Causality as an integral characteristic of our Universe.

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Abstract: The existence of causality between events is a consequence of the existence of the limiting speed of transmission of interactions in the Universe (speed of light). Therefore, using a single 4-dimensional space-time continuum and interval, it is shown that causality is an integral characteristic of our Universe. In the quantum world, causality also exists initially, since the Heisenberg uncertainty principle is a consequence of the limiting speed of light in the Universe.

Keywords: Causality, speed of light, 4-dimensional space-time continuum, timelike interval, light cone, wave-particle duality.

INTRODUCTION.

To prove the existence of causality between events, it is necessary to use the modern achievements of physics, because our reality in the physical sense is the Universe, that is, our space-time. According to Einstein's STR, space and time can no longer be considered separately, since in reality there is a single 4-dimensional space-time continuum (x, y, z, t). It is this continuum that represents the place where all events take place in time and space, to which we attribute causal relationships. Therefore, it is impossible to understand the essence of causality in our Universe without taking into account the existence of a single 4-dimensional continuum.

"…In 1907, Minkowski proposed a geometric representation of the kinematics of the theory of relativity, introducing a four-dimensional pseudo-Euclidean space (now known as Minkowski space).

In this model, time and space are not different entities, but are interconnected dimensions of a single space-time, and all relativistic effects have received a clear geometric interpretation.

Minkowski declared:

"From now on, time itself and space itself become an empty fiction, and only their unity preserves the chance for reality".

Minkowski's model significantly helped Einstein to develop the general theory of relativity, fully based on similar ideas…" [1].

Note that philosophers and scientists of the past presented space as a place of events. Moreover, such a "Newtonian space" does not depend on time. Time was accepted as universal and unchanging. This is an absolutely erroneous idea about our reality, that is, about space and time.

Since, depending on the speed of movement of the observer, both space and time can change their characteristics: time can slow down, and space can be curved. As a consequence, such an incorrect model of “Newtonian space and time” leads to the fact that the existence of causality cannot be proved, and it is accepted as a fact. Considering Einstein's theory of relativity, causality in our world appears logically and inevitably. Here is a proof.

RESULTS AND DISCUSSION.

Causality in the physical and philosophical sense means that when one object (cause) acts, the corresponding expected change of another object (effect) occurs.

Event 1 (Cause) → Event 2 (Consequence)

Naturally, cause and effect occur in the real Universe and are separated by a certain time interval (Δt).

Our Universe is a 4-dimensional space-time continuum. Therefore, to describe events in the continuum, it is necessary to use the concept that most fully characterizes the given continuum. That is, you need to use the concept of “interval” (S), and not “length” and “time”. Since the length and time in different inertial systems may differ, and the interval will always be constant. At its core, the interval (S) is the “distance” between two events in real 4-dimensional spacetime.

The interval (S) in the inertial reference system, with Cartesian coordinates (x, y, z) and time (t), for an infinitely small displacement in space-time has the form:

$$dS^2 = c^2 * dt^2 - dx^2 - dy^2 - dz^2$$

or

$$dS^2 = c^2 * dt^2 - dL^2$$

where S - is the interval,

L - is the distance between two points,

c - is the speed of light, t - is time.

For finite differences of coordinates, you can write:

