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# Superluminality and Finite Potential Light-Barrier Crossing

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**Abstract:** Superluminal movements are subject of discussion since many decades. The present work investigates how an electrical charged real matter particle can traverse the energy barrier at the speed of light in vacuum. Here, parity reflexion takes place with respect to space, time, and mass. It is postulated this traversal can occur by a jump-over supported by electrical attraction between the subluminal particle and its virtual superluminal co-particle producing an electrical field opposite in sign. The jump over the light barrier implies a zero in time and here the particle becomes undetectable in position and mass. The result of the calculation shows two exclusive speeds where light-barrier crossing can occur from a sub- to a superluminal state or reverse. This leads to three different kinds of objects, where the first is denoted a subluminal mono-particle Bradyon, the second a superluminal mono-particle Tachyon, and the third a luminal twin Luxon consisting of two parts absolutely complementary in their states alternating between the both speeds, those touch the light-barrier, and traveling with an average of light-speed. A relation between the distance of a subluminal particle to its superluminal co-particle and the wavelength of the system can be manifested. The constant in speed of light is discussed.

**Keywords:** Special Relativity, Superluminality, CPT Operation, Time Reversal

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## 1. Introduction

Superluminal objects or particles traveling faster than the vacuum speed of light were first proposed by Sommerfeld [1, 2] and are called Tachyons ( $T$ ) as derived from the Greek ταχύς, “quick” [3]. In contrast, the term Bradyon ( $B$ ), from Greek βραδύς, “slow”, was introduced for ordinary subluminal objects or particles, traveling slower than the vacuum speed of light [4-6]. Luxons ( $L$ ), finally, are objects at exact the speed of light. Among these three classes of objects,  $T$  have not been experimentally detected yet.

Introducing the theory of special relativity (SR) in 1905 Einstein [7] led mainly to the conviction the vacuum speed of light  $c$  is the upper limit of any possible speed [8-10]. Other studies pointed out the existence of particles moving faster than  $c$  would be paradox as they would be able to send information into the past [11]. The fact that an effect could be observed before its cause was strictly rejected. This ideology was widely accepted and stopped investigations in that direction for more than five decades with an exception of an article in 1922 [12].

In the fifties and sixties speculations about  $T$  were resumed.

It was pointed out that rather SR suggests a possibility for superluminal objects, even though SR itself was assumed to deny their existence; it was further suggested that faster-than-light (FTL) particles might actually exist due to a possible “loophole” in Relativity Theory [13]. Later contributions found some theoretical approaches for  $T$ 's properties, *i.e.*, regarding mass ( $m$ ) and electrical charge [4, 14, 15].

With regard to give evident proof of  $T$ , it has been proposed  $T$  could be produced from high-energy particle collisions, thus, the searches concentrated on cosmic rays [16]. In 1973, a putative superluminal particle in an air shower could be identified using a large collection of particle detectors [17] and revived the discussions about  $T$  (Recami, 1979). Their result has never been reproduced since. The lack of direct experimental evidence and, especially, strong concerns about causality [18, 19] led again to a diminishing in  $T$  interest.

In the 90s, again, several experimental data on signal velocities faster than light [20-23] seemed to make superluminal objects become part of our realistic world rather than a fantastic science-fiction construction of a time machine. The basic problem still persists in the fact of a to infinity growing mass with a speed strongly converging to  $c$ , and the confrontation to deal with infinite momentum and energy. An

approach to overcome this obstacle is provided by quantum tunneling admitting probability transport for  $B$  [24, 25] as well as for  $L$  [22, 23, 26-28]. However, an approach revealing the proper  $B$ - $T$  interaction is still missing. This is mainly due to an undefined behavior of these particles for  $v = c$ . Moreover, as a consequence of the Lorentz transformation the associated time interval tends to zero as  $v$  tends to  $c$ . As a consequence, an infinite mass is confronted with a time interval zero, in which measurement of mass would not be reasonable. Finally, the finite-momenta-energies of  $L$ , e.g., are given by the operation "zero over zero", and that would be

$$\frac{m_0 \cdot c^2}{(1 - v^2/c^2)^{1/2}} \equiv \frac{0 \cdot c^2}{(1 - v^2/c^2)^{1/2}} \equiv \frac{0 \cdot c^2}{0}, \quad (1)$$

which can be of any value  $\omega$  [29].

Due to the lack of a description of the transition from an object's bradyon character into its tachyon one and reverse when crossing the light barrier, the first object of this paper is to provide a transformation factor appropriate to serve the characters of both particles in one and appropriate to incorporate their characters. The theory is worked out on the basis of the quantum vacuum [30]. A second aim is to find out how the problem at  $v = c$  can be overcome.

