

OBSERVATION OF PHOTONS EMITTED DURING INHIBITED SPONTANEOUS EMISSION

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We present the results of an experiment to observe inhibited spontaneous emission of a parametric downconverter by an optical cavity that is switched off in a time that is short compared with the round trip time of the light. The question is, can photons be detected immediately after the switch, or only after some retardation time? Our results confirm the cavity QED prediction that photons can be counted immediately.

When an excited atom is placed near a mirror, it is allowed to radiate only into the set of electromagnetic modes that satisfy the boundary conditions imposed by the mirror. If none of these modes are compatible with the emission modes of the atom, it will not radiate. This phenomenon, known as inhibited spontaneous emission, has been observed for atoms, for trapped electrons, and for parametric downconverters (PDC), in which incident pump photons spontaneously decay into pairs of lower-energy signal and idler photons.¹

In 1995, Fearn *et al.*² proposed an interesting thought experiment: suppose an excited atom is placed in an inhibiting cavity, and after some time, one mirror of the cavity is instantaneously replaced by a photon-counting detector. Will the photodetector count a photon immediately (because the counter-propagating field amplitudes have been in the cavity all along), or will there be some round-trip delay due to the necessity of the atom first seeing the changed mode structure of the cavity, and then radiating a photon into this new mode structure?

The experiment is currently impractical to carry out for atoms, but because very long cavities can be used to inhibit a PDC, it is possible to perform the variation shown in Fig. 1a using an electro-optic switch (Pockels cell).³ A pump laser beam is directed into a PDC, where pairs of signal and idler photons may be created (Process 1). The pump, signal, and idler beams are reflected back into the PDC, where there is another chance for downconversion to occur (Process 2). Because there is no way to distinguish which downconversion process gives rise to the detected photons at A (see Fig. 1b), interference is possible; the relative phases are adjusted via a dispersive “tilt glass,” to produce fringes at detector A (see Fig. 2).

The “sudden mirror replacement” experiment is conducted with the tilt

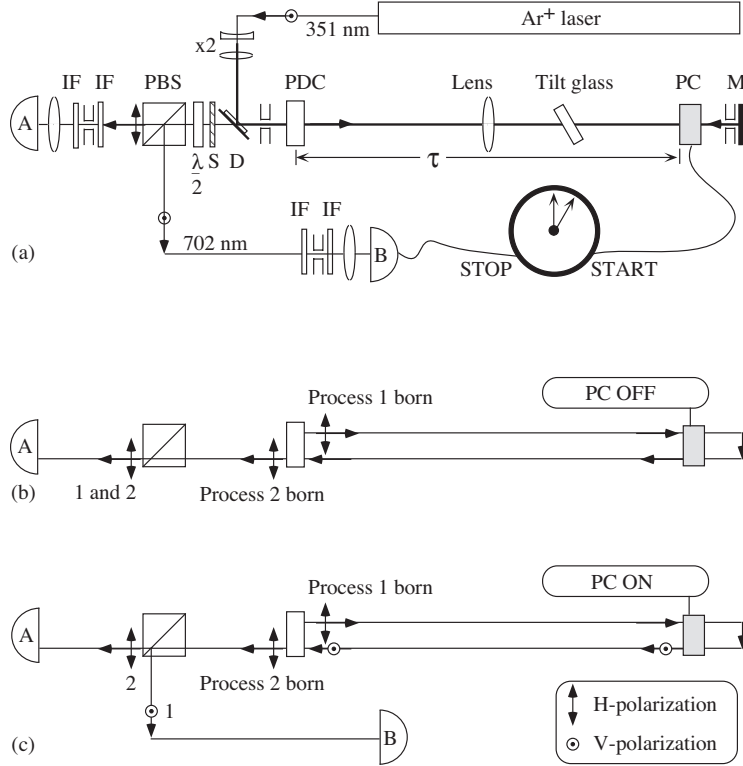


Figure 1. (a) Experimental arrangement. The PDC is a 6.25-mm KDP crystal, while the PC is 44.7 mm of KD*P. The Schott glass (S), dichroic mirror (D), and interference filters (IF) allow only the downconversion to impinge on the avalanche photodiode detectors A and B. (b) With the PC off, Process 1 and Process 2 photons go to the same detector. (c) With the PC on, Process 1 photons are rotated from H to V, and deflected to detector B.

glass fixed at the fringe minimum, where the emission is (partially) frustrated (Fig. 2). The Pockels cell (PC) is activated and quickly (within 7.5 ns) rotates the signal and idler polarizations by 90 degrees. The Process 1 light in the cavity now travels through the PDC without interfering, and is directed by the polarizer (PBS) to detector B (Fig. 1c).

