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RESEARCH ARTICLE

SHINING LIGHT ON THE ENTANGLEMENT PHENOMENON

***Ahmadi Karvigh, Hassan**

Professor Emeritus, Hydraulics Technical Faculty, University of Tehran, Iran

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ABSTRACT

Quantum entanglement offers unique insights into the fundamental principles of physical world, because entangled states exhibit correlations that have no classical analog. However, despite a great deal of highly sophisticated work by a large number of very bright people, the phenomenon still looks as a manifestation that humans' intuition, shaped by classical physics for many years, cannot describe all of its intricacies. In this paper, the possibility of considering null frames and null points is shown. All events consisting in a light wave traversing various points in space, in the null frame would be both simultaneous and single-positioned. The null frame concept clearly explains why and how the entanglement and other seemingly weird phenomena of the quantum theory happen. The null point is, in fact, a singularity of four-dimensional space-time. There is no time flowing, no distance, and no direction in a null frame.

INTRODUCTION

Due to some reasons such as the lack of decoherence, photons are generally accepted as the best candidate for quantum communication. The generation of entangled photons is nowadays routine work in the laboratory, and a lot of interesting articles have been published describing the theory and application of entanglement. However, the qualitative intrinsic properties underlying this phenomenon are not clear yet. What is the cause of the strange quantum correlations which apparently travel much faster than the speed of light (Fickler *et al*., 2013; Michael Brooks, 2013)?

The author believes that these quantum correlations do not emerge from outside space-time. There is a concept in space-time that could be represented in purely verbal fashion with little elementary mathematics. This concept shows why and how the entanglement and other strange phenomena of the quantum world happen. To explain this concept, first the null frame and null point will be introduced to better put the subject matter into context followed by describing why the entanglement correlations happen.

The Null Frame and the Null Point

Let us start with a simple imaginary experiment which illustrates the concept we have named it the null frame concept.

Corresponding author: Ahmadi Karvigh, Hassan,
Professor Emeritus, Hydraulics Technical Faculty, University of Tehran, Iran.

Assume a particle, is moving uniformly and rectilinearly in an arbitrary inertial frame fixed to the earth. The assumption of uniform velocity is for simplicity of calculations; since we know the proper time can also be introduced for an object moving with acceleration, provided that we consider the frames co-moving with the object. In that case, object's proper time, is the overall time measured in many inertial frames co-moving with the object or the time registered by an ideal clock fixed rigidly to the object and not affected at all by an acceleration of the object. Of course, acceleration affects the clock rate in a varying degree depending on the design of the clock.

Proceeding from these considerations, assume v is the uniform velocity of the particle along the x axis of the inertial reference frame S fixed to the earth and S' is the inertial reference frame moving with the particle along x axis. Suppose the particle initially be located at the point $x = 0$ in the frame S and $x' = 0$ in the frame S', and the origins of the reference frames, the points O and O', are seen coinciding. Let us draw the x, τ axes of the frame S at right angles to each other (Fig. 1). The world line of the particle or the origin of the frame S', in the frame S shall be a straight line inclined at the angle $\theta = \arctan (v/c)$ to the τ axis. After $t_a = 1$ sec, according to the synchronized clocks of the frame S, the particle has travelled the distance of $x_a = t_a v$, and the event associated with that is shown by the world point **a**, having the coordinates ($x_a = t_a v$, $\tau_a = t_a c$) in the frame S and the following coordinates in the rectilinear oblique-angled system of coordinates x' and τ' of the frame S'.

$$\tau'_a = c\,t'_a = \tau_a \sqrt{1-\left(\frac{v}{c}\right)^2},\; x'_a = v\,t'_a \quad \ldots\ldots\ldots\ldots\ldots (1)$$

Assuming several numerical values for v, we get the following results, noting that the velocity v is the same in both frames.

$\frac{v}{c}$	t_a sec	x_a km	t'_a sec	x'_a km
0.10	1	30,000	0.994987437	29,850
0.707107	1	185,410	0.707106781	150,000
0.90	1	270,000	0.435889894	117,690
$0.99 = 1\text{-}10^{-2}$	1	297,000	0.141067360	41,897
$1\text{-}10^{-10}$	1	300,000	0.000014142	4.243
$1\text{-}10^{-14}$	1	300,000	0.000000141	0.042
$1\text{-}10^{-16}$	1	300,000	0.000000014	0.0042
$\rightarrow 1$	1	300,000	$t'_a \rightarrow 0$	$x'_a \rightarrow 0$

