ON THE PHENOMENOLOGY OF TACHYON RADIATION. (*)

Ron Folman

Physics Department, Weizmann Institute of Science, Rehovot, Israel.

and

Erasmo Recami

Facoltà di Ingegneria, Università Statale di Bergamo, Dalmine (BG), Italy;
I.N.F.N., Sezione di Milano, Milan, Italy; and
Dept. of Applied Mathematics, State University at Campinas, Campinas, S.P., Brazil.

Abstract – We present a brief overview of the different kinds of electromagnetic radiations expected to come from (or to be induced by) space-like sources (tachyons). New domains of radiation are here considered; and the possibility of experimental observation of tachyons via electromagnetic radiation is discussed.

PACS nos.: 14.80.P ; 52.25 ; 41.10 ; 03.30 .
Keywords: Tachyon radiation; Cherenkov radiation; Refraction index; Drag effect; Plasmas.

[0(*)] Work partially supported by INFN–Sezione di Catania, MURST and CNR (Italy), and by CNPq (Brazil).

1. Introduction – The theoretical possibility of existence of Superluminal ($V^2 > c^2$) particles has been discussed thoroughly and seems to need no introduction.[1] Recently, this topic received new impulse by a series of interesting experimental results, about the seemingly Superluminal speeds associated *both* with evanescent waves (let us recall the Cologne, Berkeley and Florence results),[2] − 4 *and* with electron neutrinos[5] and muon neutrinos.[6]

In the past, all experiments performed with the aim of detecting tachyons had reported —in practice— negative results;[7] but those searches were mainly devoted to look for the electro-magnetic (EM) emission signature of tachyons, on the basis of poor theoretical assumptions. In the following, we first define the different forms of expected EM radiation due to tachyons, and then re-examine previous conclusions about tachyon radiations. Finally, we discuss a possible framework for future experiments. We shall always confine ourselves within the realm of (relativistic) classical physics. Below, we shall call "bradyon" any sub-luminal ($v^2 < c^2$) particle.

2. Radiation definitions – Since it seems that clear definitions are still lacking with regard to the possible forms of EM radiation, let us define what follows:

Definition a): << Let us call IER any EM radiation *induced from a medium* by a particle (bradyon or tachyon), i.e., coming from the medium after that the particle has excited it.>> This radiation can a priori be conic ("coherent") or not. Defined as such, this radiation cannot be induced by any particle (in particular, by any tachyon) in vacuum [unless one assumes a suitable vacuum structure, passing to quantum field theories].

Definition b): << Let us call CER (*Cherenkov* EM radiation) any IER provoked by a particle which is outside its "allowed speed–region": i.e., by a bradyon endowed with a speed w larger than the light speed v in the medium, or by a tachyon which happens to possess a speed W smaller than the light speed V in a suitable medium.>> Notice that also CER is not necessarily conic, a priori.

Definition c): << Let us call OER (*ordinary* EM radiation) any radiation emitted directly by the particle itself, due to its acceleration or deceleration.>> Defined as such, this radiation can be emitted by a particle (e.g., by a tachyon) also in vacuum, of course. In this note, we shall not deal with this kind of radiation [for details cf. refs.[1]]. Here, let us only recall the following, particular cases:

case A1) CER(B): in a medium with proper refraction index n_0, we may have CER from a bradyon B when $v < w < c$, that is to say, only when $n_0 > 1$; in this case the CER is *conic*;

case A2) CER(T): in a medium with proper refraction index n_0, we may have CER from a tachyon T when $c < W < V$, that is to say, only when $n_0 < 1$; in this case the CER will be *non-conic*, since the tachyon position will always remain inside the (spherical) waves;

while:

case B1) OER(B): in vacuum (for instance), the OER from a bradyon B is *non-conic*;

case B2) OER(T): in vacuum (for instance), the OER from a tachyon T will be on the contrary *conic*.

3. Tachyon radiation domains – Recami and Mignani[1] observed that the experimental searches for (tachyonic) CER(T) had probably failed due to the mere fact that no such radiation is expected to be emitted by the vacuum, nor by *normal* sub-luminal media. They overlooked, however, that —as we saw for example under point *A2*) above— a CER(T) *can* come also from *suitable* sub-luminal media. We want here to discuss such a possibility. Let us specify that below we shall refer ourselves to sub-luminal observers O only, while a medium cam be either sub-luminal $[u^2 < c^2]$ or Super-luminal $[U^2 > c^2]$ with respect to the observer O.

