Tachyons and EPR correlations

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Abstract

No causal paradoxes will occur if a preferred reference frame for tachyons propagation is assumed, and results of Bell’s inequality experiments may be well explained without using any telepathy effect. We can read G. Faraci’s and others’ results, Lettere al Nuovo Cimento, 15, 607-611 (1974), as a first quantitative indication on the tachyons preferred reference frame velocity with respect to the Earth, as well as on the tachyons velocity in their preferred reference frame. In order to experimentally prove this assumption’s validity, Aspect-like experiments should be slightly modified.

Introduction.

In this letter, I will show how it could be possible to explain the Aspect results [1] (and similar experiments) without using any “telepathy” effect. This is done by assuming the existence of a preferred reference frame in which tachyons propagate isotropically.

I will follow this logical scheme:

a - To have causal paradoxes we need tachyons + relativity principle.

b - Imagining that tachyons have a preferred reference frame in which they propagate isotropically\(^2\) (so as sound) the causal paradoxes disappear.

c - I suppose that tachyons mediate wave function collapse.

\(^1\)The literature on the EPR paradox is very extensive. I found G. C. Ghirardi (1997) [2] like a very powerful book to enter this subject. In a certain sense, my reading of that book is the origin of this paper. To have a report on Aspect’s experiments as well as other experiments on the Bell’s inequality you may see F. Selleri (1999) [3] and references there shown.

\(^2\)Substantially we assume that relativity principle is not suitable for tachyons (so as for sound) nor for events related with tachyons. Of course all the other known physics remains unchanged. We’ll only suppose that wave function collapses are related with tachyons. We do not mean that no other effect related with tachyons exists, but only that, if any other exists, it is not yet known.
I mean this:
we have a couple of entangled particles and detect one of it. At the detection a tachyon leaves from the point where the detection took place and go to "communicate" at the other particle the result.

d - using such tachyons the two measurements, \( m1 \) and \( m2 \), could be no more "space like":
- \( m1 \) detection of the left particle;
- \( m2 \) detection of the right particle.

e - they could be no more "space like" because
the tachyon left from right reaches the left particle before its detection or
the tachyon left from left reaches the right particle before its detection.

f - There are particular experimental situations in which what described in e is not true. Measurements are not correlated when these particular experimental situations are satisfied (\( \Delta m < \Delta < \Delta M \) in following notations). This happens because, in such experimental situations, the two measurements are really "space like", it is really impossible that one could be the cause of the other.

g - Perhaps G. Faraci and others (1974) casually reproduced an uncorrelating experimental situation in one of its five measurements.

I’ll discuss points a and b in the appendix I, points c-f in the part 1 and g in the part 2.

1 **EPR correlations and their possible link with tachyons.**

Let’s assume the existence of a preferred inertial reference frame \( R' \) in which tachyons propagate isotropically. We call \( V_t \) the magnitude of the velocity at which tachyons propagate isotropically in \( R' \). I am assuming that \( R' \) clocks was synchronized by using standard relation, that is by using light beams and

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\[ \text{signing the instant } \tau \text{ and the clock fixed in } A \text{ is signing the instant } \tau \text{. At the arrival in } B \text{ the travelling clock signs the instant } \tau + \Delta \tau. \text{ If the distance between } A \text{ and } B \text{ is } d \text{ and if we want synchronize by using standard relation, then the clock fixed in } B \text{ will be set at the instant}\]

\[ \bar{t} + \Delta \tau \sqrt{1 + \left( \frac{d}{c} \right)^2}. \text{ The clock motion must be uniform, no matter on the interval time value } \Delta \tau \text{ measured by the travelling clock (that is no matter on its velocity: the transport} \]

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fixing at $\tilde{t} + l/c$ the instant of the clock when it receives the light beam departed, from a point at a $l$ distance, when the clock there fixed was signing the $\tilde{t}$ instant.

Let’s now assume that “entangled” couples of particles are furthermore characterized by the fact that when a measurement is done on one of them a tachyon leaves and “communicates” to the other particle that it must “correlate” to the result of the already performed measurement (that is we imagine that tachyons are “hidden variables”).

Let’s call $R$ the laboratory inertial reference frame and let’s assume that $R'$ moves at $\beta c$ speed ($-1 < \beta < 1$), with respect to $R$, along the $x$ axis direction ($c$ is the light speed\(^6\), and we assume that also in $R$ we have synchronized clocks by using standard relation). For simplicity we treat the question as if it is one-dimensional, so we are only interested in the tachyon speed towards the two directions on the $x$ axis. Called $V_t^+$ the tachyon velocity toward the positive $x$ direction, and $V_t^-$ the velocity in the opposite direction, we obtain by the speed composition law\(^7\):

$$V_t^+ = \frac{\beta_t + \beta}{1 + \beta \beta_t} c \quad ; \quad V_t^- = \frac{\beta_t - \beta}{1 - \beta \beta_t} c$$

where we set $\beta_t \equiv \frac{V_t}{c}$ (it will be $\beta_t > 1$)\(^8\).

It could be probably useful to briefly discuss the above\(^1\). It can be immediately noticed that both $V_t^+$ and $V_t^-$ can assume negative values: $V_t^+$ assumes negative values when $\beta < -\frac{1}{\beta_t}$ and $V_t^-$ when $\beta > \frac{1}{\beta_t}$. We just noticed that $V_t^+$ ($V_t^-$) is meant to be the tachyon speed propagation toward the positive (negative) $x$ axes direction. A tachyon propagating at $V_t^+ < 0$ ($V_t^- < 0$) is not a tachyon propagating toward negative (positive) direction, it is simply a tachyon that, while propagating toward the positive (negative) direction, will meet along its travel clocks signing lower instants\(^9\). That is, once clocks are synchronized must not be “slow”). Uniform motion means that, $\forall \alpha \in (0, 1)$, the clock signs the instant $\tau + \alpha \Delta \tau$ when its distance from $A$ is ad.