## 2. Theory

This study is strongly based on symmetry considerations. Its first task is to work out a relativistic relation appropriate to serve the range  $c < v \leq 2c$  in analogy to the conventional Lorentz factor in SR. In accordance to its first postulate the laws of physics will take the same form under the Lorentz' transformation for any  $B$  and any  $T$  reference system, except the sign change must be taken into account. In addition, two definitions are introduced with regard to the subluminal and superluminal speeds  $v_B$  and  $v_T$ , respectively. This formulation is based on the postulate that the characteristics of a particle like a mass  $m$ , time interval  $\tau$ , and a distance  $s$  be symmetric with respect to parity reflection  $P$ , i.e., identically mirrored at  $c$  under a light-barrier traversal to obey  $CPT$ -operation. This demand entails the ensemble

$$\begin{aligned} \gamma_B &= +(1 - v_B^2/c^2)^{-1/2}, & \text{bradyon} \\ \gamma_T &= -(1 - v_B^2/c^2)^{-1/2}, & \text{tachyon} \\ v_B &= v, & \text{for } 0 \leq v < c \\ v_T &= 2c - v, & \text{for } c < v \leq 2c \end{aligned} \quad (2)$$

as an extension to the conventional Abelian half-group provided in the Lorentz' transformations.

As a consequence, a superluminal  $m_T$  tends to zero as the speed  $v_T$  is approaching  $2c$ . At  $v = 2c$   $m_T$  can even become zero or just recognized as "superluminal rest-mass"  $m_{T,0}$  compared to its complementary at  $v = 0$ . The construct of a

hypothetical superluminal  $T$ -system then follows the above demands and can predict superluminal behaviour. It serves envision the condition revealed later and is not redundant, thus. In the following, light-barrier crossing will be discussed on basis of the eq. (2).

Due to the  $CPT$ -symmetry between the subluminal and superluminal systems it is sufficient serving simplicity to consider a  $B$  at speed  $v_B = v$ , alone, omitting its sub-index, thus. In accordance to the second postulate  $c = c_0$  in the vacuum is postulated in SR a constant rather than a speed limit. Certainly,  $m$  grows to infinity while time interval  $\tau$  and length  $s$  tend to zero as  $v$  is approaching  $c$ . Thus, it is emphasized the current study consequently deals with speeds  $v < c$  and  $v > c$ , explicitly excluding  $v = c$ . Those facts restrict a light-barrier crossing to a discrete "jump over" rather than a continuous transverse from ( $v_B = c - a$ ) to ( $v_T = c + a$ ). It remains a defined speed-interval  $\Delta v = 2a$  untouched as "gap" between sub- and superluminal movements with  $a$  a constant determined below. The consequence of this speed gap points as light-barrier speed-width towards the fact neither  $m$  nor  $\tau$  can be determined within. That leads to the following thought-experiment:

Consider a real particle  $m_0 \neq 0$  with elementary point charge  $q = \pm e$ . As soon as this particle is expected a jump-over from sub-into superluminality the above eqs. (2) imply a reversal in state in accordance to a mirroring in accordance to  $CPT$ -operation taking the particle considered right into its superluminal state "before" leaving its subluminal state. Then,  $m$ ,  $\tau$ , and space vectors are entirely mirrored entailing the electrical-field to change in sign. In other words, immediately before crossing the light barrier the same particle is already in its superluminal state appearing as its own "co-particle" and can "see" the original particle still before crossing in borrowing the energy from the quantum vacuum. Consequently, the particle can interact with itself appearing the co-particle in no time by an attractive electrical force from electrostatics revealing the energy

$$E_e = \frac{q^2}{4\pi\epsilon_0 \cdot s} \equiv \frac{q^2}{4\pi\epsilon_0 \cdot 2r} \quad (3)$$

in the interaction or respective separation distance ( $s = 2r$ ) between its appearance as  $B$  particle and as  $T$  co-particle, respectively (Figure 1). That process is associated a mechanical energy

$$E_m = m c^2 \quad (4)$$

with the consequence the "critical" speeds where the jump-over takes place to determine from equating  $E_e = E_m$ . That is explicitly

$$m \cdot c^2 = \frac{q^2}{4\pi\epsilon_0 \cdot (2r)} \rightarrow r \cdot m = \frac{(q/c)^2}{8\pi\epsilon_0} \quad (5)$$