The question is, how soon after the cavity is switched off will photons be registered at B? The two plausible scenarios in the thought experiment lead to two different answers: if photons (or photon amplitudes) were present in the cavity all along, then the delay should be τ (the propagation time from the PC to the PDC) plus a propagation time from the PDC to the detector. On the other hand, if the PDC had to wait to emit light until the mode structure was changed, this would incur an extra round-trip delay of 2τ (from

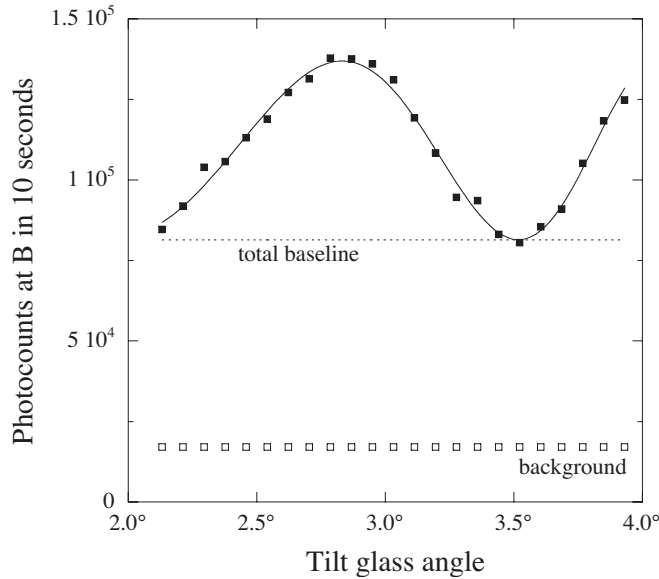


Figure 2. Single-channel interference fringe obtained by scanning the tilt glass incidence angle within the cavity. The background-corrected fringe visibility is $(30 \pm 1)\%$. The difference between the minimum and the background is the non-interfering total baseline rate.

the PC to the PDC and back). These two possibilities can be experimentally distinguished so long as the switching time is less than 2τ . In our experiment, the PC has a rise time of 7.5 ns and it is (1856 ± 5) mm away from the center of the PDC, so $2\tau = (12.37 \pm 0.03)$ ns.

The experimental results are shown in Fig. 3. The dots record the number of photon counts at various time delays, starting from just before the activation of the PC. For comparison, the photon arrivals from a HeNe laser in the same apparatus are shown as a thin line. The HeNe light is not suppressed or enhanced by the cavity, and must arrive at the early time. The downconversion arrivals are consistent with this early arrival, and inconsistent with an additional delay of 2τ by 29 standard deviations.

An important caveat is that because the fringe in Fig. 2 does not have perfect visibility, we observe a non-interfering rate of downconversion that is always taking place from both Process 1 and Process 2 (the “total baseline rate”). It is then hardly surprising that some photons arrive at detector B at the same time as the HeNe photons. The only photons that can be unambiguously identified as having come from an inhibited spontaneous emitter are those which remain after this baseline is subtracted. The mean counting rate

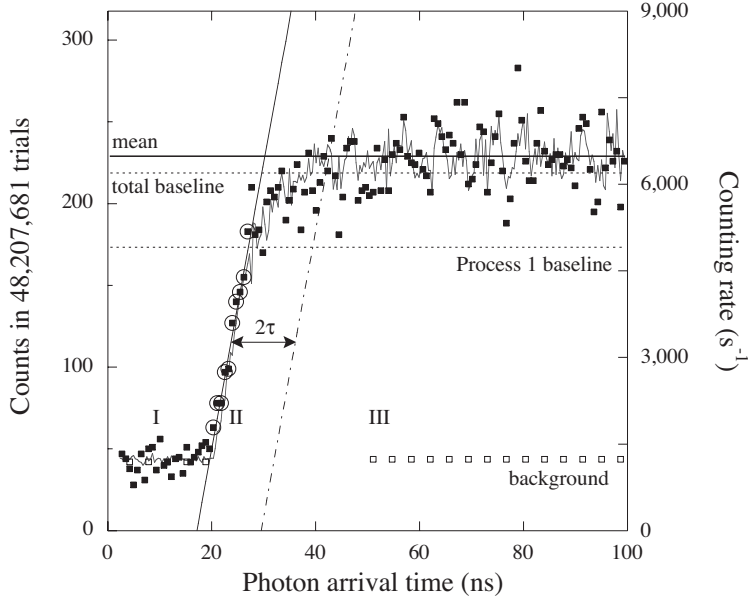


Figure 3. Arrival-time data for downconverted photons in the cavity (dots) and for a HeNe beam (solid line.) In region I, the Pockels cell has not been activated and no photons arrive at B. In region II, the Pockels cell voltage is rising. In region III, the photon counting rate at B reaches a steady-state value that is 2.2 standard deviations above the total baseline rate (see Fig. 2); this rate is also 28 standard deviations above the baseline rate of photons from only Process 1.

in region III of Fig. 3 is $(5252 \pm 74) \text{ s}^{-1}$. This exceeds the baseline rate (after correction for background, drifts, and PC efficiency⁴) by $(290 \pm 130) \text{ s}^{-1}$, or 2.2 standard deviations. Alternatively, we note that detector B can only register Process 1 photons (see Fig. 1), which are suppressed by 30% at the fringe minimum in Fig. 2 (along with the Process 2 photons). The mean counting rate in region III of Fig. 3 exceeds this suppressed “Process 1 baseline rate” by $(1576 \pm 57) \text{ s}^{-1}$, or 28 standard deviations.

References

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