

A HYPOTHESIS ON PRODUCTION OF TACHYONS**J. K. Kowalczyński¹***Institute of Physics, Polish Academy of Sciences, Al. Lotników 32/46, 02–668 Warsaw, Poland*

Received 24 April 1999, in final form 10 February 2000, accepted 22 February 2000

An exact solution of the Einstein–Maxwell equations yields a general relativistic picture of the tachyonic phenomenon, suggesting a hypothesis on the tachyon creation. The hypothesis says that the tachyon is produced when a neutral and very heavy (over $75 \text{ GeV}/c^2$) subatomic particle is placed in electric and magnetic fields that are perpendicular, very strong (over $6.9 \times 10^{17} \text{ esu/cm}^2$ or oersted), and the squared ratio of their strength lies in the interval (1,5]. Such conditions can occur when nonpositive subatomic particles of high energy strike atomic nuclei other than the proton. The kinematical relations for the produced tachyon are given. Previous searches for tachyons in air showers and some possible causes of their negative results are discussed. Experiments with the use of the strongest colliders and improvements in the air shower experiments are suggested. An unfortunate terminology is also discussed.

PACS: 14.80.Kx, 04.20.Jb, 25.90.+k

1 Introduction

The long-lasting discussion on the tachyonic causal paradoxes has yielded a large number of self-contradictory publications, which has caused a cautious attitude of many physicists towards the tachyon. The problem of these paradoxes has lucidly been reviewed by Girard and Marchildon [1] (though in fact I disagree with some of their conclusions), and the essence of construction of the known paradoxes has thoroughly been analyzed in Ref. [2]. A large part of the most representative literature of the subject is cited in Refs. [1,2] (see also the end of Footnote 14). It has been concluded that the problem of whether the paradoxes may be eliminated within the standard theory of relativity remains still open (see, however, the end of the paragraph next but one), and that there exist such consistent extensions of this theory in which the known paradoxes are eliminated. The latter conclusion means that there is no contradiction between relativity and the tachyon's existence, though today we do not yet know whether the tachyon exists in nature.

The discussion on tachyons has been conducted mainly at the special relativity level with its standard poor pictures of the tachyonic phenomenon. In these pictures the tachyon does not generate any field. In general relativity the situation is different, since there we know some exact solutions of the Einstein and Einstein–Maxwell equations that describe spacetimes generated by the tachyonic sources. These spacetimes, filled with gravitational and electromagnetic fields,

¹E-mail address: jkowal@ifpan.edu.pl

are bounded by tachyon shock waves which are singular in terms of these solutions. Creation of the tachyon shock wave occurs also in a quantum description of the tachyon's motion [3].² It is interesting that this description includes certain tachyonic four-momentum relations that agree with the general relativistic pictures of the tachyonic phenomenon but do not agree with the special relativistic ones. In sum, our present-day knowledge of the tachyon strongly suggests that special relativity is too confined to describe tachyons (in classical terms), and that at least general relativity is necessary.

In fact, one of the exact tachyonic solutions seems to be of special importance for the problem of tachyons and for our hypothesis. This solution is presented in Section 2. It differs from the rest of the known tachyonic solutions in two properties: first, it has neither a bradyonic nor a luxonic counterpart, i.e. it is a *specifically tachyonic* solution; and second, it has no independent term which would include a masslike quantity.³ The second property is important for our hypothesis and is discussed at the beginning of Section 3. If we assume the picture of the tachyonic phenomenon resulting from this solution, i.e. a picture obtained *within* standard relativity, then the construction of the known paradoxes becomes questionable [4].

Various experimental searches for ionizing tachyons have been described in a number of papers. A large majority of them is cited in Refs. [5–10]. The experiments were of low and high energy type. Failure of the low energy experiments is explicable by our hypothesis, as will be seen in Sections 4 and 5. In the high energy experiments air showers were exploited; and many of the experiments have reported detection of tachyon candidates but as statistically insignificant data. A single possibly positive result [11] has also been rejected [5]. This situation has presumably disheartened most experimenters (the last relevant record in the Review of Particle Properties [9] is dated 1982 [8]), though some efforts were still made [10]. According to our hypothesis, however, air shower (and accelerator) experiments may be successful and they are discussed in Section 5. Though the tachyons considered in this paper are ionizing objects, experiments yielding tachyonic (?) neutrinos are briefly commented in Section 6, where also an unfortunate terminology is criticized.

2 The solution

The basis of our hypothesis is an exact solution of the current-free Einstein–Maxwell equations

$$G_{\mu\nu} = 2c^{-4}\kappa (F_{\rho\mu}F_{\nu}{}^{\rho} + \frac{1}{4}g_{\mu\nu}F_{\rho\tau}F^{\rho\tau}),$$

$$F_{[\mu\nu,\rho]} = 0, \quad F^{\mu\nu}{}_{;\nu} = 0,$$

where $G_{\mu\nu}$, $F_{\mu\nu}$, and $g_{\mu\nu}$ are the Einstein, electromagnetic field, and metric tensors, respectively, c is the speed of light in vacuum, and κ is the Newtonian gravitational constant. The solution in question is as follows:

$$ds^2 = ds_0^2 + ac^{-4}\kappa p^{-1} (2\theta + \frac{1}{2} \ln |q| - p^{-1}q) dq^2, \quad (1)$$

²In Ref. [3] there is a misprint. Namely, Eq. (22) should read $F = a_{-1} \int M d\zeta$ (notation after Ref. [3]).

