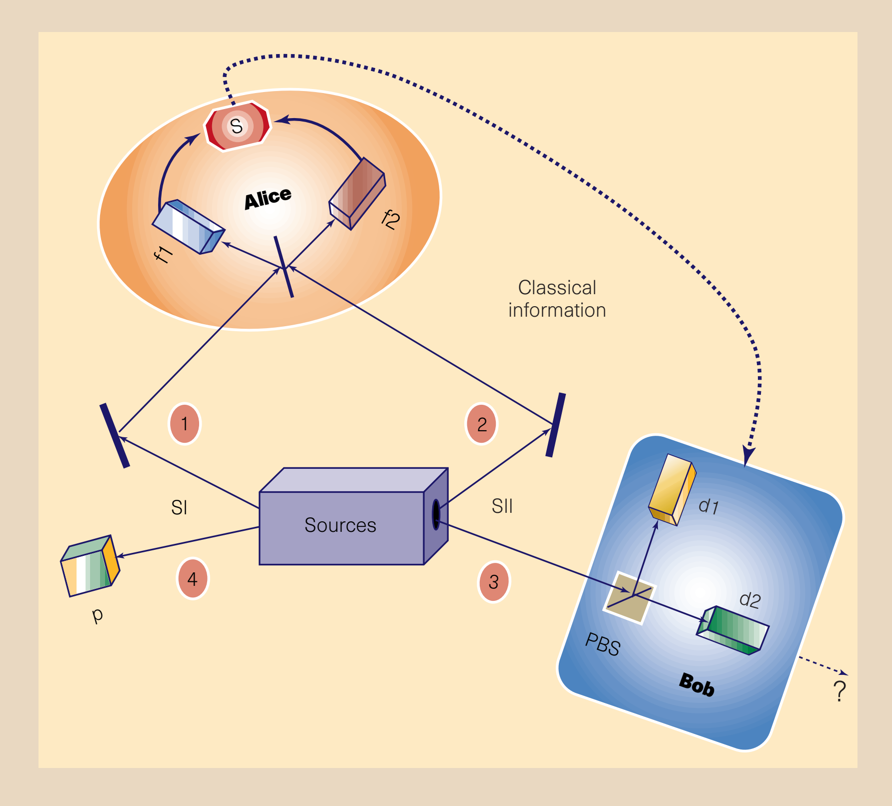

Figure 1 The teleportation set-up of ref. 1. PBS, polarizing beam splitter.

polarization state of a single-photon wavepacket (in beam 1) from Alice's sending station to Bob's receiving station (in beam 3). Statistics consistent with teleportation are obtained for events with a fourfold coincidence (from detectors f1 and f2, d1 or d2, and p). We ask whether the detection of all four quanta is essential for teleportation in this scheme. To answer this question, we calculated the teleportation fidelity, *F*, when the coincidence condition is relaxed to exclude detection at Bob's station (d1, d2).

Under relaxed conditions, requiring only threefold coincidence of detectors p and (f1, f2), teleportation is achieved when the fields of beams 1 and 3 match with sufficiently high fidelity. In the simplest approximation, type II parametric down-conversion of modes (*i*, *j*) generates wavepacket states as follows:

$$A_0|0\rangle_{ij} + A_1|\psi^-\rangle_{i,j} + A_2|\chi\rangle_{i,j} + \ldots, \qquad (1)$$

where A_0, A_1 and A_2 are the coefficients for obtaining no (vacuum), one and two down-converted pairs, respectively, and $(i, j) = (1, 4)\ (2, 3)$. Of these terms, only states corresponding to the second term are selected by fourfold coincidence, as specified by equations (2) and (3) of ref. 1. However, anything less than complete destruction of the output 3 necessarily leaves undesirable terms that reduce *F*.

The initial input state to Alice's station, $|\Phi\rangle$, is prepared by detecting the state in field 4 at detector p, which projects the field in beam 1 accordingly. Joint detection at (f1, f2) then provides threefold coincidence with p, yielding a statistical mixture for the field 3 arriving at Bob's station. The fraction of the state $|\Phi\rangle$ in this mixture gives *F*. To the lowest order in the down-converter coupling strength, the Bouwmeester *et al.* scheme yields a 50:50 mixture of the vacuum state $|0\rangle$ and the desired state $|\Phi\rangle$, with $F = 1/2$, so that there is never a physical state with high teleportation fidelity. Indeed, Bob could achieve this same fidelity, $F = 1/2$, by abandoning teleportation altogether and transmitting randomly selected polarization states. Faced with this state of affairs, the experiment of ref. 1 obtains a surrogate for high fidelity by destructively recording the field 3 at (d1, d2).

We emphasize that the nature of the mixture containing the vacuum state has definite physical implications, which can be verified by more general measurements than photon counting (for example, by quantum-state tomography). Moreover, the freedom of a potential consumer of the output from Bob's receiving station to select alternative detection strategies means that classical analogies fail.

To achieve conventional *a priori* teleportation, the set-up in ref. 1 would have to be modified to eliminate the vacuum from the mixture. Because the vacuum appears when two pairs of (1, 4) photons are created, we might seek to resolve one- and two-photon detection events at p. Upgraded detection (for example, by cascading conventional detectors) could provide an effective remedy. Appropriate selection could be implemented with a polarization-independent quantum non-demolition measurement of the total photon number at Bob's end. Alternatively, pre-selection could be implemented by enhancing the coupling between modes (2, 3) relative to modes (1, 4).

Despite our comments, we believe that the experiment of Bouwmeester *et al.* is a significant achievement in demonstrating the non-local structure of teleportation.

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2. Bennett, C. H. *et al. Phys. Rev. Lett.* **70,** 1895–1899 (1993).

Bouwmeester et al. *reply* — Braunstein and Kimble observe correctly that, in the Innsbruck experiment, one does not always observe a teleported photon conditioned on a coincidence recording at the Bell-state analyser. In their opinion, this affects the fidelity of the experiment, but we believe, in contrast, that it has no significance, and that when a teleported photon appears, it has all the properties required by the teleportation protocol. These properties can never be achieved by "abandoning teleportation altogether and transmitting randomly selected polarization states" as Braunstein and Kimble suggest. The fact that there will be events where no teleported photons are created merely affects the efficiency of the experiment. This suggests that the measure of fidelity used by Braunstein and Kimble is unsuitable for our experiment.

During the detection of the teleported photons, no selection was performed based on the properties of these photons. Therefore, no *a posteriori* measurement in the usual sense as a selective measurement was performed. The detection of the teleported photon could have been avoided altogether if we had used a more expensive detector, p, that could distinguish between one- and two-photon absorption. The inability of our teleportation experiment to perform such refined detections does not, however, imply that "a teleported state can never emerge as a freely propagating state...". Braunstein and Kimble do not, therefore, reveal a principal flaw in our teleportation procedure, but merely address a non-trivial practical question.

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