A Means to Purify an Entangled Source

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Abstract

A technique is presented for improving the ratio of entangled photons to un-entangled photons for any means of generation. The approach takes advantage of the entangled nature of the photons of interest and their concomitant temporal coherence length, to separate that component by a combination of beam convergence, destructive interference, Faraday-Rotators, polarising filters and then beam divergence. The method applies to energy-time entangled photons and matter waves too.

1. Introduction

Entanglement is a multi-body phenomenon peculiar to quantum mechanics. It is related to classical correlation if two or more particles are constrained by a rule. For instance (this example due to J. S. Bell[1]), if we had a sock with a red or green ball and two people could only chose a ball blindfolded, the first person on eventually looking at their colour would immediately know the other person's ball colour. This rule is a toy model of conservation laws and we could say too that if the rule was that the balls had equal and opposite angular momentum, person 1 on receiving a left spinning ball would immediately know that person 2 had a right spinning ball.

The situation in Quantum Mechanics is intriguing due to the indeterminacy of the measurement process. In the contrived example with the sock and the balls, in a quantum setting it wouldn't be correct to say before measurement that we know we must have a red or green ball before measurement and looking at the result only reveals what had been predetermined; the balls are in a superposition of red and green and the act of measurement sets the state, not just locally but over space-like separation[2].

There is no "spooky action at distance" involving forces moving faster than light but what we can ascertain and tabulate by experiment number, after the fact, by coincidence testing[3] if many such experiments are performed. Any unitary[4] (i.e. non-measurement) operation performed on one particle of the set only changes the correlations perceived at the end. For instance, in our contrived example with balls, imagine there was a unitary operation that substituted (or "rotated") our "colour states" from red-green to yellow-blue respectively and this was only applied to one ball of the pair (say the first), coincidence counting after measurement would then find, 1:yellow/2:green or 1:blue/2:red instead of 1:red/2:green or 1:green/2:red *randomly*. We don't influence the distant system even though it is subject to the same conservation law (we made 1's balls yellow or blue, it doesn't follow that 2 will see yellow or blue balls too). Remote operations cannot influence physical quantities over space-like intervals, they can only collapse the remote wavefunction and change the statistics from being indeterminate to being fixed[5].

As a slight digression, it is believed that the "No-communication theorem" saves Special Relativity[6] but the author believes that, somehow, only information is passed because it has no mass-energy and so it not speed constrained[7, 8] by showing an omission in the no-communication theorem (it doesn't take account of phase and this can be ascertained by an interferometer).

Thus on the level of pure science, if not philosophical, work with entangled systems is en vogue, though more prosaic reasons of engineering a communications device by the measure/no-measure protocol[7, 8] are greatly assisted by better entangled sources.

2. Entangled sources

Entangled photons can be generated by a variety of means: spontaneous parametric down-conversion in non-linear material[9], radiative decay of electron-hole pairs in a quantum dot[10-12] or energy-time entanglement from ions in potential traps[13].

An example of the first case, figure 1 shows the spatial layout of the single photon down-conversion system, where a high frequency

laser source is incident on a crystal. The majority of the pumping high frequency radiation passes through the crystal (some 10^{12}:1) and various non-linear processes occur producing uncorrelated beams of different frequencies. Of most interest is the process that leads to down conversion to photons of half the energy *and* correlation/entanglement. At the intersection of the two middle cones one finds with a ratio of some 1:10,000, entangled photon pairs occasionally created by spontaneous emission and constrained by energy and momentum conservation. Higher powered pumping of the crystal generates more entangled photons though the ratio suffers. Cryogenic temperature can boost the ratio of the desirable entangled photons to un-entangled.

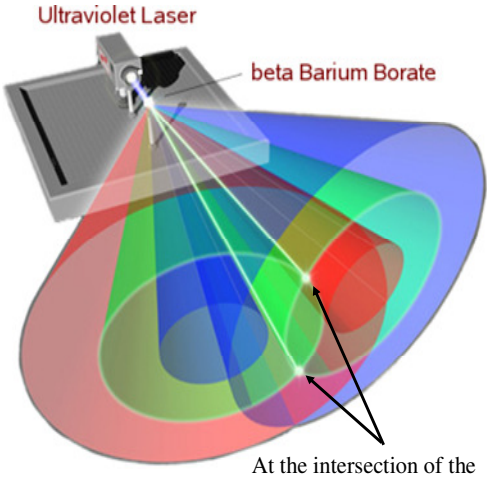

Figure 1 – Entanglement by down conversion

Obviously physical filtering by restricting most of the gathered photons to the intersection points (we can also use colour filters) increases our chances of recovering the entangled photons and we arrive at a density matrix (without the unwanted element) below[14].