³We do not know what the counterparts of the bradyonic mass and/or charge mean in the tachyonic formulae (an example is given in Section 6), since we do not have any operational definitions of such quantities. I have therefore proposed to use the terms “masslike quantity” [3,4] and “chargelike quantity” [4] for these counterparts. (The terms “pseudo-mass(-charge)” or “quasi-mass(-charge)” are shorter but semantically inferior.) In the tachyonic literature it is stated, from time to time, that the subluminal electric (magnetic) charge becomes, or behaves like, a magnetic (electric) charge when it becomes superluminal. So far, however, there is no operational model for this statement.

$$ds_0^2 := p^2 (d\theta^2 + e^{-2\theta} d\phi^2) + 2 dp dq + dq^2, \tag{2}$$

$$aq \geq 0, \tag{3}$$

$$F_{\phi\theta} = -\chi e^{-\theta}, \quad F_{\phi q} = \frac{1}{2}\chi q^{-1} e^{-\theta}, \quad F_{\theta q} = -\frac{1}{2}\varepsilon q^{-1},$$

$$F_{pq} = -\varepsilon p^{-2}, \quad F_{\phi p} = F_{\theta p} = 0, \tag{4}$$

$$\chi^2 + \varepsilon^2 = aq, \tag{5}$$

$$F_{\mu\nu} F^{\mu\nu} = 2p^{-4} (\chi^2 - \varepsilon^2), \tag{6}$$

$$F_{\mu\nu} \tilde{F}^{\mu\nu} = -4p^{-4} \chi \varepsilon, \tag{7}$$

where ϕ and θ are dimensionless coordinates, p and q are coordinates having the length dimension, a is an arbitrary constant having the energy dimension, and $\tilde{F}^{\mu\nu}$ is the dual of $F_{\mu\nu}$. All these quantities are real.

The form ds_0^2 is the flat part of form (1). Inequality (3) is a condition of solvability of the Einstein–Maxwell equations in the case under consideration. The metric form (1)–(3) describes more than one spacetime. Each of the spacetimes has boundaries S_p and S_q , where S_p is determined by relations $p = 0$ and $aq \geq 0$, and S_q by $q = 0$ with a limit $p = 0 \cap q = 0$. These spacetimes can be extended neither through S_p nor S_q , since each of the conditions $p = 0$ and $q = 0$ determines the strongest curvature singularity of our solution, namely a singularity (infinite value) of $R_{\mu\nu\sigma\tau} R^{\mu\nu\sigma\tau}$ and of $R_{\mu\nu\sigma\tau} R^{\sigma\tau\omega\kappa} R_{\omega\kappa}{}^{\mu\nu}$. Every two-dimensional surface determined by conditions (1), (2), $p = \text{constant} \neq 0$, and $q = \text{constant}$ has the negative Gaussian curvature. This and the fact that our solution belongs to the Robinson–Trautman class [12] mean that the metric form (1)–(3) describes spacetimes generated by tachyons [13–15].⁴ The geometric standards of recognition of the solution under consideration are given in Ref. [15]. In Ref. [4] our solution is referred to as Ω_1 .

Formulae (1)–(7) are simple but they do not depict the physical situation. After making the coordinate transformation

$$\phi = y(T - x)^{-1}, \quad \theta = \frac{1}{2} \ln (T^2 - x^2 - y^2) - \ln (T - x),$$

$$p = j (T^2 - x^2 - y^2)^{1/2}, \quad q = Z - p,$$

$$T \geq (x^2 + y^2)^{1/2} \geq 0, \quad j = \pm 1, \quad ja < 0, \quad jp \geq 0,$$

$$Z := \gamma (z - vt), \quad T := \gamma (ct - c^{-1}vz),$$

$$\gamma := (1 - c^{-2}v^2)^{-1/2} \geq 1, \quad |v| < c, \tag{8}$$

⁴Solutions describing gravitational waves also belong to the Robinson–Trautman class [12,13]. It is therefore interesting from the psychological point of view that the problem of gravitational waves is considered as very important whereas some physicists consider that the problem of tachyons cannot be treated seriously, though both phenomena have the same empiric status: they are not yet confirmed. Massive experiments to search for gravitational waves have been performed and very expensive ones are planned, while the experimenters searching for tachyons have been very modestly equipped.

where v is a transformation parameter having the speed dimension, Eqs. (1) and (4) explode, but from Eq. (2) we get a familiar form

$$ds_0^2 = dx^2 + dy^2 + dz^2 - c^2 dt^2. \quad (9)$$

In terms of the obtained coordinate system x, y, z, t we can explicitly describe the situation both in spacetime and in space, and we can reveal a property of our electromagnetic field $F_{\mu\nu}$ important in the context of our hypothesis; and this is done in brief just below.

In spacetime the boundary S_p is a semi-infinite light wedge. Its edge is a semi-infinite spacelike line $x = y = T = 0$ which is the world line of the tachyon generating each one of the spacetimes (1)–(3). The boundary S_q is a fragment of the light cone. In the case under consideration these two boundaries are smoothly⁵ tangent and form a null hypersurface $S = S_p \cup S_q$ enveloping the generated spacetime. The beginning of the edge and the vertex of the light cone coincide at a spacetime point (event) which can therefore be interpreted as a *creation point* of the tachyon and, consequently, of the whole tachyonic phenomenon considered here. The existence of this geometrically distinguished event is an invariant property of our solution and makes a reasonable physical interpretation possible. Transformation (8) was chosen so as to have $x = y = z = t = 0$ at this event.

In space we have a surface consisting of two parts, conical with axis z (S_p in space) and spherical with centre $x = y = z = 0$ (S_q in space), which are smoothly tangent. This surface expands along its normals with the speed of light. In consequence, the vertex of the cone moves along a semi-axis z with a constant velocity w such that

$$vw = c^2. \quad (10)$$

Thus $|w| > c$, i.e. we have a *pointlike tachyon*. The spherical part can be interpreted as a shock signal of a birth at the point $x = y = z = 0$ and instant $t = 0$, and the conical part as a shock wave of the born tachyon. Since these two parts are smoothly tangent, the picture of the whole phenomenon is quite realistic. This picture is the most realistic one among the general relativistic pictures of the tachyonic phenomenon known today, and it is probably the simplest realistic picture obtainable within general relativity.

The infinite curvature and electromagnetic field on the null hypersurface S (by relations (1)–(7) and the condition $p = 0$ or $q = 0$), and thus on the shock surface in space, are of course mathematical exaggerations frequently occurring in theoretical descriptions of nature. In reality there is a thin “skin” enveloping the spacetime (space) generated by the tachyon. This “skin” is made of finite but relatively strong fields – gravitational and electromagnetic. The presence of the electromagnetic field means that our tachyon is an *ionizing* object.

