Entanglement: A myth introducing non-locality in any quantum theory

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Abstract

The purposes of the present article are: a) To show that non-locality leads to the transfer of certain amounts of energy and angular momentum at very long distances, in an absolutely strange and unnatural manner, in any model reproducing the quantum mechanical results. b) To prove that non-locality is the result only of the zero spin state assumption for distant particles, which explains its presence in any quantum mechanical model. c) To reintroduce locality, simply by denying the existence of the zero spin state in nature (the so-called highly correlated, or EPR singlet state) for particles non-interacting with any known field. d) To propose a realizable experiment to clarify if two remote (and thus non-interacting with a known field) particles, supposed to be correlated as in Bell-type experiments, are actually in zero spin state.

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1 Introduction, or what is non-locality

Non-locality, [1, 2], has been investigated by several authors. For some recent reviews, see [3, 4] for quantum entanglement, [5, 6, 7, 8] for the non-locality problem from the hidden variables quantum theory point of view, or [9] for some applications in quantum information theory. Our purpose, in the present part of the article, is to prove that two or more correlated particles, even when they are unable to interact with a certain Hamiltonian (i.e.: when they are at great distance, even with walls of Pb between them, even when every particle with its measuring devices is entrapped in rooms deep beneath the surface of the earth), they exchange energy and angular momentum, and this is what I call "non-locality".

We will also prove that every quantum theory, orthodox or of hidden variables, suffers from this non-locality. This holds, because neither the current theory nor the alternative ones are responsible for non-locality. We will try to prove that the idea of two, non-interacting, distant particles in zero spin state "together" is solely responsible for the whole novelty of non-locality.

Let single particles in zero spin state decay into two correlated fermions, the fermions traveling northwards and the fermions traveling southwards, or let a positronium with zero angular momentum decay into its constituents, the electron and the positron. When performing a spin measurement on the "north" $N$ fermions along $z$–axis, we find $N/2$ in $|+z\rangle$ spin state. We ignore the others. Performing a new spin measurement along $x$–axis, we find $N/4$ in $|+x\rangle$ spin state. We ignore the others. Performing again a spin measurement along $z$–axis, we find $N/8$ fermions in $|-z\rangle$ spin state. We ignore the others. Let us now see the state of the "south" fermions correlated with the above $N/8$ north fermions. The north fermions have passed from $|+z\rangle$ to $|-z\rangle$ spin state. So, the correlated south fermions have passed from $|-z\rangle$ to $|+z\rangle$ spin state, so energy and angular momentum were exchanged between the north set of $N/8$ fermions and the south one.

