Teleportation and Information Decoding: a Revision

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ABSTRACT.
The possibility for a type of communication using teleportation alone without any adjacent classical communication channel, discussed in two previous papers, is re-examined. It is concluded that, except possibly by playing with some physically quite special critical situations, such communication is not possible.

In two recent publications[1,2], the possibility for a fully non-classical type of communication using teleportation has been raised. The initial motivation of the author in discussing this possibility was strongly linked with the feeling that, as Michel Le Bellac puts it, “even if the non-locality of quantum mechanics is not in contradiction with special relativity, at best, what we observe is a kind of pacific coexistence between them”[3]. The author wondered - and still does - whether the possibilities of quantum mechanics and teleportation in particular could not be explored a little further without harming the “peaceful coexistence” alluded to by Le Bellac, especially since teleportation does not need to be accompanied with any measurable mass or energy transfer.

Unfortunately, the main idea discussed in articles [1] and [2], strongly inspired by NMR techniques, overlooked the key issue of the difference between single quantum experiments and standard NMR techniques and NMR concepts, which apply to macroscopic systems. The last part of article [2] also proposed in a last “complement” the idea of a completely different experimental set-up based on the diffraction of particles interacting with other ones influenced by the sender. It was suggested that fully non-classical communication might be achievable with such a set-up. The idea presented in this “complement” presents some affinity with the “which-way” experiments of Scully *et al*[4]. As the reader can guess from this comparison, the interference effects conjectured by the author in ref. [2] have no reality. Twice in a row, the negligence of the author led him to examine misleading suggestions, for which he wishes to apologise.

The aim of the present paper is to try to close the discussion started in ref. [1]. In order to spare the reader with the need to consult [1] and [2], this paper presents briefly the main idea of articles [1] and [2], analyses and criticises it, and concludes.

Let us therefore start by considering again the situation when two parties Alice and Bob each possess one spin, the pair of which is entangled in the singlet state. Alice measures her spin along the axis *xx'* in case (i), or along *zz'* in case (ii). After her measurement (Bob does not need to wait for the time light would cover the distance between him and Alice for the word “after” to be valid here, as teleportation experiments tend to show), Bob suddenly submits his own spin to a magnetic field H oriented along *zz'*. After the field H has been raised, and if we are in case (i), Bob’s spin orientation rotates in the plane *xy* at a frequency ω proportional to H. In case (ii), Bob’s spin orientation remains aligned along *zz'*. Simultaneously, in both cases, the $|+\rangle$ part of Bob’s wave function is affected by spontaneous decay (which progressively modifies the orientation of Bob's spin).

If we rely on the so-called "vector model" widely used by NMR experimentalists (such as the author himself) to analyse what can be detected by Bob with a horizontal reception coil, we conclude that in case (i), since the axis of orientation of Bob's spin is known, the horizontal reception coil can detect a signal that can be predicted up to a factor π (depending on whether the result of Alice's measurement is $|+>_x$ or $|->_x$). In case (ii), the spontaneous decay of Bob's spin from $|+>_z$ to $|->_z$ (which takes place if Alice's measurement has given $|->_z$ so that Bob's spin before decay is $|+>_z$) generates a signal in the horizontal reception coil whose phase is clearly random. Therefore, it would seem that cases (i) and (ii) can be distinguished. Unfortunately, the "vector model" that can be found in most NMR textbooks has the same validity in NMR than, in another context, "semiclassical optics" can have in laser physics. The assumption that "vector model" conclusions can be valid for a single spin is unwarranted. The author tried to propose in refs. [1] and [2] an experimental set-up equivalent to that of a standard NMR experiment, except that it could work on the single quantum level. The experimental set-up proposed in article [1] was ill conceived. The set-up evoked in the first part of ref. [2] amended the first one, and correctly proposed a measurement device designed for working at the single quantum level in a somewhat analogous way to how standard NMR works for macroscopic numbers of spins. If this set-up had been examined more closely in ref. [2], the fact that the "vector model" is unfit for the description of single quantum events would have appeared quite clearly. This set-up is represented here in Fig.1. At the bottom of the figure, a horizontal disk is represented. This disk is supposed to rotate synchronously with the (very low frequency!) emitted photons. This disk is conceived so as to be conducting along only one axis in the *xy* plane (this can be achieved if the disk is composed of metallic thin wires aligned along a single direction within *xy*). Let us look at the electric field associated with an emitted photon that, for simplicity, we consider to have been emitted towards *z'*. The amplitude of the electric field associated with such a circularly polarised photon possesses the same norm in any direction of the *xy* plane, contrarily to what the "vector model" would suggest. Therefore, in case (i) (corresponding to the measurement of Alice along *xx'*), the amplitude of the electric field in the rotating frame that we can call *R* (rotating horizontally synchronously with the photons) is +**E** or –**E** along xx'_R and +i**E** or –i**E** along yy'_R. The presence of an imaginary electric field along yy'_R might seem strange. Its physical effect can be conveniently understood by analysing, in a very simplified case, the wave function of a conducting electron that belongs to the rotating disk, from the point of view of the rotating frame. For the sake of the most extreme simplicity, we suppose that, in the rotating frame, this electronic wave function $\psi_{S/R}$ has a symmetry *s* and that it can be excited into a wave function $\psi_{2px/R}$ of symmetry *2p*. If the electric field along xx'_R is +**E** or –**E**, $\psi_{S/R}$ is respectively excited into $\psi_{2px/R}$ or $-\psi_{2px/R}$ (i.e., the same function $\psi_{2px/R}$ with a phase change). If the electric field along xx'_R is +i**E** or –i**E**, $\psi_{S/R}$ is respectively excited into $i\psi_{2px/R}$ or $-i\psi_{2px/R}$. It appears that the norm of the occupation of $\psi_{2px/R}$ is the same for all possible electric field phases. Therefore, if we try measure the number of photons absorbed by the rotating disk by counting those moving outside of the rotating disk, the result is the same for all photon phases. If we try another measurement technique equivalent to NMR, by measuring the amplitude and the phase of the electric current induced in the rotating disk (with a kind of galvanometer for instance), the result of the measure amounts to nothing else than noise, whatever the number of photons involved in the measurement, since the results of all individual measurements of Alice are uncorrelated and random. Therefore, in the end, the rotating measurement device evoked in ref.[2] seems unable to differentiate between cases (i) and (ii).

