Fast Wave–Wave–Particle Triality

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ABSTRACT

Aims: The Planck's constant has two parts; one part shows the 'rest action', 'rest energy' of wave and another part shows the 'kinetic action', 'kinetic energy' of waves. These two parts change synchronized and they make possible a superluminal velocity of the particle in tunneling. Particles (waves) with superluminal velocity are fast wave.

Methodology: The de Broglie wavelength describes wave-particle duality. The de Broglie wavelength formula and the Planck's law seem to be contradicted in tunneling. Tunneling fast waves have longer wavelengths than "normal" waves. According to the de Broglie formula, a longer wavelength means smaller momentum (smaller energy). But fast waves have the same amount of energy as normal waves, since they can be transformed into each other.

The barrier in tunneling cannot be seen as an optical medium, rather a special kind of space made out of matter that other matter is able to use as space. Here we show that the 'rest actions', 'rest energies' of fast waves in different spaces can resolve the contradiction. This 'rest action' of the wave is a new concept that hasn't been considered. It is hidden in the Planck's constant.

Results: Fast waves are made out of normal waves (or particles). Fast wave is the same particle in a different form. The Fast Wave–Wave–Particle Triality describes a new kind of metamorphosis of matter—how tunneling electrons travel faster than light without violating special relativity. Using the Fast Wave–Wave–Particle Triality, we can realize that the speed of light is not a speed limit for particles with mass, since they can be transformed into fast waves. The Fast Wave–Wave–Particle Triality shows the border of scope of the special theory of relativity.

Keywords: tunneling, fast light, fast wave, de Broglie wavelength, Planck's law, Planck's constant, wave-particle duality, fast wave-wave-particle triality

1. WAVE–PARTICLE DUALITY

Wave–particle duality is the concept that all matter can exhibit two behaviors—a particle-like behavior and a wave-like behavior. In other words, every elementary particle or quantic entity may be partly described in terms not only of particles, but also of waves. The well-known de Broglie wavelength λ [1] shows the connection between the momentum of the given particle *p* and the Planck's constant *h* [2]. See Eq. (1).

$$\lambda = \frac{h}{p} \tag{1}$$

In general, the momentum of a particle that has mass is $p = m \times v$, where *m* is the object's mass, and *v* is its velocity. The momentum of a particle that has no mass, e.g. a photon, is written in Eq. (2).

$$p = \frac{E}{c}\ , \tag{2}$$

where *E* is the photon's energy and *c* is the speed of light in a vacuum. Theoretically vacuum is space void of matter. To be more precise, space's vacuum is a medium from where everything is taken out that can be taken out and the "rest" remains there. In other words: space is no matter. It seems to be evident, but in the following you will see, it isn't.

2. HIDDEN PRESUPPOSITION BEHIND WAVE–PARTICLE DUALITY

The original version of the de Broglie wavelength means that particle turns into wave, if Eq. (3) is true:

$$\lambda \geq l_{paticle}, \quad (3)$$

where $l_{paticle}$ is the size (length) of the particle. λ is the wavelength of the particle if it is a wave.

Actually there is a hidden presupposition behind the formula of the wave-particle duality: there is no space wave, therefore there is no wavelength of space wave. Therefore there is no effect of space we have to examine, calculating the de Broglie wavelength.

Nowadays we know that space waves exist [3], that is, the original formula has a lack. If we involve the wavelengths of space waves in the formula of wave-particle duality, this leads us to the fast wave-wave-particle triality.

2.1. Planck's law and de Broglie wavelength

From Eq. (2) and from the Planck's law [4] Eq. (4)

$$E = h \times f, \quad (4)$$

comes Eq. (5).

$$p = \frac{E}{c} = \frac{h \times f}{c} = \frac{h}{\lambda}, \quad (5)$$

Where $f = \frac{\varpi}{2\pi}$ is the frequency and ϖ is the angular frequency of the wave. Eq. (4) and (5) show that there is a close connection between the Planck's law, the Planck's constant and the de Broglie wavelength.

