Relativistic Selftrapping of Hadrons.

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(ricevuto l'8 Settembre 1977)

It has been shown (1) that a free bradyon of mass m_1 and a free tachyon of mass m_2 may trap each other in a relativistically invariant way, forming, if $m_1 > m_2$, another bradyon with mass $m = (m_1^2 - m_2^2)^{\frac{1}{2}}$. This is possible because the equations

$$\Box\psi_1 = \varkappa_1^2 \psi_1 , \qquad \Box\psi_2 = -\varkappa_2^2 \psi_2 \qquad (\varkappa_1 = m_1 c/\hbar,\ \varkappa_2 = m_2 c/\hbar)$$

yield the equation

$$\Box\psi = \varkappa^2 \psi ,$$

with $\psi = \psi_1 \psi_2$, $\varkappa^2 = \varkappa_1^2 - \varkappa_2^2$ provided that

$$\partial_\mu \psi_1 \partial_\mu \psi_2 = 0 ,$$

i.e. provided that the energy-momentum four-vectors of the two particles are orthogonal. This, of course, is a relativistically invariant parameter-free condition, and it defines a type of invariant interaction between the two particles. Any two plane waves with momenta $\boldsymbol{p}_1, \boldsymbol{p}_2$ may then combine to form a plane wave of momentum $\boldsymbol{p}_1 + \boldsymbol{p}_2$, mass $(m_1^2 - m_2^2)^{\frac{1}{2}}$ provided that the angle θ_{12} between $\boldsymbol{p}_1$ and $\boldsymbol{p}_2$ satisfies the condition

$$p_2^2 \sin^2\theta_{12} < m_2^2 c^2 .$$

In addition, several spacelike states with masses $m_2, m_3 \ldots$ could combine with a timelike state to give a mass $(m_1^2 - m_2^2 - m_3^2 \ldots)^{\frac{1}{2}}$ provided that this quantity is real.

There exists a remarkable number of examples in the meson spectrum where this « invariant trapping » of timelike and spacelike waves is experimentally verified, and the purpose of this note is to provide similar evidence from the observed baryon spectrum. The basic idea, as first emphasized relatively recently (2), is that tachyons are

(1) H. C. CORBEN: *A relativistically invariant bootstrap*, Scarborough College preprint (August 1977), submitted to *Proc. Erice Conference on Tachyons and Related Topics* (1976).

(2) M. BALBO, G. FONTE and E. RECAMI: *Lett. Nuovo Cimento*, **4**, 241 (1970); R. MIGNANI and E. RECAMI: *Riv. Nuovo Cimento*, **4**, 209 (1974); H. C. CORBEN: *Lett. Nuovo Cimento*, **11**, 533 (1974).

TABLE I. – *Fifteen relations between 17 different baryon states and 11 different meson states, using data of ref.* (3). Combined with table I of ref. (1), this gives 27 different relations between 17 different baryon states and 18 different meson states.