\(^6\)That is the numerical value of $c$ is given by the number of back and forth consecutive travels performed by a light beam on a journey whose length is $(1/2)u_t$, where $u_t$ is the unit length, to say that an assumed unit time interval $u_t$ is spent.

\(^7\)I would remember that this law is an easy consequence of Lorentz transformations, that is it follows by assuming $R$ and $R'$ both inertial reference frame and $-1 < \beta < 1$. No matter on $\beta_t$ value.

\(^8\)Noticing that $\left(V_t^+ < -c \lor V_t^+ > c\right) \land \left(V_t^- < -c \lor V_t^- > c\right)$ is true for each $-1 < \beta < 1$ we obtain that in every inertial reference frame tachyons propagate “faster than light” toward any direction, that is, sending instantaneously a tachyon and a photon from $A$, the tachyon will always arrive in $B$ before the photon. So we are not assuming this but we are obtaining it as a consequence of the velocity composition law and the existence of a preferred frame in which tachyons propagate isotropically at a certain $\beta_t > 1$. Substantially, if a preferred reference frame in which tachyons propagate “faster than light” exists, then they will propagate “faster than light” in every inertial reference frame.

\(^9\)This fact doesn’t give any problem. We could imagine analogue facts in every day life that are perfectly comprehensible. Earth clocks could be conventionally synchronized in the following way: each clock will be set at 0.00 when it receives the signal “Sun is rising”. Once clocks are synchronized it could happen that travelling by plane from New Zealand to Italy we meet clocks signing always lower instants. For example at the departure New Zealand clocks could sign 8.00 and at the arrival Italian clocks could sign 7.00.
by standard relation, a tachyon leaving from point \( A \) (cause) when the clock fixed in \( A \) signs the \( t_A \) instant, will reach point \( B \) (effect) - that belongs, with respect to \( A \), toward the positive (negative) \( x \) axes direction - when the clock fixed in the point \( B \) signs the \( t_B < t_A \) instant. There is no cause and effect exchange on this.

We could ask now:

if velocity doesn’t give us the particle propagation direction, how could we decide the “correct” (that is, if the sign of \( t_B - t_A \) does not tell us what the cause and the effect are, which is the physical entity we must ask to know that)?

The answer to this question is in my opinion among the main results that we could obtain by the full comprehension of the conventional character of synchronization (to have a report on the conventionality of simultaneity, see R. Anderson, I. Vetharaniam, G. E. Stedman (1998) [4]). Both the time interval measured by two clocks fixed on different points, and velocity (that is strictly joined with that time interval), are conventional entities that could never give us physical meaningful results, but if we take into account also the chosen synchronization as well. By the simple observation that \( t_B - t_A < 0 \) (or \( V_t^+ < 0 \)) we could not obtain any physical meaningful result.

The entity that gives us the particle propagation direction is its momentum \( \mathbf{p} \) that is not conventional like every tridimensional vector given by the spatial components of tetravectors\(^{10}\) (see Anderson and others (1998) [4] pag 127 and following). I think that, as well as any other known particle, also tachyons propagating toward positive (negative) direction should have \( \mathbf{p} \) directed toward the positive (negative) direction, whatever the sign of \( V_t^+ \) (\( V_t^- \)) (that sign is related with the conventionally chosen synchronization whilst \( \mathbf{p} \) is decided by the experiment, not by our choices). I will discuss this point in more detail in appendix II.

Let’s now imagine that a couple of entangled particles is created, in \( R \), in the point \( x = \bar{x} \), at the instant \( \bar{t} \), and that two detectors are placed respectively in \( x = -d \) and \( x = d \) \((-d < \bar{x} < d\)). We call \( v_1 = \beta_1 c \) (\( 0 < \beta_1 < 1 \)) the magnitude\(^{11}\) of the particles speed in the reference frame \( R \).

We’ll call

\( L \)particle (or left particle) the particle directed toward the detector placed in \( x = -d \);

\( R \)particle (or right particle) the particle directed toward the detector placed in \( x = d \);

\( L \)tachyon (or left tachyon) the tachyon which left, from \( x = -d \) when the detection was there performed, toward the \( R \)particle;

\( R \)tachyon (or right tachyon) the tachyon which left, from \( x = d \) when the detection was there performed, toward the \( L \)particle.

\( L \)tachyon travels at velocity \( V_t^+ \), whilst \( R \)tachyon travels at velocity \( V_t^- \).

\(^{10}\)I call here tetravector the vector written by means of its contravariant components.

\(^{11}\)We are assuming here that the entangled particles have the same velocity magnitude. If this is not true then the argument hereby stated should be slightly modified.
R_{\text{particle}} will be detected at the instant $t^+ = \bar{t} + \frac{2d}{V_t}$ whilst $L_{\text{particle}}$ will be detected at the instant $t^- = \bar{t} - \frac{2d}{V_t}$.

To let (a) $R_{\text{particle}}$ reach the detector placed in $x = d$ before it is reached by $L_{\text{tachyon}}$, it must be:

$$t^+ < t^- + \frac{2d}{V_t} \iff \frac{\bar{x}}{d} > -\beta_1 \frac{1 + \beta_1 \beta}{\beta_t + \beta}.$$  

To let (b) $L_{\text{particle}}$ reach the detector placed in $x = -d$ before it is reached by $R_{\text{tachyon}}$, it must be:

$$t^- < t^+ + \frac{2d}{V_t} \iff \frac{\bar{x}}{d} < \beta_1 \frac{1 - \beta_1 \beta}{\beta_t - \beta}.$$  

To let the measurements be uncorrelated both (a) and (b) must be true, that is both measurements must take place before the arrival of the correlating tachyon which departed when the other measurement was performed.