In evaluating the photon momentum in a given medium the phase velocity v_{phase} is used.

2.2. Refractive index means changing wavelength

When the medium is not the vacuum, Eq. (6) is used in calculations of phase-matching in nonlinear optics.

$$p = n\frac{E}{c}, \quad (6)$$

where in general $n = \frac{c}{v} > 1$ is the refractive index of a transparent optical medium, also called the index of refraction of the material in which the signal propagates. v is the velocity of light in non-vacuum, that is, in medium. The index of refraction [5] is the factor by which the phase velocity v_{phase} is *decreased* relative to the velocity of light in a vacuum. In the case of one photon wave $v_{phase\_c} > v_{phase\_M}$ and $v_{phase\_c} = \frac{c}{n}$, where v_{phase_c} represents light velocity in the vacuum and v_{phase_M} represents the light velocity in medium. The phase velocity describes the velocity of the crests of the wave. Phase velocity is given as $v_{phase} = \frac{\varpi}{k}$, where k is the wave number. During the refraction the frequency of light wave remains unchanged $f_{phase\_c} = f_{phase\_M}$, while the wavelength of light wave decreases $\lambda_{phase\_c} > \lambda_{phase\_M}$.

Let's see the fast light experiment carried out at the University of Rochester USA [6]. In this experiment a "normal" light impulse (with velocity *c* and made out of group of lights) travels on an optical medium and a fast light impulse (made out of group of lights) travels on normal light. Fast light has a longer wavelength than normal light traveling with *c* $\lambda_{fl} > \lambda_c$ and a measurable superluminal velocity of fast light: $v_{fl} > c$. This velocity of impulse is group velocity (envelop), where generally Eq. (7) is true.

$$v_{fl} = v_{group} \neq v_{phase} \quad (7)$$

In the fast light experiment the envelop (fast impulses) is built out of a spread of optical frequencies: out of sinusoidal (sine, cosine) component waves [7]; that is—phase velocities v_{phase}. In the given experiment every component's wave has one wave number. So Eq. (8) must be true, because if Eq. (7) is true, the fast wave impulse collapses.

$$v_{fl} = v_{group} = v_{phase} \tag{8}$$

The wavelength of the fast light *increased* compared to the wavelength of the normal light traveling with *c* velocity in a vacuum. It means that the wavelengths and velocities of its spectral component waves increased in the given medium (λ_{phase_M}) [8], compared to the wavelengths and velocities of spectral component waves of light in vacuum v_{phase_c}. The velocities of the components waves of fast light are also superluminal velocities, see Eq. (7), that is, $v_{phase} > c$ and $\lambda_{phase\_M} > \lambda_{phase\_c}$. According to Boyd [8] the refracting index of the superluminal velocity is $n_{sl} = n - 1 < 0$, and *n* can be a great number with negative sign. If n_{sl} and *n* are great numbers with negative sign, it means that Eq. (6) doesn't work. n_{sl} is a confusing solution. The confused Using $n_{space} = n^{-1}$ instead of n_{sl}
According to my opinion, in the case of superluminal velocity we have to use Eq. (9) instead of Eq. (6).

$$p = n_{space}\frac{E}{c} = n_{space}\frac{h \times f}{c} = n_{space}\frac{h}{\lambda}, \tag{9}$$

where $n_{space} = n^{-1}$ is "space index" that describes the medium as a "special space". In the fast light experiment the normal light wave is this "special space". Note n_{space} is not a refracting index of the given medium.

From the above mentioned we know that during the refraction the frequency of light wave remains unchanged while its wavelength grows. This law also remains true in the case of superluminal velocities. So we may suppose changing the wavelength $\lambda_{phase\_c} < \lambda_{phase\_M}$ is a general working method of light if $v_{phase\_c} \neq v_{phase\_M}$, where v_{phase_c} is the velocity of light in vacuum and v_{phase_M} is the velocity of light in a "different space".