The subject-matter of the three preceding paragraphs is discussed wider in Ref. [16] and much wider in Ref. [4]. The tachyonic phenomenon under consideration is depicted in various reference frames by figures in Refs. [4,16].

When the electromagnetic field (4) and (5) is investigated in terms of the coordinate system x, y, z, t , it appears that there exists a part independent of x, y , and z . In the quasiflat case ($ds^2 \cong ds_0^2$), considered in the further text, x, y , and z are spacelike coordinates (see Eq. (9)), i.e. we have then a background part of our electromagnetic field. The existence of this part is one of the guides to our hypothesis. Details are given in Ref. [4].

⁵We take here into account the expanding ($T \geq 0$) and convex ($ja < 0$) spacetimes since only such a type of spacetimes (1)–(3) can be real and autonomous [4,16]. References [2,16] are commented in Appendix A in Ref. [4].

3 Premises of the hypothesis

The creation point of the tachyon is singular in terms of our solution (see Section 2), and therefore the conditions of production of the tachyon cannot be calculated within the exact theory based on this solution. The calculation of these conditions needs some additional assumptions, e.g. that regarding the finite strength of the fields present on S (see the last but two paragraph in Section 2). Though these assumptions are not contradictory to our solution, we speak here of a hypothesis only and not of a theory.

The known tachyonic solutions of the Einstein–Maxwell equations different from our solution, as well as their luxonic and bradyonic counterparts, include terms containing a masslike quantity (mass in the bradyonic solutions; see Footnote 3). These terms are independent of the electromagnetic ones and therefore each of them can be removed only by virtue of our arbitrary assumption. From relations (1)–(5) we see that our solution does not include such a term. This is an essential property of the metric form (1) and (2). In fact, for this form such a term is additive and reads $2m_0c^{-2}\kappa p^{-1}dq^2$ [4,14,15], where m_0 is a constant masslike quantity, but for $a \neq 0$ the coordinate transformation $\theta \rightarrow \theta - a^{-1}m_0c^2$ and $\phi \rightarrow \phi \exp(-a^{-1}m_0c^2)$ annihilates this term and restores the form (1) and (2). In our case therefore the gravitational field, i.e. the direct cause of spacetime curvature, does not exist autonomously but is generated by the electromagnetic field (4) and (5). The factor $c^{-4}\kappa \approx 10^{-49} \text{ g}^{-1}\text{cm}^{-1}\text{s}^2$ (see Eq. (1)) is, however, so small that even if the field (4) and (5) were by many orders of magnitude stronger than the strongest electromagnetic fields observed so far, the spacetime curvature would be completely negligible. Thus, even for a very strong field (4) and (5), our spacetime is practically flat everywhere, $ds^2 \cong ds_0^2$, including the “skin” (see the last but two paragraph in Section 2). This means that our solution is proper to describe an ionizing tachyon *belonging to the microworld*. (From time to time general relativity directly enters the microworld; see, e.g., Section 7 in Ref. [17].) When passing to the flat spacetime and microworld, our picture of the tachyonic phenomenon is preserved, since in virtue of relations (3)–(7) our electromagnetic field is (formally) infinite everywhere on the boundary S (as $p = 0$ or $q = 0$ on S).

Equation (5) is analogous to $\chi_0^2 + \varepsilon_0^2 = b^2$, where b is an electromagnetic constant occurring in the well-known Reissner–Nordström (R–N) solutions of the Einstein–Maxwell equations. In the bradyonic R–N solution constants χ_0 and ε_0 are charges of magnetic and electric monopoles, respectively, and in the tachyonic R–N solution they are charginess quantities of monopoles of indefinite meanings (see Footnote 3). Thus the case $\chi_0 = 0$ and $\varepsilon_0 \neq 0$ and the case $\chi_0 \neq 0$ and $\varepsilon_0 = 0$ are pure cases in which only one type of charges or charginess quantities occurs. Considering the analogy just mentioned, we have a pure case when $\chi = 0$ and $\varepsilon \neq 0$ or when $\chi \neq 0$ and $\varepsilon = 0$. By Eq. (7) in each of these two cases the electric and magnetic fields are perpendicular everywhere. (This takes also place in the pure cases of the R–N solutions.) The tachyon generating the field (4) and (5) with $\chi = 0$ and $\varepsilon \neq 0$ will be called the *e-tachyon* (electric type tachyon; predominance of the electric field since $F_{\mu\nu}F^{\mu\nu} < 0$, see Eq. (6)), and that with $\chi \neq 0$ and $\varepsilon = 0$ will be called the *m-tachyon* (magnetic type tachyon; predominance of the magnetic field since $F_{\mu\nu}F^{\mu\nu} > 0$, see Eq. (6)). Note that nothing is said about the charginess quantities of these tachyons.

On the analogy of the subluminal microworld, in which only one type of charges (electric) is known, we may suspect that only one type of our tachyons exists in nature (i.e. either the e-tachyons or the m-tachyons), but today we do not yet know which one. Thus, for safety, both

types should be considered. Note that the existence of mixed cases (our $\chi\varepsilon \neq 0$, $\chi_0\varepsilon_0 \neq 0$ of R–N called dyon in the bradyonic case) seems unnatural when no pure case exists autonomously.

It is known that, in terms of relativity, no tachyon can be at rest⁶ (i.e. every tachyon is always in motion and therefore it determines a direction in space), and that there is no invariant (with respect to all the time-irreversible Lorentz transformations) past-future orientation along the tachyon’s world line. Besides, in our case the event of tachyon’s birth and the spacelike orientation along the tachyon’s world line are determined, owing to the existence of the creation point in our solution (see Section 2). In contrast, the flat spacetime (being now the arena of our considerations, see the second paragraph of this section) includes the past-future orientation and its space is believed to be homogeneous and isotropic. Thus the tachyon should be “informed” already *in statu nascendi* of its properties just mentioned, to “let him know” how to come into being in our space of undistinguishable points and directions. Such “information” can, however, be introduced into this space only by creating proper physical conditions. In our case it is most natural to have an electromagnetic field which will coincide with the background⁷ part of the field generated by the tachyon (see the end of Section 2), and a material micro-object immersed in this field. Such a micro-object determines the place of the tachyon’s birth (creation point demanded by our solution), and the electromagnetic field indicates the direction and sense of the tachyon’s motion. Further these micro-object and electromagnetic field are called the *generative particle* and the *initiating field*.