Setting $\Delta = \frac{\bar{x}}{d}$, we will have uncorrelated measurements if

$$-\beta_1 \frac{1 + \beta_1 \beta}{\beta_t + \beta} < \Delta < \beta_1 \frac{1 - \beta_1 \beta}{\beta_t - \beta}.$$  

As it is well known, experiments testing Bell’s inequality almost always gave correlated measurements. This could be due to the fact that the investigated $\Delta$ values were almost always outside the range that gives uncorrelation (and this, as we’ll see, could be very likely). As far as I know, only in three cases [5]-[7] changes on $\Delta$ value were experimentally investigated. Faraci and others (1974) [5] observed, in one of their five measurements, a statistically relevant decrement of the correlation value. We will analyze this point in more details in the part 2.

Setting

$$\Delta_m = -\beta_1 \frac{1 + \beta_1 \beta}{\beta_t + \beta} \quad ; \quad \Delta_M = \beta_1 \frac{1 - \beta_1 \beta}{\beta_t - \beta} \quad (2)$$

it could be easily demonstrated that, in the assumed conditions, $0 < \beta_1 < 1$, $-1 < \beta < 1$ and $\beta_t > 1$, the following relations occur:

$$\Delta_M > \Delta_m, \quad -1 < \Delta_m < 1, \quad -1 < \Delta_M < 1.$$  

Whatever the values of $\beta$, $\beta_t$ and $\beta_1$, it will always be possible to find an interval of $\Delta$ values, included between -1 and 1, for which uncorrelated measurements are obtained. That is, by opportuneely varying $\bar{x}$ inside the interval

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12With this we obviously mean that the clock fixed in $x = \bar{x}$ (in $\mathbb{R}$) is signing the instant $\bar{t}$ when, in that point, particles are created, the clock fixed in $x = d$ (in $\mathbb{R}$) is signing the instant $t^+$ when, in that point, $R_{\text{particle}}$ is detected, and the clock fixed in $x = -d$ (in $\mathbb{R}$) is signing the instant $t^-$ when, in that point, $L_{\text{particle}}$ is detected.
it will always be possible to individuate an interval of values for which measurements will be uncorrelated.

Figures 1, 2 and 3 schematically show the three cases $\bar{x} < \Delta_m d$, $\Delta_m d < \bar{x} < \Delta_M d$ and $\bar{x} > \Delta_M d$, figure 4 shows the same three cases in the Minkowski space.

Figure 1: a) The couple of particles is created in $\bar{x} < \Delta_m d$; b) $L_{\text{particle}}$ reaches the detector and $L_{\text{tachyon}}$ leaves toward $R_{\text{particle}}$; c) $L_{\text{tachyon}}$ reaches $R_{\text{particle}}$; d) $R_{\text{particle}}$ reaches the detector after the reception of $L_{\text{tachyon}}$. Measurements are correlated.

Figure 2: a) The couple of particles is created in $\Delta_m d < \bar{x} < \Delta_M d$; b) $R_{\text{particle}}$ reaches the detector before the reception of $L_{\text{tachyon}}$; c) $L_{\text{particle}}$ reaches the detector before the reception of $R_{\text{tachyon}}$. Measurements are not correlated.

Figure 3: a) The couple of particles is created in $\bar{x} > \Delta_M d$; b) the $R_{\text{particle}}$ reaches the detector and $R_{\text{tachyon}}$ leaves toward $L_{\text{particle}}$; c) $R_{\text{tachyon}}$ reaches $L_{\text{particle}}$; d) $L_{\text{particle}}$ reaches the detector after the reception of $R_{\text{tachyon}}$. Measurements are correlated.

Figure 4: The curves was obtained by setting $\beta_1 = 1$, $\beta_t = 8$ and $\beta = -0.4$ (we remember that $\beta c$ is the velocity of $R'$ with respect to $R$, so the velocity of $R$ with respect $R'$ is $-\beta c$). By using eqs. 2 we get $\Delta_m = 11/38 \approx 0.29$ and $\Delta_M = 0.5$.

a) The couple of particles is created in $\bar{x} = 0.2d < \Delta_m d$ (squared spot); $L_{\text{particle}}$ reaches the detector and $L_{\text{tachyon}}$ leaves toward $R_{\text{particle}}$ (gray circled spot); $L_{\text{tachyon}}$ reaches $R_{\text{particle}}$
before its detection in \( x = d \) (black circled spot). We may notice that, in R, Ltachyon is travelling “backward in time”. Measurements are correlated.

b) The couple of particles is created in \( \Delta_m d < \bar{x} = 0.42d < \Delta_M d \) (squared spot); Rparticle reaches the detector before the reception of Ltachyon and Lparticle reaches the detector before the reception of Rparticle (gray circled spots). Measurements are not correlated.

c) The couple of particles is created in \( \bar{x} = 0.6d > \Delta_M d \) (squared spot); Rtachyon leaves toward Lparticle (gray circled spot); c) Rtachyon reaches Lparticle before its detection in \( x = -d \) (black circled spot). Measurements are correlated.

Experimentally detecting \( \Delta_m \) and \( \Delta_M \) it will be possibile to obtain, for a given \( \beta_1 \), the values \( \beta \) and \( \beta_t \).