These results show that the limiting case $v \rightarrow c$, results in $x'_a \rightarrow 0$ and $\tau'_a \rightarrow 0$, and therefore, if we show the world point **a,** at the limiting case by the point $\mathbf{a}_{\text{lim}}$, this point and the origin point O' shall coincide. In Special Relativity there are two types of fast moving particles with different kinematic and dynamic properties: the particles with mass (called relativistic mass points) and photons. Obviously, the limiting case $v \rightarrow c$, corresponds to the moving of a photon, and in this case the whole oblique-angled coordinates frame defined by the x' and τ' axes, which is named the null frame, will shrink into a unique point, we name it the null point. It is meaningless to speak of the x' and τ' axes and their directions at the null point. Again according to Special Relativity, there is no real inertial reference frame in which a photon would be at rest, and just as meaningless is to speak of time flowing in the reference frame fixed to a photon. However, we are considering just such a frame, no matter how strange it may seem, since it must be admitted that the calculated sequences of the numerical values of x'_a and t'_a do not contradict the assumption of this frame. In fact those sequences show that for $v \rightarrow c$, we certainly have $x'_a \rightarrow 0$ and $\tau'_a \rightarrow 0$.

In summary, it is known that any object and particle possessing a finite rest mass, including any feasible frame of reference, cannot reach the velocity c. But we claim it is possible to consider an inertial null frame moving with the speed of light c, as a limiting frame of reference among all feasible reference frames. A photon, no matter we assume it as a particle or as a wave, regardless of the direction of its travelling in space, would be at rest in the null frame at the null point, and the spatial and temporal distances of the photon between any two events are zero.

Considering this, the following question arises: is it possible to find the time interval of the photon motion between events in an arbitrary reference frame based on the information found in the null frame? As is explained below, it turns out that under no stipulation this becomes possible and the time interval between events and the direction of motion of photon could only be determined by observing the motion in one other ordinary reference frame. The proper time interval is the time interval between two events measured in a certain reference frame in which the events are single-positioned. Let us consider again the inertial reference frames S and S' and a particle moving with uniform velocity v, in the above mentioned imaginary experiment.

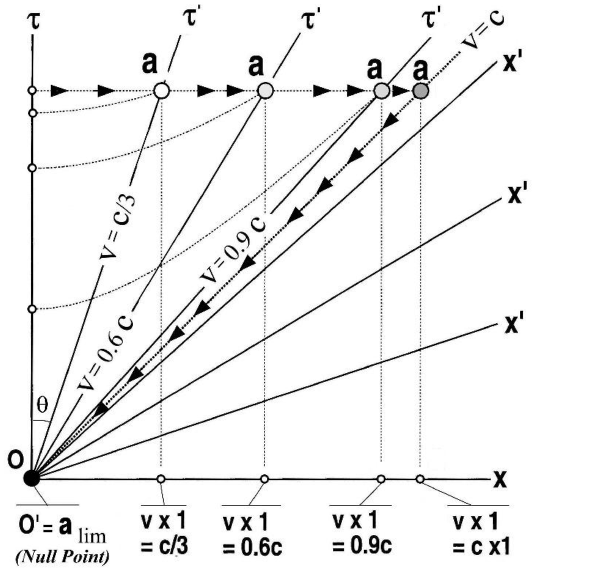

Fig. 1. The case $v \rightarrow c$, corresponds to $a \rightarrow a_{\text{lim}}$.

A time interval Δt between events occurred in the frame S at the points x_1 and x_2 is related to the proper time interval Δt° between the same events in terms of the frames S', by the relation $\Delta t = \Delta t^{\circ} / \sqrt{1-(v/c)^2}$. If we designate the null frame by S^n, since $v \rightarrow c$, we shall have $S' \rightarrow S^n$, $\Delta t^{\circ} \rightarrow 0$, the x' and t' axes do not exist at the null point and consequently the direction of x axis or the direction of motion cannot be specified, and finally the time interval Δt is indeterminate since $\Delta t = \lim (0 / 0)$. On the other hand, all these motion parameters are known in terms of the frame S. The photon moves along the selected direction of the x axis and the time interval Δt is measured in the frame S. So far, we have shown the possibility of assuming the null frame based on the calculated results of an imaginary experiment. There is another line of reasoning to prove this possibility. Let us consider two events 1 and 2, in two assumed inertial reference frames S (x, y, z, t) and S' (x', y', z', t'). The interval between events 1 and 2 is the invariant of the Lorentz transformation:

$$s_{12} = \sqrt{c^2(t_2-t_1)^2-(x_2-x_1)^2-(y_2-y_1)^2-(z_2-z_1)^2}.$$

It is convenient to introduce the designations for the spatial and temporal distances between events as:

$$t_{12} = t_2 - t_1\ ,\ \ell^2_{12} = (x_2-x_1)^2+(y_2-y_1)^2+(z_2-z_1)^2.$$

Having written out the squared interval between events in the frames S and S', we obtain the condition for the interval invariance $s^2_{12} = s'^2_{12}$ as