The production conditions mentioned just above are kinematical and should be supplemented with the strength of the initiating field and with the information about the generative particle. We can do this by using the Heisenberg time-energy uncertainty relation. The combining of this relation, fundamental in quantum physics, with our classical description of the tachyonic phenomenon seems to be a proper move since we deal here with a tachyon belonging to the microworld. This combination and the following procedures, simple or involving laborious calculations, are presented in detail in Ref. [4]. Here we present only their results. It appears that the initiating field must be very strong,⁸ and that the generative particle must be a neutral subatomic particle of very large rest mass (inequality (20)). This mass is an additional fuel required by the energy conservation law for producing the tachyon. Our hypothesis says nothing about other properties of the generative particle, e.g. quantum numbers. We may assume that depending on the situation some additional entities may be produced, e.g. if the proper conservation laws hold.⁹

⁶It has been shown in terms of the invariant properties of the light cone [2] (and less precisely but in a simpler and shorter way in Ref. [18]) and in terms of the group theory [19] that the concept of superluminal reference frame (i.e. the frame in which a tachyon may be at rest) does not exist in relativity, and that every consistent extension of relativity by adding this concept yields a notional system unacceptable from the physical point of view. Unfortunately, an extensive literature exists in which superluminal frames and transformations are seriously treated in the context of relativity (cf. Footnote 15).

⁷We have here an analogy to the wave-particle duality of the subluminal microworld. Namely, nonlinear electrodynamics describes faster-than-light electromagnetic signals which, however, must have a background electromagnetic field to propagate [20,21].

⁸We have here an analogy to the spontaneous creation of bradyonic particles in very strong electromagnetic fields (for review see, e.g., Ref. [22]). The minimal strength of these fields is by only one order of magnitude smaller than that of our initiating field (given by relations (11)–(13) and (19)). The essential difference consists in that those bradyons are created in vacuum whereas our tachyon in the generative particle.

⁹This problem is discussed in Footnote 26 in Ref. [4]. Let us supplement that footnote by noting that the simultaneous production of tachyonic neutrinos (if they exist, see Section 6) would be an interesting possibility.

4 The hypothesis

The hypothesis says that the tachyon is produced when a neutral subatomic particle of sufficiently large rest mass (the generative particle) is placed in the strong electromagnetic field (the initiating field) described just below. The generative particle is then annihilated giving birth to the tachyon.

In this section we use the Lorentzian coordinate system introduced in Section 2 (see Eq. (9)). According to Sections 2 and 3 the *proper* reference frame of the generative particle can be endowed with this coordinate system in such a way that the generative particle is at the origin $x = y = z = 0$ of the spacelike coordinates. In this section all quantities, relations, and situations are presented in terms of this reference frame.

Let \mathbf{E} and \mathbf{H} be accordingly the electric and magnetic three-vectors of the initiating field, and let their components be denoted by E_i and H_i . In order to produce the tachyons under consideration we should have the following two types of the initiating field:

$$\begin{aligned} E_x &= \mp\gamma\lambda\Xi, & E_z &= \pm 2j\lambda\Xi, & H_y &= \mp j\gamma\lambda\Xi, \\ E_y &= H_x = H_z = 0, \end{aligned} \quad (11)$$

in which the e-tachyon is produced, and

$$\begin{aligned} E_y &= \pm\gamma\lambda\Xi, & H_x &= \mp j\gamma\lambda\Xi, & H_z &= \pm 2\lambda\Xi, \\ E_x &= E_z = H_y = 0, \end{aligned} \quad (12)$$

in which the m-tachyon is produced, and where

$$\lambda := (\gamma^2 + 4)^{-1/2} > 0, \quad \Xi > 0, \quad (13)$$

and j is determined by relations (8). The tachyon produced in the generative particle and fields (11)–(13) will be moving along a semi-axis z with a velocity w such that

$$jw < 0, \quad (14)$$

where w is related to γ by relations (8) and (10).

From relations (11)–(13) we see that

$$\mathbf{E} \perp \mathbf{H}, \quad |\mathbf{E}| \neq |\mathbf{H}|, \quad |\mathbf{E}||\mathbf{H}| \neq 0, \quad (15)$$

and that $\Xi = |\mathbf{E}| > |\mathbf{H}|$ in the case (11) and $\Xi = |\mathbf{H}| > |\mathbf{E}|$ in the case (12).

Let U be defined as follows: $U = |\mathbf{H}|^{-1}|\mathbf{E}|$ in the case (11) and $U = |\mathbf{E}|^{-1}|\mathbf{H}|$ in the case (12). Thus, by relations (11)–(13), we have $U > 1$ and

$$U^2 = 1 + 4\gamma^{-2} = 5 - 4c^2w^{-2}, \quad (16)$$

i.e.

$$1 < U^2 \leq 5. \quad (17)$$

Note that in accordance with the known properties of the spacelike world lines we may have $|w| = \infty$. If the angle between the tachyon path (a semi-axis z) and the longer three-vector of the initiating field is denoted by α , then

$$\sin\alpha = U^{-1}. \quad (18)$$

By generating perpendicular electric and magnetic fields we determine empirically the directions in space. If these fields satisfy the condition (17), then, according to the hypothesis, for each type of tachyons under consideration Eqs. (16) and (18) determine four variants of the complete kinematical conditions for the produced tachyon. The existence of four variants results from relations (11)–(14) and (18). Namely, there are double signs of the nonzero components E_i and H_i , a double sign of j (i.e. a double sign of w since $fw < 0$), and $\sin\alpha = \sin(\pi - \alpha)$, i.e. we apparently have eight variants, but each one of these three items depends on two others.

