© M.H.Shulman, 2008 (shulman@dol.ru)

Way to understand EPR-nonlocality

The way to understand the EPR-nonlocality phenomena is formulated. It is based on the superluminal quantum particle "tunneling" possibility and the "Shrödinger cat" model that is applied to an EPR-pair.

Introduction

After the famous paper **[EPR, 1935]** some nervousness appeared in the middle of physicists relative to "instantaneous" possible correlation between physical events separated by a spacelike distance. The article **[Bell, 1964]** revealed the fundamental collision between the quantum mechanics (QM) just predicting nonlocal interaction and special relativity (SR) limiting this interaction by the velocity of light.

One usually performs an experiment to test the photon nonlocality using the EPR-Bohm schema where a pair of coherent photon fly away from the common source to the two polarizers, or interferometer test (see review **[Belinskii and Klyshko, 1993]**). A fast configuration switching is especially provided in these experiments just after photon fly starting but before they arrive at polarizers. It was experimentally confirmed that the final configuration (not initial or intermediate) has only significance as QM predicts.

This seems to be *paradoxal*, because at the configuration switching moment the distance between the photon and the detector is *less* than the residual trevelling time multiplyed by the velocity of light, so one can believe that any information is not able to pass ahead of the flying photon.

Indeed, in the Aspect team's EPR-experiments the distance L between switches was 13 m. Since the configuration switching times (6.7 ns and 13.3 ns) as well as emission time difference (mean value – 5 ns) were small comparing to L/c (43 ns), then the detected event was separated from the position of a corresponding orientation switching by a space-like interval **[Aspect, 2000]**. In the EPR-experiments of Zeilinger group's the distance L between parts of the setting was 400 m, and the measurement duration was selected deliberately less than the photon fly time L/c (1.3 μs) **[Weihs et al., 1998]**. In the recent experiments with interferometer with delayed choice the optical path length L was equal to 48 m, that corresponded to the time light propagation 160 ns. While switching the time choice warranted that any configuration choice information must propagate four times faster then light to have an influence on the photon behavior at the setting entry **[Jacques et al., 2008]**.

Note that we can talk as well about a superluminal *correlation* as about superluminal photon *propagation* experiments (see, for example, **[Chiao et al., 1995]**, **[Cialdi et al., 2008]**).

Light barrier overcoming

Recently a possibility for a particle to overcome the space-like interval was theoretically considered in the work **[Wang and Xiong, 2005]**. Accordingly to SR it seems to be impossible, however, the authors stated that a number of disagreements about the superluminal displacement exist. For example, they say: "both theoretical and experimental studies had obtained the same conclusion that photons inside an undersized waveguide propagate superluminally".

A particle superluminal propagation can be explained using the new combined SR and QM (non classical mechanics) reformulation. The right *quantum version of relativity* should give the same results as *relativistic version of quantum mechanics* (like quantum field theory). In the frame of realization this program the authors obtained the conclusion that *a particle is able to overcome a space-like distance if it has the order of its Compton wavelength.* This fact is due to the Heisenberg's uncertainty relation and in agreement with quantum field theory. Moreover, one can show that such particle propagation corresponds to the its tunneling through a potential barrier.

In a typical case the Compton wavelength is very small. However, one can suppose that in EPR-experiments *this length is just equal to the distance between the coherent particles of the EPR-pair*, i.e. to the specific system size (let us remember that the particles continue to interfere). If this fundamentally important assumption is true, then this paper results can be generalized on the EPR-phenomenon too. Some additional analysis is given below.

Applying "Shrödinger cat" model to EPR-pair

Two *coherent* particles are generating and flying away in an EPR-experiment. This coherence remains conserved just before a measurement moment, i.e. they are staying in the superposed state and continue to *interfere*. "The instantaneous picture" of such particle *pair* configuration is *like* "Shrödinger cat" model (a superposition of *two single particle* states). The paper **[Zurek, 2002]** contains this model description and consideration of its evolution.

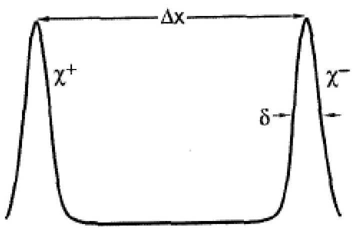

Figure 1 **[Zurek, 2002]**. A "Schrödinger Cat" State or a Coherent Superposition. This cat state φ(x), the coherent superposition of two Gaussian wave packets, could describe a particle in a superposition of locations inside a Stern-Gerlach apparatus or the state that develops in the course of a double-slit experiment. The phase between the two components has been chosen to be zero.

The model operates with the wave packet density matrix. The density matrix contains a *nondiagonal* terms, which correspond with the different basic states *intrference*, i.e. with the superposed state as such. Because of that the transition from the quantum superposed state to the classical mixted may be treated as the transition to a new matrix that *contains diagonal terms only*.

