ISTITUTO NAZIONALE DI FISICA NUCLEARE

Sezione di Catania

INFN/AE-78/1
1 Febbraio 1978

P. Castorina and E. Recami: HADRONS AS COMPOUNDS OF BRADYONS AND TACHYONS.

Servizio Documentazione
dei Laboratori Nazionali di Frascati

Istituto Nazionale di Fisica Nucleare
Sezione di Catania

INFN/AE-78/1
1 Febbraio 1978

P.Castorina[(+)] and E. Recami[(*)]: HADRONS AS COMPOUNDS OF BRADYONS AND TACHYONS[(o)].

SUMMARY. -

In a series of recent papers, Corben recovered various properties of many hadronic resonances by considering them as compounds of a bradyon and of one (or more) tachyons. In this note we explain why that success follows from considering the tachyon four-momenta orthogonal to the bradyon one, and why - in such a case - the bradyon and tachyons can be formally dealt with as non-interacting even if they keep partecipating in the "self-trapping". Finally we attempt, in a preliminary way, understanding (on the basis of the model by Caldirola, Pavšič and Recami where hadrons are condidered as "strong" blach-holes") why in general those compound hadrons decay and why in this decay the trapped tachyons are - quantum-mechanically - emitted in the corresponding bradyonic form.

(+) Scuola di Specializzazione in Fisica, Università di Catania, Catania, Italy.

(*) Also: Istituto di Fisica Teorica, Università di Catania, Catania, Italy; and C. S. F. N. eS. d. M. , Catania.

(o) Work partially supported by MPI, ex-art. 286 T. U.

Since a decade[(1)] it has been suggested that virtual particles[(2)] (having negative[(3)] four-momentum squares: $p^2 < 0$) can be classically interpreted in terms of tachyons[(1-4)]. In particular, resonances were proposed to be composed of bradyons and tachyons[(1-5)]. More generally, the possible rôle of tachyons in hadron structure has been in the past frequently stressed[(5)].

Very recently, CORBEN[(6)] started - within "Extended Relativity[(7)]- from the known fact[(8)] that a free bradyon (=slower-than-light particle) of mass m_1 and a free tachyon of mass m_2 can trap each other in a relativistically invariant way. If $m_1 > m_2$ the compound particle will always be a bradyon[(8)]. CORBEN[(6)] noticed that the mass of the compound bradyon is

$$m^* = \sqrt{m_1^2 - m_2^2} \,, \tag{1}$$

provided that the four-momenta P and p of the two particles are supposed to be orthogonal (such a condition being a relativistically invariant one):

$$P \perp p \longrightarrow P_\mu \, p^\mu = 0 \tag{2}$$

Then, CORBEN[(6)] has been able to derive masses and quantum numbers of many baryonic and mesonic resonances by considering them as originated from the self-trapping of a bradyon (B) and one or more tachyons (T), and by using the formalism of relativistic quantum-mechanics. Thus, he put forth a Lorentz-invariant "bootstrap"theory. Moreover, he found the mass-differences of various members of given isospin-multiplets by letting hadrons trap space-like leptons.

In this paper we wish:

1) to clarify the meaning of Corben's condition eq. (2), (and rederive eq. (1),within a more detailed analysis of classical mechanics with tachyons;
2) to explain way the "ground-states" of the compound hadrons correspond to an infinite speed ("trascendent") tachyon[(7)] trapped by a bradyon;
3) to attempt understanding, on the basis of the model where hadrons are considered as "strong black-homes"[(9,10)], or "strong (micro) universes"[(9)], the fact that in general these compound hadrons decay and that in such a decay[(11)] the trapped tachyons can be emitted in the corresponding bradyonic form[(7)].

Let us start with point 1). The condition eq. (1) means that the constituents B and T have divergent relative speed, as follows e. g. from

Fig. 12c) of ref. (7). In particular, if B is considered at rest - as in the following - then it is evident that the four-momentum P of B is aligned along the E-axis, whilst the four-momentum p of T lies on the hyperplane E=0 so that.

$$P \perp p \quad ; \qquad (2')$$

notice that the condition (2') is Lorentz-invariant and then it will remain true also in different frames (where B is no more at rest): cf. Fig. 1 of ref. (7).