It is perhaps useful to remember that the roots of this apparent impossibility are quite basic and general in scope. This can be illustrated by the wave function of Bob’s spin in case (i) mentioned above. Up to an overall phase factor, this wave function is:

$$S_B = \pm 1/\sqrt{2}(|+\rangle_z + \pm|-\rangle_z) \qquad (1)$$

The sign noted by ± in (1) is random. This prevents both parts of S_B in eq.(1) to interfere in any statistically meaningful way at any time, even if both parts evolve in very sophisticated ways. Because of this randomness, $S_B = \pm 1/\sqrt{2}(|+\rangle_z + \pm|-\rangle_z)$ seems indistinguishable from $S_B = |\pm\rangle_z$. This might not be necessary the case if quantum mechanics was non-linear. However, the linearity of quantum mechanics seems, so far, to have no exception.

If we were to close our discussion at this point, our conclusion about the feasibility of fully non-classical teleported communication would be completely negative. It is fair to note, however, that it is always delicate to be sure that something is “impossible”. The validity of an “impossibility” statement is always somewhat provisional, possibly linked to our ignorance, and can always be challenged by new questions. Therefore, instead of ending this discussion with a fully negative assessment of the possibility of non-classical communication, the author wishes to raise a question that struck him when pondering on whether, in the rotating frame of Fig.1, an imaginary field ±i**E** is really always indistinguishable from a real field ±**E**. In order to precise our questioning, let us first of all consider the *gedanken* experiment illustrated in Fig.2. A hydrogen atom possesses an electron whose wave function at t=0 is supposed to be a linear combination of 1s and $2p_x$. The whole atom is placed at the centre of an electric ring situated within the plane *xy*. The ring is electrically charged, the total charge being positive and quite uniformly distributed along the ring. We make the supplementary exorbitant assumption that all electronic orbital states of the hydrogen atom have exactly the same energy, although this energy can vary when the atom moves inside the ring. This assumption, of course, is enormously demanding and unrealistic, but since Fig.2 only illustrates an imaginary experiment, we take the liberty to examine what happens just in that case. If the wave function of the electron is initially $\sqrt{(1-\varepsilon)}.\mathbf{1s} + \sqrt{\varepsilon}.\mathbf{2p_x}$, the electron density is higher on *x* side, so that the ring attracts the electron towards *x*. Since the electron itself attracts its nucleus, in the end, the hydrogen atom has great chances to collide with the ring on the *x* side. Symmetrically, if the wave function of the electron is initially $\sqrt{(1-\varepsilon)}.\mathbf{1s} - \sqrt{\varepsilon}.\mathbf{2p_x}$, the hydrogen atom has great chances to collide with the ring on the *x'* side. If the initial wave function of the electron is $\sqrt{(1-\varepsilon)}.\mathbf{1s} \pm i.\sqrt{\varepsilon}.\mathbf{2p_x}$, the electron does not know whether it must direct itself towards *x* or towards *x'*. Eventually, we guess that it will also end by colliding with the ring but that this event may happen somewhat *later* than in the first two cases. Physically, the situation of the $\sqrt{(1-\varepsilon)}.\mathbf{1s} \pm i.\sqrt{\varepsilon}.\mathbf{2p_x}$ case seems therefore slightly analogous to critical situations such as that of a pencil standing on its tip[5]. As far as the author is aware, no experiments of this kind of critical situations have been reported at the single quantum level in the literature. Certainly at least one reason is that the requirements for making such situations happen seem very difficult to fulfil in quantum mechanics. In Fig.2, for instance, as soon as **1s** and $\mathbf{2p_x}$ have different energies, the combination $\sqrt{(1-\varepsilon)}.\mathbf{1s} + \sqrt{\varepsilon}.\mathbf{2p_x}$ isn't preferentially attracted towards *x* any more, so that it does not behave differently than $\sqrt{(1-\varepsilon)}.\mathbf{1s} \pm i.\sqrt{\varepsilon}.\mathbf{2p_x}$. Perhaps just the good starting point for preparing realistic experiments similar to that of Fig.2 is to use a mechanically moving measuring apparatus such as the rotating disk present in Fig.1. Indeed, if we examine what happens in the rotating frame in Fig.1, the fundamental frequency of reference becomes zero thanks to the mechanical rotation, so that the problem of having eigenstates with exactly comparable energies softens.

