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One-Bit Photon Polarization in Two-Photon Experiments. An Information Mechanics Perspective

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Two-photon experiments of Aspect, Grangier, and Roger, directed toward testing Einstein, Podolsky, and Rosen's thought experiment, are seen in the context of Kantor's information mechanics as illustrating some consequences of the fact that the amount of information represented by the photon's polarization is one bit.

In this paper is presented a detailed treatment of amount and representation of photon polarization information in the two-photon experiments of Aspect, Grangier, and Roger (Aspect *et al.*, 1981, Clauser *et al.*, 1969), seeking to test Einstein, Podolsky, and Rosen's thought experiment (Einstein *et al.*, 1935). Newton's mechanics, Einstein's relativistic mechanics, and quantum mechanics do not treat as fundamental the amount and representation of information in physical systems (Kantor, 1986, Wigner,[2] 1986). The line of reasoning presented here was reached via Kantor's information mechanics (Kantor, 1977). The information bookkeeping presented here appears to offer a simple, physical insight into what the apparatus and the photons are doing together.

First, how much information is represented by a photon's polarization? One can choose to represent the photon's polarization as right- or left-helicity. Detection of this helicity is not affected by choosing different angular positions of rotation of the detector about the axis of propagation of the light. Only two possibilities are presented. Thus, the amount of information, in bits, is log base 2 of 2, which is 1.

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[2] Wigner noted, "the process of measurements cannot be described by the equations of quantum mechanics because their existence is in contradiction to its principles. It is important to realize this fact" (Wigner, 1986, page 5, paragraph 3, lines 1-3).

One can transcribe photon polarization information between representation as helicity and representation as linear polarization; e.g., by using a quarter-wave birefringent plate. This does not change the amount of polarization information represented. Thus, one can recognize that linear polarization of a photon represents only one bit of information.

What are some ways in which that one bit might be represented in the system?

Consider an idealized apparatus which produces pairs of photons having correlated polarizations emitted along two paths (Aspect *et al.*, 1981; Clauser *et al.*, 1969). One could set up two polarizing films, *PA* and *PB*, each in front of its respective photon detector, *DA* or *DB*, located on the respective photon paths *A* and *B*. When the polarizing films are suitably aligned, the detection of photons by the respective detectors in paths *A* and *B* would show close to unity correlation. That is, for an (approximately) idealized case, one might say (approximately) that one would detect a photon at detector *DA* if and only if one would detect a photon at detector *DB*. If both polarimeters were rotated together to suitable new positions, this correlation would not be lost.

Complete correlation when the two polarizing films are aligned would mean that the amount of polarization information represented by the difference between the two photons would be log base 2 of 1, which is zero.

One can illustrate this by considering a second configuration, in which the light in path *B* is sent out and reflected back, to provide additional time delay before it reaches the polarizing film. A normally closed gate *GB* is placed after the additional time delay and before the polarizing film in path *B*. The extra time delay provides enough time for the detection of a photon by detector *DA* to be used to open, for a time interval, the gate *GB* in path *B* so that it not block the photon in path *B*.

Consider the case of photon emission with, for example, half or more as pairs, with average time between emissions very large compared to the time interval the gate is open: if detector *DA* and the optics in path *A* together have an efficiency less than unity, then sometimes the gate in path *B* would block a properly polarized photon of a pair. But, with reasonably good polarizing film in path *A*, detector *DA* would not be likely to be fired by an improperly polarized photon in path *A*. For this reason, it would be unlikely for the gate in path *B* to be open to pass an incorrectly polarized photon.

Notice what happened here: because the path-*B* gate is controlled by a photon passing through the polarizing film in path *A*, the correspondingly aligned polarizing film in path *B* has turned out to be unnecessary. So, suppose we take the polarizing film out of path *B*. This gives us an apparatus in which the opening and closing of the gate produces a highly linearly-polarized beam of photons. In an idealized case, with perfect equipment and no losses or straying of photons, about half the photons in path *A* would pass through polarizer *PA*, and the path-*B* gate would be open for about half the photons in path *B*.