3. SUPERLUMINAL VELOCITIES IN TUNNELING

Quantum tunneling refers to the quantum mechanical phenomenon where a particle (with or without mass) tunnels through a barrier that it classically could not surmount. Particles that travel with superluminal velocities in tunneling will be called fast waves in the following.

First Nimtz [9], Enders and Spieker measured superluminal tunneling velocity with microwaves in 1992. According to them, the puzzle is that the jump of the particle over the barrier has no time (it spends zero time inside the barrier) and the particle is undetectable in this condition. The tunneling does take time, so this time can be measured**.**

$\psi(x)$ is the phase wave function of the tunneling particle outside the barrier. According to Nimzt, the particle cannot spend time inside the barrier, because the wave function has no missing part (and no missing time). The tunneling method of the particle is unknown and immeasurable. If the wave doesn't spend time inside the barrier, what is the tunneling time? Nimtz supposes that the measured barrier traversal time is spent at the front boundary of the barrier.
The second riddle in tunneling: experiments show [10] that the tunneling particles are faster than light, and these facts are *not* compatible with the theory of relativity. The growing velocity of the particle with a mass (for example electron) causes growing mass according to the theory of relativity, and if v→c, then m→∞. Since the mass (of electron) won't be ∞, and the tunneling is fact, we have to suppose that v=c never occurs. There is a discrete jump in the velocities, and after v<c occurs v>c.

Nimzt [11] measured that the tunneling time τ approximately equals the oscillation time T, see Eq. (10)

$$\tau \approx T = \frac{1}{f_{tun\ part}}, \tag{10}$$

where $f_{tun\ part}$ is the frequency of the tunneling particle. (The tunneling time equals approximately the reciprocal frequency of the wave of the particle.) Eq. (9) shows how the barrier traversal time is connected with energy

$$\tau \approx \frac{h}{E_{tun\ part}}, \tag{11}$$

where $E_{tun\ part}$ is the energy of the tunneling particle. According to Eq. (11), the bigger the energy of the particle, the higher its velocity, and the shorter its tunneling time.

3.1. Wavelengths in tunneling

During the tunneling we speak about single phase waves. Waves of photons and other particles (eg. electrons) work the same way. We may suppose that the rule $v_{phase} > c$ occurs growing wavelength of waving particle remains true in the case of every particle:.
If *L* is the length of the barrier, then the velocity of the tunneling photon (or other particle) can be given by Eq. (12)

$$v_{tun\ part} = f_{tun\ part} \times \lambda_{tun\ part} = \frac{L}{\tau} \tag{12}$$

$$\frac{1}{T} \times \lambda_{tun\ part} = \frac{1}{\tau} \times L \tag{13}$$

$$\lambda_{tun\ part} \approx L \tag{14}$$

Eg. (13) and Eq. (14) show that the wavelength of the tunneling photon (or other particle) $\lambda_{tun\ part}$ is as long as the length of the barrier. It means, the tunneling particle has one wave inside the barrier.
We know that in tunneling there can be more kinds of fast wave. Here photons without mass and electrons with mass travel with superluminal velocities. That is, the superluminal velocity in a given barrier is possible. Here *n* refractive index doesn't play any role in the velocities of particle. In this case the barrier made out of matter acts as space$_M$. This space$_M$ is a real space for the tunneling particles, but it is a special space made out of matter The tunneling can be explained with the following. First we need three new definitions [12]:

- Space is that the given matter is able use as space (space$_M$); matter is that the given space accepts as matter. This seems to be an open definition, but the physics doesn't have tool to describe it another way. According to this definition space$_M$ is able to work as (a special) space that a tunneling photon (or electron) uses as space.
- The are space waves. Space waves has been measured by LIGO [13]. Matter uses waves of the given space as signal of reference. If the space is space$_M$ the definition remains the true.
- Space doesn't work without time. Time is the action-reaction phenomenon between space and matter. Time appears for matter as the wave of space. Every space has its own time. If the space is space$_M$ the definition remains the true.

