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Superluminal Communication in Quantum Mechanics

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One consequence of the special theory of relativity is that no information can be transmitted between two parties in a time shorter than it would take light, propagating through vacuum, to travel between the parties. That is, the speed of information transfer is less than or equal to the speed of light in vacuum c. Hypothetical faster-than-light (superluminal) communication is very intriguing because causality would be violated [8]. Causality is a principle where an event is linked to a previous cause; superluminal communication would allow us to change the outcome of an event after it has happened. I'm sure all of us at one point in our lives would like a cell-phone with superluminal capabilities!

Soon after Einstein published the theory of relativity, scientists began the search for examples where objects or entities travel faster than c. There are many known examples of superluminal motion [8], yet explaining, in simple terms, why such motions do not violate the special theory or allow for superluminal communication can be exceedingly difficult. Also, approximations used to solve models of the physical world can lead to subtle errors, sometimes resulting in predictions of superluminal signaling. For these reasons, studying superluminal signaling can be an interesting exercise because it often reveals unexpected aspects of our universe or the theories we use to describe its behavior.

The possibility of superluminal motions in classical physics have been known for over a century. For example, the group velocity of a pulse of light propagating through a dispersive dielectric can exceed c, where the group velocity gives (approximately) the speed of the peak of the pulse [10]. There exists a simple mathematical proof demonstrating that such behavior cannot be used for superluminal communication, but this proof sheds little insight on recent experiments that report clear evidence fast group velocities. One current explanation is that points of non-analyticity are created on the optical waveform at each moment when new information is encoded on the optical carrier, and that these points travel precisely at c [6]. Other points on the waveform (such as the pulse peak) convey no new information that cannot already be determined from the non-analyticity point and hence fast motion of the waveform in between points of non-analyticity do not violate the special theory. Another example of apparent superluminal motion occurs in certain expanding galaxies, known as superluminal stellar objects [12]. This motion can be explained by considering motions of particles whose speed is just below c (i.e., highly relativistic) and moving nearly along the axis connecting the object and the observer. Hence, these are not superluminal motions after all.

Quantum mechanics also appears to provide a mechanism for superluminal communication because of its nonlocal characteristic. A measurement performed on a system ► wave function collapse at all locations simultaneously [11], an effect that does not occur in classical physics and hence deserves further consideration with regards to superluminal communication.

One *gedanken* experiment that has received recent attention involves correlated particles generated by an Einstein–Podolsky–Rosen (► EPR problem) source. For concreteness, let's consider a system that generates two correlated photons (► light quantum) that travel in opposite directions and have zero total angular momentum. Furthermore, two observers, Alice and Bob, are located on opposite sides and at large distances from the source. They are equipped with optical components that can analyze the state of polarization of the arriving photons. Bob is slightly further away from the source than Alice, and we want to establish a one-way superluminal communication link from Alice to Bob.

In one scenario, Alice places a special type of polarizing beam splitter that spatially separates one state of linear polarization (say vertical, V) from the other state of polarization (horizontal, H). The output ports of the polarizing beam splitter are directed to single-photon detectors. Bob has an identical apparatus, which is at a great distance from Alice, and he aligns the axis of his polarizing beam splitter the same as Alice's. Because of the fact that their total angular momentum of the photons is zero, whenever Alice measures V, the wavefunction collapses and Bob is assured of measuring H essentially instantaneously after Alice performs her measurement. Similarly, Bob will measure V whenever Alice measures H. In this configuration, the polarization beam splitters and single-photon detectors perform measurements in the "linear" basis.

Alice and Bob can also perform measurements in the "circular" basis, where the analysis apparatus will determine whether the photons are left circular (LC) polarized or right circular (RC) polarized. This measurement can be performed by placing a birefringent plate – known as a quarter-wave plate – in front of the polarizing beam splitters, where the optical axis of the plate is orientated at 45 degrees to the axis of the linear polarizing beam splitter. The birefringent plate converts incident circularly polarized light into either H or V linearly polarized light, which is subsequently