Setting \( \beta_1 = 1 \), that is assuming to perform the experiment with a couple of photons, by the inversion of (2) we obtain:

\[
\beta_t^2 - 2 \frac{1 - \Delta_M \Delta_m}{\Delta_M - \Delta_m} \beta_t + 1 = 0
\]

\[
(\Delta_M + \Delta_m) \beta_t^2 + 2 (1 + \Delta_M \Delta_m) \beta_t + (\Delta_M + \Delta_m) = 0.
\]

The first equation gives the only acceptable solution

\[
\beta_t = \frac{1 - \Delta_M \Delta_m}{\Delta_M - \Delta_m} + \sqrt{\left(\frac{1 - \Delta_M \Delta_m}{\Delta_M - \Delta_m}\right)^2 - 1}
\]

because the other solution, in the hypothesis \(-1 < \Delta_m < 1 \) and \(-1 < \Delta_M < 1 \), is less than 1 so not acceptable. If \( \Delta_M \gtrless \Delta_m \) we obtain

\[
\beta_t \simeq 2 \frac{1 - \Delta_M \Delta_m}{\Delta_M - \Delta_m}.
\]

The second equation gives the only acceptable solution

\[
\beta = -\frac{1 + \Delta_M \Delta_m}{\Delta_M + \Delta_m} + \sqrt{\left(\frac{1 + \Delta_M \Delta_m}{\Delta_M + \Delta_m}\right)^2 - 1} \quad \text{if} \quad \Delta_M + \Delta_m > 0,
\]

\[
\beta = 0 \quad \text{if} \quad \Delta_M + \Delta_m = 0,
\]

\[
\beta = -\frac{1 + \Delta_M \Delta_m}{\Delta_M + \Delta_m} - \sqrt{\left(\frac{1 + \Delta_M \Delta_m}{\Delta_M + \Delta_m}\right)^2 - 1} \quad \text{if} \quad \Delta_M + \Delta_m < 0,
\]

because the other solution, in the hypothesis \(-1 < \Delta_m < 1 \) and \(-1 < \Delta_M < 1 \), is greater than 1 or less than -1 so not acceptable. If \( \Delta_M \lesssim \Delta_m \) (that is \( \beta_t \gg 1 \)) we obtain

\[
\beta \simeq -\frac{\Delta_M + \Delta_m}{2}.
\]

We notice that the interval of the acceptable \( \Delta \) to obtain uncorrelated measurements is given by \( \Delta_M - \Delta_m = 2 \beta_1 \beta_t \frac{1 - \beta_t^2}{\Delta_t} \) so, for all the acceptable \( \beta_1 \) and \( \beta \) values, it will always be
\[
\lim_{\beta_t \to +\infty} (\Delta_M - \Delta_m) = 0
\]

that is, for all kind of particles used in the experiment (photons or not) and for any speed of \( R' \) with respect to \( R \), the interval of \( \bar{x} \) values to obtain decorrelated measurements will be very little (compared with \( d \)) if the magnitude of the speed of the tachyons in \( R' \) is very big (compared with \( c \))\(^{13}\).

We finally notice that, if things go the way hereby supposed, in the experimental conditions in which uncorrelated measurements occur, any conservation law will sure be violated. For example, measuring spins of \( e^+ \ e^- \) couples, it happens that, even if spin detectors are placed along the same direction\(^{14}\), all the results, \((+;+), (+;-), (-;+), (-;-)\) will be possible with the same probability\(^{15}\), giving an evident violation, in two of the four possible results, of the angular momentum conservation law\(^{16}\). Parity should be obviously violated because the interval of \( \bar{x} \) values giving uncorrelated measurements is symmetric with respect to the origin only when \( \beta = 0 \).

\(^{13}\)This fact could be perhaps very interesting from a philosophical point of view (if experiments always show correlations we could anyway believe on local tachyons interactions that are not experimentally proven, or not yet proven, because \( \beta_t \) value is too high) but, of course, would give a situation not very interesting from a physical point of view.

\(^{14}\)To have uncorrelated measurements there will be no need to casually change the direction of the detectors and this will probably give a big simplification in the experimental set up compared with the usual delayed-choice experiments.

\(^{15}\)Or with a probability depending somehow on the \( \Delta \) value. However, if \( \Delta_m < \Delta < \Delta_M \), probability of results \((+;+), (-;-)\) will not be zero being this fact the experimental proof of the uncorrelation of the measurements.

\(^{16}\)We could anyway imagine that such violation disappears taking into account angular momentum of experimental devices too.
2 Experimental situation.

Let’s go now to analyse experimental results \[5\]-\[7\].

We must consider the tri-dimensional situation. We call $\vec{v} = \vec{\beta}c$ the velocity of the preferred tachyon reference frame $R’$ with respect to the laboratory reference frame $R$ (see figure 5).

Entangled particles flight is related to a certain $x$ axis in the laboratory reference frame $R$. The $x$ axis is defined by $\theta$ and $\varphi$ angles, and we choose its orientation in such a way that $0 < \theta < \frac{\pi}{2}$. We want obtain the tachyon velocity toward both the $x$ axis directions: $V^+_t$ and $V^-_t$. $V^+_t$ is related to $\theta$ and $\varphi$ whilst $V^-_t$ is related to $\theta = \pi - \theta$ and $\varphi = \varphi + \pi$. Because of to the axial symmetry, $\varphi$ does not enter the computation, so, following J. D. Jackson (1975) \[9\], eq (11.32), we obtain:

$$\tan \theta = \frac{\beta_t \sin \theta}{\gamma (\beta_t \cos \theta' + \beta)}$$

(5)

and

$$V^+_t = \sqrt{\beta^2_t + \beta^2 + 2 \beta_t \beta \cos \theta' - (\beta_t \beta)^2 (1 - \cos^2 \theta')} c$$

(6)

where we setted $\gamma = \frac{1}{\sqrt{1 - \beta^2}}$.

By inversion of (6) we may express $\cos \theta'$ in terms of $\theta$ so, after substituting in (5), we finally get the wanted relations.

We show the calculation results in the assumption $\beta_t \gg 1$.

