WHAT IS INTUITIVELY PARADOXICAL ABOUT DISTANT CORRELATIONS IN QUANTUM MECHANICS

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We are considering a two-particle system described by a wave vector $|\Phi_{12}\rangle$. We have shown [1] that, within the fremework of quantum mechanics, this system can be equivalently described in terms of the separate states of the two particles (the reduced statistical operators ρ_1 and ρ_2) and the statistical correlations between them (the antiunitary correlation operator U_a mapping the range of ρ_1 onto that of ρ_2): $|\Phi_{12}\rangle \leftrightarrow \{\rho_1, U_a, \rho_2\}$. Inspired by Schrödinger, [2,3] we made a systematic investigation [1] of the nature and physical implications of the correlations established by U_a. Let us restrict ourselves in this note to the two-photon system used in the Freedman and Clauser experiment [4]. When one finds out, by measurement, that the first photon is in the state of polarisation $|\phi_1\rangle$, then the second photon is necessarily in the state of polarisation $U_a|\phi_1\rangle$. Quantum mechanically, $|\Phi_{12}\rangle$ collapses into $|\phi_1\rangle \otimes U_a|\phi_1\rangle$ without any interaction with the second particle. This quantum mechanical prediction was confirmed by direct polarisation measurement on the second photon in the Freedman-Clauser experiment.

More generally, measurement of any observable A_1 on the first photon implies the distant measurement of the observable $A_2 = U_a A_1 U_a^{-1}$ on the second photon. What is more, if one considers two incompatible observables A_1 and A_1' on the first photon (e.g. linear polarisations through two mutually rotated planes) the corresponding observables on the second photon are also incompatible because the above similarity transformation by U_a preserves commutators. This means that one can distantly (hence without disturbance) measure any of the two incompatible observables on the second photon, which may lead to the conclusion that the second photon "knows the answer" to both measurements, suggesting incompleteness of the quatum mechanical description by $|\phi_{12}\rangle$. This is the essence of the famous Einstein--Podolsky-Rosen paradox[5,6].

The fact that the state of the second photon is changed from ρ_2 into $U_a|\phi_1\rangle$ as a consequence of the direct measurement on the first photon can be intuitively (i.e. from the point of view of physical realism) understood in two ways:

(a) either the change is taking place in reality (under distant influence without interaction of any type that we know today),

(b) or the change is only in our knowledge, so that the second photon was in the same quantum mechanical state $U_a|\phi_1\rangle$ also before the measurement on the first photon.

It should be noted that from the standard quantum mechanical point of view (the Copenhagen school of thought) the question of the realistic meaning of the collapse $|\phi_{12}\rangle \rightarrow |\phi_1\rangle \otimes U_a|\phi_1\rangle$ is not physical. Contrarywise, Einstein, Schrödinger and others did consider this question physical, but they could not accept alternative (a).

As far as alternative (b) is concerned, both Einstein and Schrödinger had their visions how it is realised in Nature. Schrödinger's resolution [3] of the difficulty was on a purely quantum mechanical level: he envisaged (similarly as Furry [7]) that $|\phi_{12}\rangle$ goes over spontaneously into a mixed state ρ_{12}, where the phases in the coherent mixture $|\phi_{12}\rangle$ disappear when the two particles get sufficiently apart so that they are out of the range of mutual interaction. In this mixed state quasi-classical statistical correlations appear and this type of correlation is intuitively easy to grasp. This mixed state gives some predictions that are different from those implied by $|\phi_{12}\rangle$, so that experiment could decide. The Scrödinger-Furry model was experimentally refuted[8,9].

In the Bell model [10] (inspired by Einstein) the existence of quasi-classical statistical correlations was assumed on a subquantal level.* This model enables one to view each individual pair of photons as having a definite state of polarisation in every plane simultaneously. Bell's theorem[10] revealed a contradiction between this model and quantum mechanics, so it became possible to make an experimental decision, [11,4] which disproved the model of local hidden variables.

At present, as far as we know, there is no third way within alternative (b). Thus the apparent untenability of this alternative is what is intuitively paradoxical about distant correlations: it remains either to reject physical realism independent of the measuring arrangements or to consider seriously alternative (a). One wonders if Einstein were alive today how he would react to this dilemma, to which the new experimental facts have brought us. We believe that alternative (a) deserves systematic investigation. We feel that we are in a position to make efforts in this direction having singled out the correlation operator U_a as the entity describing the quantal distant correlations in a pure composite state, and having studied the basic distant effects: conditions on the direct measurement to give a distant one, which states and which obeservables can be distantly measured etc.[1]

In our view alternative (a) does not necessarily imply falling back to any concept of classical type like determinism (introduced through hidden variables), quasi-classical statistical correlations etc. We expect that the understanding of Nature extracted from studying distant quantal correlations might lead to an even more "crazy" picture of the world than we have today.

*This is the so-called model of local hidden variables. We will show elsewhere that locality amounts to quasiclassical statistical correlations.

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