Erratum: Photonic quantum memory using an intra-atomic frequency comb **[Phys. Rev. A *99*, 052314 (2019)]**

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The treatment of the effect of Doppler broadening on the intra-atomic frequency comb (I-AFC) in Sec. IV is incorrect. Specifically, the assumption that the light emitted from each atom in the thermal ensemble will add incoherently is not correct. Here, we rectify this mistake. The new calculations show that the I-AFC-based quantum memory is useful for temperatures up to around 10 K. All other claims and calculations in the paper are correct.

An atom moving with velocity $\mathbf{v}$ experiences a change in frequency of the incoming light from ω_L to $\omega_L + \mathbf{k} \cdot \mathbf{v}$, where $\mathbf{k}$ is the wave vector of the incoming light such that $|\mathbf{k}| = \omega_L/c$. This will modify the detuning of a given transition from δ to $\delta + \mathbf{k} \cdot \mathbf{v}$. In the I-AFC system, this frequency shift results in the following expression for the atomic polarization:

$$\mathcal{P}(z, \omega, \mathbf{v}) = 2\mathcal{N} \sum_n \frac{i|d_{n0}|^2}{2\hbar} \frac{\tilde{\mathcal{E}}(z, \omega)}{\gamma/2 + i(\delta_n + \mathbf{k} \cdot \mathbf{v} + \omega)}. \quad (1)$$

In an atomic ensemble in thermal equilibrium at temperature T , the probability of an atom having velocity $\mathbf{v}$ is $p(\mathbf{v}) \equiv p_v \propto \exp(-mv^2/2k_B T)$. Thus, the effects of temperature can be incorporated in the atomic polarization by averaging the polarization over the velocity distribution p_v [1]. Here, m is the mass of the atom, and k_B is the Boltzmann constant. Since only the velocity component along the direction of propagation of light contributes to the Doppler shift, we consider the velocity only along the z axis, i.e., $\mathbf{v} = v\hat{z}$. The average macroscopic polarization is given as

$$\mathcal{P}(z, \omega) = \int \mathcal{P}(z, \omega, v) p_v dv. \quad (2)$$

The analytic form of this expression contains error functions which are not easy to handle. In order to solve for the atomic polarization analytically, we replace the Gaussian probability distribution with a corresponding Lorentzian of the form $L_v = \frac{a}{\pi(a^2 + v^2)}$ where the width $a \propto \sqrt{\frac{2k_B T}{m}}$ [2]. Since Lorentzian and the Gaussian distributions are different mostly in the tail part, this substitution will result in the introduction of more atoms with extreme velocities. Hence, this approximation will provide the lower bound of the atomic polarization.

On replacing $p_v \rightarrow L_v$, Eq. (2) reads

$$\mathcal{P}(z, \omega) = 2\mathcal{N} \sum_n \frac{i|d_{n0}|^2}{2\hbar} \frac{\tilde{\mathcal{E}}(z, \omega)}{\gamma/2 + ka + i(\delta_n + \omega)}, \quad (3)$$

which shows that the natural broadening is increased due to the thermal velocity distribution. Using Eqs. (3) and (14) in the paper, we can calculate the outcome electric field for temperature T .

In Fig. 1(a), we plot the photon echo at temperature $T = 10$ K, and in Fig. 1(b), we present the efficiencies of the forward and backward propagations as a function of temperature. Figure 1(b) shows that the I-AFC-based quantum memory can be useful for temperatures as high as 10 K. We can also see the variation of the finesse ($\mathcal{F}) = \Delta/(\gamma + 2ka)$ as a function of temperature where the average comb spacing (Δ) is obtained by inverting the echo time.

FIG. 1. (a) In this figure, we show the photon echo in Cs atoms which occurs 3 ns after the input pulse in the presence of Doppler broadening at 10-K temperature. In (b), we show the photon-echo efficiencies for the forward and for the backward propagations for the $\Delta m = \pm 1$ combs and the corresponding finesse as a function of temperature. Finesse for the two combs is the same as their echo time is identical.

[1] L. Mandel and E. Wolf, *Optical Coherence and Quantum Optics* (Cambridge University Press, Cambridge, UK, 1995), p. 815.

[2] P. Meystre and M. Sargent, *Elements of Quantum Optics* (Springer Berlin Heidelberg, Berlin, 2007), p. 126.