The reality we are assuming $\beta_t \cos \theta' \gg 1$, that is, in the limit $\beta_t \gg 1$, our approximation is not good only for $\theta' \approx \frac{\pi}{2}$. The angles $\theta' \approx \frac{\pi}{2}$ are important in the case $\gamma \gg 1$, so, in the following, we are assuming that $\gamma \gg 1$ does not occur. Of course only experimental results could prove the validity of such assumption.
When \( \tan \theta > 0 \), as in the case of \( V^+ \), the inversion of (5) gives \( \cos \theta' = \frac{1}{\sqrt{1 + \gamma^2 \tan^2 \theta}} \), and, substituting in (6), we get:

\[
V^+_i = \frac{\beta_i}{\beta_i \sqrt{1 + \gamma^2 \tan^2 \theta}} c. \tag{7}
\]

When \( \tan \theta < 0 \), as in the case of \( V^- \), the inversion of (5) gives \( \cos \theta' = -\frac{1}{\sqrt{1 + \gamma^2 \tan^2 \theta}} \), and, substituting in (6), we get:

\[
V^-_i = \frac{\beta_i}{\beta_i \sqrt{1 + \gamma^2 \tan^2 \theta}} c. \tag{8}
\]

Remembering that we choose \( x \) axis direction so as to give \( \cos \theta > 0 \), \( \theta = \pi - \theta \), and setting \( \beta^* \equiv \beta \cos \theta, \gamma^* \equiv \frac{1}{\sqrt{1 - (\beta^*)^2}} \), \( \beta_i^* \equiv \frac{\beta_i}{\cos \theta \sqrt{1 + \gamma^2 \tan^2 \theta}} = \beta_i \frac{\gamma^*}{\gamma} \), (9)

we could rewrite (7) and (8) in the forms\(^{18}\):

\[
V^+_i = \frac{\beta_i^* + \beta^*}{1 + \beta_i^* \beta^* c}, \quad V^-_i = \frac{\beta_i^* - \beta^*}{1 - \beta_i^* \beta^* c}. \tag{10}
\]

Comparing (1) with (10) we can finally conclude that the one-dimensional problem is equivalent to the tri-dimensional one upon substituting \( \beta_i \) with \( \beta_i^* \) and \( \beta \) with \( \beta^* \). So, given \( \theta, \beta \) and \( \beta_i \gg 1 \), we have an uncorrelating region centered in \( \Delta \equiv \Delta_M + \Delta_m \) whose largeness is \( d\Delta \equiv \Delta_M - \Delta_m \) (see eqs. (3) and (4)):

\[
\Delta \simeq -\beta^*, \quad d\Delta \simeq \frac{2}{\beta_i^* (\gamma^*)^2}. \tag{11}
\]

where \( \beta^*, \gamma^* \) and \( \beta_i^* \) are given by (9).

Because of Earth motion the \( \theta \) angle changes with a period of approximately 1 day. This motion change the \( \Delta \) value and, if \( \beta_i \gg 1 \) (so \( \beta_i^* \gg 1 \) and \( d\Delta \ll 1 \)), it could be very difficult to get an experimental situation in which the particle source is inside the uncorrelating region\(^{19}\). Anyway we have no theoretical indication on the \( \beta_i \) value, so we could think that it is high but not so high to give no possibility to the experimental proof. Moreover, we could read the already performed experiments and, since in one of them \(^5\) a statistically

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\(^{18}\)Because of the approximation \( \beta_i \gg 1 \) we could add or subtract \( \beta^* \) at the numerator of eqs (10).

\(^{19}\)We could direct \( x \) axes (that is particle flight direction) parallel to the Earth axes, so \( \theta \) angle should remain constant. Anyway, if \( \beta_i \) is too big then \( d\Delta \) could be so little to give no possibility to the experimental proof of the existence of the uncorrelating region.
relevant decrement of the correlation factor was already observed, we could hope that decrement was due to the tachyons effects here supposed.

Faraci and others (1974) [5] gave the results of five measurements: three of them related to the same \( \Delta \) value (they changed only \( d \) leaving \( \bar{x} = 0 \)) the other two related to \( \Delta \approx 0.37 \) and \( \Delta \approx 0.72 \). The four results related to \( \Delta \approx 0 \) and \( \Delta \approx 0.37 \) gave the same correlation value but the fifth one gave a clearly lower value\(^{20}\). We will now analyze this fifth measurement by supposing that the correlation decrement was due to tachyons effect. By comparing the lower correlation value with the other four we could argue that, during the fifth measurement, the source spent \( \frac{1}{3} \) of the total time inside the uncorrelating region. The total time for each measurement was several weeks\(^{21}\) so the \( \theta \) variation due to Earth motion was well mediated. We call \( d\Delta \) the daily variation of \( \Delta \), and we saw that it should be three times the uncorrelating region amplitude, \( d\Delta \). Since \( d\Delta \) is little\(^{22}\) also \( d\Delta \approx 3d\Delta \) must be little. The variation \( d\Delta \) could be little only if the direction of \( \vec{v} \) (the velocity of the tachyon aether with respect to the laboratory reference frame) is close to the Earth axis. We call \( \delta \) the angle between the direction of \( \vec{v} \) and the Earth axis and we suppose \( \delta \ll 1 \). The experiment took place on Catania (Italy) and \( x \) axes (the direction of the entangled particle flight path) was close to the South-North direction\(^{23}\). Taking into account the Catania latitude value \( \theta_C = 37^\circ 30' \), we could say that because of Earth motion \( \theta \) changed from \( \theta_C - \delta \) to \( \theta_C + \delta \) (we assume that the direction of the entangled particle flight path was exactly the South-North). So the variation \( d\Delta \) was approximatively given by (see (9) and (11)):

\[
d\Delta \approx 2\delta \beta \sin \theta_C.
\]