In Fig.1, if the rotating axis xx'_R coincides with the conducting axis of the rotating disk and if it is submitted to the electric field +**E** (respectively -**E**) with E>0, electrons flow towards x'_R (respectively towards x_R.). In fact, if the pieces of aligned conducting wire constituting the rotating disk of Fig.1 do not conduct electricity in a closed loop, electrons do not flow, but at least they can induce non-zero electric polarization along xx'_R. This polarization, in turn, brings along with it a polarization of the phonons, so that the centre of gravity of the rotating disk deviates slightly towards x'_R (field +**E**) or towards x_R (field **-E**). If the electric field along the conducting axis xx'_R is ±i**E**, no deviation of the centre of gravity of the rotating disk is clearly predictable. In reality, it seems unlikely to expect that no deviation at all may occur in the ±i**E** case. Let us bear in mind that, whether we are in the ±**E** or the ±i**E** case, the norm of **E** is indifferently small, proportional only to the square root of the number of photons[6], because of the randomness of Alice's measurements results. What is more, the ±i**E** situation seems rather unstable, and therefore more difficult to predict; possibly even some subtle decoherence effects can intervene in this case. In order to give Bob a reasonable chance to measure something meaningful connected with Alice, we feel that the question is therefore not so much whether the centre of gravity of the rotating disk also deviates in the ±i**E** situations, as whether such deviation takes place *later* than in the ±**E** situation. If our conjecture that some difference can be expected in this timing between both situations is correct, there might be hope for Bob to hear something from Alice after all, even if Alice lives very far away. In order to know whether this hope is founded or not, Bob (i.e., ourselves) first needs to learn how to prepare and measure the evolution of some critical situations at the quantum level. At the macroscopic level, anybody can put a pencil on its tip. It seems quite harder to do something analogous in some way at the single quantum level. Maybe, as has been suggested above, the use of mechanically moving measuring devices would be a key for achieving that goal in a future that remains to be written.

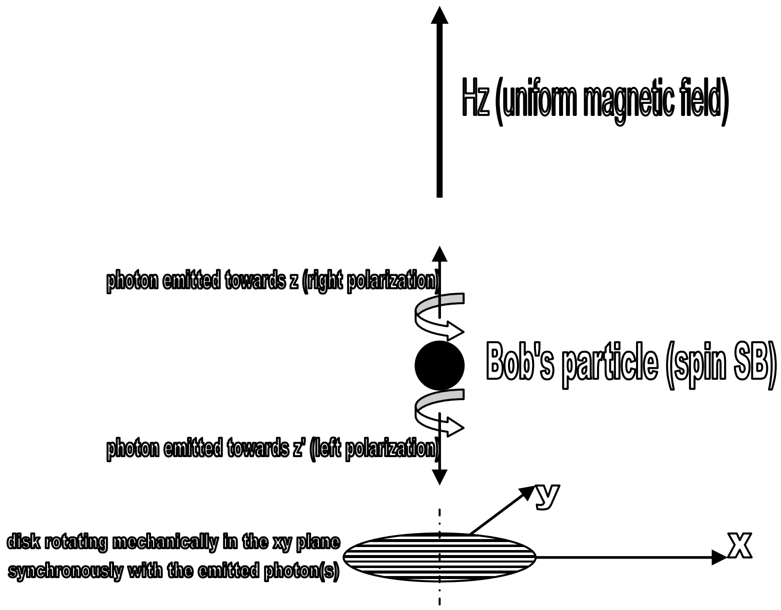
Hz (uniform magnetic field)
photon emitted towards z (right polarization)
Bob's particle (spin SB)
photon emitted towards z' (left polarization)
y
disk rotating mechanically in the xy plane
synchronously with the emitted photon(s)
x