Large numbers of particles, statistical behavior and "strong" or "weak" versions of entanglement do not affect our discussion. Let us imagine a single particle decaying into two correlated fermions, the north and the south one. There is 12.5 per cent probability the north fermion to be caught in $|+z\rangle$ spin state at the first measurement, and in $|+x\rangle$ spin state at the second measurement, and in $|-z\rangle$ spin state at the third measurement. So, at least for this pair of fermions, energy and angular momentum transferred from the one fermion to the other, because the south fermion was in $|-z\rangle$ initially and in $|+z\rangle$ finally, though no measuring device interacted with it. (In fact, one can easily prove, by taking into account all the possible outcomes of the experiment, that this angular momentum transfer takes place with 50 per cent probability.) This is the very meaning of non-locality. How did this energy penetrate walls to pass from the one fermion to the other? How did it travel
the long distances of the experiment? What kind of Hamiltonian is this, which does not decrease with distance? What kind of Hamiltonian is this, which would prevent Newton from his first law proposition (“a remote body can not be affected strongly by other bodies, so the total force on it is negligible and consequently it can be taken as an inertial frame of reference”)? Is there any field (equivalently force) that makes the correlated particle to reverse its spin, or there is not such a thing? If the second holds, the angular momentum (and/or energy and momentum in other cases) changes without a "reason", i.e.: without a field(/force) enforcing this change, so we should wave Lagrangian/Hamiltonian and Newtonian formulations goodbye. Newton lied when he wrote \( \frac{dL}{dt} = \tau \), here we do have \( \frac{dL}{dt} \) (and the uncertainty relations have nothing to do with our discussion), but we have no \( \tau \), namely there is neither a measuring device in the vicinity of the overturned particle nor a field to cause this change in the particle spin. Schrödinger, on the other hand, lied when he postulated that the evolution of some system is determined by his equation, this is not true not only when one measures this system, but also when one measures some other systems somewhere in the world. In other words, when Schrödinger claimed that the correlated particle, the one for which no measurement is performed, is in \( |\ -z\rangle \) spin state, and, because \( \hat{H} = 0 \), it remains in this state, just lied. A magic measurement in another particle inevitably changes \( |\ -z\rangle \) into \( |\ +x\rangle \) or \( |\ -x\rangle \). After all, nobody knows when Schrödinger equation holds, because nobody knows when someone else decides to perform its measurements, destroying the validity of the equation for the correlated particles. If there exists a field "joining" together the entangled particles, carrying the above amounts of energy and angular momentum, what sort of physical object is this, that does not decrease with distance? Is there an infinite-energy source which covers the total space? Or the field has not to cover the total spacetime, but it is so "smart", so as to recognize which two particles are really entangled and orientate itself from the one particle to its entangled partner, like a smart and unbelievably reliable messenger? If I had a positron at the galaxy of Andromeda and its correlated electronic partner here in Earth, mixed with many other electrons within a metal, how smart should this energy be, coming from the positron, so as to recognize the entangled electron within the metal, and overturn this electron and not another one? Or the energy has not to find out the correlated particle but overturns the first electron that happens to meet when traveling? Do my electrons suffer from such unwarned spin-flips, because my neighbour uses to produce correlated fermions and to overturn the set of the positrons? Such a hypothesis may be easily tested experimentally, but has nothing to do with genuine non-locality. So, the energy coming from the one, the measured, fermion is clever enough to distinguish between an "entangled" fermion, and \( 10^{23} \) "un-entangled", identical fermions. Does the entanglement mark the correlated particles with some
number/color or is it something like a disease? In a somewhat different case, I use $10^{23}$ hiding places (equal in number stars from our galaxy or others) to hide $10^{23}$ positrons. The electrons correlated to the above positrons consist the fermion sea of my wristwatch. As it is well known, these positrons are not identical because their wave functions do not overlap, [10,11]. So, the electrons in my watch are not identical (though their wave functions overlap, and they overlap because Schrödinger equation seems to hold, at least under "normal" conditions, with measurements neither here, nor anywhere in the world for fear of happening upon a correlated partner), they have a label, the name of the star that I hide the correlated positron. So, quantum statistics is gone. No "weak" version of correlation can be applied: The positrons do not mix, I may label them one by one and, consequently, I may label the electrons one by one, so, the energy/angular momentum coming from the a-Taurus positron can not be absorbed by the b-Scorpio electron, this energy will be absorbed only by the a-Taurus electron (i.e.: by the electron correlated to the a-Taurus positron).

The situation described in the above paragraph is not a mere scandal; It is an obvious dilemma: Either non-locality, or Physics.

An energy-momentum non-conservation has been proposed by some authors, not arising from the uncertainty relations, because the change in angular momentum of the second particle is permanent, after the third measurement in the first particle. This non-conservation is impossible to arise from the interaction between the particle and the measuring device for two reasons: No measurement is performed in the second particle, and no energy, momentum or angular momentum can be exchanged between the devices and the system of the particles, as it is supposed to be in zero spin state (unless it is not in zero spin state, as we claim here), and this state never exchanges angular momentum with anything in the world.

Some authors believe that a measurement on one of the correlated particles affects instantly its partner, changing for example its spin. Others try to formulate a covariant theory for these measurements, claiming that the energy or other measurable quantities should travel with the velocity of light. Few believe in retrospective signals. These arguments do not affect our discussion. The above peculiarity in energy and angular momentum transfer, what we called non-locality, remains, whichever is the frame of our work, Newtonian or Einsteinian. And, after all, our problem is this very telepathy (much "stronger" than the rumored human one, because in physics there are physical quantities that travel and not simply some "information" between different persons), not its covariance or its retrospective character.

Some believe that non-locality comes from the hidden variable quantum mechanics. On the other hand, it is a common belief, especially among quantum information theorists, that the orthodox theory is fundamentally non-local. We said nothing here about hidden variables, stochastic formulations of
quantum theory, quantum potentials or pilot waves. We said nothing about which model, the orthodox, or an alternative one, we prefer. We said nothing about the other, the "epistemological", problem, if the different quantum mechanical models are fundamentally different theories, or their existence just consists a secondary matter of interpretation. We just reproduced the results of the orthodox theory, also reproduced by the experiments and by hidden variable theories (at least by serious competitors of the orthodox theory) and found that non-locality, in the sense that energy and angular momentum is transferred, is present.

