Photon Bunching and the Hong-Ou-Mandel Dip

with the Qubitekk Quantum Mechanics Lab Kit

For centuries, the nature of light and atomic phenomena had eluded the most brilliant of scientific minds. How can particles be both waves and discrete particles at different times? How can a single particle be in two places simultaneously? These are but a couple of the questions that students of quantum mechanics have grappled with for decades.

Background

We demonstrate a quantum phenomenon called photon bunching. It is not always possible to predict the exact behavior of an individual photon. Even given all information about the photon and the environment, there are still some behaviors that are random. When a photon encounters a non-polarizing beamsplitter (BS), it gets randomly reflected or transmitted. However, when two photons are identical in every way, or indistinguishable, their random behaviors can be correlated.

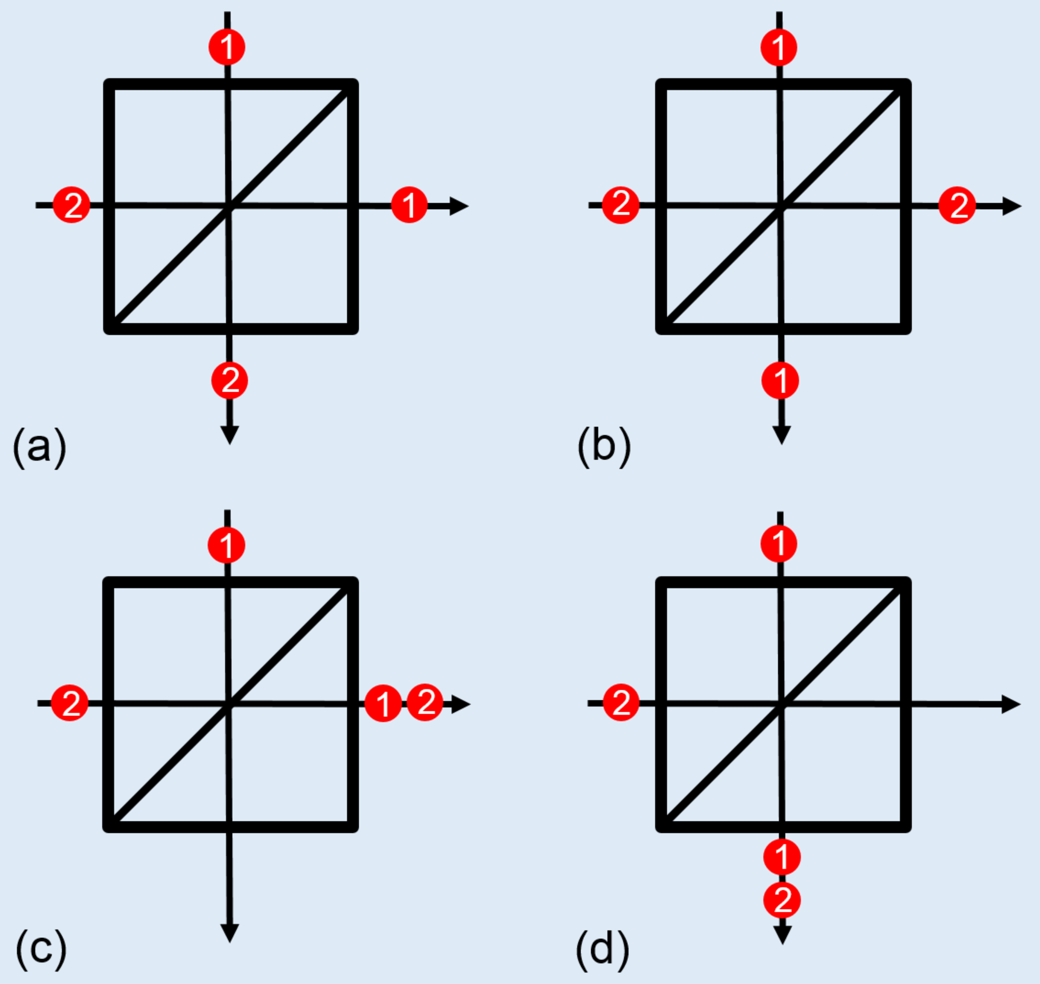

Figure 1 – Four possible scenarios for bi-photon interaction.

When two photons are incident on a 50/50 non-polarizing beamsplitter at the same time, there are four possible outcomes, as shown above. In (a) and (b), both photons exit out of separate ports. In (c) and (d), both exit out of the same port. If both photons are identical, we show that only scenarios (c) and (d) occur.

Experimental Setup

A 405nm laser pumps a Type-II periodically-poled KTP (PPKTP) crystal to produce two 810nm down-converted photons: one horizontally polarized and the other vertically polarized. These two photons are separated at a polarizing beam splitter (PBS); one travels through a fixed delay, the other through a variable delay. They are rejoined at a 50/50 beam splitter (BS) before being detected. This is illustrated in Figure 2.