Recami and Mignani had based themselves on their generalization of the "drag effect" for Superluminal speeds, i.e., on their extension of the *apparent* (= relative to the observer O) velocity $v \equiv c/n$ of light, in a moving medium, for tachyonic media.[1] The equation for the "apparent" refraction index $n(u)$ was [both for subluminal and for Superluminal speeds u]:

$$n \;\equiv\; n(u) \;=\; \frac{n_0 c + u}{c + n_0 u} \; . \tag{1}$$

In ref.[1], however, only the particular case was considered in which the proper refraction index n_0 of the considered medium is larger than 1 (see our Fig.1, as well as Fig.22 in the first one of refs.[1]). This led them to claim: (i) that a bradyon B is not expected to "emit" CER(B) in any Super-luminal media, due to the fact that the apparent refraction index n in this case is smaller than 1, thus giving rise to an apparent light speed v in the medium larger than c: a speed that B will never exceed [actually, in Fig.1 we can see that Super-luminal media possess a refraction index n which is smaller than 1 and aims asymptotically at $1/n$]; and, because of the Duality Principle:[1] (ii) that analogously a tachyon T will not be able to "emit" CER(T) in any sub-luminal media.

But, of course, media also exist possessing a proper refraction index n_0 *smaller* than 1; in this case, eq.(1) yields the behaviour depicted in our Fig.2. And from Fig.2 one can infere that in fact a tachyon T can "emit" CER(T) in a sub-luminal medium with $n < 1$, provided that its speed w obeys the constraint $c < w < v$, where $v = c/n > 1$.

Analogously, because of the Duality Principle, a bradyon B will be able to "emit" CER(B) in a Super-luminal medium such that $n_0 < 1$ (as can be derived from Fig.2).

4. Experimental considerations. – The fact that tachyons T are now expected to emit CER(T) also in *suitable* sub-luminal media (for speeds ranging between c and c/n) has of course some experimental consequences. In fact, we do not know of any Super-luminal media; on the contrary, sub-luminal media with $n_0 < 1$ are available, e.g., in the form of *plasmas*. We shall therefore consider the possible signature of CER(T) in a plasma.

Let us first *assume* the following: Any particle in a medium will find its way to loose quickly energy (e.g., by inducing emissions from the medium), when it happens to be outside its "allowed speed–region"; namely, in the case of a tachyon, when its speed w is between c and the apparent light speed v. This Assumption seems to be supported also by the observation that —in the case of bradyons— the function $-\mathrm{d}E/\mathrm{d}x$ vs. speed presents for most particles an enhancement when crossing the $v = c/n$ line (the so-called "relativistic rise"). Such an enhancement, incidentally, is observed in several energy–deposit channels, and not solely in the EM channel (which constitutes just a portion of the energy loss).

A tachyonic CER(T) in a plasma is expected to be non-coherent, i.e., *non-conic*; and therefore weak. In fact, the interested tachyon has to move slower than the apparent light speed, so that the standard Cherenkov geometry is not realysed. This does constitute a real difficulty for any experimental search dedicated to CER(T) in plasmas, and it might seem preferable to look for *conic* IER(T) in the speed range above c/n, if it weren't for our Assumption above. Actually, tachyon interactions with electromagnetic fields and with ordinary matter are not yet completely known [different effects, such as that a point charge when Super-luminal is expected to be spread over a double cone,[1,8] have not yet been fully dealt with]; and in particular we do not know how and how much IER would be emitted by a tachyon. In any case, those tachyon interactions can be predicted to be weak, on the basis of the fact that a Super-luminal electric charge is predicted to behave as a magnetic pole[1,9] [in the sense, roughly speaking, that the intensities of the electric and magnetic fields generated by a charge get interchanged between themselves when passing from the speed w to the "dual" speed $W = c^2/w$].[10] Therefore, in force of our Assumption, we are entitled to consider as theoretically reasonable a search for CER(T), in the speed range c to c/n.

We might then suggest the use of an array of detectors, situated parallel to the tachyonic flight path, in order to try to observe the advance of the Super-luminal source. Another suggestion would be to confine the plasma within a $n > 1$ substance (the border between the two substances being parallel to the expected tachyonic track and close to it), in which a part of the radiation circles emitted by the plasma will form a coherent

Cherenkov front with angles larger than those permitted for bradyon sources.

5. Conclusions and discussion – After having mentioned some recent experimental results, that might indicate the existence of Superluminal objects, we revised and corrected in this note the theoretical reasons why it seemed till now that direct detection of Cherenkov radiation, induced by tachyons in ordinary (subluminal) media, was impossible.

Then, we presented arguments favouring —on the contrary— the *possibility* of searching for Cherenkov emission induced by tachyons *in* (subluminal) *plasmas*.

We wish to conclude with the following discussion.

First of all, one should not forget that, as mentioned above, while the electric interaction constitutes the major interaction betwen a charged bradyon and matter, on the contrary the magnetic interaction will possibly be the dominant one for a charged tachyon interacting with ordinary matter.[1,9,10] So that, generally speaking, one ought to try to detect Super-luminal sources via the magnetic field they are supposed to generate. More in general, it would be quite useful to solve —before all— the Maxwell equations suitably generalized for Superluminal charges, in order to find out the electric and magnetic field that a charged tachyon is expected to create in space-time; since such a study (preliminary performed in ref.[11], at an elementary level) will indicate how a Superluminal charge is expected to interact with ordinary matter. Let us recall that two different generalizations for Maxwell equations have been proposed: cf. refs.[1,10] and refs.[12], respectively.