In order to determine the principal empiric conditions for the production, we should also know the quantity Ξ and the rest mass M of the generative particle. By using the Heisenberg time-energy uncertainty relation (cf. the end of Section 3) we can estimate the lower limits of Ξ and M .

In the case of Ξ , we fairly easily [4] get

$$\Xi \gtrsim 6.9 \times 10^{17} \text{ esu/cm}^2 \text{ or oersted}. \quad (19)$$

In the case of M , I am able to estimate its lower limit only when $|w| \cong c$ (thus for $U \cong 1$; note that $|w| > c$ and $U > 1$), i.e. when the produced tachyon is very “slow” in the proper reference frame of the generative particle.¹⁰ Laborious calculation [4] gives

$$M \gtrsim 75 \text{ GeV}/c^2. \quad (20)$$

Our hypothesis concerns the production of the tachyons for which the hypersurfaces S (see Section 2) are convex; and such tachyons can exist autonomously. Let us call them *principal tachyons*. Each principal tachyon may be accompanied with an arbitrary (formally) number of tachyons for which the hypersurfaces S are concave. The latter tachyons cannot exist autonomously but they can exist if they form a “star of tachyons” together with a principal tachyon. Let us call them *accompanying tachyons*. All the tachyons forming their “star” are born at one event (common creation point, for details see Refs. [4,16]).

5 Comments on the empiric possibilities

The production conditions determined by our hypothesis can occur in high energy collisions with atomic nuclei other than the proton. In such collisions we can locally obtain the conditions (15) (for details see Ref. [4]) and the relativistic intensification of the electromagnetic fields of nuclei necessary to satisfy the condition (19). It is easy to calculate that this intensification gives $U \cong 1$, i.e. the condition (20) holds. Thus the gauge boson Z^0 is the lightest known candidate for the generative particle. Though the mean life of this boson is very short, the production conditions

¹⁰Such a tachyon can, however, be observed as considerably faster than light if the sense of its velocity is opposite in the laboratory reference frame to the sense of the generative particle velocity (sufficiently high but subluminal of course); cf. remarks on the backward tachyons in Section 5.

can be satisfied. In fact, if a subatomic particle of sufficiently high energy strikes a nucleon included in an atomic nucleus and produces the boson Z^0 , then *in statu nascendi* this boson moves with respect to the nucleus (its remainder) with a velocity that sufficiently intensifies the electromagnetic field. In particular, neutrons present in nuclei should be struck by neutral particles, while protons by negatively charged ones. In the case of nuclei so large that we may speak of peripheral nucleons, the collision with such a nucleon (“tangent” collision) is the most effective. Note that the principal m-tachyon is produced *only* when the proton in the ^2H , and perhaps ^3H , nucleus is appropriately struck. When designing controlled collisions, we can practically use only electrons or antiprotons as the striking particles. In all the mentioned collisions we have $U \cong 1$ and therefore, by Eq. (18), the striking particle and the produced principal tachyon have practically the same direction of motion, but according to our theory they may have different senses. In the case of opposite senses for brevity we shall be speaking about *backward tachyons*, and in the case of the same senses about *forward tachyons*. This nomenclature relates to the principal tachyons only.

The collisions described above should occur in air showers and can be realized in or at some high-energy colliders. Let us discuss these two cases in terms of the *laboratory* (and thus the *earth*) reference frame.

The collisions producing tachyons should occur in the air showers initiated by cosmic (primary) particles of energy of $\sim 10^{13}$ eV and greater (events above 10^{20} eV have been reported [23]). Thus our hypothesis justifies air shower experiments designed to detect tachyons. The time-of-flight measurement experiments (e.g. described in Refs. [8,24,25]) are obviously more credible than the experiments described and/or cited in Refs. [5–7,10,11] and designed only to detect charged particles preceding the relativistic fronts of air showers, though a massive-measurement experiment of the latter type performed by Smith and Standil with the use of detector telescopes [26] has had great weight. Tachyon candidates were observed in the time-of-flight experiments [8,24,25] and in many “preceded front” ones including that described in Ref. [26], but these unlucky candidates were sunk in backgrounds and/or statistics. Thus, formally, we have to consider the results as negative. In the light of our hypothesis, however, properly designed experiments with air showers (“poor man’s accelerator” [25]) are worth repeating, the more so as they are relatively inexpensive.

Let us note that no forward tachyons can be observed in any air shower experiment performed in the terrestrial reference frame, since these tachyons cannot practically precede the shower fronts. In fact, it is easy to calculate from relations (16), (19), and from the relativistic law of addition of velocities that the forward e-tachyons produced in collisions with nuclei ^{40}Ar can move in this reference frame with speeds not greater than $\sim 1.0000008c$. In the case of nuclei ^{16}O or ^{14}N , or ^2H in the case of production of the forward m-tachyons, the upper speed limit is still lower. On the other hand, some tachyons accompanying those “slow” forward tachyons may travel considerably faster than light towards the ground. This is possible provided that the angle, denoted by ψ for short, between the motion directions of such a forward tachyon and of its accompanying tachyon is sufficiently large.¹¹ Unfortunately, these fast accompanying tachyons cannot be observed in typical “preceded front” experiments since they escape from the showers

¹¹In every given reference frame, if a principal tachyon moves with a speed $|W| < \infty$ and if the angle ψ between the velocity W and velocity V of a tachyon accompanying this principal one is, for simplicity, smaller than $\pi/2$, then $|V| \leq c|W|/[c \cos\psi + (W^2 - c^2)^{1/2} \sin\psi]$ and there is a lower limit for ψ , namely $\arccos(c/|W|) < \psi < \pi/2$ in the case under consideration. Of course $|V| > c$ and $|W| > c$.

sidewise. They could be observed in the previous time-of-flight experiments in the cases when the shower axis was largely inclined with respect to the flight corridor of the detector (large ψ).