$$c^2 t^2_{12} - \ell^2_{12} = c^2 t'^2_{12} - \ell'^2_{12}.$$

If we are interested in the reference frame in which the events would be both single-positioned and simultaneous, i.e. the two conditions $t'_{12} = 0$ and $\ell'_{12} = 0$ would be satisfied, this is possible only when $s'^{2}_{12} = 0$ and $s^{2}_{12} = 0$. If the events in question are not coincided in the frame S, that is, the conditions $t_{12} = 0$ and $\ell_{12} = 0$ are not satisfied, the interval s_{12} can be zero only in the case that the events represent the sending and reception of light signals or photons, that is s_{12} be a light-like interval. A light-like interval links together two events consisting in a travelling a photon between two points in space defined by the frame S. These events shall be both simultaneous and single-positioned in the frame S', and if the frame S' co-moves with the photon, both events shall be located at the origin of the frame S', i.e. τ' = 0 and x' = 0. The concept of the null frame in which the events are both simultaneous and single-positioned, must not contradict the causality principle. On one hand it is true that the absolute meaning of the notions 'earlier' and 'later' is a requisite condition for the concepts 'cause' and 'effect' to make sense, and on the other hand, according to the cited definition of the null frame, the 'cause' and 'effect' happen in one point at the same time in the null frame. But since the time sequence of events remains the same in all reference frames, analogous with the determination of the motion parameters, the condition of causality must be satisfied in other ordinary reference frame. The criteria for the possibility of the cause-and-effect relationship in any ordinary reference frame, based on the premise of the finite velocity of light signal transmission, are classic.

The events separated by a space-like interval cannot be in a cause-and-effect relation and the intervals between events that happen at different points must be time-like or space-like and in the direction that the 'cause' precedes the 'effect'. It should be added that some scientists have questioned the realness of past, present and future (Peterson and Silberstein, 2010). For example, Callender believes that even if there is a preferred reference frame, there is no reason to believe that this reference frame would provide any one a suitable 'now' upon which to base presentism. Specifically, Callender is concerned with preferred frames required for instantaneous collapse accounts of quantum mechanics (Callender, 2007). Although they may look alike, but the null frame concept differs from the time dilation phenomenon which shows the moving clocks run slow and if we visualize two systems of clocks, each of which runs slow according to the other. Finally, the null frame concept does not violate the laws of physics and does not set any limit to their application, since all laws of physics are formulated in reference frames other than the null frame. Now it is time to assume the second imaginary experiment. Suppose we have several particles under consideration, each on of them is moving in a different direction, but with common and uniform speed v, provided that all of them are initially (t = 0) located at the fix point O. To explain the meaning of initial moment t = 0, we consider several fixed identical reference frames S, each one having its own τ and x axes in different directions. Only the fix point O and the origins (τ = 0 and x = 0) of all reference frames S are coinciding. Since all the frames S are fixed, the sets of clocks belonging to these frames are synchronized, thus the initial moment t =0 applies to all these frames. For each particle, we consider one fixed frame S and one moving frame S', exactly as we did in the first imaginary experiment. The origin O' of all moving frame S' at time τ' = 0 shall be coincide to the point O. The velocity of each particle is along the axes x and x' of the corresponding pair of the frames S and S'. Since the magnitude of the velocity of all frames S' is equal to v, all the sets of clocks belonging to the moving frames S' are synchronized with respect to each other and thus the initial moment t' =0 applies to all frames S'. If all of the particles be photons and each one moves with the speed of light, c, in a different direction, for each photon we may consider a null frame consisting of only a null point for which the directions of the τ' and x' are meaningless. All the corresponding null points will be located at the point O, and in fact we shall have only one null frame, and correspondingly one null point for all the photons.

Application of the Null Frame Concept

According to the null frame concept, the events consisting in a light wave or photons traversing consecutively various points in space defined by a certain reference frame, in a null frame which moves with the speed of light, are both simultaneous and single-positioned. The world point of these events in the null frame is the null point. Only photons that can travel with the speed of light could be imagined to be in the null frame and the concept of null frame does not apply to any relativistic mass point and object that cannot travel exactly with the speed of light. Now, using the null frame concept, let us explain some phenomena of the quantum mechanics. The null frame concept shows why and how the entangled photons phenomenon happens. In the entanglement experiment considered in an ordinary frame, one of the two entangled photons is sent away as far as possible with instructions to carry out a measurement at a precise time in this frame. An instant just before that measurement occurs; some measurement is done on the first photon and there is not enough time for any influence to travel between the two photons to collapse the wave function of the second photon, except the influence travels with the speed much higher than the speed of light. How this is possible? According to the null frame concept, when we think two photons are separated by a large distance, we are observing the events from the point of view of our own fixed frame. In the null frame, the photons are always at the null point, that is, they are motionless and at the same moment, which in this case is the moment of entanglement. Whatever influences one photon shall influence the other entangled one at the same moment, regardless of how far we think they are apart in our own frame. The entanglement, separation, and measurements are all taking place simultaneously at the null point. The proper time of both photons during the whole period of experiment is equal to zero in the null frame.

