Lab 1c The Photon Exists - Week 3

Phys434L Quantum Mechanics Lab
2018

February 17, 2018

1 Introduction

Once down-conversion pairs are produced, one type of experiments that can be done involves sending one photon through a particular optical setup and have the other one herald the presence of the first one. The coincidence detection makes this source mimic the ideal quantum source: a single atom undergoing a single-photon transition. Such a quantum source will emit a single photon. When one photon is incident on a beam splitter it is either transmitted or reflected, but not both. In contrast, a wave splits at a beam splitter. This source gives us the opportunity to prove that light is made of photons and not classical waves.

2 Theory

A photon incident on a beam splitter provides a definite proof the photons exist. Contrary to common belief, the photoelectric effect and even the Compton effect do not constitute a proof that photons exist because they can be explained using classical waves and quantum detectors. Photons are whole items. We detect either the whole photon transmitted or reflected. The alternative is that light is made of classical waves that split at the beam splitter, which would trigger simultaneous recordings at both sides of the beam splitter.

We measure this quantum probability via an anticorrelation parameter, also known as the degree of second-order coherence, $g_2(0)$. If we have detectors B and C at the two outputs of the beam splitter, then

$$g_2(0) = \frac{\mathcal{P}_{BC}}{\mathcal{P}_B \mathcal{P}_C}, \tag{1}$$

where P_B and P_C are the probabilities of detection at detectors B and C, respectively, and $\mathcal{P}_{BC}$ is the probability of detecting photons in both detectors simultaneously. Thus, for the ideal single-photon source $g_2(0) = 0$. The equivalent measure for classical waves is obtained from the Cauchy-Schwartz inequality, giving $g_2(0) \geq 1$. A more complete description can be found in the physics education literature.[1] With heralded photons we account for the probabilities in the following way. If the heralding photon is recorded at detector A, then based on the detections at detectors A, B and C,

$$\mathcal{P}_B = \frac{N_{AB}}{N_A} \tag{2}$$

$$\mathcal{P}_C = \frac{N_{AC}}{N_A} \tag{3}$$

$$\mathcal{P}_{BC} = \frac{N_{ABC}}{N_A}. \tag{4}$$

Note that the last equation involves triple coincidences. The degree of second-order coherence then becomes

$$g_2(0) = \frac{N_{ABC}N_A}{N_{AB}N_{AC}}. \tag{5}$$

We can estimate the uncertainty based on simple propagation of Poissonian statistical errors in the counts:

$$\Delta g_2(0) = g_2(0)\left(\frac{1}{\sqrt{N_{ABC}}} + \frac{1}{\sqrt{N_{AB}}} + \frac{1}{\sqrt{N_{AC}}} + \frac{1}{\sqrt{N_A}}\right) \tag{6}$$

This type of experiment was first conducted by Hanbury Brown and Twiss in 1956, and in doing so, inspiring the field of quantum optics.

When considering these correlated-photon experiments, one might ask: Why go through all of this trouble if a simple laser beam attenuated strongly enough can easily provide an average of one photon moving through the apparatus at any given time? The answer is that there is something misleading in the term "average." Using an attenuated laser source one gets $g_2(0) = 1$! A statistical source of light behaves the same way. Of course, we believe in photons, as no experiment has proven the contrary. However, an attenuated laser source mimics a classical wave, and so fails the beam-splitting test. This is because photons coming out of a laser are in a coherent state, which is an infinite superposition of states where more than one photon is emitted simultaneously. As a consequence, when the laser light is incident on a beam splitter some photons may be transmitted and others reflected, mimicking the classical wave. Therefore, we cannot do experiments with an attenuated laser and claim that it involves one photon at a time. In contrast, heralded photons do so, and the Hanbury-Browm-Twiss experiment proves it.

3 Procedure

To do this experiment we only need to add a few components to the previous one. These involve mostly the hardware for detecting photons following a third path involving the reflection from a beam splitter. The parts that are needed are listed in the table below, and refer to Fig. 1

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[1] J.J. Thorn et al. *American Journal of Physics* 72, 1210-1219 (2004).

Qty	Part	Description/Comments
1	Beam splitter	(BS) Non-polarizing.
1	Fiber collection assembly.	(DC) Multimode fiber with FC type connectors, mounted collimator plus concentric iris mounted on the collimator mount.
1	Band-pass filter	800-810 nm center, 40-nm bandwidth.
1	Detector.	Avalanche photodiode, fiber-coupled.

1. Assemble the apparatus shown in Fig. 1 by adding a beam splitter. Align it so that its sends reflected photons at 90° from the incident direction.

2. Add and align a third fiber collimator (C) to collect the light reflected by the beam splitter. Use the same collimator alignment technique done before.

3. The data acquisition setup has to be adjusted to detect double coincidences between A and B, and A and C; and triple coincidences between A, B and C.

4. Accumulate data for a period of about 1 minute. Thus, the data acquisition period may be very short: we only need 1 data point!

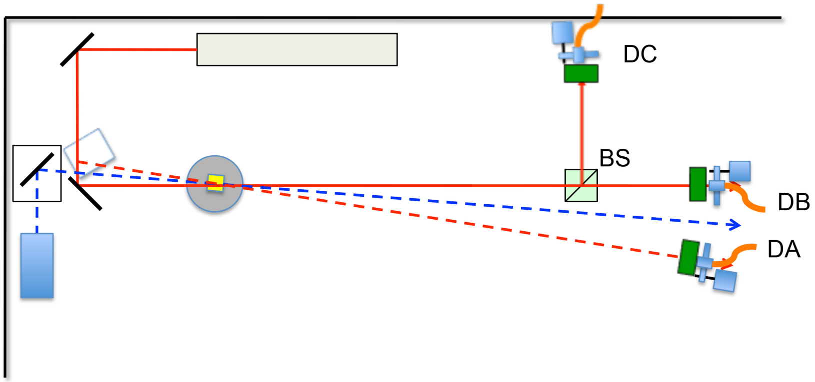

Figure 1: Apparatus to do the test that photons do not split at a beam splitter (BS). It requires 3 detectors A, B and C, and the ability to detect double and triple coincidences.

4 Questions

1. Find the value of $g_2(0)$ from your data and Eq. 5.

2. Calculate the uncertainty $\Delta g_2(0)$ from Eq. 6.

3. Discuss the experimental results and state your conclusion on what they mean.