We want now to study in detail (in the case of motions along the x--axis, for simpliticy) the effect of the fourmomentum-conversation law on the absorbtion of a tachyon - with rest-mass m and speed V - by a bradyon with rest-mass M:

$$|\vec{p}| = \frac{m}{2M^2}\, m\, |\vec{P}| + \sqrt{(\vec{P}^2+M^2)(m^2+4M^2)+M^2\Delta} \qquad (3)$$

where $\vec{p}$, $\vec{P}$ are the tachyon and bradyon 3-momenta, respectively, and where $\Delta \equiv M'^2 - M^2 = 2p_\mu P^\mu - m^2 \gtrless 0$ is the difference between the initial (before absorption) rest-mass M and the final (after absorption) rest--mass M' of the bradyon B. When choosing, as before, the rest-frame of B as our reference-frame, then eq. (3) becomes

$$|\vec{p}| = \frac{m}{2M} \sqrt{m^2 + 4M^2 + \Delta} \qquad (3')$$

which yields

$$|V| = \sqrt{1 + 4M^2/(m^2+\Delta)} \qquad (4)$$

It is intuitive e. g. that an infinite-speed tachyon - carrying no energy but a finite (minimal) 3-momentum $|\vec{p}| = m$, - cannot be absorbed by a body B at test, unless it lowers its rest-mass. Actually, from eq. (4) it immediately follows that bradyon B can absorb trascendent tachyons or antitachyons ($|V| = \infty$) only when it lowers its rest-mass M of the amount $\Delta = m^2$, so that the rest-mass of the final "compound" will be (as immediately deducible also from $\Delta = 2p_\mu P^\mu - m^2$ when $p_\mu P^\mu = 0$):

$$M^* = \sqrt{M^2 - m^2}. \qquad (1')$$

Since the direction of trascendent tachyons along their motion-line is not defined (in fact they can be equivalently considered as antitachyons going the opposite way(7-12)), eq. (1') must hold also in the case of emission of a trascendent tachyon or antitachyon by a body at rest.

Actually, from the 4-momentum conservation-law in the case of tachyon emission

$$\begin{cases} M = \sqrt{\vec{p}^2 - m^2} + \sqrt{\vec{p}^2 + M^2 + \Delta} \quad , \\ \Delta \equiv M'^2 - M^2 = - m^2 - 2M\sqrt{\vec{p}^2 - m^2} \lesssim -\vec{p}^2 \lesssim - m^2 , \end{cases}$$

eq. (1') follows again.

Let us pass to point 2). We have to remember that, for instance in the gravitational field associated to a bradyonic source, a test-tachyon will suffer in our cosmos a repulsive force(13) (even if, due to another change of sign entering the fundamental equation of tachyon mechanics, the test-tachyon will kinematically "bend" - or "fall down" - towards the gravitational source). In other words, from the dynamical (and energetical) viewpoint, the test-tachyon appears as gravitationally repulsed, but from the kinematical one it appear as gravitationally "attracted".

For semplicity, let us consider the trapped tachyon as rotating along circles around the trapping bradyon.

At this point, we shall follow the model in ref. (9), i. e. we shall assume that hadrons (="strong universes") are systems similar - within a dilatation-covariant theory(9) - to our cosmos (="gravitational universe"). Therefore, inside the "compound hadron" the tachyon T will feel a (strong) field similar to the gravitational one, - in the sense that the strong field is got from the gravitational field through a contraction(9) by the suitable scale factor ϱ . Namely, the test-tachyon T is subject to the force (see ref. (9))

$$|\vec{F}| = \frac{m}{\sqrt{1-\beta^2}}\, a = \frac{m}{\sqrt{\beta^2-1}} \left[\frac{NM}{r^2} + \frac{Hr}{3} + \cdots \right] \tag{5}$$

where $N \equiv \varrho^{-1} G \approx 10^{40} G$, quantity G being the gravitation universal-constant(9). The ("classical-like") first step in eq. (5) is relativistically correct when(14) - and only when - we assume $\vec{F}$ orthogonal to the motion of T, i. e. totally centripetal (in accordance with our previous assumption that the trapped test-tachyon already reached an equilibrium-state and makes circular revolutions around the bradyon B). The eq. (5) reduces(9) to the first term for small values ($r \lesssim 1$ Fermi) of r. If you prefer to avoid adopting this(9) model, then it is enough to postulate that the strong force behaves with respect to tachyons analogously to the gravitational one. In any case, the total energy of the rest-tachyon will be

$$E = \frac{mc^2}{\sqrt{\beta^2-1}} + \frac{NmM}{r\sqrt{\beta^2-1}} \tag{6}$$

where the first term is the total free energy and the second one the potential energy. Instead of NmN, if you prefer, you may write gg' (the latter quantities being the strong-charges corresponding to m, M[9]). Let us repeat that our procedure depends on eq. (6), rather than on eq. (5): we can adopt any variation of eq. (5) compatible with eq. (6). (Even our very procedure can be rephrased, by differently choosing the form of the Action Principle and the Lagrangian for tachyons).