2 How to reintroduce locality

Our purpose is not to measure the violation of Bell inequalities in ensembles of entangled particles or in isolated pairs of entangled particles. Our purpose it to pose the question of the possibility of the zero spin state for remote particles (never phrased, up to our knowledge) and to propose some ideas to test this possibility experimentally. The zero spin state assumption for remote particles is a necessary one for the proof of Bell inequalities and leads, according to the discussion of the above paragraph, to a series of peculiar phenomena. It is clear that the usual theorem "realism+determinism" ⇒ "Bell inequalities" ⇒ "non-locality", which can be found in several versions in any review of the topic, is deceptive. A more formal formulation of the theorem, according to our present ideas, is: "realism+something else that one likes (usually determinism)+zero spin state assumption for distant, non-interacting particles" ⇒ "non-locality". I hope that the quite tiring discussion of the previous section made as plain as a day that the right formulation is "zero spin state assumption for distant, non-interacting particles" ⇒ "non-locality", because no realism or determinism or anything like that, but only the above assumption, slipped into our discussion. Up to our knowledge, nobody rejects the existence of zero spin state for distant, non-interacting particles. They all regard it as a simple truth.

How can two particles be in zero spin state? In the positronium example there is a Hamiltonian interaction between them. The same holds true for the zero spin mesons and their constituent quarks. They are not automatically in zero spin state. So, when the constituents of the positronium are at distance, they can not be in zero spin state, because such a Hamiltonian does not exist.

In the present article we claim that two particles coming from the decay of a single zero spin object are not in zero spin state, but in \( | + n \rangle_1 | - n \rangle_2 \) spin state, where \( n \) is a random vector in the usual space. The angular momentum is conserved when the initial particle decays, but it is not conserved when measurements are performed either to one or to both of the product particles. To experimentally test this assumption we should use single pairs
of correlated particles. As one can easily prove, for ensembles of correlated particles, both $| + n\rangle_1 - n\rangle_2$ and $|0\rangle$ spin state show similar behavior and, thus, can not be distinguished experimentally.

We remind that this energy/angular momentum non-conservation before and after a measurement is widely known in quantum mechanics, as measuring devices and particles exchange energy (expect for some rare states, like $|0\rangle$ one). The above particles are in an eigen-state of the $L_n$ operator and they will remain in this state if we perform a spin measurement along $n-$axis. But if we perform a spin measurement along an $n'-$axis, the angular momentum will not be conserved for the measured system.

So, when measuring the angular momentum of the $| + n\rangle_1 = a| + z\rangle + \sqrt{1-a^2} | - z\rangle$, $0 \leq a \leq 1$, fermion along $z-$axis, there is $a^2$ probability to find it in $| + z\rangle$ spin state and $(1-a^2)$ to find it in $| - z\rangle$ spin state. When measuring the angular momentum of the $| - n\rangle_2 = \sqrt{1-a^2} | + z\rangle + a| - z\rangle$ fermion along $z-$axis, we find $(1-a^2)$ probability for the $| + z\rangle$ spin state and $a^2$ probability for the $| - z\rangle$ spin state, independently of the result of the measurement in the other fermion. Why "independently"? Because $| + n\rangle_1 - n\rangle_2$ is not an eigen-state of the $L_z$ operator, as the zero spin state is. So there is no energy or angular momentum transfer between the two product particles, thus there is no correlation, and thus there is no need to introduce non-locality. The only energy and angular momentum transfer takes place between the particles and the measuring devices.

The above paragraph shows a straightforward way to test our claim for the $| + n\rangle_1 - n\rangle_2$ state of the particles that arise from the decay of a zero spin particle. If the two fermions continue to be in zero spin state, i.e.: if they are "entangled", after their release from the initial particle, any measurement of their angular momentum along $z-$axis, will give two possible results with equal probabilities: either $| + z\rangle_1 - z\rangle_2$, or $| - z\rangle_1 + z\rangle_2$. The possibility for both particles to be in $| + z\rangle$ or in $| - z\rangle$ spin state is zero. But if the two particles are not correlated after their release, and, as we claim here, they are in $| + n\rangle_1 - n\rangle_2$ spin state, then there is $a^2(1-a^2) \neq 0$ probability for $| + z\rangle_1 + z\rangle_2$ spin state and $a^2(1-a^2)$ probability for $| - z\rangle_1 - z\rangle_2$ spin state. (The only case that the quantity $a^2(1-a^2)$ equals to zero would be our misfortune to accidentally choose the axis $z$ of measurement the same with $n-$axis. So, we may use at least two different axes for the same pair of particles.)