With

$$\Delta r = r_0 - r, \quad \Delta m = m - m_0$$

the due to eqs (1) extended Lorentz' transformations

$$r = r_0(1 - v^2/c^2)^{+1/2}, \quad m = m_0(1 - v^2/c^2)^{-1/2} \quad (6)$$

leave

$$\Delta r = r \cdot [(v^2/c^2)^{-1/2} - 1], \quad \Delta m = m \cdot [1 - (1 - v^2/c^2)^{+1/2}] \quad (7)$$

Since, those equations of sixth grade in accordance to Abel (e. g., Childs, 2009) can not be resolved analytically very large values  $v$  allow the approximations

$$r \approx \Delta r(1 - v^2/c^2)^{+1/2} \quad \text{and} \quad m \approx \Delta m \quad (8)$$

turning eq. (5) into

$$\Delta r \cdot \Delta m \sqrt{1 - \frac{v^2}{c^2}} = \frac{(q/c)^2}{8\pi\epsilon_0} \quad (9)$$

From multiplication by  $v$  and re-arranging yields

$$\Delta r \cdot \Delta m \cdot v = \frac{v(q/c)^2}{8\pi\epsilon_0 \sqrt{1 - v^2/c^2}} \quad (10)$$

If in the Heisenberg's uncertainty  $\Delta r \cdot \Delta p \geq \hbar/2$  the equal sign is true expression (10) will get

$$v = 4\pi\hbar\epsilon_0 \cdot \left(\frac{c}{q}\right)^2 \cdot \sqrt{1 - \frac{v^2}{c^2}} \quad (11)$$

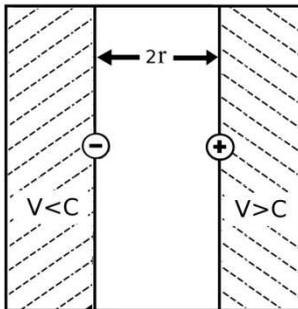
and finally

$$v = \frac{(2h\epsilon_0 c/q^2)}{\sqrt{1 + (2h\epsilon_0 c/q^2)^2}} \cdot c \quad (12)$$

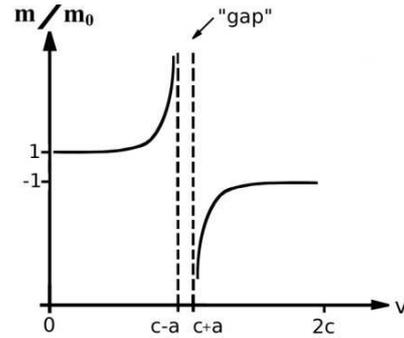
For the elementary charge  $q = e$  the fastest vacuum speed  $v$  for a  $B$  and the slowest of a  $T$  are

$$v_B = 0.99997301784 \cdot c \quad \text{and} \quad v_T = 1.00002698215 \cdot c \quad (13)$$

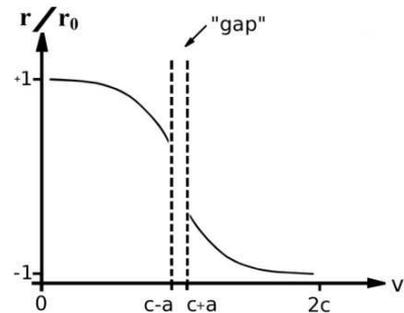
These are the "critical speeds" where jump-over at the light-barrier can occur. Following the current model the vacuum light speed  $c$  is therefore never reached by a real particle (Figures 2, 3).



**Figure 1.** The distance  $2r$  of electrical interaction between the particle in subluminal state and its co-particle in superluminal state immediately before and respective after crossing the light barrier.



**Figure 2.** Schematic presentation of the particle's relativistic mass difference as function of the speed  $v$ . It shows the speed-gap (dashed lines) between sub- and superluminal states and the change in sign of  $\Delta m$  under light-barrier traversal.



**Figure 3.** Schematic presentation of the behavior of the relativistic distance difference  $\Delta r$  as function of the speed  $v$ . It shows the speed-gap (dashed lines) between sub- and superluminal states and the change in sign of  $\Delta r$  under light-barrier traversal.

