How the Quantum No-communication Theorem misuses the formalism and loses phase information

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Abstract

This paper follows on from the author's previous thoughts on the subject of the "No-communication Theorem" and Ghirardi's critique of a communication scheme by the author and then his response to this. It is an addendum to lay bare the inadequate use of the formalism by Ghirardi, Hall et-al. To make our argument convincing, we find it necessary to explicitly lay out the machinery of the density matrix formulated argument, so that it can be seen by the incredulous, the gapping hole in the Ghirardi-Hall belief. We shall see that phase information, crucial to the interferometer setup in previous papers, is lost when: the joint evolution of the system is not considered, superposition is not explicitly brought in as an operation itself and finally, when the act of taking the reduced trace is taken too early (the act of exclusion of one system). This has lead to the limiting belief that components of entangled systems considered in isolation, are only ever in a mixed state. We shall see that when the reduced trace is taken at the right point in the analysis, phase information pertaining to the remote system is still present and this concurs with the state vector approach used to analyse the same problem.

1. Introduction

Previously[1] the author gave an initial response to a critique of his entangled communication scheme[2] by Ghirardi[3]. Summarising the author's initial response:

- A single photon was analysed through the right-hand interferometer (figure 1, at the end of the document) to show how the setup could distinguish a mixed state from superposition.

- Then the *state vector* approach was used for the entangled system of two photons and this claimed that, by joint evolution of the system, that the pure entangled state was able to traverse both the empty space on the LHS and the interferometer on the RHS, such that if a measurement was performed on the LHS, the mixed state resulting could be discerned on the RHS. For the incredulous, all the working of this will be laid bare in this paper.

- Then examined the density matrix method used previously by Ghirardi et-al[4-6] to disprove any such communication scheme. It questioned whether such analysis could be used in an argument about interference effects (regardless of what Ghirardi was saying about the off-diagonal terms disappearing on taking the reduced trace), when it couldn't even distinguish between the cases of single photon mixed state or a superposition through an interferometer.

The function of this paper then is: i) to lay analysis bare, where it was only suggested in the first paper[1] for the incredulous and ii) correct Ghirardi, Hall et-al to show the density matrix treatment explicitly interfering and concurring with the state vector method by: showing the joint evolution of the system, interfering the horizontal and vertical channels *as an operation itself* and *only then*, taking the reduced trace.

This is the crux of the argument against the No-communication Theorem: that a sequence of operations has not been correctly performed and phase information has been lost. We trust that the readership will see the correct method employed and that the result is beyond question, pending some hidden deus ex-machina in our tried and trusted machinery of quantum mechanics.

In the conclusion we find it necessary to dispel ridiculous "the sky is falling" notions pertaining to "the threat" to Relativity from superluminal signalling. We shall try to bring together the author's previous thoughts on the issue of metrology with superluminal signals. Although this programme is not quite complete, yet, we should embrace superluminal effects as part of The Picture without recourse to batty notions of signals coming from the future affecting the past or multiple universes. The picture that emerges, if one trusts the data[7] and thinks logically, is of a universal *instant* and hence simultaneity, an absolute preferred frame (as suggested by Bell[8]) from which one observes constant light speed, retarded time effects, length contraction and time dilation –

in short the Lorentz transform emerging from an absolute transform underneath.

2. The State Vector method

(In the following argument we don't need to needlessly complicate matters by introducing phase shifts, such as from the reflected component of the beam-splitter, they can always be "tuned out").

The joint evolution of a system is given by the tensor product of the operators on the tensor product of the state vector:

$$|\psi_1\rangle \otimes |\psi_2\rangle\big|_n = (U_1 \otimes U_2)\left(|\psi_1\rangle \otimes |\psi_2\rangle\big|_{n-1}\right) \quad \text{eqn. 1}$$

The characteristic of entangled systems is that the state vector cannot be factorised. We shall concentrate of one Bell State only but this, of course, doesn't affect the generality of the argument. Taking figure 1 as our starting point, let us consider the evolution of the two entangled photons through empty space and the interferometer:

$$|\psi_{12}\rangle = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\begin{pmatrix} e^{i\theta} & 0 \\ 0 & e^{-i\theta} \end{pmatrix}\begin{pmatrix} 0 \\ \frac{1}{\sqrt{2}}|H_1\rangle|V_2\rangle \\ \frac{1}{\sqrt{2}}|V_1\rangle|H_2\rangle \\ 0 \end{pmatrix}$$

$$\Rightarrow |\psi_{12}\rangle = \begin{pmatrix} 0 \\ \frac{1}{\sqrt{2}}|H_1\rangle|D_2\rangle \\ \frac{1}{\sqrt{2}}|V_1\rangle|D_2\rangle \\ 0 \end{pmatrix} \quad \text{eqn. 2}$$

