5.2 A Test of Quantum Nonlocal Communication

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"Quantum entanglement", a phrase first coined by Erwin Schrödinger[1], describes a condition of the separated parts of the same quantum system in which each of the parts can only be described by referencing the state of other part. This is one of the most counter-intuitive aspects of quantum mechanics, because classically one would expect system parts out of speed-of-light contact to be completely independent. Thus, entanglement represents a kind of quantum connectedness in which measurements on one isolated part of an entangled quantum system have non-classical consequences for the outcome of measurements performed on the other (possibly very distant) part of the same system. This quantum connectedness that enforces the measurement correlation and state-matching in entangled quantum systems has come to be called quantum nonlocality.

Nonlocality was first highlighted by Albert Einstein and his coworkers Boris Podolsky and Nathan Rosen in their famous EPR paper[2]. They argued that the nonlocal connectedness of quantum systems requires a faster-than-light connection that appears to be in conflict with special relativity. Despite this objection, quantum nonlocality has been demonstrated in many quantum systems. In the physics community it is now generally acknowledged to be implicit in the quantum formalism as applied to entangled systems.

The question we are investigating is whether quantum nonlocality is the private domain of Nature, or whether it can be used in experimental situations to send signals from one observer to another. A number of authors[3] have presented proofs that such nonlocal observer-to-observer communication is impossible within the formalism of standard quantum mechanics. However, it has recently been pointed out[4] that at least some of these proofs ruling out nonlocal signaling are tautological, assuming that the measurement process is local and thereby building the final conclusion of no signaling into their starting assumptions. Standard quantum mechanical Bose-Einstein symmetrization has been raised as a counter-example, shown to be inconsistent with initial "proof" assumptions. Therefore, the possibility of nonlocal communication in the context of standard quantum mechanics seems to remain open and appropriate for experimental testing. We have undertaken such an experimental test, because it represents an unusual opportunity to address very fundamental issues of quantum mechanics with a relatively simple table-top experiment.

The experiment, shown in Fig.1, is presently under development in the UW Laser Physics Facility in the basement of the Physics-Astronomy Building. It tests for the possibility of

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[1]Erwin Schrödinger, Proc. of Cambridge Phil. Soc., **31**, 555-563 (1935); **32**, 446-451 (1936).

[2]A. Einstein, B. Podolsky, and N. Rosen, , Phys. Rev. **47**, 777-785 (1935).

[3]P. H. Eberhard, Nuovo Cimento B **38**, 75 (1977), ibid. B **46**, 392 (1978); G. C. Ghirardi, A. Rimini, and T. Weber, Lett. Nuovo Cimento **27**, 293-298 (1980).

[4]K. A. Peacock and B. Hepburn, Proc. of Meeting of Society of Exact Philosophy (1999), quant-ph/9906036.

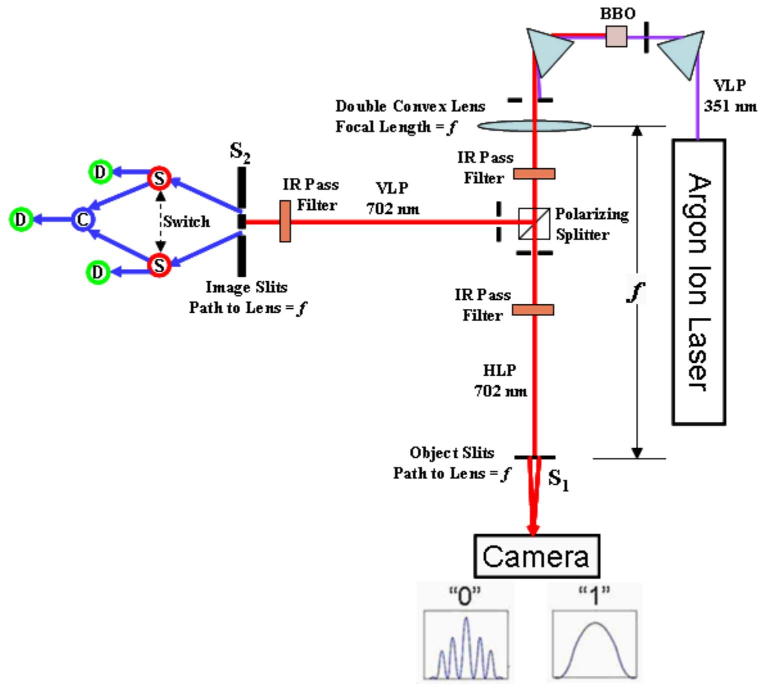

Figure 1: (Color online) Schematic diagram of the quantum nonlocal communication test setup

