Nonlinear Optics With Less Than One Photon

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Outline

• Can a nonlinear effect be observed between two photons?

• Is 100% efficient upconversion possible at the quantum level?

• Can we make a two-photon optical switch?

• Suppression and enhancement of spontaneous down-conversion by quantum interference.

• Experimental setup and Results.
Spontaneous Parametric Downconversion

Downconversion

Momentum is conserved..

Pump

\( s \)

\( i \)

- A pump photon is spontaneously converted into two lower frequency photons in a material with a nonzero \( \chi^{(2)} \)

\( k_s \)

\( k_i \)

\( k_{PUMP} \)

..as well as energy

\( \omega_{PUMP} \)

\( \omega_s \)

\( \omega_i \)

\( \varphi_{PUMP} = \varphi_s + \varphi_i \)
Consider...

Spontaneous Parametric Down-conversion

Time-Reversed

- 100% efficient upconversion
Which-Path Information

\[ \phi_{\text{PUMP}} \]

\[ \omega \]

\[ \phi_{\text{LO}} \]

\[ 2\omega \]

Intensity

\[ \phi_{\text{PUMP}} - \phi_{\text{LO}} \]
The Feynman Paths

\[ \phi_{\text{PUMP}} + 2 \times \phi_{\text{LO}} = P_{\text{COINC}} \approx \cos^2(\Delta \phi) \]
The Switch

•Phase chosen so that coincidences are eliminated
Type II Downconversion

Downconverted Photon Pair

Pump Photon

$\phi_{\text{PUMP}}$

$2\omega$

$H$

$V$

$\omega$

$P_{\text{COINC}}$

$2 \times \phi_{\text{LO}}$

$H$

$V$

$\phi_{\text{PUMP}}$
Experimental Setup

Mode-locked Ti:Sa

Delay

ND

\( \lambda/2 \) Pol.

SHG

DC

IF

PBS

Spatial Filter

Det. A

Det. B
Suppression and Enhancement of Coincidence Counts

Visibility = 48%
(57% background corrected)
Intensity Modulations: The Switch

Both LO’s blocked

Both LO’s unblocked

Vertical LO blocked

Horizontal LO blocked
Upconversion of Photon-Pairs

Coincidence Counts (/30s)

Total Coinc.

Down-conversion

Local Oscillators

15.7% Upconversion

Delay Time (fs)
We have demonstrated a quantum interference effect which is an effective nonlinearity at the single-photon level.

Pairs of photons can be removed from independent laser beams.

A single-photon switch was demonstrated by observing a change in the intensity of the beams.

A conditional phase-shift may be possible: Controlled phase gate?