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Some Comments on the EPR

(The reasons why experiments should still be done)

It seems to us that much of the contradictions that we hear about the Einstein Podolsky Rosen Paradox (EPR), can be framed into the diverse ways of using or misusing the principle of "collapse," (a principle, which according to Wigner, is very "attractive" but not very "informative").

To make our points, we will mainly use the model [Lamehi-Rachti, Mittig, *Phys. Rev.* **D14** (1976)] of two free protons scattering in the well known state of singlet, ud-du = SS, according to the Pauli Principle. (An equivalent description can be done with the polarization of photons.)

We ask the important question whether, on separation, the two fermions will remain in the state SS, where neither proton has a definite state and the whole two fermion system has exactly zero component in any direction.

The formula ud-du has the peculiar property of being invariant under rotation, but when the distance between the two particles becomes large with respect to, say, the dimension of the apparatus, then the formula loses its validity. That is so because, in general, a system of two bound particles changes importantly when the particles are separate and at a distance from each other. Indeed, there might be interactions which make the particles interact essentially only if they are near to each other. Obvious examples are exchanges of charge or of spin states, or of neutrons in atomic reactors.

DISCLAIMER

In the case of ud-du, quite clearly the formula expresses that one particle is in the state u "if and when" the other particle is in state d. For bound particles, that is possible via exchanges of quanta, so ud-du can have a clear QM interpretation in terms of an exchange.

However, when the distance between the particles is sufficiently large, the exchange can no longer occur with significant speed and intensity, and the total correlation represented by ud-du must disappear according to QM. If the experiments show that it does not, we should search for a reason, because as Gottfried wrote, "QM has peculiarities, but not superstitions" (nor contradictions).

On the other hand, nothing prevents us from accepting that the final state is reached by a collapse of the initial state into a state which is common to the initial as well as to the final state. Such a process is very frequently assured in the situations such as the one we are discussing, and the experiment consistently confirms its validity (see for example, the interpretation of the scattering of pions on protons). Thus, we can accept that for the settings described as EPR QM dictates that the state ud-du will "collapse" into a mixture of ud along randomly chosen directions. One thing is to accept the collapse as a fact, and another is to understand its mechanism.

To be noted, the above reasoning is not based on subtle properties of physics, like Bell's relations. (We do not use Bell's relations because Classical Mechanics (CM), which is admitted by Bell relation, is more powerful than QM in establishing correlations. On the other hand, there is no doubt that QM is correct for the elements involved in the EPR.) Neither can one doubt that the EPR photons are exactly the same elements as the ordinary components appearing in many experiments; see for instance Piccioni, *et al* in "The Superworld II," Edited by Zichichi, Plenum, 1990.

Thus, our reasoning does not depend on any particular experiment. It just naively, says that an object A cannot respond to invitations emitted by another objects B, if no invitation of B reaches A.

Yet, frequently one reads of "non local QM," and of the "fact" that "in QM a two photon system" is not made of two separate photons "even if the photons are a million miles apart." We interpret those words to mean that all we know about the EPR is that "somehow" QM must be correct at any distance. We agree.

We also think that the EPR will find a solution coherent with QM, as it was, for example, for the "mesotron" of Rome. For the EPR, one may not necessarily expect a nicely continuous function for the waves density, because it is difficult to describe exactly what happens inside a random roulette made of two elementary particles.

Moreover, we do not expect that QM will be damaged from the finding that it is not compatible with the EPR. Similarly, and fortunately, QM did not appear compatible with the "mesotrons" of the cosmic rays.

Note also that the agreement between the expected correlation and that of the experiment is determined by two points only, because the shape of both curves must follow the shape determined by photons.

From all said above, it is clear that in order to prove that the EPR is compatible with QM we should show that two perfect roulettes, clearly separated by a large distance, predict the results of each other. No experiment which we are sure we understand completely gives us any reason to accept such an extreme idea.