From our viewpoint the barrier is matter, but in tunneling we cannot consider the barrier as an optical medium, since the barrier has a "normal" refractive index $n > 1$ and $\psi_{fw}(x)$ has a superluminal speed. On the other hand, the $\psi_{fw}(x)$ is a "normal" wave, which means there are no half (or part) waves inside the barrier. $\psi_{fw}(x)$ travels is a special space, in space$_M$. The space$_M$ of the tunneling fast wave $\psi_{fw}(x)$ is different from our space, since space$_M$ is inside the barrier, or to be more precise: the barrier is space$_M$. $\psi_{fw}(x)$ uses the matter (mass) as space$_M$, where space$_M$ made out of

matter has very long "space wavelengths". $\lambda_{barrier}$ is the wavelength of space$_M$, that is, the barrier itself acts as space this way.
In tunneling a given photon or electron particle makes two metamorphoses—first from a normal wave condition into an unknown condition ("it disappears via the tunneling") [14], and after the tunneling it reappears as the same photon or electron it was.
If the particle travels in the barrier, we cannot measure it. It has a new form, a fast wave form, since its velocity is superluminal, travelling in a special kind of space.

Let's take a look now at a *tunneling* photon in the space$_M$ (in barrier). Every light wave works using the basic law of Eq. (15):

$$v = f \times \lambda \,, \tag{15}$$

where f is the frequency, λ is the wavelength. v velocity depends on the space where the light propagates, in *our* space's vacuum $v = c$. Note using different *spaces* we don't use different refracting indices, we use different phase velocities of photons (or electrons).
The frequencies of the waves are not affected by above mentioned. See Eq. (16).

$$f_c = f_{fw} \,, \tag{16}$$

where f_c is the frequency of light in vacuum and f_{fw} is the frequency of tunneling photon in the barrier. *fw* is the abbreviation of 'fast wave'.
According to Eq. (17):

$$\lambda_c < \lambda_{fw} \,. \tag{17}$$

Photons have two metamorphoses, so their energy must be the same in both cases—as a normal photon and as a fast wave in tunneling. That is shown by Eq. (18).

$$E_c = E_{fw} \,, \tag{18}$$

But we know that in the tunneling their wavelengths grow, so Eq (19) is the following:

$$p_c = \frac{h}{\lambda_c} > p_{fw} = \frac{h}{\lambda_{fw}} \,. \tag{19}$$

Note that there is not used velocities here; there is used the wavelengths of photons. Eq. (19) shows that the two conditions of a photon don't have the same momentum. But they must have the same momentum (energy), since this is the same photon and a photon with larger amount of energy cannot be built out of a photon with less energy. How do we solve the problem?

4. FAST WAVE–WAVE–PARTICLE TRIALITY

Did p_{fw} and/or *h* change?

1. p_{fw} mustn't change, since the law of conservation of momentum must remain true. Fast light is considered as fast wave (fw).
2. *h* is a constant; we don't accept that it changes.

Now we can conclude that the de Broglie formula is not applicable to fast waves. Or we can rewrite the de Broglie and Planck formulas in new ways that work with fast waves. See the following equations. Eq. (15) remains true, so $f \times \lambda_{fw} = v_{fw}$ and $f \times \lambda_c = c$; now we study the same wave in two different spaces:

$$\frac{c}{\lambda_c} = \frac{v_{fw}}{\lambda_{fw}} \,. \tag{20}$$

$$\lambda_c = \frac{c}{v_{fw}} \times \lambda_{fw} \,. \tag{21}$$

Now we can rewrite Eq. (20) and (21) into Eq. (22) and Eq.(23).

$$\frac{h}{p} = \frac{c}{v_{fw}} \times \lambda_{fw} \,, \tag{22}$$

$$\lambda_{fw} = \frac{v_{fw} \times h}{c \times p} = (\frac{v_{fw}}{c} \times h) \times \frac{1}{p} . \quad (23)$$

If $v_{fw} = c$, then we get back the original formula from Eq. (4).