The RHS photon has been rotated into the diagonal basis on both arms of the interferometer. We now take the expectation to find the output of the interferometer output sensor by performing the trace-out of the distant system **after** interference:

$$\begin{aligned} \langle \text{detector} \rangle &\propto tr_1\left(\langle \psi_{12}|\psi_{12}\rangle\right) \\ &= tr_1\begin{pmatrix} \frac{1}{2}\langle D_2|\langle H_1|H_1\rangle|D_2\rangle \\ \pm\frac{1}{2}\langle D_2|\langle H_1|H_1\rangle|D_2\rangle \end{pmatrix} \\ &= 0 \text{ or } 1 \end{aligned} \quad \text{eqn. 3}$$

Constructive and destructive interference has been modelled with the result obtain. In general, the correct use of the rules for obtaining the expectation of a multi-particle system is:

$$\langle O \rangle_2 = tr_1\left(\langle \psi_{12}|O_{12}|\psi_{12}\rangle\right) \quad \text{eqn. 4}$$

Which represents the expectation of the joint operator on the system wavefunction and then the tracing out of the remote system. Notably this result is dependent on the measurement on remote system $|\psi_1\rangle$; if a measurement had been performed on the system in eqn. 2, with the formation of the mixed state $\frac{1}{\sqrt{2}}|H_1\rangle|V_2\rangle$ or $\frac{1}{\sqrt{2}}|V_1\rangle|H_2\rangle$ then the interferometer would give a different result.

3. The Density Matrix method

The brief tenant of the no-communication theorem is that distant operations (on $|\psi_1\rangle$) don't affect the local system ($|\psi_2\rangle$). It simply seeks to show how the joint evolution can be factorised into operation occurring on solely one system.

$$\begin{aligned} tr_{\rho_1} &= tr_{\rho_1}\left[(P_1 \otimes \mathbf{I})^* \rho_{12} (P_1 \otimes \mathbf{I})\right] \\ &= tr_{\rho_1}\left[(P_1 \otimes \mathbf{I})^* (\rho_1 \otimes \rho_2)(P_1 \otimes \mathbf{I})\right] \\ &= tr_{\rho_1}\left(P_1^* \rho_1 P_1 \otimes \rho_2\right) \\ &= tr_{\rho_1}\left(\rho_1' \otimes \rho_2\right) \\ &= tr(\rho_2) \end{aligned}$$

We use the previous state vector example to make obvious the flaw in the no-communication theorem by taking the density matrix as a discussion point. Thus the density matrix of the system after joint evolution is:

$$\rho_{12} = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & |H_1\rangle|D_2\rangle\langle D_2|\langle H_1| & |H_1\rangle|D_2\rangle\langle D_2|\langle V_1| & 0 \\ 0 & |V_1\rangle|D_2\rangle\langle D_2|\langle H_1| & |V_1\rangle|D_2\rangle\langle D_2|\langle V_1| & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}$$

eqn. 5

The expectation of any operation is a function of the diagonal elements. This allows any function which allows a well defined expectation in simile to eqn. 3. After this the distant system is traced-out:

$$\begin{aligned} & tr_{\rho_1} = tr_{\rho_1}\left[(M_1 \otimes M_2)^* \rho_{12} (M_1 \otimes M_2)\right] \\ & \Rightarrow \\ & tr_{\rho_1} \propto fn\{M_1 \otimes M_2\} \end{aligned} \quad \text{eqn. 6}$$

Inescapably, as per the state vector example, distant measurements affect the local system, at least in terms of interference and effects due to phase.

4. Conclusion and discussion: Wither Relativity?

We stand at the cross-roads in Physics between the fanciful and mad or objective reality. Bell's[9] great result has been proven by Aspect[10] beyond all reasonable doubt and some would seem to believe that the matter is one of a philosophical discussion on the nature and logic of existence. Zbinden-Gisin et-al[7] shows the problem straining at the leash: retrospectively we know entanglement correlations seem to go at least 10,000c; the author[2] has suggested that some influence, the passage of pure quantum state information might even have infinite speed because it has no mass-energy.