Apparatus

Our apparatus (See figure 1) essentially follows the well known concepts used when a down converter (DC) is used to produce from a laser beam of 351 nanometers, pairs of photons, here indicated as x and y, which have a good phase relation between each other. Their wave length is about 702 nanometer and the number of pairs per second varies according to the particular set up. x and y indicate the orthogonal polarizations. Two mirrors are used to direct both photons toward the same point of a "beam splitter BS" (a semitransparent mirror). Two wave packets are generated, R_x and R_y per incident photon.

The layer which produces the reflection in the BS is orthogonal to the plane of the paper, and forms equal angles with x and y as they enter the BS.

The electronics has the important function of demanding one and only one detection per each detector DA and DB. That distinguishes mathematically the events of the transmitted type T_x T_y from the reflected ones, R_y R_x, though, of course, we cannot physically separate those reflected from those transmitted.

Rather, the four packets T_x, T_y, R_y, R_x form a "body" {1} [T_x T_y - (or +) R_y R_x] which conserves energy and momentum and provides a rational description of the states if we simply assume that the packets are within interaction distances.

The analysis with a counter makes it plainly obvious that when the packets arrive at the detectors they are separate and cannot provide the communication that is needed by the EPR state. The situation is identical to that illustrated above on more physical terms and the mere evidence that a state can be described in that binomial form would be enough to prove that the state has the peculiar properties of the EPR. These considerations are equivalent to those given at the beginning of this writing except that the direct approach toward the impossibility of the EPR (rather than the use of Bell's relations) appears to allow a better point of view.

On reading the description of the experiment done by Ou and Mandel [Ref. Z. Y. Ou and L. Mandel, *Phys. Rev. Lett.* **61**, 50 (1988)] it seemed to us that the narrow energy filters were large enough to produce a peculiar effect, as follows.

Traveling toward the detectors, each packet $|Kx\rangle$ or $|ky\rangle$, of any pair, changes its phase at a rate equal to the momentum times the displacement of the packet. Thus, the product of the transmitted waves Tx Ty in formula {1} changes its phase by an amount PHT = a (kx) + b (ky), where a and b are respectively the distances from BS, of DA and of DB. Similarly, the product of the reflected waves R_y R_x changes phases by PHR = a(ky) + b(kx). Indicating momenta by their wave numbers and their polarization, for small production angle by the laser beam, the wave number KP of the incident photon is 1.8 x 10^5 radius/cm. Thus, the difference of the phase of the two terms of {1} is PHT - PHR = (2 kx - kp) (a-b). Since no particular need for a small value of (a-b) existed in the cited experiment, we assume it was at least one millimeter. Thus, (2kx-KP) varied within the range of +/- 0.23% X 1.8X10^5 = +/-400 radians/cm, and PHT-PHR varied from -40 to +40 radians. Therefore the detectors DA and DB received not the QM state xy + yx, but a classical mixture of xy and yx which could have given no correlation at all when the analyzers were turned by 45 degrees relative to the xy frame.

We note that the graphs of the results are so good that unreasonably great errors are not suggested.

This point prompts us to recall that our analysis is based on the recognition that the state which is a(kx)+/- b (ky) in the BS will eventually become a state of two separate, non interacting states. An alternative would be to think that all states are always interacting with each other, which picture would give a result different from ours. (Private communication by Professor D. Mermin.)

However, we again recall that at a distance, that introduces a concept which cannot be tolerated by our knowledge of physics. Moreover, in the accurate work by H. Rauch and M. Suda "Dephasing in Neutron Interferometry" (*Appl. Phys.* **B60** (1995) 181-186) the authors find that "dephasing is an unavoidable effect caused by intrinsic fluctuations inherent to any physical system."