$$S^2 = c^2 * \Delta t^2 - \Delta L^2$$

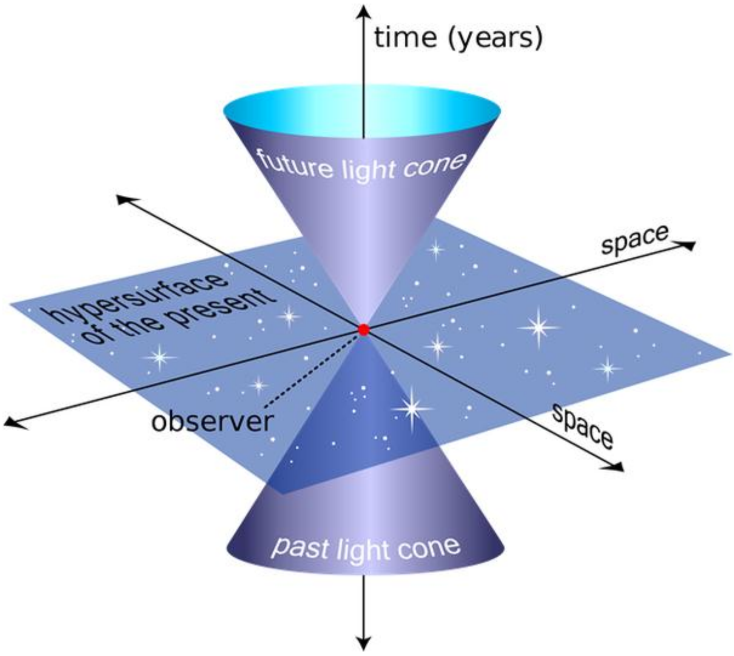
Since we are considering causal events (Cause → Effect), the interval should be timelike. That is, the square of the interval between both events must be greater than zero ($S^2 > 0$).

The essence of the timelike interval ($S^2 > 0$) is that there is such a frame of reference in which both events took place in the same place, but at different times (Δt). In fact, in this case, the frame of reference plays the role of a kind of "Newtonian space".

It is important to note that for causally related events, any interaction between them always propagates at a speed no greater than the speed of light in a vacuum. Consequently, the very existence of causality between events is a consequence of the fact that the speed of light is the limiting speed of transmission of interactions in the Universe. And since the speed of light in a vacuum is a fundamental constant of the Universe, then causality between events is also a fundamental characteristic of our really existing Universe. That is, the Universe initially possesses causality, and causality is an integral characteristic of the Universe.

Therefore, causality in the Universe can be absent only if it is possible to overcome the speed of light in a vacuum. This is impossible in principle, therefore, in our Universe, all events will always be causally related.

The above is well demonstrated by such a concept as "light cone" [2].



If we consider an observer who is in the present time, then all causally related events form a light cone directed into the future (the present is the top of the cone). This is an area of the absolute future, the so-called cone of the future. Within such a cone, the interval between any two events will always be timelike ($S^2 > 0$), and therefore, all events will be causally related.

There is also another cone of light, directed into the past (the present is the top of the cone). This is the realm of the absolute past. Inside the past cone, the interval is also timelike ($S^2 > 0$), and therefore, this cone contains all the events that could affect the event in the present.

Note that "...the light cone can be defined as the set of all points for which the interval separating them from the given event (the top of the light cone) is lightlike (that is, equal to zero, isotropic interval).

...in both special and general relativity, the concept of a light cone... makes sense for spaces of 4-velocities and 4-momenta of bodies taken in a locally Lorentzian reference frame.

The 4-speed or 4-momentum of a massive body (having a positive mass) will always lie strictly inside the cone of the future. (My note: that is, all events in our Universe will lie inside the cone of the future, since the Universe consists of massive objects: elementary particles, nuclei, atoms, planets, stars, black holes, galaxies, etc.).

From the point of view of the theory of relativity, all rays lying strictly inside the cone of the future are "equal" and "equally distant" (more precisely, infinitely distant) from the surface of the light cone. Therefore, it is impossible to accelerate a massive body to the speed of light, no matter how much and in which direction it is pushed; this phenomenon is also called light barrier.

Massless particles, on the other hand, have 4-momenta lying on the light cone itself (its surface). The concept of 4-speed for such particles is defined only up to multiplication by a positive number (its "length" is equal to 0)…" [3].

The physical essence of the light cone is simple: our Universe is the light cone. Since all events in the Universe are strictly inside the light cone of the future (the 4th momentum of a body with a positive mass will always lie inside the cone of the future), therefore, all events in our Universe have a causal relationship.