With regard to the object's or respective particle's speeds at both sides of the light barrier has to be noted the expression for those are driven from the electrical charge alone, see below eg. (15). It is, however entirely independent on any value  $m$  including  $m = 0$  (zero). This points to the fact an electromagnetic wave consists of two light speeds, i.e.,  $v_B = c - a$  and  $v_T = c + a$  oscillating around  $c$  instead of an exclusive one  $c$  alone. Therefore, the propagation  $c$  of light is just the average of  $v_B$  and  $v_T$ . As a consequence, a particle or wave packet of rest mass zero is only existent between these two speeds keeping the particle and its co-particle together; there is no reason to "relax" from  $(v_B = c - a)$  down to  $v_B = 0$  or from  $(v_T = c + a)$  up to  $v_T = 2c$ , respectively rather it points to the enormous constant in light propagation.

Since, sign reversal of the electrical charge is due to the change in the property between the states as  $B$  particle and its  $T$  co-particle, both bordering the light-barrier, their relativistic contracted distance  $2r_0$  in units of  $\pi$  should be expected half-wave length  $\lambda/2$  of the system,

$$\lambda/2 = 2r_0 \quad (14)$$

That can be proven in representing eq. (2) for the electrostatic energy per mediate the pure electrical attraction alone using the charge  $q = e$  together with the relativistic contracted distance  $r_0$  in eq. (6). Then, the speed from eq. (13) becomes

$$E_e = \frac{q}{4\pi\epsilon_0 [1 + (2h\epsilon_0 c/q^2)^2]^{-1/2}} \frac{1}{2r_0}$$

or

$$E_e = \frac{q^2 \cdot (2h\epsilon_0 c/q^2)}{4\pi\epsilon_0} \frac{1}{2r_0}$$

and finally

$$E_e = \frac{hc}{2\pi} \frac{1}{2r_0}. \quad (15)$$

Combination with the expression for light,

$$E_L = \frac{hc}{\lambda} \quad (16)$$

yields after re-arranging

$$\lambda \approx 4\pi \cdot r_0$$

and thus

$$\frac{\lambda}{2} \approx 2\pi \cdot r_0 \quad (17)$$

Quod erat demonstrandum.

### 3. Results

The general result is that there is a finite energy and momentum of a particle crossing the light barrier. The electrically charged particle having a non-vanishing mass at rest is identically mirrored under light-barrier traversal, *i.e.*, in its  $m$ ,  $\tau$ , and distance  $s$  or  $2r$ , respectively: it is symmetric with respect to parity reflection  $P$  and obeys  $CPT$ -operation in ideal mirroring its property.

With regard to an object's or particle's speeds, respectively, at both sides of the light-barrier it has to be noted the expression for these speeds is driven by the electrical charge alone remaining independent on any mass. This points to the existence of two vacuum (light-)speeds, *i.e.*,  $c - a$  and  $c + a$  instead of an exclusive one  $c$  alone. Therefore, the propagation of light is interpreted the average of both.

For clarity: An electrically charged particle having a non-vanishing mass at rest moving at a speed of  $2c$  in the vacuum will reach a target twice earlier than an electromagnetic wave, *i.e.*, light; then, the mass as well as the electrical field will appear opposite in sign explaining the oscillation of the electromagnetic field. The moving particle will not reverse in direction when it changes from subluminal into superluminal speed. Of course, the time inside an inertial system at speed  $2c$  will exactly run anti-clockwise with respect to a reference system at rest, but a particle moving faster than light will never reach a target earlier than or before leaving the start.

In case of an object or electromagnetic-wave packet, respectively, a relation between the distance from a

subluminal particle to its superluminal co-particle – one touching the light-barrier at the left and the other at the right side – and the wave length of the system is established. The comparison between those two facts leads to an exact result based on the electrical elementary charge.

It has to be highlighted the present theory is based principally on the discussion of particles with a non-vanishing rest-mass traversing the light-barrier at a finite potential. In the case of a particle of the electrical elementary charge the speeds where light-barrier crossing occurs are

$$v_{T,B} \approx c \pm 8\,067.66\,285 \text{ m/s}$$

or and a particle must reach a percentage of 99.997 the speed of light, respectively.

### 4. Discussion

A general result is that there is a finite energy and momentum of a particle crossing the light barrier. The presentation allows  $T$  particles to have negative real mass, what is in agreement with former studies [12]. A possible representative of a  $T$  was found experimentally on neutrinos [29].

A way to overcome the difficulty of light-barrier traversal in nature as well as in experiments was introduced in strict analogy to quantum tunneling for particles [32, 33]. A so-called instantaneous tunneling [34] was pointed out as the most likely process to penetrate even an infinitely high energy barrier to allow real subluminal objects to gain superluminal speed. The dispute due to an undefined mass and energy at the critical speed  $c$  revealed strong doubts in former theories, though the doubts were mainly due to a supported instantaneous process rather than a finite tunneling time occurred in real (or thought) experiments [35-37]. In contrast to that, the current model presents there is no infinity energy barrier to overcome at light speed but a finite potential wall, instead. The actual investigation is dealing with a particle as an individual rather than an ensemble tunneling in the sense of quantum tunneling.