Second, the question of wherefrom (i.e., from what sources) tachyons are expected to come is still an open problem; even if different sources (including cosmic showers[13]) have been suggested.[1,14]

At last, let us remark that another interesting search could be the one devoted to detect the (conic) OER(T) emitted by tachyons —in vacuum, for instance— when accelerating because of *bremsstrahlung*–type processes.

Acknowledgements: This brief note is dedicated to the memory of the late Professor W. Yourgrau and the many discussions we had with him (and T.K. Shah) on similar subjects at Trieste about fifteen years ago. One of us (R.F.) would like to thank M.T. Teli for enlightening discussions; while the second author (E.R.) acknowledges the kind collaboration of A. Bugini, R. Garattini, L. Lo Monaco, R. Monaco, E.C. de Oliveiras, M. Pignanelli, G.M. Prosperi, W.A. Rodrigues, S. Sambataro, P. Saurgnani, M.T. Vasconselos and particularly F. Raciti and G. Salesi.

Figure Captions

Fig.1 – The "drag effect" behaviour considered by Recami and Mignani,[1] on the basis of equation (1). It refers to the case in which the proper refraction index of the considered medium is $n_0 > 1$.

Fig.2 – The "drag effect" complementary behaviour [still derived from eq.(1)] for the case in which the proper refraction index of the considered medium is $n_0 < 1$. This case had been overlooked in ref.[1]. For the possible consequences, see the text.

References

[1] See, e.g., E. Recami and R. Mignani: Rivista Nuovo Cim. **4** (1974) 209-290, E398; E. Recami: Rivista Nuovo Cim. **9** (1986), issue no.6, pp.1-178, and refs. therein.

[2] A. Enders and G. Nimtz: J. Physique I **2** (1992) 1693; **3** (1993) 1089; Phys. Rev. B**47** (1993) 9605; E**48** (1993) 632; (subm. to Phys. Rev. Lett.); and (in preparation); G. Nimtz, A. Enders and H. Spieker: J. Physique I **4** (1994) 1; "Photonic tunnelling experiments: Superluminal tunnelling", in *Wave and particle in light and matter (Proceedings of the Trani Workshop, Italy, Sept. 1992)*, ed. by A. van der Merwe and A. Garuccio (Plenum; New York, in press).

[3] A.M. Steinberg, P.G. Kwiat and R.Y. Chiao: Phys. Rev. Lett. **71** (1993) 708, and refs. therein; Scientific American **269** (1993) issue no.2, p.38. See also P.G. Kwiat, A.M. Steinberg, R.Y.Chiao, P.H. Eberhard and M.D. Petroff: Phys. Rev. A**48** (1993) R867; E.L. Bolda, R.Y. Chiao and J.C. Garrison: Phys. Rev. A**48** (1993) 3890.

[4] A. Ranfagni, P. Fabeni, G.P. Pazzi and D. Mugnai: Phys. Rev. E**48** (1993) 1453, and refs. therein.

[5] V.S. Olkhovsky, E. Recami and A.K. Zaichenko: Solid State Commun. **89** (1994) 31.

[6] M. Baldo Ceolin: "Review of neutrino physics", to appear in *Proceed. XXIII Int. Symposium on Multiparticle Dynamics (Aspen, CO; Sept. 1993)*; Ch. Weinheimer et al.: Phys. Lett. B**300** (1993) 210; E. Holzschuh, M. Fritschi and W. Kündig: Phys. Lett. B**287** (1992) 381; H. Kawakami et al.: Phys. Lett. B**256** (1991) 105; R.G.H. Robertson et al.: Phys. Rev. Lett. **67** (1991) 957.

[7] See, e.g., E. Giannetto et al.: Phys. Lett. B**178** (1986) 115 and refs. therein. See also the second one of refs.[1].

[8] For some experimental data, and their discussion, see refs.[1] and refs. therein.

[9] Cf., e.g., A.O. Barut, G.D.Maccarrone and E. Recami: Nuovo Cimento A**71** (1982) 509; Lett. Nuovo Cim. **37** (1983) 345.

[10] R. Mignani and E. Recami: Phys. Lett. B**62** (1976) 41; Lett. Nuovo Cim. **9** (1974) 367; Nuovo Cimento A**30** (1975) 533.

[11] See, e.g., M.M. Ferreira: (in preparation).

[12] H.C. Corben: Nuovo Cimento A**29** (1975) 415; Int. J. Theor. Phys. **15** (1976) 703; in *Tachyons, monopoles, and related topics*, ed. by E. Recami (North-Holland; Amsterdam, 1978), p.31.

[13] Cf., e.g., R.W. Clay and P.C. Crouch: Nature **248** (1974) 28.

[14] Cf., e.g., T. Alvager and M.N. Kreisler: Phys. Rev. **171** (1968) 1357; C. Baltay et al.: Phys. Rev. D**1** (1970) 759; J.S. Danburg et al.: Phys. Rev. D**4** (1971) 53.