Fig. 1

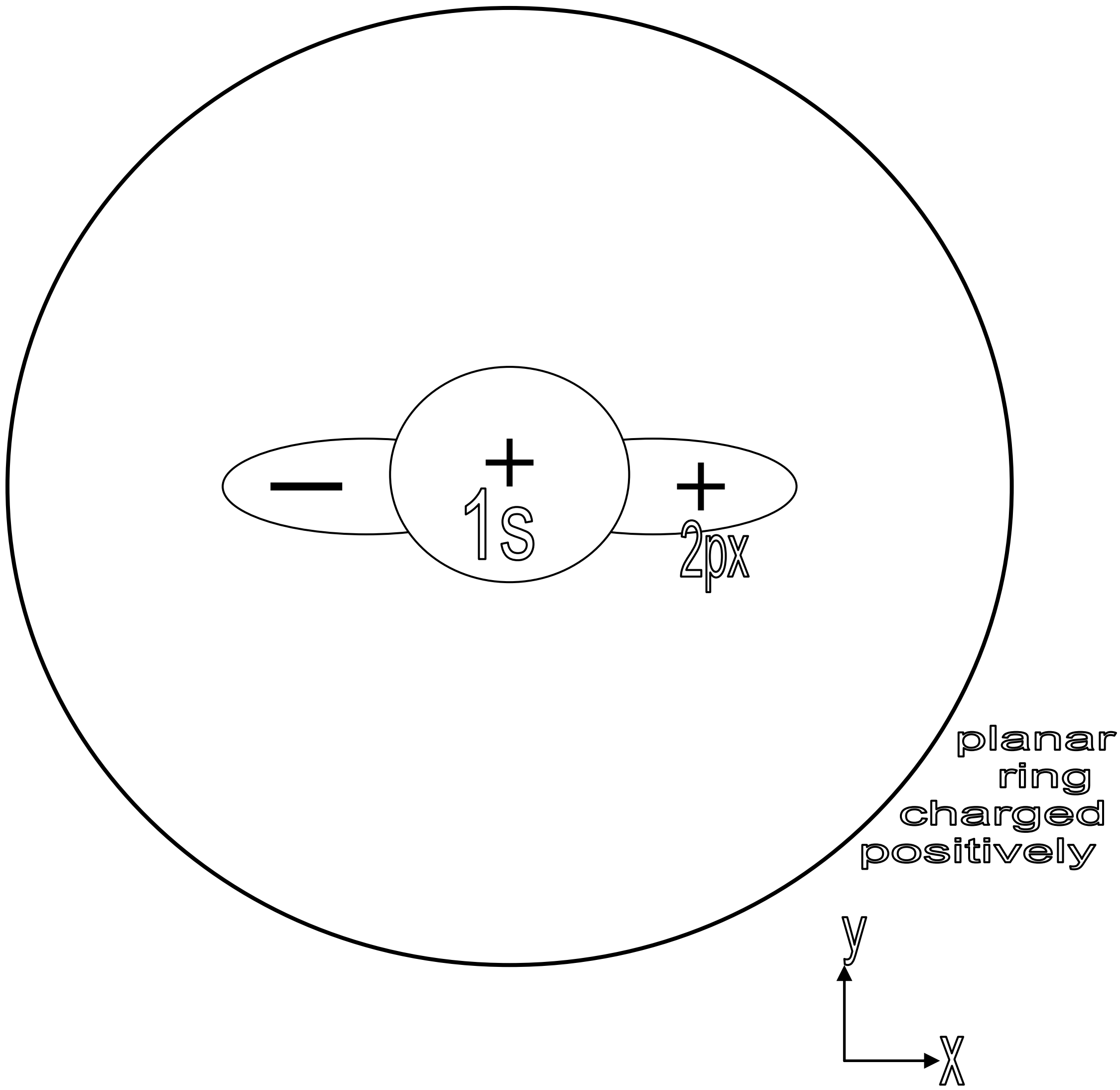

Fig. 2

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