Timelike state			Spacelike state			Composite	Identification		
State	$I(J^P)$	m_1^2	State	$I(J^P)$	m_2^2	$m_1^2-m_2^2$	State	$I(J^P)$	m^2
$\Delta(1670)$	$\frac{3}{2}(\frac{3}{2}^+)$	2.79 ± 0.33	$\bar{\mathcal{N}}$	$\frac{1}{2}(\frac{1}{2}^-)$	0.88	1.91	A_2 (1310)	$1(2^+)$	$1.72\ \pm0.13$
$\Delta(1910)$	$\frac{3}{2}(\frac{1}{2}^+)$	3.65 ± 0.38	$\bar{\mathcal{N}}$	$\frac{1}{2}(\frac{1}{2}^-)$	0.88	2.77	ρ' (1600)	$1(1^-)$	2.56
$\Delta(1890)$	$\frac{3}{2}(\frac{5}{2}^+)$	3.57 ± 0.47	$\bar{\mathcal{N}}$	$\frac{1}{2}(\frac{1}{2}^-)$	0.88	2.69	A_3 (1640)	$1(2^-)$	$2.69\ \pm0.49$
$\Delta(1950)$	$\frac{3}{2}(\frac{7}{2}^+)$	3.80 ± 0.43	$\bar{\mathcal{N}}$	$\frac{1}{2}(\frac{1}{2}^-)$	0.88	2.92	g (1680)	$1(3^-)$	$2.86\ \pm0.30$
$\mathcal{N}(1700)$	$\frac{1}{2}(\frac{1}{2}^-)$	2.89 ± 0.26	$\bar{\Delta}(1650)$	$\frac{3}{2}(\frac{1}{2}^+)$	$2.72\ \pm0.23$	~0.1	π	$1(0^-)$	0.019
$\Lambda(1690)$	$0(\frac{3}{2}^-)$	2.86 ± 0.10	$\bar{\Lambda}$	$0(\frac{1}{2}^-)$	1.245	1.615	f	$0(2^+)$	$1.62\ \pm0.23$
$\Lambda(1830)$	$0(\frac{5}{2}^-)$	3.35 ± 0.17	$\bar{\Lambda}$	$0(\frac{1}{2}^-)$	1.245	2.105	f′	$0(2^+)$	$2.30\ \pm0.06$
$\Sigma(1765)$	$1(\frac{5}{2}^-)$	3.12 ± 0.23	$\bar{\Sigma}$	$1(\frac{1}{2}^-)$	1.42	1.70	f	$0(2^+)$	$1.62\ \pm0.23$
$\Sigma(1940)$	$1(\frac{3}{2}^-)$	3.76 ± 0.43	$\bar{\Sigma}$	$1(\frac{1}{2}^-)$	1.42	2.34	f′	$0(2^+)$	$2.30\ \pm0.06$
$\Sigma(1940)$	$1(\frac{3}{2}^-)$	3.76 ± 0.43	$\bar{\Sigma}(1670)$	$1(\frac{3}{2}^+)$	$2.79\ \pm0.08$	0.97	η'	$0(0^-)$	0.917
$\Sigma(1940)$	$1(\frac{3}{2}^-)$	3.76 ± 0.43	$\bar{\Sigma}(1765)$	$1(\frac{5}{2}^+)$	$3.12\ \pm0.23$	0.64	ω	$0(1^-)$	0.613 ± 0.008
$\Lambda(1690)$	$0(\frac{3}{2}^-)$	2.86 ± 0.10	$\bar{\mathcal{N}}$	$\frac{1}{2}(\frac{1}{2}^-)$	0.88	1.98	$\bar{K}^*(1420)$	$\frac{1}{2}(2^+)$	$2.02\ \pm0.15$
$\Lambda(1690)$	$0(\frac{3}{2}^-)$	2.86 ± 0.10	$\bar{\Sigma}(1670)$	$1(\frac{3}{2}^+)$	$2.79\ \pm0.08$	0.07	π	$1(0^-)$	0.019
$\Xi(1530)$	$\frac{1}{2}(\frac{3}{2}^+)$	2.34 ± 0.02	$\bar{\Xi}$	$\frac{1}{2}(\frac{1}{2}^-)$	1.729	0.611	ω	$0(1^-)$	0.613 ± 0.008
					1.746	0.594			
$\Delta(1232)$	$\frac{3}{2}(\frac{3}{2}^+)$	1.52 ± 0.14	$\bar{\mathcal{N}}$	$\frac{1}{2}(\frac{1}{2}^-)$	0.88	0.64	ρ	$1(1^-)$	0.598

the same type of particle as those with which we are familiar, with the same mass, isospin, strangeness, spin, baryon number and, where applicable, G-parity and charge-conjugation parity. However, the space parities of spacelike mesons and antibaryons are supposed to be opposite to those of the corresponding timelike mesons and baryons. Thus for instance it was shown in ref. (1) that a timelike $\omega(I^G(J^P)C_n = 0^-(1^-)_-)$ could combine with a spacelike $\pi(1^-(0^+)_+)$ to form the timelike state $1^+(1^-)_-$ which not only has the same quantum numbers as the ρ but has a mass of $771\,\text{MeV}/c^2 = (m_\omega^2 - m_\pi^2)^{\frac{1}{2}}$ (the experimental value is $(773 \pm 3)\,\text{MeV}/c^2$). Alternatively a timelike ω could combine with a spacelike ρ to give a timelike π.

Ahother example of the combination of two mesons was cited as a timelike $\varphi(1019.7)$ $0^-(1^-)_-$ with a spacelike $K(493.71)$ $\frac{1}{2}(0^+)$ to form a timelike $K^*(892.2)$ $\frac{1}{2}(1^-)$, the calculated mass being precisely that observed, to four significant figures. Again the K could be regarded as a superposition of a timelike φ with a spacelike K*.