To get out of the light cone, you need to move faster than light, which is impossible. Consider the formula for the interval:

$$S^2 = c^2 * \Delta t^2 - \Delta L^2$$

If you do small conversions, you can show that the spacing is [4]:

$$S = L * (1 - v^2 / c^2)^{0.5} * c / v$$

It is clearly seen from the last formula that the timelike interval ($S^2 > 0$) is possible only when the velocity of the body or particle is within (0, c). Within the cone of the future (and the past) there is only a timelike interval. That is, the interval in the light cone will be greater than zero ($S > 0$), which is quite reasonable, since the distance between points and the speed of a body in the Universe are always positive.

It is also obvious that if the speed of the body is greater than the speed of light, we get an imaginary interval, that is, a spacelike interval ($S^2 < 0$, $S = i * a$), which is outside the light cone.

If the speed is equal to the speed of light, we get a lightlike interval, that is, the interval is zero ($S^2 = 0$, $S = 0$). This is an isotropic interval. Light always propagates in Minkowski space in isotropic directions ($S^2 = 0$). In fact, the surface of the cones of the future and the past consists of lightlike intervals that are associated with the present.

CONCLUSION.

Thus, taking into account the above, we can strictly assert that all events in the Universe have a causal relationship, since they are inside the light cone. It may seem that this statement is in conflict with quantum mechanics, which studies the phenomena of the microworld, since, according to the Heisenberg uncertainty principle, microparticles do not have a trajectory in quantum phenomena. But this is not the case. Causality has no contradiction with quantum mechanics. Simply, elementary particles cannot be represented as small particles that have a certain size and shape, and have absolute hardness ("elementary" means that microparticles must be indivisible).

According to A. Einstein's theory of relativity, elementary particles should be strictly considered as pointlike. Moreover, the point structure of elementary particles is a consequence of the existence of the limiting speed of transmission of interactions in the Universe (speed of light). If an elementary particle had finite dimensions, then it must be absolutely solid (cannot deform, collapse). But, the theory of relativity shows the impossibility of the existence of absolutely rigid bodies [5]. Therefore, elementary particles are point particles. The point structure implies that the size of such particles, that is, their spatial extent, actually tends to zero: no matter how accurately we measure the radius of an elementary particle, it will always be smaller...

An elementary particle exists in the real world, therefore, it cannot have an extension in space equal to zero. How then can one explain the existence of microparticles in the Universe? Nature, in this case, found an ingenious way out - this is wave-particle dualism.

Since the theory of relativity forbids elementary particles to have spatial extent, they are "forced" to additionally exhibit wave properties. By definition, a wave is extended, therefore, with wave-particle duality, the problem of the length of point particles is solved automatically. That is, in the real world, an elementary particle manifests itself both as a point particle and as a wave. Moreover, precisely because of the manifestation of wave properties, microparticles fundamentally do not have a trajectory, and their position can be determined only with a certain accuracy according to the principle of uncertainty, which is logically derived from the wave-particle duality [4, pp. 6-9].

Consequently, all events in the quantum world initially have causality, since the Heisenberg uncertainty principle (point structure of particles, wave-particle duality), like causality, is a consequence of one fundamental fact, that the speed of light in vacuum is the limiting speed of transmission of interactions in the

Universe. And if there is a finite rate of transmission of interaction, causality between events appears automatically.

REFERENCES.

1. Parshin D. A., Zegrya G. G. Special theory of relativity and an introduction to general relativity (2016). Physics STR. Lecture 18: Interval. Minkowski geometry... Light cone. P. 10 - 11. http://www.decoder.ru/media/file/0/1243.pdf
2. An Example Of A Light Cone, The Three-dimensional Surface - Three Dimensional Light Cone. Pngkey (Largest Archive Of Transparent PNG). https://www.pngkey.com/maxpic/u2r5a9t4t4r5t4u2/
3. Light cone. Wikipedia. https://en.wikipedia.org/wiki/Light_cone
4. Bezverkhniy V. D., Bezverkhniy V. V. De Broglie Interval Wave and Heisenberg's Uncertainty Principle. SSRN Electronic Journal (August 2019). P. 3. https://dx.doi.org/10.2139/ssrn.3435852
5. Landau L. D., Lifshits E. M. Theoretical physics. Volume 2. Theory of the field. Moscow: Nauka, 1988. P. 67 - 69.