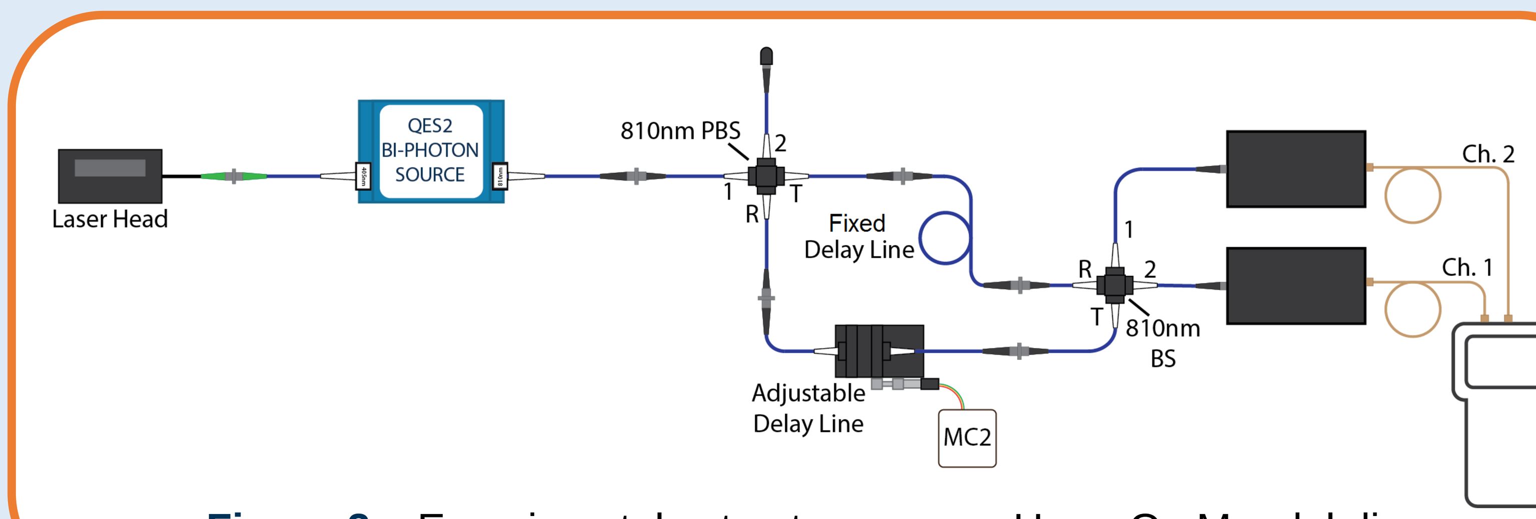

Figure 2 – Experimental setup to measure Hong-Ou Mandel dip.

Scanning over the variable delay, we change the arrival time of the photons on the two paths relative to each other. With a certain delay, the photons arrive at the BS at the exact same time, at which point we observe bunching.

Temperature Dependence

The down-conversion occurring in the PPKTP crystal is highly temperature-dependent. When the temperature diverges too much from the ideal, the two photons exiting the crystal have slightly different wavelengths, and are no longer indistinguishable. When the photons aren't indistinguishable, we no longer observe bunching.

We can test this effect by changing the temperature of the crystal.

Results and Conclusions

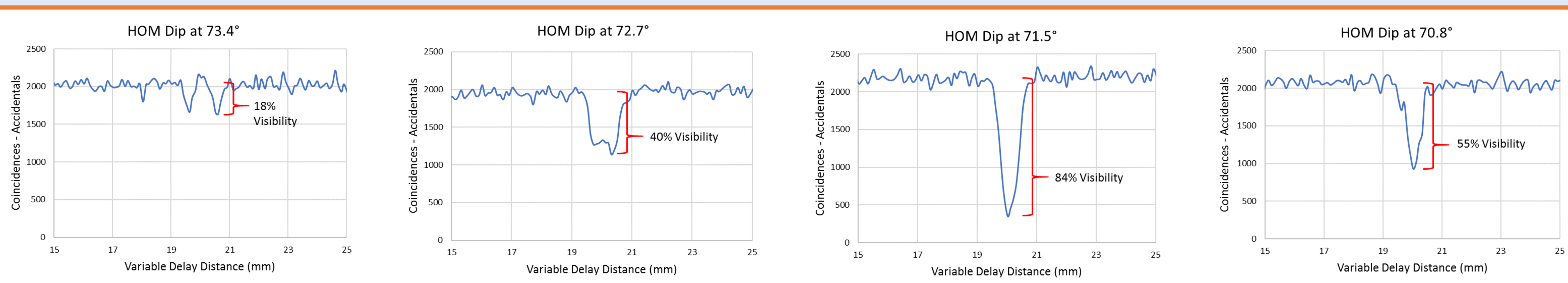

Figure 3 – Temperature dependence of bunching at a beam splitter.

When bunching occurs, and the photons exit the beamsplitter from the same port, we don't see a coincidence, which causes the Hong-Ou-Mandel dip. Deeper dips indicate a more "degenerate" output – all the photons are the same wavelength and therefore indistinguishable at the beamsplitter. Unfortunately, the dip never reaches zero, because there is always some "noise": photons at different wavelengths, photons from the pump beam, photons that aren't part of pairs, etc.

The graphs in Figure 3 illustrate the temperature dependence of bunching at a beam splitter. The visibility is a measure of the depth of the dip versus the signal outside the dip. When the wavelengths diverge at non-ideal temperatures, small divergences still result in a smaller dip, continuing until no dip is seen at all.

Qubitekk's **Quantum Mechanics Lab Kit** tears down the barrier between the theoretical and the practical by offering an educational and research tool for both students and scientists alike. Finally, the power of quantum mechanics can be experienced firsthand by all.

The kit opens the gateway for anyone to visualize the theories of quantum mechanics in a practical way. We have included all of the equipment and instruction necessary to perform six fundamental experiments in quantum mechanics. Based on Qubitekk's zero alignment quantum sources and fiber optic components, these experiments can be quickly set up and completed within a traditional 2-3 lab hour period. A detailed lab handbook, written at the senior undergraduate level (for physics and engineering), is included to provide a self-guided tour to amazing quantum mechanics phenomena.

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