A reversal in causal principle due to light-barrier crossing as revealed by the current study is in agreement with theoretical results predicted earlier [25, 38]. Experiments with photons in a linear dispersive medium demonstrated the transmitted Gaussian pulse to exit the medium before the incident peak entered it [22, 23, 27, 39, 40]. This phenomenon is used here to support the particle's light-barrier traversal. The current work neither violates the Lorentz' transformation nor confronts SR [41]. It especially takes into account the kind of a co-particle at  $v > c$  to be compared to QED studies identifying evanescent modes with virtual photons [22, 23, 41-44]. The same properties describing a  $B$  can, thus, be used with opposite sign for a  $T$ , *i.e.*, they behave symmetric with respect to  $P$  [45].

The present paper demonstrates that there is no infinite potential to overcome but rather a finite-energy barrier. It agrees with earlier results in the fact that there is a light-barrier traversal in zero time that is here a direct consequence

from the relation between mechanical and electrical energy as depending on speed and electrical charge of the object; the Heisenberg's uncertainty, then prohibits the existence of the considered particle within the traversal of the light barrier. It, then becomes undetectable here in position, time, and mass when crossing, which agrees, again with the results gained by experiment on evanescent modes [22, 39]. An infinite mass or energy, respectively, is therefore no fact of consideration.

The attempts on the proper symmetry of  $T$  made elsewhere [46] could thoroughly be established. Former statements [47] also found  $B$  and  $T$  do possess symmetry with regard to real  $C$  operation, and  $CPT$ -operation is required for symmetry conservation for anti-particles [48]. In contrast to former studies the current deals with two speeds where light-barrier crossing can occur: both being very close to  $c$ , but one is subluminal and the other superluminal, thus defining a speed gap or light-barrier width between them.

The advantage here is that 'crossing' is considered a 'jump-over' in contrast to a 'traversal' the light barrier, instead. This means rather a discrete than a continuous treatment. Due to the Heisenberg uncertainty an electrically charged subluminal particle can only appear as and interact with its superluminal twin at two exactly defined points, *i.e.*, the "fastest" subluminal speed and the "slowest" superluminal speed as its pendent as both are touching the light barrier. With regard to this clearly restricted condition a particle in its both forms is therefore exclusively existent at these two speeds. Within this so defined range of the light-barrier the presented "gap" is a forbidden region. Here, the character of a particle and the variables leave an uncertainty and can not be defined; outside that region its character can be exactly defined but has no twin.

These conditions are a hint to a hypothetical particle of rest-mass zero that is only existent at both of the above derived "critical speeds" forming the "gap". Otherwise, it would be within this "forbidden" region or not detectible as a consequence of presenting itself in a state of a single particle with no rest mass. Further, even this zero rest-mass avoids the particle considered to "relax" from its actual speed to a speed zero or to that of twice  $c$ , respectively. Since it always appears in its two complementary states electric attraction appears keeping the particle-twin together and should be "born" in that state. As a consequence, these facts explain the enormous constant of light propagation in vacuum. The results have long-ranging consequences due to, *e. g.*, the fine structure constant  $\alpha$ .

## 5. Conclusion

It has been pointed out light-barrier crossing can be enabled per mediate a jump-over avoiding explicitly to touch the speed of light. This is achieved in the consideration of superluminal co-particle or twin created from the original subluminal itself electrically interacting with the first. Here, reversal in causal principle and a light-barrier traversal appears in no time. Based on this theory a subluminal particle can form its twin or co-particle after crossing in no time

entailing an electrical attractive force between subluminal particle and its superluminal twin at the same time. The speed necessary to traverse depends alone on the particle's electrical charge, but it is independent from any rest mass. The energy for this process is borrowed from the quantum vacuum.

An electrically charged particle having a non-vanishing mass at rest is symmetric with respect to parity reflection  $P$ , *i.e.*, its parameters  $m$ ,  $\tau$ , and half-separation distance  $r$  are ideally mirrored under light-barrier traversal. The final result is a defined and finite critical speed where light-barrier crossing can occur.

In case of an object or respective electromagnetic-wave packet a strong relation between the distance from the subluminal particle to its superluminal co-particle – both bordering the light-barrier – and the wave length is established. The reason for the constant of light propagation in vacuum and the wave-particle dualism are discussed.

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