The described situation seems to explain the poor statistics obtained from the previous experiments, and suggests how to design new air shower experiments to search for tachyons. It seems that the best solution would be an *apparatus with many time-of-flight corridors of various directions*. In order to increase efficiency, such an apparatus should be possibly close to the region of tachyon production (mountains? balloons?). To increase credibility, simple air shower detectors (placed on the ground for convenience) can additionally be used. They should be far from the main apparatus (its projection on the ground) to act when ψ is large, i.e., when the registered showers are remote or largely inclined. If some tachyon flights through the main apparatus coincide with the signals from some of the additional detectors, then we get stronger evidence that tachyons are produced in air showers. The use of the main apparatus alone should also give us valuable results without detecting any showers.

The appearance of tachyon candidates in some previous “preceded front” experiments can be explained as the arrival of tachyons accompanying the backward tachyons. The backward tachyons produced in air showers are slightly faster than $5c/3$ in the terrestrial reference frame. Thus, at sufficiently high altitudes (balloons? satellites?), they should be easily identified as tachyons.

Failure of the previous air shower experiments may also be explained by the very low deuterium content (cf. the beginning of this section) in the earth’s atmosphere. Indeed, if the principal e-tachyons do not exist in nature but the principal m-tachyons do (cf. the fourth paragraph in Section 3), then the probability of production of principal tachyons is very low. Then, however, this probability strongly depends on weather. Roughly speaking, the cloudier the skies the higher the probability. It seems that this aspect has not been taken into account in the experiments performed hitherto. If the principal tachyons are only the m-tachyons, then the efficiency of air shower experiments may be increased by introducing extra deuterium. For instance, we can place the above mentioned apparatus (i.e. that with many time-of-flight corridors) *inside* a large balloon filled with hydrogen and next dispatch the balloon to the region of tachyon production.

In the case of performing tachyon search experiments with the use of accelerators we can choose the striking particles (practically either electrons or antiprotons), the nuclei to be struck, and the energy of collisions. Relations (19) and (20) mean that the strongest colliders should be employed. At present, however, we can only direct a beam of electrons or antiprotons onto a stationary target. This would give us principal tachyons such as in the case of air showers, i.e. forward tachyons so “slow” that indistinguishable as tachyons and backward tachyons slightly faster than $5c/3$. As regards accompanying tachyons, we would have a much better situation since the target can be surrounded with tachyon detectors, e.g. with time-of-flight ones. The fact that tachyon candidates were observed in air shower experiments indicates that there should be no problems with the range of tachyons in the collider experiments. A collider with a high energy beam of atomic nuclei would extend our empiric possibilities. We could then control the observed speeds of backward and forward tachyons and, in consequence, change the observed velocities of the accompanying tachyons. Besides, we could then produce principal m-tachyons (cf. the preceding paragraph), which is impossible in the near future when a stationary target is used. For instance, a beam of electrons of energy of ~ 25 GeV or a beam of antiprotons of energy of ~ 0.1 TeV when colliding with a beam of deuterons of energy of ~ 1 TeV (~ 0.5 TeV/u) or of ~ 0.24 TeV (~ 0.12 TeV/u), respectively, would already realize the production conditions,

whereas in the case of the deuterium target the energy of the striking negative particles must be ~ 26 TeV. When using stationary targets to produce principal e-tachyons, we need the striking negative particles of energy of ~ 0.8 TeV for the targets made of heavy nuclei, and of ~ 2 TeV for the targets made of light nuclei.

Let us note that in the experiments designed to detect tachyons the existence of a reference frame preferred for the tachyons should be taken into account.¹² In terrestrial experiments we should therefore analyze the measurements in correlation with the time of the day, and additionally, in long-lasting experiments, with the season of the year. It seems obvious that from this point of view the experiments with the use of colliders are more suitable than those with air showers.

6 Comments on tachyonic neutrinos and on unfortunate terminology

The results of some experiments from which the neutrino mass is being squeezed out, astonish physicists for over two decades. Namely, when the relativistic formulae for conservation of four-momentum are used, the experimenters obtain “negative” values for the squared rest mass of neutrinos. (A good deal of the literature concerning the muon neutrino is given in, e.g., Refs. [30,31], and that concerning the electron neutrino is given in Refs. [32–34].) Two problems then arise – physical and terminological.

The squared mass values mentioned above are burdened with empiric errors so large that the opinion that the neutrinos have zero mass can still be maintained. A detailed critical analysis and list of empiric data concerning the electron neutrino from β -decay are given in Ref. [32]. However, it is striking that independent experiments systematically give the “negative squared rest mass” of neutrinos (which in reality would be neither negative nor rest mass as we shall see below), especially in the case of the muon neutrino from π -decay, i.e. from a simple phenomenon. If these results were confirmed, then, in terms of relativity, such neutrinos would really be faster than light, and the universe would be filled with almost noninteracting tachyons.¹³

In the tachyonic literature it is frequently stated that “the squared rest mass of tachyons is negative”, and consequently some authors conclude that “the rest mass of tachyons is imaginary”. Besides, the sentence “photons have zero rest mass” is almost commonly used. Thus someone may be under the impression that many authors use relativistic terms and formulae without understanding their meanings. Let us make a few elementary remarks.

In relativity the term “rest mass” does not make sense in the case of luxons and tachyons, since the state of rest can be reasonably defined for these objects neither within standard relativity

¹²The existence of such a reference frame has been considered or postulated by many authors. Most of the relevant literature is cited in Refs. [1,2,27]. Some ideas are, however, in conflict with empiric data, some others can only be verified by means of tachyons. According to the latter ideas such a frame is imperceptible for bradyons and luxons, which means that this frame is a usual non-preferred inertial reference frame for all the tachyonless phenomena. This is not contradictory to relativity (which has been verified only in the bradyonic and luxonic domains) and is not empirically ruled out since tachyons have not yet been employed. The most natural idea (i.e. when the (local) Minkowski’s spacetime is assumed to be spatially isotropic also for tachyons) has thoroughly been analyzed in Section 3 of Ref. [2]. Following this idea, many authors suggest that the frame in question is that in which the cosmic microwave background radiation is isotropic. If their intuition is correct, then in terrestrial experiments this frame can be revealed only by means of tachyons which are very fast (over $\sim 800c$) in the laboratory reference frame. If, however, the “tachyon corridor” described by Antippa and Everett [28,29] did exist, then “slow” tachyons would be sufficient to reveal it.