This seems quite mad, until we consider the alternatives – "retrocausality", signals coming from the future to affect the past, the universe spawning off multiple instances of itself to cope with every quantum measurement outcome, like some badly configured unix program spawning a process for every little operation a program might do or even *superdeterminism,* in a version even more pre-ordained the Newtonianism. The author merely asks between these two great edifices of Relativity and Quantum Mechanics if a middle ground can be sought?

That middle ground might be to ask what mass-energy-less signalling (or at least something "fast") between two points on a space-time diagram might look like[2] (see figure 2 at the end of the document from[2]). Could it be that Lorentz transform emerges from another transform "underneath" it?

The Lorentz transform has terms which are related to the transit time of a light speed limited signal between two points. If these were removed we might perceive the transformation between different frames with a set of collinear axis. We'd find in this system (and revealed by experiment with entangled signalling) that one frame was *absolutely* time dilated with respect to the other, as there would be no reciprocity with this transform. The author reminds the readership that Doppler shift has been found relative to the cosmic background radiation. So what frame is this radiation, created at the Beginning, if it is not the absolute frame?

Does Relativity permit any absoluteness? A body distant from a gravitating body knows that everything in the gravitation well is absolutely time dilated and length contracted. The author[11] has gone on to extend the absolute transform from relative motion to general relativity to arrive at a privileged observation point in space-time of absolute rest and zero field – then truly everything else is time dilated and length contracted. All of this thought is from the segue of superluminal effects into Relativity.

There is no conflict with Relativity, light speed limited signals still travel at light speed but the Lorentz transform is built from an underlying absolute transform with length contraction and time dilation effects caused by the metric and motion through absolute space. Two persons in possession of their absolute speed would then, using light speed signals, derive the reciprocal Lorentz transform between them.

The situation is akin to bats in a cave using echolocation. Due to the finite speed of sound and the bat's relatively fast motion, they would derive strange notions in their system of metrology. If a light was shone (and they had the power of sight) they could see the discrepancy in how they place things in their version of space-time with the new superfast signals.

Are the bats in this cave example to believe that strange things happen when one exceeds the speed of sound? Do they travel backwards in time? Do messages come to them from the future? Do they seek a way out from the cognitive dissonance of the new fast signals by talk of multiple universes or superdeterminism? The light signal is showing them objective reality in their cave: it can place everyone and every event into an instant of time at a definite place in the cave. There is no Relativism, no lack of object reality. Moving on, the bats then, in cave coordinates, might begin to understand the plenum filling their cave[12] (the air) and understand that disturbances propagate at a certain speed due to an underlying reason – there is no "just so" story to just accept how things are.

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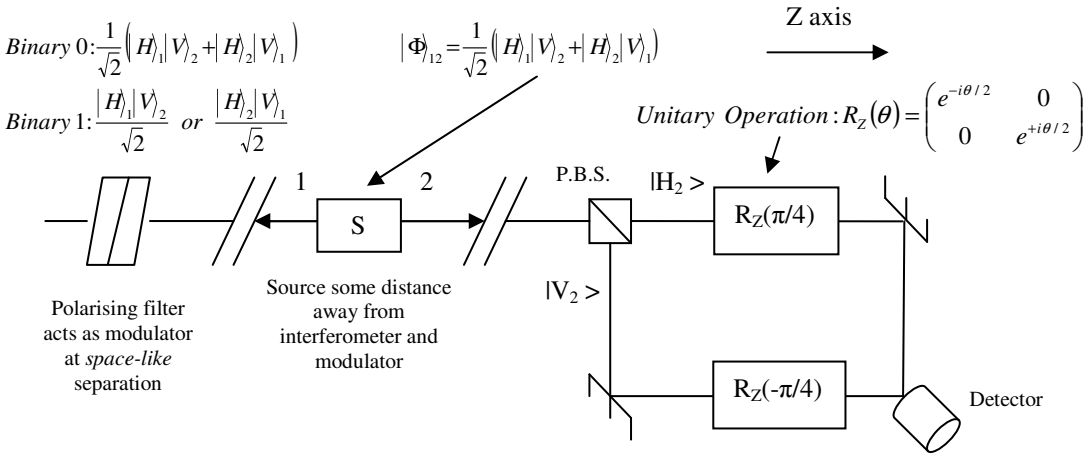
Figure 1 – Transmitting Classical Data down a Quantum Channel