The null frame concept can be used to predict the nature of events to be anticipated in quantum entanglement experiment in space, in which links are free of atmospheric attenuation and earth's curvature (Richard, 2010). In this experiment, a pair of two entangled photons shall be beamed up to two satellites moving at speed towards one another, and measurements at both satellites shall be made concurrently from the point of view of a reference frame attached to the earth. To each of the two satellites, the other's measurement appears to have happened first.

So which measurement shall cause the influence to travel faster the speed of light? Which measurement could be the as the 'cause' and which measurement as the 'effect'? Not considering the other effects such as effect of gravity on running of clocks and focusing on our subject matter, according to the null frame concept, the causal order is irrelevant in this experiment, and in the null frame, all events happen in the same point at the same time, thus simultaneous correlations between entangled photons are anticipated.

Entanglement is not the only quantum phenomenon we can examine by the null frame concept. Interferometer experiment in which single photon is pinged along two paths of equal length and then made to combine at the other end, have seemingly shown that photon can be in two places at once. According to the null frame concept, in interferometer experiment, the photon pinged along two paths is, in fact, always at the null point in its null frame, no time has passed during the time interval the photon travels the paths and no distance has been travelled. Of course all of our reasoning is in terms of the null frame. Comparing events in the motionless frame of experiment and null frame, shows how much can be hidden in the null frame. Time is the most strange and confusing phenomenon of the nature and no wonder it has always been discussed so deeply in physics, philosophy, and metaphysics. Moment of time is not a quantity or quality such as points of space (Bars and Terning, 2010). In the frames fixed to all microscopic and macroscopic objects in the universe, galaxies, stars, planets, particles, atoms, electrons, relative mass points such as high energy electrons generated in the accelerators, etc., having a non-zero rest mass and travelling with the velocity less than the velocity of light, time possesses existence as a quality before a measurement. The positive numerical value of time passing rate (depending on the choice of units of time) in any frame looks different from the point of view of another frame moving with respect to the former. In terms of any of these frames, time and distance intervals exist for moving photons and the velocity of photons is equal in all these frames, in any region of a given frame, in all directions. The only difference is, as we have shown, in the null frames moving with the speed of light in which the photons are at rest, there is no such a quality as time or even distance and direction.

We are mentally and biologically accustomed to the rate of time passing in the frame fixed to the earth and we measure all time intervals in this frame. The evolution of living organisms, time interval between natural events, ageing, everyday life, the claim that the Big Bang occurred 13.7 billion years ago, and etc. are completely dependent on this frame. Apparently, living organism, object, particle, and relativistic mass point, which have been evolved or developed in this frame, preserve their time dependence characteristics if considered in another frame co-moving with them. The classic example of time passing rate in the frame fixed to relativistic muons generated in upper layers of atmosphere which is around ten times slower than the time passing rate in the frame fixed to the earth where laboratory muons are generated, proves the constancy of the lifetime of muons. The relativistic muons travel longer distance (about 6 km) before breaking up into other particles and we could observe muon showers on the earth. The only exception is the photons since if we consider them in the co-moving null frame, the time becomes meaningless. This violation of time concept is not perceptible in everyday life.In summary, according to what has been told in this article, time is a unidirectional quantity, quality or property that exists in all imaginable reference frames in the universe moving with the velocity $v < c$. Only in the reference frame moving with the speed c, there exist no time and even no distance. For example, let us consider the free photons, which have been created around 10^{-4} sec after the Big Bang, have continued to move freely after the matter coalesced into neutral atoms (Bars, 2010) around 380,000 years after the Big Bang, and finally have filled the expanding universe as cosmic background radiation. In the null frames of these freely moving photons, no time has passed, no distant have been travelled by photons, and they are at the same moment and place they have been created, roughly speaking, at the Big Bang time and point.

Conclusion

If different strange phenomena of quantum world, such as entanglement phenomenon are visualized in the null frame, we can say that, there is no paradox, no spooky action, nothing is wrong with relativity, reality, causality, free will, and our understanding of the quantum universe. The null frame concept may also be used to discuss more complicated entanglement applications and some other seemingly weird phenomena of quantum theory such as wave-particle duality, as well as other large-scale phenomena of the nature such as cosmologic inflation and expansion.

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