¹³A peculiar model of the universe, according to which some known phenomena are caused by tachyons, has been proposed by Steyaert [35,36].

nor in its consistent extensions. This is obvious in the luxonic case since, e.g., the Lorentz transformation is singular for speeds equal to c . For the tachyonic case see Footnote 6.

As regards the phrases “negative squared mass”, “imaginary mass”, and “photon’s zero mass”, we shall proceed step by step.

Consider the world line $x^\mu(\sigma)$ of a pointlike object. Assume, for simplicity, that the object is free in flat spacetime endowed with the Lorentzian coordinates (i.e. $x^\mu(\sigma)$ is straight), that σ is the normalized affine parameter of $x^\mu(\sigma)$, and that the signature is, e.g., $+++ -$. Note that in the metric form expressions, $ds^2 = dx_\mu dx^\mu$, ds^2 is only a conventional symbol, and therefore it need not be the square of an infinitesimal real quantity. In the case under consideration

$$ds^2 = dx^2 + dy^2 + dz^2 - c^2 dt^2, \quad (21)$$

and for $x^\mu(\sigma)$ we have

$$ds^2 = -k (d\sigma)^2, \quad (22)$$

where $d\sigma$ is indeed an infinitesimal real quantity, and where the discrete dimensionless parameter k is as follows:

$k = 1$ in the bradyonic (timelike, subluminal) case,

$k = 0$ in the luxonic (null, luminal) case, and

$k = -1$ in the tachyonic (spacelike, superluminal) case.

(If the signature $----$ were chosen, then by Eq. (22) we would have $k = -1$ in the bradyonic case and $k = 1$ in the tachyonic case.) Dividing Eqs. (21) and (22) by $(d\sigma)^2$ we get

$$-k = (u^x)^2 + (u^y)^2 + (u^z)^2 - (u^t)^2, \quad (23)$$

where $u^\mu := dx^\mu/d\sigma$ is a four-velocity vector. The kinematical Eq. (23) concerns every type of world lines – timelike, null, and spacelike. The type is determined by k .

Multiplying Eq. (23) by $m^2 c^2$, where m has the mass dimension (we do *not yet* determine physical meanings of m), we get the well-known special relativistic formula for a four-momentum vector p^μ :

$$-km^2 c^2 = (p^x)^2 + (p^y)^2 + (p^z)^2 - (p^t)^2 \equiv \mathbf{p}^2 - c^{-2} E^2, \quad (24)$$

where

$$p^\mu := mcu^\mu, \quad (25)$$

and where $(p^x)^2 + (p^y)^2 + (p^z)^2 \equiv \mathbf{p}^2$ and $(p^t)^2 \equiv c^{-2} E^2$. If we had $m = 0$, then by definition (25) we would have no four-momentum, i.e. no object on our world line (not speaking of that the multiplication of equations by zero does not make sense). Thus

$$m \neq 0. \quad (26)$$

If m were imaginary, then by definition (25) also the four-momentum components p^μ would be imaginary, which would give us a new physics yet unknown.¹⁴ If we had real $m < 0$, then by definition (25) we would have opposite senses of the four-vectors u^μ and p^μ . Such a situation is yet unknown and today seems strange, though perhaps it will be considered in future. Anyway, we are entitled to put real $m > 0$ for every type of the objects under consideration (Ockham's principle!).

The unfortunate phrases have resulted from the fact that some authors have not taken into account the existence of three values of k (1, 0, -1) and have applied the bradyonic variants of Eqs. (21)–(24) for luxons and tachyons.¹⁵ The use of proper values of k allows to avoid the difficulties. If, for instance, the general formula for energy, $E = (\mathbf{p}^2 c^2 + km^2 c^4)^{1/2}$ (for the signature + + + -), had been applied in the mentioned works on neutrinos, instead of its bradyonic variant $E = (\mathbf{p}^2 c^2 + m^2 c^4)^{1/2}$, then the embarrassing “negative squared rest mass” would not have appeared; there would then have been a positive quantity, for $k = -1$ under the assumption that those neutrinos are tachyons. Of course the term “rest mass” would then be improper.

In the bradyonic case, m is the rest mass of our object. In the luxonic case the physical meaning of m is not determined in general, though it is so for the photon for which $m = c^{-2} E = c^{-2} h\nu > 0$. Anyway, the dynamical luxonic relation $\mathbf{p}^2 c^2 = E^2$ does *not* result from the condition $m = 0$, which is false (inequality (26)), but it does result from the condition $k = 0$, i.e. it is determined at the *kinematical* level of Eqs. (21)–(23). In the tachyonic case we have yet no operational definition of m (for lack of rest), and therefore the term “masslike quantity” has been proposed (cf. Footnote 3).

7 Concluding remarks

Solution (1)–(7) of the Einstein–Maxwell equations yields a realistic picture of the tachyonic phenomenon. The existence of this solution can therefore be regarded as an indication on the part of general relativity in favour of the tachyon's existence in nature, considering the analogy to many theoretical predictions that found later empirical confirmation. The solution is the basis of the hypothesis presented in this paper.

The hypothesis determines the principal empiric conditions of tachyon production. These conditions can occur when nonpositive subatomic particles of high energy strike atomic nuclei

¹⁴The first appearance of imaginary mass in the tachyonic literature is fairly funny. Namely, some authors have put $v^2 > c^2$ in the known relativistic formula for energy, $E = mc^3(c^2 - v^2)^{-1/2}$, which is valid for bradyons and not for tachyons, and to avoid the imaginary energy (interactions?) they assumed an imaginary m . The tachyonic literature is full of surprising ideas, including incantations, e.g., “pseudo-antiorthogonal transformations” [37] or the requirement to use the term “pseudo-Riemannian” with regard to the Riemannian space with the relativistic signature + + + - or + - - - [37,38]. Some ideas are brilliant, e.g., to use simultaneously two signatures (+ + + - and + - - -) in one description of spacetime relations [37]. The largest list of tachyonic publications is given in Ref. [37]. Most of them, however, represent the unfortunate trends (see the beginning of our Section 1, the end of Footnote 6, and Footnote 15), whereas a number of papers criticizing these trends is omitted (some of them are cited in Refs. [1,2,19]).