By imposing that \( \Delta \approx 0.72 \), the experimental value of \( \Delta \) that gave less correlation, must be inside the interval \( \Delta \pm \frac{d\Delta}{2} \) we get:

\[
\beta = \frac{0.72}{\cos \theta_C} \pm \delta \tan \theta_C = 0.91 \pm 0.76\delta.
\]

Unfortunately we have no indication on the \( \delta \) value. We just know, as already noticed, that it should be “little”. Only the repetition of the experiment to directly measure the \( d\Delta \) amplitude could give a realable \( \delta \) value. Once known \( \delta \), we get \( \beta_t \) value by setting \( d\Delta \approx 3d\Delta \) (see see (9) and (11)):

\[
\beta_t \approx \frac{3\gamma}{\delta \beta \sin \theta_C (\gamma^*)^3}.
\]

Of course, if the effects is real, it could be better revealed by means of similar experiments that use faster statistics (minutes, not weeks) so as, for example, A. Aspect and others (1981) [1].\(^{20}\) As far as I know standard quantum mechanics interpretation does not give any explanation of this correlation value decrement. I want also outline that Faraci experiment showed a very good repeatability in the four results related to \( \Delta \approx 0 \) and \( \Delta \approx 0.37 \).

\(^{21}\)G. Faraci: private communication.

\(^{22}\)\( \beta_t \gg 1 \) so \( d\Delta \ll 1 \) and \( \beta_t \) must be very much greater than 1 because if \( d\Delta \) was not very little then the effects here conjectured should be already observed several times.

\(^{23}\)G. Faraci: private communication. I thank very much G. Faraci for these communications.
As far as Wilson and others [6] and Bruno and others [7] experiments are concerned I must notice that a reliable comparison is possible only after knowing photons flight direction (and I do not know it). Since they never observed a decrement of correlation value the only conclusion we may obtain by their results is that, if Faraci and others results [5] is due to tachyons hereby supposed, then the daily variation of $\Delta$, $\Delta\Delta$, should be “little” and, as a consequence, $\delta$ angle should be “little” too.
Appendix I

Probably the first one to talk about causal paradoxes due to tachyons was A. Einstein (1907) [8]. Similar statements were later given by W. Pauli in “Relativitätstheorie” chapter 1.6, Leipzig (1921). Both of them essentially deny tachyons possibility because speed composition law already shown in this paper, \( V_t^+ = \frac{\beta_t^+ + \beta}{1 + \beta \beta_t^+} c \) and \( V_t^- = \frac{\beta_t^- + \beta}{1 - \beta \beta_t^-} c \), would give signals propagating “backwards in time” for suitable \( \beta \) values. For example, if \( \beta < -\frac{1}{\beta_t} \), we get \( V_t^+ < 0 \) and a signal which left from position \( x = 0 \) at the instant \( t_{in} \) (i. e. when the clock fixed in \( x = 0 \) signs the instant \( t_{in} \)) would reach point \( x = d > 0 \) at the instant \( t_{fin} = t_{in} + \frac{d}{V_t^+} < t_{in} \) (i. e. when the clock fixed in \( x = d \) signs the instant \( t_{fin} \)).

In this form the statement is surely wrong. Conventionality of simultaneity gives no physical meaning to the comparison of instants signed by clocks fixed on different points\(^{24}\).

Later the discussions on tachyons and causal paradoxes assumed a little bit more subtle form (I am not able to say if this form was implicitly supposed by Einstein and Pauli). Substantially, we assume that at least one reference frame in which tachyons propagate isotropically exists, then, assuming that the relativity principle is suitable for tachyons, the fact that tachyons could propagate isotropically is extended to all inertial reference frames. Moreover, still because of relativity principle, it can be shown that if in a certain reference frame tachyons could propagate toward the positive \( x \) axes direction at a certain velocity, then, in any other reference frame, they could propagate toward the negative \( x \) axes direction at the same velocity.

This gives the following paradox:

the frame \( R_2 \) moves, respect to \( R_1 \), at the \( \beta c \) (-1 \( < \beta < 1 \)) velocity toward the positive direction of the \( x \) axes. Let’s call \( \beta^* c \) (\( \beta^* > 1 \)) the tachyon velocity toward the positive \( x \) axes direction in \( R_1 \). Because of what we just saw, in \( R_2 \) tachyons could propagate at a \( \beta^* c \) velocity toward the negative direction of the \( x \) axes. From composition velocity law it follows that tachyons propagating in \( R_2 \) at a \( \beta^* c \) velocity toward the negative \( x \) axes, have in \( R_1 \) a velocity (in the negative \( x \) direction) given by \( \frac{\beta^* - \beta}{1 - \beta^*} c \). This means that, if in \( R_1 \) we send a going and returning tachyon along the segment \( AB \) of length \( d \) (we suppose also here that clocks were synchronized by standard relation) we’ll obtain that, if the going tachyon, the one travelling at velocity \( \beta^* c \), leaves \( A \) when the clock fixed in \( A \) was signing the instant \( t_{in} \), then it will arrive in \( B \) when the clock fixed in \( B \) signs the instant \( t_{in} + \frac{d}{\beta^* c} \); moreover, if the returning tachyon, the one travelling at velocity \( \frac{\beta^* - \beta}{1 - \beta^*} c \), leaves \( B \) when the clock fixed in \( B \) was signing the instant \( t_{in} + \frac{d}{\beta^* c} \), (that is the returning tachyon leaves from \( B \) simultaneously with the arrival in \( B \) of the going tachyon), then it will arrive in \( A \) when the