Eq.(23) shows the momentum of the fast light (fast wave). Note we have found Eq. (9) a very different way. So the statement remains true: in Eq. (9) n_{space} describes the “given space”, n_{space} is not a refracting index of a given medium.

What does Eq. (23) mean? It means that *h* exists in every space. It always appears as one unity, but it has two hidden parts. One part of it can grow in the case of fast light as fast wave. Since *h* is a constant, it needs to have another part that decreases in the same time with the same scale.
The two parts of the Planck’s constant work together. One part of it depends on the velocity of the fast wave; this part is shown in Eq. (21). This is the part of the kinetic energy that increases *h* in the case of fast light. In non-vacuum spaces, the two parts change in different directions.
We know from the above-mentioned that all forms of a photon have the same amounts of energy. So, the Planck’s constant must have a part that makes this result possible. There must exist a factor that reduces this part of *h*.
We can rewrite the Planck’s law in this form in Eq. (24) and (25):

$$E_{fl} = (f_{fw} \times (h \times \frac{c}{v_{fw}})) \times (\frac{v_{fw}}{c}) = f_{fw} \times h . \quad (24)$$

$$E_{fl} = \frac{f_{fw}}{h} \times ((h \times \frac{c}{v_{fw}}) \times (h \times \frac{v_{fw}}{c})) = f_{fw} \times h , \quad (25)$$

where $h_{rest} = h \times \frac{c}{v_{fw}}$ is the rest energy part and $h_{kinetic} = h \times \frac{v_{fw}}{c}$ is the kinetic energy part of the Planck’s constant—in the case of fast light (fast wave). The physics hasn’t defined Eq. (26) earlier.

$$E_{fl} = \frac{f_{fw}}{h} \times h_{rest} \times h_{kinetic} = f_{fw} \times \frac{h_{rest} \times h_{kinetic}}{h} . \quad (26)$$

Eq. (24), (25) and (26) mean that every particle, (even the photon) has a 'rest action', 'rest energy'. The de Broglie formula and Planck’s law remain untouched, if $v_{fw} = c$. Eq. (27) shows the fast wave-wave-particle triality in one equation. m is the mass of a particle, if it has [15], *f* is the frequency of the wave or fast wave, h_{rest} is the rest action, rest energy part of *h*, $h_{kinetic}$ is the kinetic action, kinetic energy part of *h*.

$$E = m \times c^2 = f \times \frac{h_{rest} \times h_{kinetic}}{h} . \quad (27)$$

Fast waves propagate in a different space compared to normal waves and not in a different (optical) medium. That is, light can use matter as space. The statement can be expressed in a more general form. Nowadays the barrier is seen just as a barrier made out of matter. But in barriers photons and electrons travel faster than light. They travel in the barrier as fast waves. In this case, they use a matter as space$_M$, and in space$_M$ they have new forms—fast waves.

Knowing Eq. (26, 27), there is more than one space, and the Planck’s constant remains true in every space. Using the de Broglie formula and the Planck’s law in different spaces, we have a passage between known particles and fast waves. So there is a 'fast wave–wave–particle triality' instead of the 'wave–particle duality'.

The today’s physics doesn’t use the expression ‘rest energy’. In the physics the 'rest mass' of an object is the inertial mass that an object has when it is at rest relative to the observer. As the speed of the object is increased, the inertial mass of the object also increases, while the rest mass remains unchanged In the given inertial frame of reference the value of rest mass of an object cannot decrease [16-17]. Would it decrease, the object would be transformed into a different object.

4.2. When can particles or waves turn into fast waves?

Particles or waves turn into fast waves, if the particle-space relation compels this state. We know, the fast wave comes into being if the space is made out of matter. In this case the densities and the energies of particle and the given space are specified by Eq. (28)-(30).