The relevance of our analysis is the following: The laws of electromagnetism impose that the state xy + yx must be formed in the source (BS) out of the combination of polarized photon states, which are the same as those which have been the subject of enough studies to be sure of their ordinary nature, unaffected, for example, by fancy hidden variables. The same laws establish that xy + yx has become a mixture at the analyzers. Thus, we have a strong argument that an unknown mechanism is what causes the correlations and we no longer need aad to support the EPR state.

THE COLLAPSE OF ud-du

It would still be uncomfortable if a "nearly correct" application of QM imposed the production of EPR state, but that does not seem to be the case. The most-cited reasoning on this point starts by recognizing the existence of bound singlet states, like for the electron spins in helium, or for the nucleon isospins in the deuteron. Then one may reason that if the "system" of the two particles is split by a spin-independent force, the singlet state should remain unchanged after the separation. That reasoning is not safe. For example, experiments on tagged neutrons at LBL have shown that a 5.8GeV/c deuteron can be split by diffraction, that is by an isospin-conserving pomeron exchange with a nucleous [12]. However, the separated neutron proton "system" itself ceases to exist when the neutron decays. Clearly the decay is an indirect consequence of the pomeron exchange. The system changes, though the pomeron by itself would suggest no change.

Quite similarly, in the proton scattering of the EPR experiment of Saclay [7] the protons interact only in the singlet state because of the exclusion principle, but even a separation purely via a spin-independent force has the consequence of eliminating the preference for the singlet state, because the exclusion principle cannot operate for separate particles [13]. Thus, the deciding point is simply whether the singlet state can exist for separate particles, which is just what we have treated previously, concluding with a negative answer. Note that the notion that the spins should remain "as they were in their initial state" is erroneous, because if the particles interact in the ud-du state, which has no privileged direction, each spin is not in a single, determined state.

On the other hand, since a mixture of ud states relative to a randomly chosen direction (Furry state) is possible for two free particles, the intermediate ud-du state can make a transition to it via the ordinary collapse (to be distinguished from the "collapse at distance") as a consequence of the physical change operated by the separation (to be distinguished from a "spontaneous evolution").

The objection that conservation of angular momentum forbids the Furry transition is not disposing of the issue this is evident first because the collapse almost always implies an apparent difficulty, second because of the relevant feature of the Saclay experiment that both the incident and target protons were unpolarized. Absent any interaction that could constrain the two free particles to be in eigenstates of their total spin, the initial states of the collisions must have been uu, dd, ud, du relative to a chosen axis. For clarity, if we repeat the experiment preparing the colliding particles in each of those four states, in equal proportion, relative to a chosen direction, changing that direction at random, we certainly expect to reproduce Saclay's results. Only the states ud and du could make a transition to the intermediate state ud-du, since they have in common the state of total spin zero. Then the transition from ud-du into ud must also be possible. Another example is the negative-pion scattering off protons at the Delta resonance (1232 MeV). Though neither the incoming nor the two outgoing channels are pure isospin 3/2 like the resonant state, yet the energy dependence of the cross sections proves that the intermediate state of both channels was the 3/2 resonance. Thus, ignoring aad, we cannot affirm that conservation of total spin imposes the production of the EPR state.

The Furry state, of course, would not by itself give the observed full correlations. As we said, a new mechanism must be present because if we assume that the collapse of the state of A must also collapse the distant B, we are inventing an aad that propagates instantaneously.

THE ACTION AT A DISTANCE

The fact that we do not understand the experiments is no evidence for the aad, phenomenon. The aad would change an unpolarized proton or photon into a specifically polarized one, which means, as shown above, that without the aad the correlation would be zero, and with it would be 100%. To have such a conspicuous property the aad should have an outstanding physical meaning, and it could not have been unnoticed in our extensive researches on elementary particles. Moreover, a wave packet producing instantaneously such a change at a distance would certainly violate relativity. That humans could not use the aad to transmit messages (which is not necessarily true [5]) does not eliminate the basic fact that two independent devices cannot give the same random sequence without communicating messages.

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