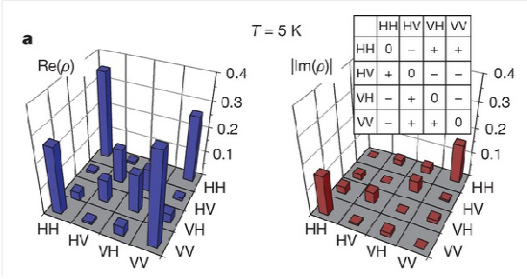

Figure 2 – Density Matrix for Entangled Photons[14]

In this paper will we present a method of improving this ratio of entangled to un-entangled ratio by using the sine-qua-non of entangled systems – their correlation.

3. Method

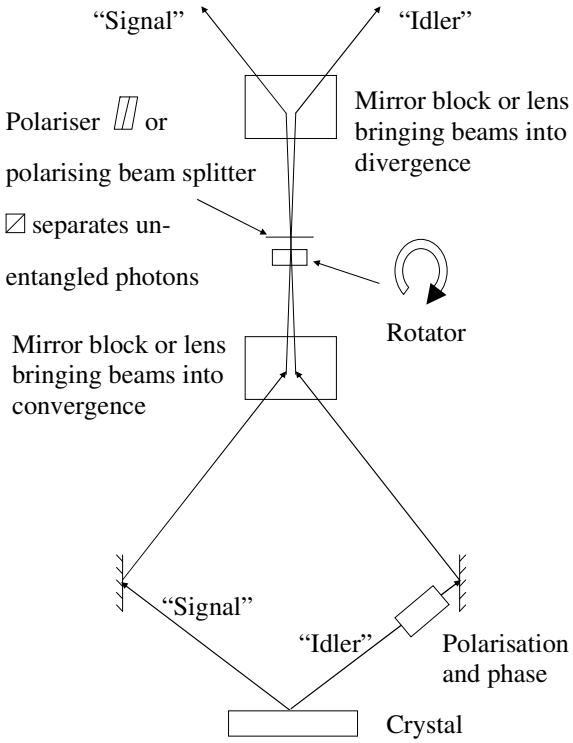

Figure 3 – The Apparatus

The apparatus depicted above makes use of the correlation (temporal, spatial) of entangled photons to make them interfere. The "idler" beam can be brought into the same polarisation and anti-phase with the "signal" beam. They then are made convergent in a region that has a Faraday Rotator then a polarizing filter or polarizing beam splitter (PBS). Since the electrical fields of the entangled photons are coherent and made to destructively interfere, the rotator, responding to the electric field strength will preferentially rotate the unwanted un-entangled photons in the statistical blend of photons travelling in the signal and idler beams. The polariser or PBS then removes these photons (figure 4). After this, the beams can be made divergent again to recover the signal and idler beams.

Improvements to the one stage scheme can be made by sending the signal and idler beams through multiple stages of the process. Figure 1 depicts a narrow beam incident on the crystal and though making the beam wider will blur the collection points at the intersection of

the middle cones, the convergence region in figure 3 would become wider and longer allowing the collection of more entangled photons. The rotation or rejection of the rotator, polariser or PBS is a function of the field strength squared and this very selectively favours the near zero field strength from the destructively interfering entangled photon field.

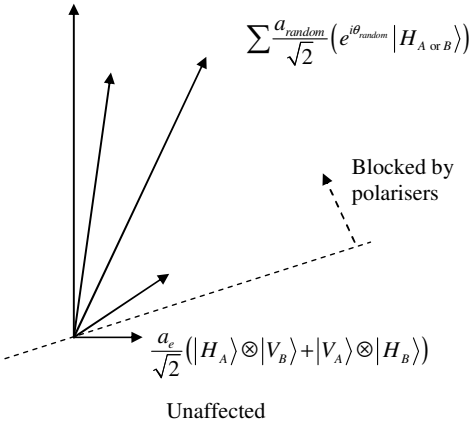

Figure 4 – How separation is affected

4. Conclusion

This paper will be updated with experimental results in due course. The method is general to all sources of entangled photon production.

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