EPR Bingo Revisited

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Abstract
There is no information transfer at superluminal speed in O. Steinmann's EPR bingo (Helv. Phys. Acta **69**, 702 (1996)).

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There is a paper by O. Steinmann [1], the "EPR bingo", presenting an EPR-like thought experiment which seems to imply the possibility of information transfer with superluminal speed. Indeed, the paper is nicely written and a pleasure to read, strongly suggesting a paradoxical result. I want to point out that, nevertheless, the result sketched by O. Steinmann, can be understood in quite natural, even classical, terms without any violation of causality.

The set-up is as follows: Assume that, in the distant future, all inhabitable planets and moons of the solar systems are colonized. There is a professional betting company, accepting bets on the outcome of an EPR experiment with a spin 0 particle decaying into two spin 1/2 particles. The spin component in the direction of the polar star of one of the particles, called A, arriving on earth will be measured, the other, particle B, will be neglected. All branch offices throughout the solar system accept bets on the outcome of the measurement until shortly before the result can become known at the place of the branch office. It is understood that the information can be transferred at best with the velocity of light. Now assume that there is a clever fellow living on Titan, the largest moon of Saturn, more than one light hour away from earth, who has gained knowledge of the source providing the decaying spin 0 particle and thus generating the particle in question, and, furthermore, that he is able to intercept the second particle and measure its relevant spin component at about the same time as the measurement on earth is performed by the betting company. Knowing his result he can conclude what is measured on earth; he has thus gained practically instantaneous knowledge of the outcome of the measurement on which bets are placed, enabling him to place a substantial bet at the local office which does not yet have any results. This possibility of gaining money by winning a bet with probability one suggests the inevitable conclusion that there is indeed a superluminal transfer of practical information, with violation of causality. Furthermore, there seems to be a problem concerning the time t_m at which particle B has "learned" that its state is a product state as far as the spin is concerned, t_m being earlier than the time of measurement of B, but possibly also earlier than the measurement of A in a suitable frame of reference.

My answer is a twofold one. As to the second question, it seems clear to me that it is not a matter of particle B "knowing" its state (as is implied by O. Steinmann's suggestive formulation) but of the observer and his knowledge. One should remember that — in the purely statistical interpretation of quantum mechanics — any state refers to an *ensemble*, i. e. yielding, in general, only probability statements as far as a single system is concerned; the state is not a property of the system but a means of description of its properties by the observer.[1] If the guy on Titan knows that a certain spin component has been, or is going to be, measured on earth, he may describe the (combined) system by a mixed state, given by the density matrix (acting in $\mathcal{H}_A \otimes \mathcal{H}_B$)

$$\rho = \frac{1}{2}(P_{u^+ \otimes u^-} + P_{u^- \otimes u^+}) \ , \tag{1}$$

where $u^\pm$ denotes the spin state with spin component up (resp. down) relative to the preferred direction, and P_φ the projection onto φ. This is the appropriate state to be used after a spin measurement on particle A without noting the result. But he may as well choose to describe the system by a pure spin 0 state

$$P_\psi, \qquad \psi = 2^{-\frac{1}{2}}(u^+ \otimes u^- - u^- \otimes u^+) \in \mathcal{H}_A \otimes \mathcal{H}_B \ , \tag{2}$$

thus neglecting what has possibly happened far away on earth. It is an easy exercise to check that both states give the same expectation values for any observable $\mathbf{1} \otimes O$ referring to particle B:

$$\langle O \rangle_{P_\psi} = \langle O \rangle_\rho \ . \tag{3}$$

The second part of my answer is that there is no superluminal information transfer involved; moreover, the bingo sketched in the paper is actually a classical bingo, not a genuine EPR bingo. There are two pieces of information which are necessary for the man on Titan in order two win with certainty. The first is the knowledge of which spin component will be measured; this is known beforehand since it is part of the rules of the game, and may well have been transferred arbitrarily slowly. The second one is the knowledge of the relevant spin component of particle B which is gained by measurement; it can be viewed as being transferred with the speed of particle B *from the source of the decaying particle*, not from earth: information about the outcome of any measurement on particle B can be obtained as soon as the particle has reached the measuring apparatus. (Cf. also the above remarks comprising equations (2)–(3).)

[1] In this respect I disagree with O. Steinmann who makes a statement to the contrary in his paper; but this is not a relevant point as far as possible superluminal speeds are concerned.

Actually the situation can be mapped onto a purely classical one, *because it is known which spin component will be measured.* This amounts to a choice of two well defined possibilities, allowing the man on Titan to infer with certainty the result of the measurement on earth by his own measurement. The same would be the case if there were two (classical) balls sent from the source which were known to be either red or green. Everybody will agree that in this case no velocities larger than that of light are involved; nevertheless, the Titan man will win having gained information by intercepting the second ball.

A truly quantum mechanical situation would mean, inadequately expressed in classical language, that the two balls could, *at the same time*, be either red and green or blue and yellow or any of many other pairs of colours, depending on what pair of colours is chosen as the relevant one.

Let us change the rules of the bingo to make it truly EPR: a certain celestial half sphere is defined as the positive one; it is left open which spin component $\vec{a} \cdot \vec{S}$ of particle A will be measured, $\vec{a}$ being a unit vector pointing into a "positive" direction which will be chosen at random immediately before the measurement is carried out. Bets can be placed on whether the result will be positive or negative. Of course, under these circumstances no measurement on particle B can give any information, or allow any conclusion as to the outcome of the first measurement.

Using the inappropriate pseudoclassical language of the colored balls one might ask whether there is an interaction at arbitrarily large distances between the two balls making them change stochastically from red-green to blue-yellow *at the same time*. A more appropriate formulation is given in Steinmann's paper. He says that after a measurement of, say, the z-component of the spin of particle A resulting in, e. g., $S_z^A = +1/2$, the following is an *objective* statement: "A measurement of S_z^B yields the result $S_z^B = -1/2$ with certainty"; and to him 'objective' means that it is in a sense an objective property of particle B, or at least of the state of the combined system A-B which is now in a product state $P_{u^+ \otimes u^-}$. This causes Steinmann to ask at which time t_m the transition from the entangled spin-0 state to the product state has occured (i. e. at which time particle B has "learned" that the change has taken place). I have already given my answer in a former paragraph; to sum it up: the problem is completely avoided by the use of a strict statistical interpretation of the concept of 'state'; no objective property is ascribed to a single pair of particles; the objective statement refers to the result of the measurement.

To illustrate my point of view once more, let us consider the following setting. Assume that there is a Big Boss producing a series of decaying particles in a spin-zero-state giving rise to pairs of particles A and B, and, at the same time, issuing decrees — distributed with the speed of light — as to which is the relevant spin component to be measured on both particles of a certain pair. The results of the measurements will be strictly correlated, independent of *which* direction is chosen as relevant. Nevertheless, there is clearly no interaction at a distance and no superluminal information transfer. It is certainly misleading to say that the particles are correlating their *properties* at all times prior to the measurements; it is the *results of the measurements* which are correlated provided the experimentors abide by the decrees of the Big Boss.

Steinmann's bingo set-up is quite similar: the Big Boss is replaced by the boss of the betting company who once and for all decided that a fixed spin direction be the relevant one, thus enabling the Titan guy to win — without any need for superluminal information transfer.

References

[1] O. Steinmann, *The EPR Bingo*, Helv. Physica Acta **69**, 702 (1996)