МЕТОДИЧНІ НОТАТКИ – З ДОСВІДУ ВИКЛАДАННЯ ФІЗИКИ В ВИЩІЙ ШКОЛІ

УДК 530.1 PACS 03.30.+p, 03.65.-w

Andriy Gusak

WAVE-PARTICLE DUALITY AND TACHYON-BRADYON SYMMETRY – STRIKING SIMILARITY IN 2D SPACE-TIME (METHODIC NOTE)

Is this idea crazy enough to be correct?
Niels Bohr

Wave-particle duality can be treated (at least, formally) as a symmetry between subluminal and superluminal reference frames.

Keywords: wave mechanics, wave-particle duality, superluminal objects, Lorents transformations

In this note, we are not pretending on any new theory. We just would like to draw attention to almost evident similarity, mentioned in the title.

Last century was marked by many crazy ideas. Some of them appeared to be true (as noticed in well-known phrase of Niels Bohr in the epigraph to this paper), most of them appeared to be false, the rest are still under consideration. In this paper we shall treat two of them

(1) idea of de Broglie about wave-particle duality and, in particular, wave properties of any material object [1],

(2) idea of Terletskyy [2], Bilanyuk, Deshpande, Sudarshan [3,4], Feinberg [5] and others about existence of superluminal objects (tachyons) as a natural generalization of special relativity on the case when the relativistically invariant combination of energy and momentum $E^2 - c^2 p^2 = m_0^2 c^2 = const$ is negative, formally meaning the imaginary value of so-called "rest mass" $m_0 = i\mu$ ("Meta-relativity").

The first idea (coupled with Heisenberg's idea of matrix representation of observables) became the basis of quantum mechanics. The second idea (generated about 1960) became popular for short time among limited community of physicists, led to concept of superluminal transition (Recami, Mignani) in 70s [6-8], and eventually was almost buried by causality problems but is still being discussed in the frame of string theory and hidden mass problems in cosmology [9].

Aim of this paper is to demonstrate (using several simple examples) that the mentioned two ideas can be coupled so that tachyons, instead of being independent particles, may appear as an integral part of any material object, "responsible" for its wave properties.

We shall limit ourselves with considering relativity in 2D space-time, leaving aside the additional problems arising with transition to 4D space-time [8].

The starting point of our considerations will be the following remarkable coincidence:

(A) If p and $E = c\sqrt{p^2 + m_0^2 c^2}$ are the momentum and energy of freely moving particle, represented as de Broglie's wave, its group velocity $\upsilon = \dfrac{\partial E}{\partial p} = \dfrac{cp}{\sqrt{p^2 + m_0^2 c^2}} = \dfrac{c^2 p}{E} \le c$

and its phase velocity $V = \frac{E}{p} = \frac{c\sqrt{p^2 + m_0^2 c^2}}{p} \geq c$ are linked by the simple relation $V = \frac{c^2}{\upsilon}$. At that, group velocity describes the propagation of energy and information, and the phase velocity (velocity of constant phase front) is not linked with transfer of energy and information and therefore its superluminal magnitude does not cause any problem.

(B) On the other hand, if one adopts for a moment the hypothesis of tachyon with positive energy, moving with superluminal velocity $V > c$ in some fixed inertial frame of reference, then (according to Lorents transformations in time-coordinates and in energy-momentum spaces) in all inertial frames moving in the same direction with subluminal velocities $c > u > \frac{c^2}{V}$ the same tachyon will have negative energy and will be linked with opposite time sequence of events. As a marginal case, if the velocity of reference frame is $u^* = \frac{c^2}{V}$, then the energy of tachyon in this frame is zero, its velocity is infinite, and all events linked with this tachyon, in this reference frame, are simultaneous.