\(^{24}\)Or, as already noticed, if we would give them any meaning, we must take into account the synchronization chosen, and the simple fact that \( t_{fin} < t_{in} \) does not give any causal paradox even after taking into account the standard synchronization assumed by Einstein and Pauli.
clock fixed in $A$ signs the instant $t_{fin} = t_{in} + \frac{d}{\frac{1}{\beta^* c}} + \frac{1 - \beta^* \beta d}{\beta^* c}$. By easy calculations we obtain $t_{fin} - t_{in} = \frac{d}{\frac{1}{\beta^* c}} \frac{2\beta^* - \beta (1 + \beta^*)}{\beta^* - \beta}$ that is positive for every $\beta \ (-1 < \beta < 1)$ if $\beta^* < 1$ whilst it is negative for $\beta > \frac{2\beta^*}{1 + (\beta^*)^2}$ if $\beta^* > 1$ as assumed here. Being $\frac{2\beta^*}{1 + (\beta^*)^2} < 1$ for every $\beta^*$ value, we obtain that, for each velocity of the going tachyon in $R_1$, it will always be possible to find a frame $R_2$ (moving at velocity $\beta c$, with $0 < \beta < 1$, with respect to $R_1$) from which we could send a returning tachyon that will reach $A$ before the departure of the going tachyon.

The only chance to avoid the causal paradox seems to be the choice $\beta^* < 1$ that makes $t_{fin} - t_{in}$ always positive. That is, the only choice to avoid causal paradoxes seems to be the deny of tachyons possibility.

It is clear that we cannot invoke here the simultaneity conventionality because the comparison $t_{fin} - t_{in}$ does not concern now two different clocks, but the same clock: the clock fixed in $A$.

It is also clear that the demonstration shown above is hardly based on relativity principle. It is enough to say that such principle is not suitable for tachyons (we could for example imagine that, as far as tachyons are concerned, we are not “sotto coverta”) and the shown demonstration on causal paradoxes is no longer valid. Sure the paradox disappears if, as it is here supposed, we imagine that tachyons have a preferred frame, an “aether” in which they propagate isotropically. And, in the frames moving respect to the aether, tachyons’ velocity will be given by the velocity composition law. In such a case the tachyon back and forth travel time on a segment of length $d$, $\frac{d}{V_1'} + \frac{d}{V_2}$, is positive for each $\beta > 0$, i.e. no causal paradox will be given by tachyons existence in the hypothesis that they propagate in their “aether”.

**Appendix II**

In this appendix my intent is not to demonstrate that tachyons *must* be related to a certain momentum. I want only to explain why, in my opinion, if tachyons do exist, then a suitable momentum should be related to them. Moreover, I also want to show which could be a suitable tachyon momentum definition.

My opinion is that if we want to give a physical meaning to the propagation of any particle (as well as any signal) we must say which is the measurement to perform to know the direction of such propagation (that is which is the physical entity that describe the signal propagation direction). And the propagation direction of any particle has surely a physical meaning: it is the direction “from the cause toward the effect”. Anderson and others [4] clearly show that choosing a suitable value of the synchronization 3-vector $\vec{\kappa}$ (4 pag 127) we could set velocity\(^{25}\) of any particle (mass particles as well as photons) to any value. In my opinion this is enough to say that velocity is not a physical meaning entity. So, for example, velocity does

\(^{25}\)we are meaning “one-way” velocity.
not give us the propagation direction of a particle: it can happen sometimes\textsuperscript{26} but we cannot be sure that this always happens. So, if we think that propagation direction of any signal has a physical meaning, we must link the propagation direction of a signal to any other physical meaning entity that is not its velocity. And this physical meaning entity (as well as any other physical meaning entity), in my opinion, must be not conventional because we cannot imagine to conventionally choose a signal direction propagation, we cannot conventionally choose the direction from the cause toward the effect.

Anderson and others (\textsuperscript{4} pag 127) show that synchronization transformations affect the time component of any 4-vectors but do not affect spatial components\textsuperscript{27} as well as 4-vectors magnitude. In my opinion the synchrony invariance has a deep physical meaning: the synchrony invariant entities are measurable, so physical meaning entities, whilst not synchrony invariant entities are not measurable\textsuperscript{28}.

For example, as far as $X = (cdt, d\vec{x})$ is concerned, we have spacial components, $d\vec{x}$, and magnitude\textsuperscript{29} $\|X\|^2 = (cdt)^2 - |d\vec{x}|^2 = (cd\tau)^2$ that are measurable entities: $d\vec{x}$ is measurable by using a rigid rod, $d\tau$ is measurable by using a (uniformly) travelling clock\textsuperscript{30}. As far as a mass particle 4-vector momentum is concerned, $P_m = (mc\gamma, \vec{p})$, both the magnitude $\|P_m\|^2 = (mc)^2$ and the spacial components $\vec{p} = m\frac{d\vec{x}}{d\tau}$ are measurable entities. As far as far a photon 4-vector momentum is concerned, $P_{ph} = (h\frac{\omega}{c}, h\vec{k})$, the magnitude $\|P_{ph}\| = 0$ by definition (that is, in standard synchronization, we set clocks in such a way to have $\|P_{ph}\| = 0$) and the spatial part, $\vec{k}$, is measurable by means of interferometric experiments, that is by means of length measurements.

We may notice that the spatial part of 4-vector momentum (in both cases, mass particles so as photons) is a 3-vector having the direction of the particle propagation. So, at least for mass particles and photons, this is the physical entity...\textsuperscript{50}

\textsuperscript{26}For example this happens if we synchronize clocks by standard relation (that is imposing the isotropy of the one-way speed of light) and we never consider a signal faster than light.

\textsuperscript{27}I remember that I’m calling 4-vector the vector written by means of its controvariant components.

