Reply to Comment:
Quantum Cryptography Based on Orthogonal States?

Peres [1] claims that our protocol [2] does not present any novel feature, and it is very similar to the oldest protocol of Bennett and Brassard [3] (BB84). We completely disagree with this claim and with other points raised in the Comment. The essential novelty of our protocol is that the carrier of information is in a quantum state belonging to a definite set of orthonormal states. Any other protocol, as well as the BB84 scheme, does not have this feature, and in fact their security is based on that. Let us quote a recent paper [4] stating that:

“... cloning can give a faithful replica, while leaving the state of the original intact, only if it is known in advance that the carrier of information is in a quantum state belonging to a definite set of orthonormal states. If this is not the case, the eavesdropper will not be able to construct even an imperfect cloning device, which would give some information on the carrier without modifying it: a device of this sort would violate unitarity. Therefore coding based on nonorthogonal quantum states (which cannot be cloned) gives the possibility to detect any eavesdropping attempt”.

Thus, the security of BB84 (which uses 4 states, not all orthogonal) is assured by the ‘no-cloning’ theorem, which is not applicable to our case.

Peres claims that in our method Eve has access only to nonorthogonal states: “The $\rho'_\pm$ states, as seen by Eve, are not orthogonal. Their are identical”. However, the nonorthogonality (as seen by Eve) in our scheme is not “just as in the BB84 protocol”. As Peres admits, in the case of known sending times our protocol is not secure, yet his nonorthogonality argument remains the same. The security of our protocol is not based on nonorthogonality, but on causality. As we have proved in the Letter [2], a successful eavesdropping is possible only if some information can reach Bob before it leaves Alice’s site - therefore, the protocol is secure. This is also the feature of the protocol proposed at the end of the Comment, in which a particle is sent at a known time in one out of two GV interferometers (GV2). A successful eavesdropping is impossible in this case too, otherwise the wavepacket delayed at Alice’s location has to reach Bob’s site before
leaving Alice’ site. Note that in the case of a single GV interferometer (and known sending times) Eve can send Bob a dummy particle at the appropriate time, but here she does not know which of the two interferometers to use for sending it.

According to Peres, an important common feature of GV and BB84 (or other protocols interpolating between these two) is that “information is sent in two consecutive steps, and security is achieved by withholding the second piece of information until after Bob receives the first one”. In his view the first step is sending the particle, and the second step is sending the necessary classical information: the chosen basis (BB84), the transmission time (GV), or the chosen interferometer (GV2). The first conceptual difference between the protocols is that in BB84 the two steps are necessary for sending the information, while in GV or GV2 one step is enough. The only purpose of the second step is to assure security against eavesdropping. The second difference is that the first step of our protocol also consists of two stages: sending the first wavepacket and sending the second wavepacket (the delayed one). Alice does not have to wait until the end of the first step for announcing the sending time (GV) or the interferometer in use (GV2). She can do that after the first stage of the first step (i.e. after the first wavepacket reaches Bob), thus, ‘the second step’ might end before ‘the first step’. These two stages of the first step, i.e. the fact that the quantum signal consists of two separated parts, is the core of our method, and we do not see its analog in BB84 or any other protocol.

Finally, it seems that Peres has not understood the ‘relativistic’ versions of our protocol. First, it is not true that the storage rings have to be larger than the distance between Alice and Bob. When the communication is based on photons which travel on straight lines, the time delay can be made as small as wanted (it depends on the width of the wavepackets and on the accuracy of the clocks). Contrary to Peres’ claim (and his Fig. 1), Eve can simultaneously access the two branches of the interferometer most of the time, still the protocol is secure. A similar proof to that given in the Letter shows that a successful eavesdropping leads to superluminal signaling. Second, it is not true that in the case of the protocol with two widely separated paths and no time delay, “a team of eavesdroppers could use mirrors to redirect the photon paths toward a common inspection center, and hence to Bob, without arousing suspicion”. Such an operation invariably increases the flight-time of the photons, therefore the users
can easily expose the team by analyzing the timing. Since the information is encoded
in the relative phase between the wavepackets, even more sophisticated eavesdropping
methods cannot work, unless they use superluminal particles.

Lior Goldenberg and Lev Vaidman
School of Physics and Astronomy,
Raymond and Beverly Sackler Faculty of Exact Sciences,
Tel-Aviv University,
Tel-Aviv 69978, Israel

References

[1] A. Peres, “Quantum Cryptography Based on Orthogonal States?”, to appear in
Phys. Rev. Lett. (preprint quant-ph/9509003).

[2] L. Goldenberg and L. Vaidman, Phys. Rev. Lett. 75, 1239 (1995).

[3] C.H. Bennett and G. Brassard, in Proc. IEEE International Conf. on Computers,
Systems and Signal Processing, Bangalore, India (IEEE, New York, 1984), p. 175.

[4] A. K. Ekert, B. Huttner, G. M. Palma and A. Peres, Phys. Rev. A 50, 1047 (1994).