Since tachyons are not studied in standard university courses (it is a pity because, even if tachyon hypothesis fails, since discussion of this hypotheses would be useful for better understanding of relativity theory), we will remind shortly the basic points of classical (meaning not quantum) formal scheme of tachyons. They correspond to negative magnitudes of relativistic invariant $E^2 - c^2 p^2 = -\mu^2 c^2 < 0$, which can be formally described by the imaginary value of the “rest mass” $m_0 = i\mu$. Formally – since in any (subluminal) frame of reference the tachyon will not be in rest (like photon), moving with superluminal velocity (as can be easily checked by direct algebra of relativistic addition of velocities). Then the dependence of tachyon’s energy on velocity,

$$E = \frac{i\mu c^2}{\sqrt{1 - \frac{V^2}{c^2}}} = \frac{\mu c^2}{\sqrt{\frac{V^2}{c^2} - 1}},$$

shows that it is as impossible to slow down the tachyon to light speed in vacuum as it is impossible to accelerate the usual (subluminal) particle to the same light speed from the other side. Lorents transformations immediately give the magnitude of tachyon energy in some other reference frame moving with subluminal speed u:

$$E' = E \frac{1 - \left(uV / c^2\right)}{\sqrt{1 - u^2 / c^2}}.$$

In full analogy, time interval between two events connected by tachyon with speed V (in some fixed reference frame), is transformed in other reference frame, moving with velocity u in the same direction, as

$$\Delta t' = \Delta t \cdot \frac{1 - \left(uV / c^2\right)}{\sqrt{1 - u^2 / c^2}}.$$

Both energy and time intervals change sign at the same condition $u^* = \frac{c^2}{V}$, which allowed Bilanyuk, Deshpande and Sudarshan [3] to introduce the reinterpretation principle interpreting the tachyon moving back in time with negative energy as tachyon moving forward in time with positive energy.

What is very important for us here is that at condition $u^* = \frac{c^2}{V}$ for the velocity of new reference frame the tachyon is SIMULTANEOUSLY EVERYWHERE, its velocity in new reference frame tends to infinity. It means that becomes actually totally delocalized, as does de Broglie's monochromatic wave.

Recami and Mignani introduced the superluminal transformation as the generalization of Lorents transformation. In the frame of this concept, all particles are divided into 3 classes: subluminal (bradyons or tardions), luminal (photons) and superluminal (tachyons). Relative velocity of any tachyon in respect to any other tachyon is LESS than light speed in vacuum.

So, all tachyons are bradyons in respect to each other, and all bradyons are tachyons for them. Luminal particles are luminal for both marginal classes. This symmetric picture looks very nice if one forgets about causality. Detailed analysis of causality cycles leads to final conclusion – tachyons do not contradict experimental facts and causality principles ONLY if we cannot use them for transfer of information with superluminal speed.

Main idea

Let us asuume that bradyon and tachyon are not the independent particles but two inseparable parts (twins) of the same material object. For subluminal observer bradyonic part is responsible for corpuscular properties and tachyonic part – for wave properties. For superluminal observer (if any) these parts interchange their places – part which was bradyonic (corpuscular) for us, is tachyonic (wave) for superluminal observer. In other words, superluminal transition transfers the bradyonic part into tachyonic one and vice versa, so that material object looks the same for subluminal observer and superluminal observer (if any).

Let us assume that any particle with rest mass m_0, rest size l_0, electric charge q, velocity υ has a superluminal twin-part with rest mass im_0, rest size $-il_0$, electric charge iq, velocity $V = \frac{c^2}{\upsilon} > c$.

Energy of the superluminal twin part:

$$E^{tachyon} = \frac{im_0c^2}{\sqrt{1-\frac{V^2}{c^2}}} = \frac{m_0c^2}{\sqrt{\frac{V^2}{c^2}-1}} = \frac{m_0c^2}{\sqrt{\frac{\left(c^2/\upsilon\right)^2}{c^2}-1}} = c\frac{m_0\upsilon}{\sqrt{1-\frac{\upsilon^2}{c^2}}} = cp^{bradyon}.$$

Momentum of the superluminal twin part:

$$p^{tachyon} = \frac{im_0V}{\sqrt{1-\frac{V^2}{c^2}}} = \frac{m_0c^2/\upsilon}{\sqrt{\frac{\left(c^2/\upsilon\right)^2}{c^2}-1}} = \frac{m_0c}{\sqrt{1-\frac{\upsilon^2}{c^2}}} = \frac{E^{bradyon}}{c}.$$