In table I are listed fifteen examples of ways in which a baryon and a spacelike antibaryon appear to combine in this way to give a meson, or, alternatively, fifteen ways in which a baryon and a spacelike meson appear to combine to form another baryon. The I-spin, spin and parity of the final product is always consistent with those of the components. The data used are those published in April 1976 (3). Here we discuss in detail only the last two entries.

According to the second to last line in table I, the $\Xi(1530)$ $(\frac{3}{2}^+)$ could combine with a spacelike $\omega(782.7)$ (1^+) to form the $\Xi^0(1314.9)$ and $\Xi^-(1321.3)$, $(\frac{1}{2}^+)$. We immediately compute the mass of the $\Xi^0(1530)$ as 1530.2 MeV/c and that of the $\Xi^-(1530)$ as $1535.7\,\text{MeV}/c^2$. The experimental values are 1531.8 ± 0.3 and 1535.1 ± 0.6, respectively. However, the ω does not couple this way to the ground states of the Λ and Σ spectra.

TABLE II. – *Calculated masses in* MeV/c^2 *of* Δ_1, $\mathcal{N}'$ *and* Δ_2 *in the* $1220\,\text{MeV}/c^2$ *region.*

	++	+	0	−
Δ_1	1214	1215	1215	1215
		1214	1214	
$\mathcal{N}'$		1221.9	1222.9	
Δ_2	1229.3	1230.7	1230.3	1230.7
		1228.8	1229.3	

We turn now to the last line of table I and note that there could be several resonances in this region. — a Δ_1 which couples with the ρ to form the $\mathcal{N}$, an $\mathcal{N}'$ that couples with the ω to form the $\mathcal{N}$, and a Δ_2 which couples with ω and π to form the $\mathcal{N}$. Table II shows the calculated masses of these states. The experimental values of the Δ^{++}, Δ^0 pole-positions are at $m = (1211.0 \pm 0.8)\,\text{MeV}/c^2$ and $(1210.9 \pm 1.0)\,\text{MeV}/c^2$ in fair agreement with Δ_1. Other experiments locate the Δ between 1230 and $1234\,\text{MeV}/c^2$ in fair agreement with Δ_2. One of the calculated Δ_2^0 states lies 1 MeV above the Δ_2^{++} state also in agreement with measured values of 1.3 and 1.4 MeV. If the $\mathcal{N}'$ is formed it could be masked by the other states.

(3) T. G. TRIPPE, A. BARBARO-GALTIERI, R. L. KELLY, A. RITTENBERG, A. H. ROSENFELD, G. P. YOST, N. BARASH-SCHMIDT, C. BRICMAN, R. J. HEMINGWAY, M. J. LOSTY, M. ROOS, V. CHALOUPKA and B. ARMSTRONG: *Rev. Mod. Phys.*, **48**, No. 2, part II (1976); **48**, No. 3, 497 (1976).

A Regge recurrence could combine with two spacelike φ states to produce the state of which it is the recurrence, with spin decreased by 2 units, m^2 decreased by 2.08 $(\text{GeV}/c^2)^2$, and with the same parity. There are, of course, a number of examples in which this is the case.

Any particle-state coupled with the corresponding spacelike antiparticle state yields a state of negative parity and zero rest mass. In particular an electron and a spacelike positron in the « ortho » state combine to form what appears to be a photon. The main difference between a photon and ortho-positronium would then appear to be the spacelike nature of one of the components. A spacelike state here appears as the classiacl counterpart of a virtual state in quantum electrodynamics.

Finally it may be noted that if each nucleon in an atomic nucleus were to trap a spacelike neutral pion the total binding energy per nucleon would be 9.70 MeV.

It is not clear why some states do not appear to couple together, nor what governs the choice of a particular channel when states put together in this manner could yield more than one. It is doubtful if these questions can be answered without attempting to establish the self-consistency of the complete spectrum of baryons and mesons.

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I wish to thank the National Research Council of Canada for a grant.

Direttore responsabile: CARLO CASTAGNOLI

Stampato in Bologna dalla Tipografia Compositori coi tipi della Tipografia Monograf
Questo fascicolo è stato licenziato dai torchi il 20-XII-1977