all.

Let us discuss the simple example presented by Santos. Given an H atom in bare ground state, switching on vacuum influence at $t = 0$, the dressed H atom develops decoherence for t large enough when we trace over the photonic degrees of freedom. The degree of purity μ is calculated and found to be different from unity (13). Consider Eqs. (11) and (12) of the Letter. Let us write down the explicit time dependence of the needed matrix elements for the operators $\boldsymbol{p}$ and $\boldsymbol{A}$, respectively,

$$\langle\phi_n|\boldsymbol{p}(t)|\phi_0\rangle = \exp(\mathrm{i}\omega_n t)\langle\phi_n|\boldsymbol{p}(0)|\phi_0\rangle, \qquad (1)$$

$$\langle k|\boldsymbol{A}(t)|0\rangle = \sum_k \exp(\mathrm{i}\omega t)\langle k|\boldsymbol{A}(0)|0\rangle, \qquad (2)$$

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where ω is the energy of the one-photon state $|k\rangle$. Let us calculate the matrix element of the Letter's $U_1(t)$ in the limit $t \to \infty$. Invoking our Eqs. (1) and (2) we obtain

$$\langle\phi_n|\langle k|U_1(\infty)|0\rangle|\phi_0\rangle$$
$$= -\mathrm{i}\frac{e}{m}\sum_k \int_0^\infty \exp[\mathrm{i}(\omega_n+\omega)t]\,\mathrm{d}t$$
$$\times \langle\phi_n|\boldsymbol{p}|\phi_0\rangle\langle k|\boldsymbol{A}|0\rangle. \tag{3}$$

This expression would vanish if the vacuum interaction were switched on adiabatically. In that case the time integral would be proportional to $\delta(\omega_n+\omega)$, which is always zero since both ω_n and ω are positive numbers. Hence, for adiabatic switching on, the degree of purity μ remains equal to 1. The nontrivial result of Eq. (13) is a consequence of the sudden switching on at finite time t.

The ultimate argument against the suddenly switching on is the following. It is not at all accidental that, in the theory of quantum electrodynamics, the interaction is switched on at $t = -\infty$. Firstly, this choice most conforms with reality where interaction has already been acting since asymptotic past time. Secondly, a sudden switch at any finite time would create *real* particles even from the vacuum. In the simple case shown in the Letter, the bare ground state of the H atom becomes excited as $U(t)$ is getting to act on it for $t > 0$; the excited state will then decay and the emitted real photons will be detectable. The Born approximation yields

$$\frac{8\alpha}{3\pi m^2}\sum_n |\langle\phi_0|\boldsymbol{p}|\phi_n\rangle|^2\frac{\omega}{(\omega+\omega_n)^2} \tag{4}$$

for the spectral distribution of the emitted photon. The norm of this distribution, i.e. the overall probability of photon emission by the H atom, is equal to $1-\mu$, which is the degree of impurity of the final state.

Let us summarize our statement. In standard quantum electrodynamics bare charges are getting dressed by *virtual* photons. As a matter of fact, the bare ground states such as, e.g., the bare ground states of atoms may change (Lamb shift) but, obviously, they never emit *real* photons. To establish decoherence, one *needs* real emitted photons to trace out. On the one hand, the proposal [1] has been based on the principles of quantum electrodynamics. On the other hand, Santos has replaced the usual adiabatic switching on of the interaction by a sudden one at finite time, and this seems to raise serious problems like, e.g., spontaneous radiation of ground states. Furthermore, the experimentally observed states are dressed states. Actually, detectors are also based on electrodynamic interactions and see the photon cloud of the charge in question rather than the naked charge itself. To observe the decoherence of Santos, one has to detect the naked charges inside their photon clouds. This is possible only if we switch off again the interaction with the radiation field, which is obviously not the case in nature. Detectors, using alternative (i.e. not electrodynamic) interactions could see the naked charges even behind their photon clouds but such particular experiences of decoherence would not yield the general objectification aimed by the Letter.

Our doubts follow from standard field-theoretical considerations. We, of course, could not exclude that more refined and less standard considerations would offer a plausible implementation of the Letter's basic idea.

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