

# Quantum cryptography based on Wheeler's delayed choice experiment

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## Abstract

We describe a cryptographic protocol in which Wheeler's delayed choice experiment is used to generate the key distribution. The protocol, which uses photons polarized only along one axis, is secure against general attacks.

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In 1970, Wiesner wrote a highly innovative paper about quantum cryptography, introducing a new branch of Physics and computation. Unfortunately, his idea went unnoticed, and his paper was not published until 1983 [1]). Wiesner’s idea was brought back to life in 1980s primarily by the work of Bennett, Brassard [2]. Bennett *et al.* have recently reported the experimental realization of the first quantum cryptographic protocol [3].

Theoretical models for quantum key distributions have been proposed based on uncertainty principle [2], EPR [4] states [5], and any set of two non-orthogonal states [6]. Here we describe a model for quantum key distribution based on Wheeler’s delayed choice experiment.

Before proceeding, let us briefly describe Wheeler’s delayed choice experiment (for detailed explanation see [7], especially Fig. 4; for consistency, we use Wheeler’s notations). In the first arrangement, a single photon (or low intensity light pulse) comes in at 1 and encounters a beam splitter  $\frac{1}{2}S$  which splits it into two beams,  $2a$  and  $2b$ , of equal intensity (See Fig. 4 of [7]). The beams are reflected by mirrors  $A$  and  $B$  to a crossing point and are then detected by detectors 1 and 2. Thus one finds out by which route ( $2a$  or  $2b$ ) the photon came. In the second arrangement, a beam splitter  $\frac{1}{2}S'$  is inserted at the point of crossing in front of detectors. The beams  $2a$  and  $2b$  are brought into constructive interference so that a count is always triggered from detector 1. Thus in this arrangement, one concludes that the photon came by both routes. In Wheeler’s experiment:

In the new “delayed-choice” version of the experiment one decides whether to put in the half-silvered mirror [beam splitter in front of detectors] or take it out at the very last minute. Thus one decides whether the photon “shall have come by one route, or by both routes” after it has “*already done* its travel”. (quote from [7]).

With the above in mind, we now proceed to describe a model for quantum key distribution. The protocol, which is based on Wheeler’s delayed choice experiment, consists of the following steps:

- (1) Alice prepares a sequence of  $n$  photons (or low intensity light pulses), all polarized in one direction. She randomly inserts the beam splitter  $\frac{1}{2}S$  in front of her photons. In those instances in which she has not inserted the beam splitter (approximately for  $\frac{n}{2}$  photons), she randomly sends the photons along route  $2a$  or  $2b$ . Thus approximately  $\frac{n}{4}$  photons are sent along route  $2a$ , and another  $\frac{n}{4}$  photons are sent along route  $2b$ .
- (2) Bob randomly (and of course, independent of Alice) inserts his beam splitter  $\frac{1}{2}S'$  in front of his detectors. Thus approximately  $\frac{n}{2}$  photons are detected with the beam splitter  $\frac{1}{2}S'$  in front of the detectors and another  $\frac{n}{2}$  photons are detected with the beam splitter removed.

(3) Alice tells Bob (and to any adversary who may be listening) in each instance whether she inserted the beam splitter  $\frac{1}{2}S$  in front of her photon. Bob also announces publicly to Alice in each instance whether he inserted the beam splitter  $\frac{1}{2}S'$  in front of his detectors.

(4) Alice and Bob discard all instances in which Bob failed to register a particle.

(5) Bob tests the key distribution by checking that in all instances in which only one of them (either he or Alice) inserted the beam splitter (but the other one did not), detectors 1 and 2 were triggered with equal probability, and in all instances in which they both inserted their beam splitters, only detector 1 was triggered, i.e., beams  $2a$  and  $2b$  interfered constructively. If these conditions are satisfied, then Bob informs Alice that there was not any eavesdropping. They then keep the data only from instances in which they both happened to remove their beam splitters (approximately for  $\frac{n}{4}$  photons).

(6) Alice interprets her data as a binary sequence according to the following coding scheme:

The photon is sent along route  $2a = 0$ ,

The photon is sent along route  $2b = 1$ .

The experimental arrangement is such that when the beam splitters are removed, detector 1(2) is triggered, when the photon came by route  $2a(2b)$  (see Fig. 4 of [7]). Thus Bob interprets his data as a binary sequence according to the following coding scheme:

Detector 1 is triggered, thus the photon came by route  $2a = 0$ ,

Detector 2 is triggered, thus the photon came by route  $2b = 1$ .

(7) With this coding scheme, Alice and Bob have acquired a random bit sequence with high level of confidence that no one else knows it.

One advantage of the above protocol is that the photons are all polarized along one axis, for example along the  $x$  axis. Thus the photons that Alice sends to Bob (perhaps through a fiber) all suffer the same transmission loss while in transit (note that transmission loss depends on polarization). In contrast, schemes which use photons polarized in different directions are susceptible to different transmission losses for different photons.

## References

- [1] S. Wiesner, *Sigact News*, **15** (1), 78 (1983).
- [2] C. H. Bennett and G. Brassard, in *proceeding of the IEEE International Conference on Computers, Systems, and Signal Processing, Bangalore, India* (IEEE, New York, 1984), p.175.; C. H. Bennett, G. Brassard, and N. D. Mermin, *Phys. Rev. Lett.* **68**, 557 (1992); C. H. Bennett, G. Brassard, A. K. Ekert, *Scientific American*, October p. 50 (1992).
- [3] C. H. Bennett, G. Brassard, L. Salvail, and J. Smolin, *J. Cryptology* **5**, 3 (1992).
- [4] A. Einstein, B. Podolsky, and N. Rosen, *Phys. Rev.* **47**, 777 (1935).
- [5] A. K. Ekert, *Phys. Rev. Lett.* **67**, 661 (1991).
- [6] C. H. Bennett, *Phys. Rev. Lett.* **68**, 3121 (1992).
- [7] J. A. Wheeler, in *Mathematical Foundations of Quantum Theory: Proceedings of the New Orleans Conference on the Mathematical Foundations of Quantum Theory*, edited by A. R. Marlow (Academic, New York, 1978). Reprinted in *Quantum Theory and Measurement*, edited by J. A. Wheeler and W. H. Zurek (Princeton Univ. Press, Princeton, NJ, 1983), pp. 182-213.