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WEINBERG'S NON-LINEAR QUANTUM MECHANICS AND SUPRALUMINAL COMMUNICATIONS

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We show with an example that Weinberg's general framework for introducing non-linear corrections into quantum mechanics allows for arbitrarily fast communications.

Recently Weinberg has proposed a general framework for introducing non-linear corrections into ordinary quantum mechanics [1,2]. Although we fully support his emphasis on the importance of testing quantum mechanics, we would like in this Letter to draw attention to the difficulty of modifying quantum mechanics without introducing arbitrarily fast actions at a distance. Below we show how to construct, within Weinberg's framework, an arbitrarily fast telephone line. In ordinary quantum mechanics there is also "something" that goes arbitrarily fast, since quantum mechanics violates the Bell inequality. But this non-locality does not allow any supraluminal communications.

Our example of arbitrarily fast communications has three steps.

First step. In order to construct the telephone line between the space regions A and B install a source somewhere between them, for instance half way between A and B. The source should continuously emit pairs of spin-1/2 particles, with the spins in the singlet state and the spatial coordinates in a state such that one particle travels towards region A and the second particle towards B. Let us assume that the particles move in the y-direction. The speed of the particles is irrelevant. The line is installed once the flow of particles reaches regions A and B.

Second step. In order to send a message from A to B, the PTT officer in region A rotates a Stern–Gerlach apparatus in one of two possible directions, say the z-direction and the u-direction. (He does not need to know what such an apparatus is... do you know what is inside your phone?) In order to simplify we consider only a single-bit message. The two directions z and u are in the xz-plane orthogonal to the incoming flow of particles, and are 45° from each other. The way the inhomogeneous magnetic field acts on the particles is well-known from experimental evidence. After the apparatus there are two counters. For each particle one of the counters will click. This click will be amplified until all readers of this Letter agree that the effect of this measurement is macroscopic. This process will be repeated over many particles. The flow of the second particles consists now in a mixture of spin states one half in the up state, one half in the down state, either in the z-direction or in the u-direction, depending on the choice of the A-operator. Note that the two mixtures correspond to the same density matrix, half the identity, which is also the partial trace over the first spin of the singlet state.

Third step. In order to read the message, the operator in region B must be able to distinguish between the two mixtures of spin-1/2 states that his colleague has prepared. A linear evolution, as in ordinary quantum mechanics, is unable to make such distinctions, hence the impossibility of using quantum correlations to signal arbitrarily fast in ordinary quantum mechanics. But within Weinberg's general framework, we have non-linear evolutions. For simplicity we consider the following non-bilinear Hamiltonian:

$$h(\psi,\psi^*)=\frac{\langle\psi|\sigma_z|\psi\rangle^2}{\langle\psi|\psi\rangle}\,, \tag{1}$$

where σ_z is the usual Pauli matrix. This is a simple case of Weinberg's proposal for the interaction of a spin-1/2 and an (external) electric quadrupole. We acknowledge that the Hamiltonian (1) is oversimplified, but it makes the arithmetic simple and the same conclusion follows also from any non-bilinear Hamiltonian, as proven in ref. [3]. We assume that the external field whose interaction with the spin-1/2 is described by the Hamiltonian (1) is confined to the region B. The evolution equation for the spin-1/2 state corresponding to the Hamiltonian (1) reads (up to an irrelevant global phase)

$$\frac{\mathrm{d}\psi}{\mathrm{d}t}=-2\mathrm{i}\langle\sigma_z\rangle\sigma_z\psi\,,$$

where

$$\langle\sigma_z\rangle=\frac{\langle\psi|\sigma_z|\psi\rangle}{\langle\psi|\psi\rangle}\,.$$

Now, if the initial state is either up or down in the z-direction, then the state is stationary. In particular the mean value of the "longitudinal polarization" $\langle\sigma_y\rangle$ is always zero. However, if the initial state is either up or down in the u-direction, then the spin rotates around the z-axis with the same frequency, but the sense of rotation is opposite for the up and down states! After a time of a quarter of the "Larmor period" the spin will have the same positive value of $\langle\sigma_y\rangle$. The B-operator measures then, on many particles, the mean value $\langle\sigma_y\rangle$ and can thus "read" the message sent by the A-operator.

The most delicate point in the above example is probably the instantaneous preparation at a distance (second step). I think, however that there is evidence for it. The experiments testing quantum mechanics against local hidden variables do not only violate the Bell inequality, but they also agree remarkably well with quantum mechanics. This supports the claim that if one spin of a singlet state pair is "found" to be in the up state, then the other spin is in the down state, for the same direction. Maybe Weinberg, or someone else, will give a different description of what happens in step two, but for sure something has to be said, or one accepts the usual interpretation. A possible way out would be the assumption of spontaneous collapse of quantum correlations, as has been explored in refs. [3–9], but this is outside Weinberg's framework.

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Note added. Professor S. Weinberg (private communication) told me that the question has been independently raised by Professor J. Polchinski.

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