¹⁵Attempts to escape trouble in the tachyonic case have consisted in the confusion between mappings and transformations. This confusion, frequent in the tachyonic literature, has been discussed in Refs. [2,18] (in the context of the superluminal reference frame problem, cf. Footnote 6). Also frequent attempts have consisted in interchanging the meanings of the energy and momentum terms in the bradyonic variant of Eq. (24), without taking into account that momentum has three components in the physical spacetime. Effects of such an interchange have been described in Footnote 2 in Ref. [3].

other than the proton. Thus, if our hypothesis is true, we should expect credible tachyons to appear in properly designed experiments with air showers or with the use of the strongest colliders. In the latter type experiments, not performed hitherto, the production of tachyons can be controlled.

Acknowledgement I wish to thank Bogdan Mielnik for reading the manuscript and helpful discussions.

References

- [1] R. Girard, L. Marchildon: *Found. Phys.* **14** (1984) 535
- [2] J.K. Kowalczyński: *Int. J. Theor. Phys.* **23** (1984) 27
- [3] J.K. Kowalczyński: *Acta Phys. Pol.* **B20** (1989) 561
- [4] J.K. Kowalczyński: *The Tachyon and its Fields*, Polish Academy of Sciences, Warsaw, 1996
- [5] J.R. Prescott: *J. Phys.* **G2** (1976) 261
- [6] L.W. Jones: *Rev. Mod. Phys.* **49** (1977) 717
- [7] P.N. Bhat, N.V. Gopalakrishnan, S.K. Gupta, S.C. Tonwar: *J. Phys.* **G5** (1979) L13
- [8] A. Marini, I. Peruzzi, M. Piccolo, F. Ronga, D.M. Chew, R.P. Ely, T.P. Pun, V. Vuillemin, R. Fries, B. Gobbi, W. Guryn, D.H. Miller, M.C. Ross, D. Besset, S.J. Freedman, A.M. Litke, J. Napolitano, T.C. Wang, F.A. Harris, I. Karliner, Sh. Parker, D.E. Yount: *Phys. Rev.* **D26** (1982) 1777
- [9] Particle Data Group: *Review of Particle Properties*, *Phys. Rev.* **D50** (1994) No. 3-I, p. 1811
- [10] R.W. Clay: *Aust. J. Phys.* **41** (1988) 93
- [11] R.W. Clay, P.C. Crouch: *Nature* **248** (1974) 28
- [12] I. Robinson, A. Trautman: *Proc. R. Soc. Lond.* **A265** (1962) 463
- [13] I. Robinson, A. Trautman: *Phys. Rev. Lett.* **4** (1960) 431
- [14] D. Kramer, H. Stephani, M. MacCallum, E. Herlt: *Exact Solutions of Einstein's Field Equations*, Cambridge University Press, Cambridge, 1980; or VEB Deutscher Verlag der Wissenschaften, Berlin, 1980, p.259 (two simultaneous editions)
- [15] J.K. Kowalczyński: *J. Math. Phys.* **26** (1985) 1743
- [16] J.K. Kowalczyński: *Phys. Lett.* **74A** (1979) 157
- [17] G.C. Debney, R.P. Kerr, A. Schild: *J. Math. Phys.* **10** (1969) 1842
- [18] J.K. Kowalczyński: *Acta Phys. Pol.* **B15** (1984) 101
- [19] L. Marchildon, A.F. Antippa, A.E. Everett: *Phys. Rev.* **D27** (1983) 1740
- [20] G. Boillat: *Ann. Inst. Henri Poincaré* **A5** (1966) 217
- [21] J. Plebański: *Lectures on Non-Linear Electrodynamics*, NORDITA, Copenhagen, 1970, pp. 67–68
- [22] A. Schäfer: *J. Phys.* **G15** (1989) 373
- [23] T.K. Gaisser, T. Stanev: *Phys. Rev.* **D54** (1996) 122
- [24] F. Ashton, H.J. Edwards, G.N. Kelly: *Nucl. Instrum. Methods* **93** (1971) 349
- [25] H. Hänni, E. Hugentobler: in *Tachyons, Monopoles, and Related Topics*, ed. E. Recami, North-Holland, Amsterdam, 1978, p. 61
- [26] G.R. Smith, S. Standil: *Can. J. Phys.* **55** (1977) 1280
- [27] J. Rembieliński: *Int. J. Mod. Phys.* **A12** (1997) 1677
- [28] A.F. Antippa, A.E. Everett: *Phys. Rev.* **D8** (1973) 2352
- [29] A.F. Antippa: *Phys. Rev.* **D11** (1975) 724

- [30] R. Abela, M. Daum, G.H. Eaton, R. Frosch, B. Jost, P.-R. Kettle, E. Steiner: *Phys. Lett.* **146B** (1984) 431
- [31] K. Assamagan, Ch. Brönnimann, M. Daum, H. Forrer, R. Frosch, P. Gheno, R. Horisberger, M. Janousch, P.-R. Kettle, Th. Spirig, C. Wigger: *Phys. Rev.* **D53** (1996) 6065
- [32] E.W. Otten: *Nucl. Phys. News* **5** (1995) No. 1, p. 11
- [33] J. Ciborowski: *Acta Phys. Pol.* **B29** (1998) 113
- [34] J. Ciborowski, J. Rembieliński: *Eur. Phys. J.* **C8** (1999) 157
- [35] J.J. Steyaert: in *Low Temperature Detectors for Neutrinos and Dark Matter II*, eds. L. Gonzalez-Mestres and D. Perret-Gallix, Editions Frontières, 1988, p. 129
- [36] J.J. Steyaert: *From Experiment to Theory: an Evidence for New Physics Far Away from Standard Models, Useful Mainly in Astrophysics*, preprint, 1999
- [37] E. Recami: *Riv. Nuovo Cimento* **9** (1986) No. 6
- [38] E. Recami: *Int. J. Theor. Phys.* **25** (1986) 905; **26** (1987) 913