Interference Effects at the Single Photon Level*

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Interference effects have been demonstrated in the superposition of two light beams from two independent lasers, under conditions where the intensity was so low that one photon was absorbed, with high probability, before the next one was emitted by either one of the sources.

Since the experimental demonstration of interference effects produced by the superposition of two independent light beams [1], the question has been debated whether the effect is to be regarded as evidence for the interference of photons from one beam with photons of the other beam [2-4]. On the face of it, the observations appeared to contradict a well-known remark of Dirac [5] that "...each photon interferes only with itself. Interference between different photons never occurs".

It is the purpose of this communication to report the results of further experiments which show that the effect cannot reasonably be described as an interference between photons of one beam and photons of the other. On the contrary, it appears that Dirac's statement, in a sense, is just as applicable to the foregoing experimental situation as to conventional interferometry.

We recall that, if $\Delta\nu$ is the overall frequency spread of the two light beams, assumed to be spatially coherent over the surface S on which the interference pattern is to be received, then any interference fringes will be expected to remain stationary only over a time interval $T < 1/\Delta\nu$ [6]. There is therefore an upper limit to the 'exposure time' in which the fringes may be examined. Now let the light intensities of the two beams be reduced until the mean rates r_1 and r_2 at which photons are striking the surface S satisfy $r_1 \ll 1/\tau$ and $r_2 \ll 1/\tau$, where τ is the transit time through the interferometer. Under these conditions it can be said that one photon is absorbed at S before the next one is emitted by one or the other source, with high probability. If interference fringes are formed under these conditions they cannot easily be described as an interference between two independent photons, but must be associated with the detection of *each photon*.

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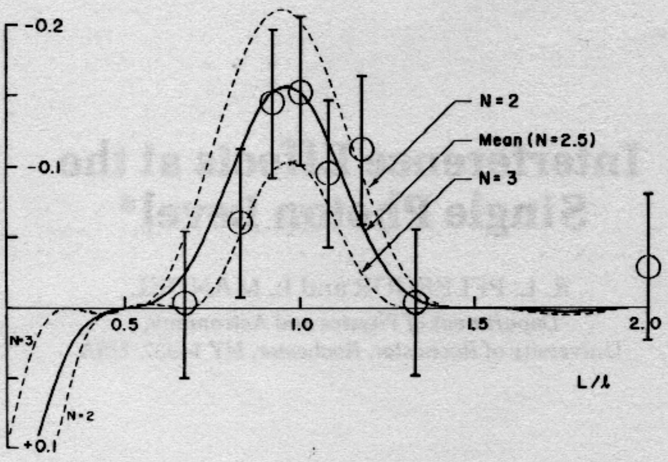

Fig. 1. Experimental results for the normalized correlation coefficient, together with theoretical curves for N = 2 and N = 3 and their mean.

In our experiment the transit time τ was approximately 3 nsec, while the photon rates r_1 and r_2 were of order 3×10^6 per sec. The 'exposure time' T was 20 μsec, which, in association with a photodetection efficiency of about 7%, resulted in about 10 detected photons per trial. It is of course important that this number should be significantly greater than unity if interference fringes are to be identified.

The light sources for the experiment were two single mode He:Ne lasers, whose beams were superposed at a small angle θ after passing through attenuators. An auxiliary arrangement involving an additional photodetector was used to measure the difference or beat frequency of the two beams. Whenever the beat frequency fell below 50 kc/sec the interference pattern was examined for 20 μsec. The interference detecting system consisted of a stack of thin glass plates, having their edges facing the beams and parallel to the interference fringes. They were arranged so that light falling on the odd-numbered plates was deflected to one photomultiplier, while light falling on the even-numbered plates was deflected to another. If the plate thickness $\frac{1}{2}L$ corresponds to a half-fringe width $\frac{1}{2}l$, and if the maxima of the interference fringes fall on the odd-numbered plates, say, then one phototube should register most of the photons and the other one practically none.

In fact the positions of the fringe maxima are not predictable and vary from trial to trial, so that the number of photons n_1 registered in one channel should decrease as the other number n_2 increases. Thus, if interference fringes are present, and if the fringe half spacing $\frac{1}{2}l$ corresponds to the plate thickness $\frac{1}{2}L$, there should be a negative correlation $\langle \Delta n_1 \Delta n_2 \rangle$. If $\frac{1}{2}l$ differs appreciably from $\frac{1}{2}L$, or if no interference fringes are formed, then $\langle \Delta n_1 \Delta n_2 \rangle$ should be close to zero, or perhaps positive.

Figure 1 shows the results of measurements of the correlation coefficients as a function of L/l, which was varied by changing the angle θ between the beams. It will be seen that a negative correlation is found when $L/l \approx 1$,