Measurement/Modulation at distant system and state of two photon system	State of distant system	State of local system	Local measurement by interferometer after modulation of distant system
No modulation: 'Binary 0' $\frac{1}{\sqrt{2}}\left(\|H\rangle_1\|V\rangle_2+\|H\rangle_2\|V\rangle_1\right)$	Entangled => Pure state $\frac{1}{\sqrt{2}}\left(\|H\rangle_1+\|V\rangle_1\right)$ (Or at least some superposition)	Entangled => Pure state $\frac{1}{\sqrt{2}}\left(\|V\rangle_2+\|H\rangle_2\right)$	Pure state results in interference (Or at least some interference since source is not ideally pure)
Modulation: 'Binary 1' $\frac{\|H\rangle_1\|V\rangle_2}{\sqrt{2}}$ or $\frac{\|H\rangle_2\|V\rangle_1}{\sqrt{2}}$	Not entangled <=> Mixed state $\frac{\|H\rangle_1}{\sqrt{2}}$ or $\frac{\|V\rangle_1}{\sqrt{2}}$	Not entangled <=> Mixed state $\frac{\|H\rangle_2}{\sqrt{2}}$ or $\frac{\|V\rangle_2}{\sqrt{2}}$	Mixed state gives no interference

Table 1 – The Protocol for Transmitting Classical Data down a Quantum Channel

The Lorentz transform: $x = \gamma\left(x' + vt'\right) \quad t = \gamma\left(t' + \frac{vx'}{c^2}\right)$

Describes the transformation between inertial frames for different observers of mass-energy phenomena. All information about the co-ordinates is sent as mass-energy too so inevitably our measurement of space and time is affected (a bit like kicking a soccer ball whilst the goal posts are moving!).

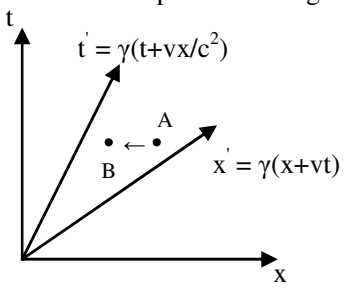
This view point leads to the space-time construct, destruction of simultaneity in space and time (events A and B below) and the consideration of co-ordinate transformations as hyperbolic rotations in 4-space (hyperbolic 'angle' α in analogy to θ in 3-space rotations).

$$u = \left(x_1 \; x_2 \; x_3 \; ict\right) \qquad u' = L(\alpha)u$$

Hyperbolic rotation matrix

$$L = \begin{matrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & \cosh\alpha & i\sinh\alpha \\ 0 & 0 & -i\sinh\alpha & \cosh\alpha \end{matrix} \qquad \text{Where } \alpha = \tanh^{-1}\frac{v}{c}$$

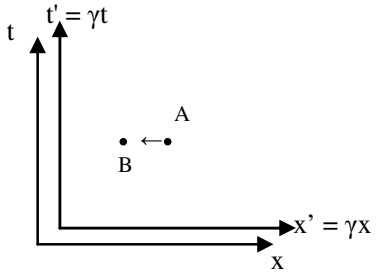
Thus we obtain the familiar space-time diagram:



Space-time diagram

The terms in the Lorentz transform $\Delta x = \gamma v \Delta t'$ and $\Delta t = \gamma v \Delta x'/c^2$ can simply be understood as the delay in sending the information about the co-ordinates to the non-primed frame. For instance if it takes the primed frame $\Delta t'$ seconds to perform a measurement then the frame will have moved a distance $v\Delta t'$ which we correct back to the un-primed frame, $\gamma v \Delta t'$ in addition to any other distance measurement. As regards the time: the frame will have moved $v\Delta t'$ once again so the light signal will require an extra $v\Delta t'/c$ seconds to reach the source, now $\Delta t' = \Delta x'/c$ so the extra time is $\gamma v \Delta x'/c^2$ in the un-primed frame.

Sending information superluminally knocks out the terms $\Delta x = \gamma v \Delta t'$ and $\Delta t = \gamma v \Delta x'/c^2$ in the Lorentz transform giving the following transformation diagram:



Lorentz's original view