If the density of an object is smaller than the density of space, this object can act as space from the viewpoint of a third object, and can act as matter from the viewpoint of another object. According to our Space-Matter Theory [11] the density of space D_{Space} can be calculated. It has the biggest density, matter D_{object} has lower densities cf. Ref. 11. The tunneling works this way. The barrier is made out of matter, but electrons and photons use it as space$_M$.
If

$$D_{object1} < D_{Space} \;\; and \;\; D_{object2} < D_{Space} \,, \tag{28}$$

then both objects are matter in space. If Eq. (26), (27) are true:

$$d_{\min} \geq \frac{D_{Matter\,1}}{D_{Matter\,2}} \geq d_{\max} \;\;, \tag{29}$$

then Matter$_2$ can use Matter$_1$ as space$_M$. The values of $d_{\min}$ and $d_{\max}$ will specify the relationship between matter and matter—making space out of one matter, if Eq. (28) is true

$$e_{\max} \geq \frac{E_{Matter\,1}}{E_{Matter\,2}} \geq e_{\min} \,, \tag{30}$$

where $E_{object1}$ and $E_{object2}$ are the energy of the Matter$_1$.and Matter$_2$. The values of $e_{\max}$ and $e_{\min}$ will specify the interval.

This relationship the wavelengths of space is not involved in the de Broglie wavelength, see Eq. (3). Actually we had to calculate with the wavelengths of space waves λ_{space_wave}, but in our normal circumstances Eq. (31) is always true,

$$\lambda_{space\_wave} << \lambda_{paticle} \,, \tag{31}$$

so Eq. (3) is enough to know studying the de Broglie wavelength. In tunneling (and in some other cases) Eq. (31) is not true. Now we need to calculate with the wavelengths of space(s), too.
Particle and wave turn into fast wave, if Eq. (28)-(30) and Eq. (32) fulfilled:

$$\lambda_{space\_m} \geq \lambda_{paticle} \text{ and } \lambda_{space\_m} \geq l_{paticle} \tag{32}$$

In Eq. (32) space$_M$ is made out of matter and its wavelength is λ_{space_m}. Eq. (33) shows it a more general form,

$$\lambda_{space} \geq \lambda_{paticle} \text{ and } \lambda_{space} \geq l_{paticle} \,, \tag{33}$$

where any kind of space made out of space or matter appears as space for the given particle (or set of particles). The fast wave-wave-particle triality makes possible to understand how matter can suit itself to the given space.

5. CONCLUSION

Nimtz, Enders and Spieker have measured superluminal tunneling velocities since 1992. The tunneling electrons travel seem to violate the special relativity, states Nimtz [18]. How can particles with masses travel with superluminal velocity? The question cannot be answered using the special theory of relativity. According to fast wave–wave–particle triality the tunneling particle doesn't violate the special theory of relativity, tunneling is out of scope of the special theory of relativity. In the case of masses there is a discrete jump in the velocities, and after $v < c$ occurs $v > c$.
This is surprising but we know a discrete jump almost like this. We thought that nothing can be colder than absolute zero on the Kelvin scale. Physicists at the Ludwig-Maximilians University and the Max

Planck Institute of Quantum Optics in Germany created an atomic gas in the laboratory that nonetheless had negative Kelvin values. This negative Kelvin values came into existence out of positive Kelvin values. The atomic gas had no zero Kelvin value. There was a discrete jump on the Kelvin scale. [19]
In tunneling, a barrier made out of matter works as $space_M$. $space_M$ is made out of matter, out of the barrier. In this $space_M$ the particles (for example photons, electrons) travel faster than *c*. The tunneling electron loses its mass and acts as a fast wave. When it leaves the $space_M$ and enters 'our normal' space, it gets back its mass. The tunneling photon act as a fast wave, too. Tunneling particles use the fast wave–wave–particle triality. Via tunneling the value of Planck's constant *h* doesn't change, but it has two changing parts. The two parts of the Planck's constant work together. The values of these parts depend on the velocity of the fast wave.

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