If we accept that every physical object tends to posses the minimal potential energy, then we get (when r is finite) that the test-tachyon T will tend to rotate around B with infinite speed:

$$1/\sqrt{\beta^2 - 1} \longrightarrow 0 \; . \therefore . \; \beta \longrightarrow \infty; \qquad (7)$$

we can conclude that, far from perturbations (i. e. in its "ground state"), any bradyon-tachyon compound will be constituted of bradyon B and a tachyon having divergent speed V = ∞ relative to B, so as to satisfy condition (2) or (2').

Let us moreover notice that, if

$$|\vec{F}| \simeq \frac{mNM}{r^2 \sqrt{\beta^2 - 1}},$$

then, when r is finite and when $\beta \longrightarrow \infty$, we get $|\vec{F}| \longrightarrow 0$. For a tachyon T, therefore the trapping force (which holds T on a circular orbit) tends to zero when the tachyon tends to become trascendent (i. e., to have $\tilde{m} \equiv m/\sqrt{\beta^2 - 1} = 0$). In such a case the interaction seems to be negligible, even if the "self-trapping" keeps itself. This fact appears to explain why CORBEN[6] could consider the B-T compounds as couples of two free particles[6,1].

Our present note might have its natural end here. Since we want to consider also point 3), let us - however - add the following. Let us consider a stable hadron h (e. g. a proton p), at rest. If we regard it as a "strong black-hole"[9,10] in the spherically symmetric case and in the "continuous" approximation the flux of such tachyons can be at any instant described (around and outside!, the black-hole) by outgoing - and incoming - spherical waves of the type

$$I \propto \left| \frac{e^{\pm imr}}{r} \right|^2 . \qquad (8)$$

Now, in the naive formulation of Extended Relativity[7], when one confines himself merely to the subluminal frames, the rest-mass of tachyons can trivially be assumed to be $m = \pm i\mu$; (μ real). Then, it is noticeable that we get from eq. (8) the Yukawian Potential by the substitution $m = + i\mu$ in the case of outgoing waves, and by the substitution $m = - i\mu$ in the case of incoming waves. In other words, in the static limit, the Yukawian Potential can be regarded as the "continuous" description of outgoing tachyons and of incoming antitachyons[7]. This accords with the theory by Caldirola, Pavšič and Recami[9].

To clarify this point, let us study the motion of outgoing tachyons T, emitted e. g. by p, when affected by the (strong) central potential surrounding p. Since the considered, hadronic[7] tachyons T are outside the "strong black-hole" p, we can now consider that strong field as attractive (e. g. because of Van-der-Waals-type interactions: cf. refs. (9)). Tachyons T, under the field action, lose kinetic energy[7] ($E_{cin} \longrightarrow 0$) and thus their speed - but not their position! - diverges[7] ($V \longrightarrow \infty$); let us suppose that this happens at a point F, at finity: cf. Fig. 1. As soon as T overtakes the position P (for instance moving along the sinusoidal world-line in Fig. 1, it starts appearing to p as an antitachyon $\overline{T}$ endowed with ingoing radial motion[7]. As a conclusion, the tachyons classically radiated by p can perform (outside p) half a "harmonic" oscillation, being afterwards reabsorbed. This classically re-

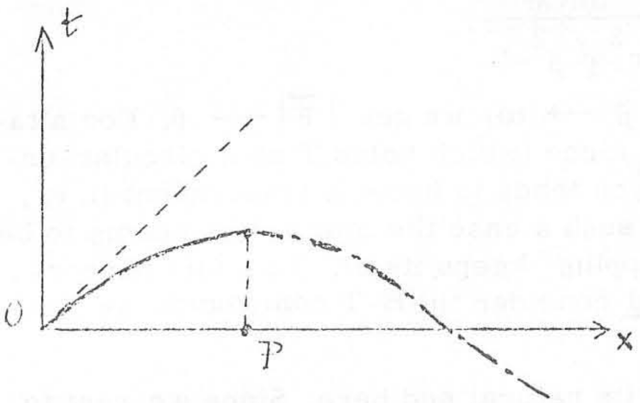

FIG. 1 - Possible world-line of a typical tachyon of the possible "tachyonic coulds" of hadrons. For the interpretation, see the text.

produces the behaviour of the "virtual cloud" ordinarily considered in quantum field theory (QFT).