Length of the superluminal twin part:

$$l^{tachyon} = -il_0\sqrt{1-\frac{V^2}{c^2}} = -il_0 i\sqrt{\frac{\left(c^2/\upsilon\right)^2}{c^2}-1} = \frac{l_0c}{\upsilon}\sqrt{1-\frac{\upsilon^2}{c^2}} = m_0cl_0\frac{\sqrt{1-\frac{\upsilon^2}{c^2}}}{m_0\upsilon} = \frac{m_0cl_0}{p^{bradyon}}.$$

If we take natural evaluation of the rest length of bradyon, $l_0 = \frac{h}{m_0c}$ (Compton length), then we get $l^{tachyon} = \frac{h}{p^{bradyon}}$.

This last equation can be interpreted as de Broglie's wavelength or as uncertainty relation: if object is immovable then it is smeared all over the universe.

The main conclusions of the above mentioned considerations are simple but may be useful at least for students training:

1. For superluminal observer (if any) corpuscular behavior looks as wave behavior, and vice versa.
2. Wave-particle duality can be treated as a symmetry between subluminal (for us) and superluminal worlds

References

1. Louis de B. Recherches sur la théorie des quanta / Louis de Broglie // Ann. de Physique. – 1925. – Vol. 3. – P. 22–128.
2. Terletsky Ya. P. The causality principle and the second law of thermo-dynamics / Ya. P. Terletsky // Sov. Phys. Doklady. – 1960. – Vol. 5. – P. 782–785.
3. Bilaniuk O. M. P. “Meta” Relativity / O. M. P. Bilaniuk, V. K. Deshpande, E. C. G. Sudarshan // American Journal of Physics. – 1962. – Vol. 30 (10). – P. 718–723.
4. Bilaniuk O. M. P. Particles beyond the Light Barrier / O. M. P. Bilaniuk, E. C. G. Sudarshan // Physics Today. – 1969. – Vol. 22 (5). – P. 43–51.
5. G. Feinberg Possibility of Faster-Than-Light Particles / G. Feinberg // Physical Review. – 1967. – Vol. 159 (5). – P. 1089–1105.
6. Recami E. Classical theory of tachyons (Special relativity extended to superluminal frames and objects / E. Recami, R. Mignani // La Rivista Del Nuovo Cimento Series 2. – 1974. – Vol. 4 (2). – P. 209–290.
7. Recami E. Magnetic monopoles and tachyons in special relativity / E. Recami, R. Mignani // Physics Letters B. – 1976. – Vol. 62 (1). – P. 41–43.
8. Recami E. More about Lorents Transformations and Tachyons / E. Recami, R. Mignani // Lettere Nuovo Cimento. – 1972. – Vol. 4 (4). – P. 144–152.
9. Rylov Y. A. Dynamic equations for tachyon gas / Y. A. Rylov // International Journal of Theoretical Physics. – 2013. – Vol. 52. – P. 3683–3695.

Анотація. ***А.М. Гусак. Корпускулярно-хвильовий дуалізм і тахіон-брадіонна симетрія - вражаюча подібність у двовимірному просторі-часі (методичні замітки).*** *Корпускулярно-хвильовий дуалізм може трактуватись (принаймні, формально) як симетрія між досвітловими і надсвітловими системами відліку.*

Ключові слова: волновая механика, корпускулярно-волновой дуализм, сверхсветовые объекты, преобразование Лоренца.

Аннотация. ***А.М. Гусак.*** *Корпускулярно-волновой дуализм и тахион-брадионная симметрия – впечатляющее сходство в двумерном пространстве-времени (методические заметки). Корпускулярно-волновой дуализм может трактоваться (по крайней мере, формально) как симметрия между досветовыми и сверхсветовыми системами отсчета.*

Ключевые слова: волновая механика, корпускулярно-волновой дуализм, сверхсветовые объекты, преодразование Лоренца.

Одержано редакцією 10/09/2014 Прийнято до друку 20/10/2014