nonlocal communication. It is synthesis of the ideas embodied in the Ghost Interference experiment of the Shih group[5] and the PhD thesis experiment of Birgit Dopfer[6]. An argon-ion laser producing vertically polarized 351 nm UV light pumps a beta barium borate (BBO) crystal, producing two 702 nm infrared photons that are collinear with and momentum-entangled with the pump beam by the process of Type II collinear spontaneous downconversion. The pump beam is deflected away from the entangled photon pairs by refraction in a prism, and the entangled photons, one linearly polarized vertically (VLP) and the other linearly polarized horizontally (HLP), are sent in separate directions by a polarizing splitter. A lens of focal length f is placed in the path after the BBO crystal and before the polarization splitter, so that both entangled photons pass through the lens. A pair of slits at S_1 is placed at a path length f beyond the lens in the path of the HLP photons, which are transmitted by the splitter. Because of the momentum entanglement, an image of slit system S_1 will be formed by the VLP photons reflected by the splitter at a path length f beyond the lens at position S_2. We note that Dopfer has already demonstrated such slit imaging with a slightly different optical arrangement.

At the image position of each slit at S_2 we place an optical fiber, as shown. The fibers conduct the light to an optical switch, at which the light is either sent directly to two avalanche photodiode detectors (providing which-way information about which S_1 slit the photon entered), or alternatively is routed to an optical combiner and then detected by a third avalanche

[5] D. V. Strekalov, A. V. Sergienko, D. N. Klyshko, and Y. H. Shih, Phys. Rev. Lett. **74**, 3600-3603 (1995).
[6] B. Dopfer, PhD Thesis, Univ. Innsbruck (1998)

photodiode, so that waves passing through both slits can contribute constructively to the detection event

A quantum sensitive CCD camera is used to measure distributions for the HLP photons and is expected to produce distributions like those shown at the bottom of Fig.1. If the switch transmits light to the outer detectors, detection provides information on the slit through which the photon's entangled twin has passed, since momentum entanglement correlates the slit positions of the two photons. In this case, the camera should record the broad diffraction pattern labeled "1" characteristic of particle-like behavior. On the other hand, if the switch is in the position leading to the combiner and middle detector, waves passing through both slits contribute coherently to the detection, no which-way information is available, and the camera should record the structured interference pattern labeled "0" in Fig.1 characteristic of wave-like behavior.

Effectively, by changing the switch one is forcing the VLP entangled photons to behave like particles when which-way information is provided and to behave like waves when it is not. The interference or diffraction patterns observed in the other arm of the experiment by the camera for the HLP photons depend on whether this photon is nonlocally forced into the same particle-like or wave-like behavior by the measurements performed on its entangled twin. The nonlocal connection would then become communication.

Observing such a change in the photon distribution at the camera as a result of the fiber switching would thus constitute a direct demonstration of nonlocal communication and would falsify the No-Signal "proofs" mentioned above. We note that such nonlocal communication will perhaps be prevented by the complementary relation that exists between wave coherence at the slits and momentum entanglement of the downconverted photons[7]. The goal of the experiment is to find the best compromise between entanglement and coherence, to see whether nonlocal communication is indeed possible, and if not, to understand in detail the physical mechanisms that prevent it.

At present, this experiment is still under construction. We are making tests at the UW Laser Physics Facility with a 300 mW argon-ion UV laser, a tilted BBO crystal, and a cooled CCD camera to observe and optimize the downconversion process. The avalanche photodiodes, associated electronics, optical switches, fibers, and high-quality filters needed for the final configuration shown in Fig.1 are not yet available, but we hope to obtain them soon.

[7] A.F. Abouraddy, et al., Phys. Rev. A **63** 063803 (2001).