The density matrix *nondiagonal* terms fastly decrease (see Fig. 2) due to decoherence, which presents a chaotic interaction with *an environment*. The decoherence rate depends on the particle mass and the interaction temperature, i.e. mean field energy or mean environment particle motion energy. Typically, the coherence disappears during a time less than 10^{-20} s. However, *if an interaction with environment is absent* (as in EPR-experiment before a measurement), *then a coherent state time life at a convenient condition may theoretically be arbitrarily long*.

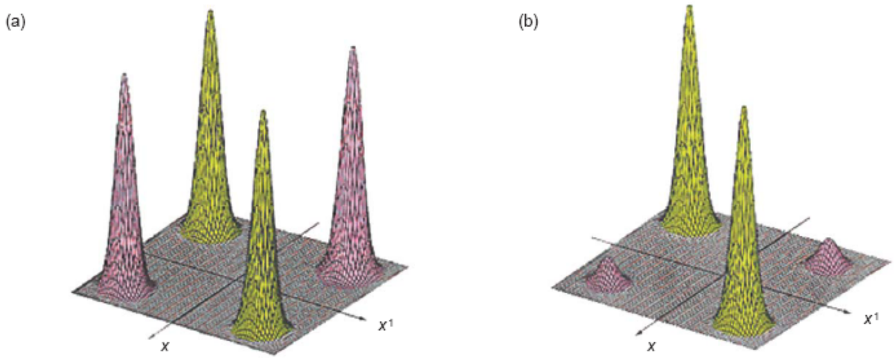

Figure 2 **[Zurek, 2002]**. Evolution of the Density Matrix

(a)This plot shows the density matrix for the cat state in Figure 1 in the position representation $\rho(x, x') = \varphi(x)\ \varphi^*(x')$. The peaks near the diagonal (green) correspond to the two possible locations of the particle. The peaks away from the diagonal (red) are due to quantum coherence. Their existence and size demonstrate that the particle is not in either of the two approximate locations but in a coherent superposition of them.

(b) Environment-induced decoherence causes decay of the off-diagonal terms of $\rho(x, x')$. Here, the density matrix in (a) has partially decohered. Further decoherence would result in a density matrix with diagonal peaks only. It can then be regarded as a classical probability distribution with an equal probability of finding the particle in either of the locations corresponding to the Gaussian wave packets.

Conclusion

So, the proposed treatment of nonlocality essence in EPR-experiments is firstly based on a representation of the coherent particle pair as the entangled quantum state having significant spatial extension. This one is physically confirmed by the fact of *interference* between two partial sub-states. In my opinion, that proves a certain exchange interaction and force field presence. Mathematically, *the distance between two particles* of the EPR-pair should be considered as a *specific quantum parameter* like a potential well width in the known QM problem. We should not take into account some difference between this case (similar to a two solitons system) and typical wave functions in QM.

Secondly, we have to conclude that in the relativistic version of QM *a superluminal velocity is possible in an area having specific system size*. Typically, this size – the Compton wavelength – is very small, but this size may become large enough in a case like EPR-experiment. So, any limits of the interaction velocity may be *invalid* in several specific configurations.

References:

[Aspect, 2000] Alain Aspect. Bell's theorem: the naive view of an experimentalist. "Quantum [Un]speakables - From Bell to Quantum information", edited by R. A. Bertlmann and A. Zeilinger, Springer (2002). Available at http://arXiv.org/abs/quant-ph/0402001

[Belinskii and Klyshko, 1993] Belinskii A.V., Klyshko D.N. The interference of light and the Bell's theorem . Uspekhi Fizicheskikh Nauk. August 1993. Vol. 163,No. 8. — 1 — 45.

[Bell, 1964] J.Bell, Physics (N.Y.) 1, p.195, 1964.

[Chiao et al., 1995] Raymond Y. Chiao, Paul G. Kwiat, and Aephraim M. Steinberg. Quantum Nonlocality in Two-Photon Experiments at Berkeley. arXiv:quant-ph/9501016v1 18 Jan 1995.
[Cialdi et al., 2008] S. Cialdi_, I. Boscolo, F. Castelli and V. Petrillo. Superluminal advancement of a single photon far beyond its coherence length. ArXiv:0805.1315v1 [physics.optics] 9 May 2008
[EPR, 1935] A.Einstein, B.Podolsky, and N.Rosen, Phys. Rev. 47, p. 777, 1935.
[Jacques et al., 2008] Vincent Jacques, E Wu, Frederic Grosshans, Francois Treussart, Philippe Grangier, Alain Aspect and Jean-Francois Roch. "Delayed-choice test of complementarity with single photons" **(**arXiv:0801.0979v1 [quant-ph] 7 Jan 2008).
[Wang and Xiong, 2005] Zhi-Yong Wang, Cai-Dong Xiong. Quantum-mechanical Lorentz transformation and superluminal phenomenon.
http://lanl.arxiv.org/ftp/arxiv/papers/0705/0705.2951.pdf
[Weihs et al., 1998] Weihs G., Jennewein T., Simon C., Weinfurter H., and Zeilinger A. 1998 Phys. Rev. Lett. 81 5039-5043
[Zurek, 2002] Zurek H. Woitech. Decoherence and the Transition from Quantum to Classical. Los Alamos Science, Number 27, 2002