That the selective opening and closing of the path-*B* gate would produce highly linearly-polarized light from substantially unpolarized light, and that in doing so the gate would be open for about one-half of the path-*B* photons, further illustrates that the amount of information represented by the photon's polarization is one bit.

Next, suppose we replace the polarizing film in path *A* with a low-dissipation polarizing means, such as a Brewster-angle-reflection beam-splitter. Now, we can use two detectors, *DA*1 and *DA*2, one for each of the two outputs from the polarizing beam-splitter. In an idealized case, a photon arriving via the polarizing beam-splitter would be detected by one or the other of the two detectors. If we use only one of the two detectors in path *A* to control the gate in path *B*, we have the same sort of situation as before.

Suppose we were to use only pairs of photons, with ideally efficient equipment, and take the output from both detectors so that a path-*A* photon detected by either *DA*1 or *DA*2 would cause the path-*B* gate to open: then, the gate would be open for almost every photon in path *B*. The output light via path *B* would be substantially unpolarized, and very little if any of the light in path *B* would be lost.

But the polarization information would still be available. Nearly every time a photon was passed in path *B*, detector *DA*1 or detector *DA*2 would have detected a photon; that is how the gate would have been opened. The triggering of one out of two possibilities represents one bit of information. Imagine that, next to the stream of photons, there is a second communication channel carrying a stream of bits, one for each photon.

Suppose this path-*B* output light were used for a photon experiment in which each photon event is treated as being substantially independent of the others. In analyzing the data, one could choose to group together all of the events for which the gate was opened by detector *DA*1, and separately group together those for *DA*2. The choice, of which set to count an event in, would represent (log base 2 of 2 =) 1 bit of information. The control of where to put the data from the event would have the same effect on apparent polarization as would have the selective control of opening the path-*B* gate: this binary allocation during data analysis would result in the light being seen as highly linearly polarized, even if the data analysis were to be done years after the experiment. It is the same bit.

Notice that, for efficient equipment and a low photon rate, the gate and the polarizing film in path *B* have turned out to be unnecessary.

Thus, the fact that one might change the orientation of the polarizer in path A after the two photons are emitted and before one of them enters it appears completely irrelevant: the one bit of polarization information per photon is carried from that path-A observation into the analysis later, thus providing, on a photon-by-photon basis, the one bit per photon needed for the path-B light to be seen as highly linearly polarized along whatever direction a polarizer in path B would have had to have to correspond to the orientation of the polarizer in path A when that one bit of polarization information was encoded.

One can see here yet another effect due to the fact that the amount of polarization information represented by a photon is only one bit: using a large amount of information to specify the orientation of a polarizer does not make the photon it allows through carry more than one bit of polarization information. This applies whether the photon passes directly through a polarizer, or passes through a gate controlled by detection of a correlated photon which passed through a polarizer, or is detected within a time slot for which that photon's polarization information has been encoded.

The electronic coincidence requirements in the experiments of Aspect *et al.* (1981) imposed the use of the path-A bit of polarization information associated with the time slot in question. This provided the information necessary to produce the effect of having the light in path B appear polarized along the direction of a hypothetical path-B polarizing film oriented in correspondence with the polarizer in path A by means of which that bit of information, for that time slot, had been encoded. Thus, in the resulting analysis, the output of the detector in path B would be counted as if the light in path B had passed through a polarizer having the orientation corresponding to that of the polarizer in path A, and then through the polarizer in path B. The expression used by Aspect *et al.* (1981), citing Clauser *et al.* (1969), citing Horne (1969), states a dependence on twice the angle between the polarizers. Because, classically, $\cos(w)^2 = \frac{1}{2} + \frac{1}{2}\cos(2w)$, dependence on twice the angle is seen to be a way of writing the probability proportional to the square of the projected amplitude, as would arise from the information process set forth above.

In the above discussion, a profound physical result is reached by keeping track of amount and representation of information in a physical system, a conceptual tool treated as fundamental in Kantor's information mechanics (1977).

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