3 Some experimental hints to test the zero spin state assumption for remote particles

Let us now see the experiment, in figure[1]. A pion can decay to a muon and a muonic neutrino: $\pi^+ \rightarrow \mu^+ + \nu_{\mu}$. Let this muon travel through the first Stern
Figure 1: A possible path for a muon through three Stern-Gerlach (SG) devices. If the muon follows the obstacle-free trajectory (1/8 probability), then its spin orientation changes from $|+z\rangle$ to $|-z\rangle$. 
Gerlach device (SGz) orientated along $z-$axis. There is 1/2 probability for the muon to be in $|+z\rangle$ spin state. The second SG device is orientated along $x-$axis. Let this measurement give $|+x\rangle$ for the muon spin. The muon and its neutrino partner will be in zero spin state, equivalently, they will be correlated, if and only if the results of the third measurement, in the last SG device, are all $|+z\rangle$. If there are any muons escaping from the whole system of devices, following the trajectory of figure 1, namely, if there are any muons being caught in $|-z\rangle$ spin state at the end of the third measurement, then the muonic neutrino, being initially in $|-z\rangle$ spin state, is enforced to turn into $|+z\rangle$ spin state at the end of the experiment, to maintain the zero total angular momentum of the two entangled particles. So: Either the neutrino changes its helicity (impossible, unless it is not massless), or the neutrino makes a U-turn, (reversing both momentum and angular momentum, so as to maintain its helicity) and the momentum is not conserved, as some authors claim (this energy-momentum non-conservation is not over a space or time interval imposed by the uncertainty relations, its an absolute, permanent non-conservation), or the neutrino is transformed into an antineutrino and the momentum is conserved but not the muonic lepton number, which is, after all, more possible than the energy-momentum non-conservation (we remind the above dilemma, non-locality or Physics), or something much simpler happens: The two remote particles are not correlated/entangled, and the neutrino is not obligated to change its spin from $|-z\rangle$ to $|+z\rangle$ state, because an inverse change happened, somewhere in the universe, to a muon, supposed to have exchanged vows of eternal entanglement with its neutrino better half.

We remind that for a free (i.e.: un-entangled) muon or other fermion, the probability, according to both orthodox quantum theory and to any serious hidden variable alternative, to follow the trajectory of figure 1 is 1/8. So, if no muon follows the trajectory of figure 1 then entanglement exists. But if $N/8$ muons follow this trajectory, either something strange and unnatural, like that described above, happens with poor neutrino, or entanglement does not exist.

One may also use Cooper pairs in superconductors and generally the technology of electron spin entanglers in condensed matter physics, [12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22] to test the existence of entanglement for a single pair of particles. The experiment we propose in figure 2 needs a superconductor, two quantum dots and two usual leads, as in, for example, [23, 24, 25, 26]. The device is quite simple. Two electrons, forming a Cooper pair within the superconductor, can tunnel, by means of Andreev tunneling, to two quantum dots, each electron to different quantum dot. Then, the electrons may tunnel from the quantum dots to two normal leads, and follow, each one, two distinct trajectories. A system of Stern-Gerlach devices can pick each one of the two electrons and test if they are in singlet (as the Physics community regards) spin state (namely, if they are entangled), or in
Figure 2: The superconductor (SC) can provide Cooper pairs in singlet spin state, tunneling to the two quantum dots (D1, D2). Each of the two electrons may follow by tunneling one of the leads, L1 or L2. According to our present ideas, the two particles continue to be in $|0\rangle$ spin state, even when traveling along different leads. Here, we proposed that the two particles are in $|+\rangle_1 |-\rangle_2$ spin state, after tunneling in the two leads, they are in $|0\rangle$ spin state only within the superconductor. We need some Stern-Gerlach devices to test the real spin state of the two particles after tunneling.
| +n⟩_1 − n⟩_2 state, with no sort of correlations between them.

In conclusion, we showed that entanglement, leading to a peculiar transfer of measurable quantities from the one entangled particle to the other, is the result of the assumption that some remote particles are in |0⟩ spin state "together". We proposed some simple experimental procedures to test this assumption.

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