Let us eventually come to our last point, 3), and analyse - for simplicity's sake - only processes as the one depicted in Fig. 2. The Fig. 2 represents the process where one of the two entering protons, reached[9] a distance $d \simeq 10^{-13}$ cm from the second one, catches a tachyon (e. g. a tachyonic pion[7])of its "tachyon cloud". Following refs(9), we shall consider all hadrons —both the entering protons p and the tachyonic pion $\pi_V \equiv \pi_T$ — as strong black-holes[9]. The two "strong black-holes" p_1 and π_T can melt, forming a unique, new "strong-hole" (that classical cannot bifurcate any more[16] into two bradyonic "strong blck-holes").

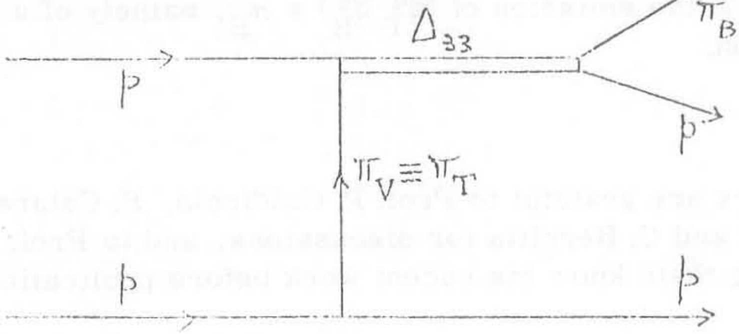

FIG. 2 - A simple process. For the classical interpretation of the virtual exchange in terms of tachyons, and of the hadrons in terms of "strong black-holes", see the text.

The new "strong black-hole", Δ_{33}, in general will be however a hadronic Resonance , i. e. an unstable hadron. The decay of such a resonance into two subluminal hadrons[17] - classically forbidden - can be explained by quantum mechanisms as HAWKING's[18], which easily allow the "evaporation" of the (ordinary) gravitational black-holes and then[9] of the strong ones. Namely, due to the celebrate Hawking effect, the Schwarzschild black-holes are predicted to avaporate by emitting a thermal spectrum corresponding to the Hawking temperature[18, 9]

$$T = \frac{\hbar c}{4 \pi k r_S} \quad , \quad r_S \equiv 2GM/c^2 \qquad (9)$$

quantity k being the boltzmann constant. In the case of strong black-holes, from relation (9) with $r_S \simeq 10^{-13}$ cm one gets[9]

$$T \approx 2 \times 10^{11} \ ^{o}K \qquad (9')$$

which corresponds to an evaporation time of the order of $\Delta t \simeq 10^{-23}$ seconds. For problems related to such an expression, see e. g. refs. (9).

Just for examplification purposes - and with reference to the particle structures in terms of quarks -, let us consider $p \equiv (q^1 \ q^2 \ q^3)$ and $\pi_T \equiv (q^4 \ \bar{q}^5)$. The ensemble of the fourth and fifth quark remains of tachyonic type after the melting of the two "strong black-holes", so as to be able to be later (quantum-mechanically) emitted[18] as an ordinary, bradyonic[17] pion. More specifically, if we wanted to follow the philosophy of refs(6), then we might e. g. consider $\pi_T \equiv (q^4_B \ \bar{q}^5_T)$, where we indicated also the possible "bradyonic" or "tachyonic" character of the constituent quarks. In such a philosophy, when p and π_T merge together, we should get roughly speaking $\Delta_{33} \equiv (q^1 q^2 q^3 q^4_B \bar{q}^5_T)$; afterwards, in the Hawking-type evaporation, we would obtain according to ref. (17) the emission of $(q^4_T \bar{q}^5_B) \equiv \pi_B$, namely of a bradyonic (ordinary) pion.

The authors are grateful to Prof. P. Caldirola, F. Catara, R. Mignani, M. Pavšić and C. Berritta for discussions, and to Prof. H. C. Corben for letting them know his recent work before publication.

REFERENCES. -

(1) E. Recami, "Possible... and Comments on Tachyons, Virtual Particles, Resonances", Univ. of Milano report IFUM-088/SM (1968), pages 4÷8; Giornale di Fisica 10, 195 (1969), pages 203÷205; V. S. Olkhovsky and E. Recami, Nuovo Cimento 63A, 814 (1962), page 822. See also refs. (4).

(2) See e. g. F. T. Hadjioannou, Nuovo Cimento 44, 185 (1966); I. Ferretti and M. Verde, Atti Accad. Scienze Torino (1966), page 318.

(3) Let us choose the signature (+---). Natural units will be adopted when convenient.

(4) See also E. C. G. Sudarshan, Ark. Phys. 39(40), 585(1969); Phys. Rev., 1D, 2428 (1970); A. M. Gleeson, M. G. Gundzig, E. C. G. Sudarshan and A. Pagnamenta, Particles and Nuclei 1, 1 (1970); Phys. Rev. D6, 807 (1972); E. Van Der Spuy, Phys. Rev. D7, 1106 (1973); C. Jue, Phys. Rev. D8, 1757 (1973).