\textsuperscript{28}I do not intend to demonstrate here this. I am simply thinking on it as a conjecture. Anyway, after \textsuperscript{4}, seems to me absolutely clear that, who wants to reject simultaneity conventionality thesis, must show the way to measure any not invariant under synchronization transformations entity. Since I cannot imagine any measurement not reducible to a length measurement, or to any scalar measurement, or to a time interval measurement performed by a travelling clock, and since all these entities are synchrony invariants, I cannot imagine how simultaneity conventionality thesis could be rejected. That is I cannot imagine how any physics law could be violated because of changing synchronization or, equivalently, how any physics law may obly us to choose a certain synchronization. If we change synchronization, each physics law must be rewritten by means of \textsuperscript{4} pag 127 prescriptions, and if a law is experimentally proven (by length, or scalar, or travelling clock time interval measurements) in standard form it will be automatically proven in non standard form too.

\textsuperscript{29}We assume standard synchronization.

\textsuperscript{30}d\tau is the interval time measured by the travelling clock that leaves the point $\vec{x}_m$ when the clock fixed in $\vec{x}_m$ was signing the instant $t_m$ and arrives in the point $\vec{x}_m + d\vec{x}$ when the clock fixed in the point $\vec{x}_m + d\vec{x}$ is signing the instant $t_m + dt$. In transport synchronization we use exactly such $d\tau$ measurement to fix clocks instants.
tity we were looking for. If we want to use only not conventional entities (that is if we want to express physical meaning statements whatever the synchronization chosen) we must say that mass particles, so as photons, propagate toward the direction of their 3-vector momentum, not toward the direction of their velocity. Changing synchronization we may change the velocity but we cannot change the momentum, that is we cannot change the signals propagation direction, that is we cannot change the direction from the cause toward the effect. Of course we cannot. This direction is not conventional, it is a matter of fact.

So, if tachyons do exist, and if their propagation have any physical meaning, I imagine that also for tachyons it should be possible to define a 4-vector momentum, and I imagine that the spacial components of the tachyons 4-vector momentum give their propagation direction.

Since there not exists any inertial reference frame where a tachyon can be at rest, so as for photons, I suppose that 4-vector momentum definition is similar for tachyons and photons.

Let’s imagine to be at rest with respect to the tachyons preferred reference frame $R'$ where clocks was synchronized by standard relations. We have that photon 4-vector momentum is given by

$$ P_p = \left( \frac{\hbar \omega_p}{c}, \hbar \vec{k}_p \right) = (p_{0,ph}, \vec{p}_{ph}) $$

and we suppose that tachyon 4-vector momentum $P_t$ is given by

$$ P_t = \left( \frac{\hbar \omega_t}{c}, \hbar \vec{k}_t \right) = (p_{0,t}, \vec{p}_{t}) $$

where $\hbar$ is a suitable constant to be experimentally determined.

For mass particles, as well as as for photons, we can define velocity by means of the ratio between spacial components and time component of the 4-vector momentum. For example, for a photon we have $\vec{v}_{ph} = \frac{\vec{p}_{ph}}{p_{0,ph}}$ and we must transform $P_p'$ into $P_{0,ph} = (p_{0,ph}, \vec{p}_{ph})$ by means Lorentz transformations to have the velocity in the laboratory reference frame $R$: $\vec{v}_{ph} = c \frac{\vec{p}_{ph}}{p_{0,ph}}$. We can observe that $\vec{p}_{ph}$ and $\vec{p}_{ph}$ have the same direction or the opposite one depending on the sign of $p_{0,ph}$. In standard synchronization this sign is always positive$^{31}$, so we can conclude that, even if velocity is a conventional entity, taking into account the synchronization chosen (the standard one), we can give it a physical meaning (at least for light velocity): for example we can say that its direction is always the same direction of momentum. We can reach similar conclusion also for mass particles: in standard synchronization their velocity has the same direction of their momentum.

\[ p_{0,ph} = \gamma \left( p_{0,ph} + \beta \cdot \vec{p}_{ph} \right) = \gamma p_{0,ph} \left( 1 + \beta \cdot \frac{\vec{p}_{ph}}{p_{0,ph}} \right) \]

where $\beta$ is the velocity of $R'$. Noticing that $|\beta| < 1$ and that, in standard synchronization, $|\vec{p}_{ph}| = p_{0,ph}$, we obtain that if $p_{0,ph} > 0$ also $p_{0,ph} > 0$ for any acceptable $\beta$.
But for the tachyons here supposed (that is tachyons propagating in their aether) the situation is very different. In $R'$ we know that, for any tachyon propagation direction, it is always $|\vec{v}'_t| = \beta c$, so, if we define tachyons velocity as well as for photons and mass particles

$$\vec{v}'_t = c \frac{\vec{p}'_t}{p'_{0,t}}$$

we obtain $p'_{0,t} = \frac{1}{\beta_t} |\vec{p}'_t| = \frac{1}{\beta_t} \bar{h} |\vec{k}'_t|$, and we could rewrite $P_t$ in such a way:

$$P'_t = \left( \frac{\bar{\omega}_t}{c}, \bar{h} \vec{k}'_t \right) = \bar{h} |\vec{k}'_t| \left( \frac{1}{\beta_t} \hat{n}' \right)$$

where $\hat{n}'$ is the versor directed toward the propagation direction. By means of Lorentz transformations we can now obtain the tachyon momentum 4-vector in the laboratory reference frame $R$. We easily see that the time component of such 4-vector, $p_{0,t} = \gamma \left( p'_{0,t} + \beta \cdot \vec{p}'_t \right) = \gamma \bar{h} |\vec{k}'_t| \frac{1}{\beta_t} \left( 1 + \beta_t \beta \cdot \hat{n}' \right)$, can be negative for suitable $\beta \left( |\beta| < 1 \right)$, that is there exist inertial reference frames where $\vec{v}_t = c \frac{\vec{p}_t}{p_{0,t}}$ and $\vec{p}_t$ have opposite directions. In such cases, if we synchronize clocks by standard relation, tachyons propagate in a certain direction (the $\vec{p}_t$ direction) even if they “are seen” propagating “backward in time”, as well as the plane travelling from New Zealand to Italy.

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