(5) M. Baldo and E. Recami, Lett. Nuovo Cimento 2, 643 (1969), page 646; R. Mignani and E. Recami, Nuovo Cimento 30A, 533 (1975), pages 583 ÷ 539; Phys. Letters 65B, 148 (1976), footnotes at page 149; E. Recami and R. Mignani, Phys. Letters 62B, 41 (1976), page 43; E. Recami, R. Mignani and G. Ziino, in Recent Development in Relativistic QFT and its Application, vol. 2 (Wrocław, 1977), page 269; M. Pavsic and E. Recami, Nuovo Cimento 36A, 171 (1976), particularly footnotes (17, 21, 32).

(6) H. C. Corben, Lett. Nuovo Cimento 20, 645 (1977); three Preprints (Scarborough College, West Hill, Ontario), Aug., Sept. and Nov. 1977, (submitted for publication); and in Tachyons and Related Topics, E. Recami editor, (North Holland, 1978), to appear.

(7) E. Recami and R. Mignani, Rivista Nuovo Cimento 4, 209÷290, 398 (1974) and references therein. See also the volume Tachyons and Re-

lated Topics, E. Recami editor, (North Holland, 1978), to appear.
(9) P. Caldirola, M. Pavšič, preprint INFN/AE-77/10 (1977), to appear in Nuovo Cimento B, and references therein; Preprint INFN/AE-77//14 (1977), to appear in Phys. Letters A, and references therein; E. Recami and P. Castorina, Lett. Nuovo Cimento 15, 347 (1976); R. Mignani, Lett. Nuovo Cimento 16, 6 (1976); F.J.Tipler, Nature 270, 500 (1977); T. W. B. Kibble, Trieste Preprint IC/75/5 (1976); V. De Sabbata and P. Rizzati, Lett. Nuovo Cimento 20, 525 (1977); F. Hoyle and J. Narlikar, Nature 218, 123 (1968). See also refs. (10).
(10) J. Pati and A. Salam, Phys. Letters 61B, 375 (1976); C. Sivaram and K. P. Sinha, Lett. Nuovo Cimento 8, 324 (1973); 9, 740 (1974), 10, 227 (1974); P. Roman and J. Haavisto, Boston Univ. Preprint BU--PNS-14(1977); E. W. Mielke, Phys. Rev. Lett. 39, 530(1977).
(11) See Refs. (9), and M. Pavšič and E. Recami, Lett. Nuovo Cimento 19, 273 (1977); V. De Sabbata, M. Pavšič and E. Recami, Lett. Nuovo Cimento 19, 441 (1977). See also the second ref. (8), and G. Cavalleri and G. Spinelli, Lett. Nuovo Cimento 6, 5 (1973).
(12) M. Pavšič and E. Recami, Nuovo Cimento 36A, 171 (1976); M. Pavšič and E. Recami and G. Ziino, Lett. Nuovo Cimento 17, 257 (1976); E. Recami, Catania Univ. Preprint PP/571 (1977), in press in Lett. Nuovo Cimento.
(13) See E. Recami and R. Mignani, ref. (7). See also R. O. Hettel and T. M. Helliwell, Nuovo Cimento B13, 82 (1973); E. Honig, K. Lake and R. C. Roeder, Phys. Rev. D10, 3155 (1974); A. K. Raychaudhuri, Journ. Math. Phys. 15, 856 (1974); R. C. Vaydia, Curr. Sc. (India) 40, 651 (1971); R. W. Fuller and J. A. Wheeler, Phys. Rev. 128, 919 (1962).
(14) See e. g. E. Recami Giornale di Fisica 6, 275 (1965).
(15) Cf. e. g. E. C. G. Sudarshan, Phys. Rev. 1D, 2428 (1970).
(16) S. W. Hawking, Comm. Math. Phys. 25, 152 (1972).
(17) V. De Sabbata, M. Pavšič and E. Recami ref. (11); E. Recami, second ref. (8).
(18) S. W. Hawking, Comm. Math. Phys. 25, 152 (1972); 43, 199 (1975); Scient. Amer. 236, 34 (Jan., 1977); and in "GR8 Lectures" (Waterloo, Ontario, 1977). See also B. Müller, W. Greiner and J. Rafelski, Phys. Letters 63A, 181 (1977); H. Bohr and H. B. Nielsen, Nuclear Phys. B128, 275 (1977); A. Salam and J. Strathdee, Trieste Preprint IC/76/107 (1977).