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ON THE EXOTIC BARYON PRODUCTION IN ANTIPROTON ANNIHILATION ON LIGHT NUCLEI

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It is shown that in the frame of a quark-gluon model for strong interaction it is possible to expect the production of exotic baryons in low energy antiproton annihilation on light nuclei. The cross-section of exotic baryon production might be of order of a few units times lo^{-3} of antiproton-proton annihilation cross-section at the same energy. Such values of cross-section give the possibility to detect exotic baryons in experiments on LEAR.

The search for exotic hadrons (i.e. the states which cannot be described as quark-antiquark or three-quark states) in one of the most actual and interesting problems of the modern elementary particle physics. Among all the exotic states the isospin $-5/2$ baryons stand out. The detection of resonances with charge $+3$ or -2 will be the most simple and clear argument supporting the existence of states consisting of more than three quarks. Some models predict [1, 2] that resonances with isospin 5/2 must have an ordinary spin which is also equal to 5/2. These models give the value for the mass of the lower state (which in [1] is called E_{55}) in the region of 1.5 GeV. Nowadays there is some experimental evidence for the existence of such resonances [3—5]. In this paper we shall discuss one possible mechanism for exotic baryon production.

The quark model, in which three quarks are connected by gluon field tubes crossing in a string junction point, is one of the most popular. The string junction which was introduced in [6] arises naturally when one tries to construct a colourless nonlocal object from three colour quarks and a gluon field. Some additional suggestions about the nature of the string junction were made in the quark-gluon string model [7—9]. In this model the exchange of string junctions at the t-channel of the baryon interaction amplitude leads to annihilation processes and to processes with a baryon number exchange [10]. In the frame of the model with a string junction the baryon (antibaryon) colour wave function is schematically drawn in fig. 1a (1b). The colourless unlocal object made from quarks and gluons which corresponds to this scheme has the wave function of the type:

$$\psi^a(x_1)\psi^b(x_2)\psi^c(x_3)G_a^{a'}(x_1, x)G_b^{b'}(x_2, x)G_c^{c'}(x_3, x)\varepsilon_{a',b',c'} \tag{1}$$

where $G_a^{a'}(x, x') = \left\{P \exp \int_{x_1}^{x'} A_\mu(z)\,\mathrm{d}z_\mu\right\}_a^{a'}$ is the gluon field string from point x to point x' and $\psi(x)$ is the quark wave function.

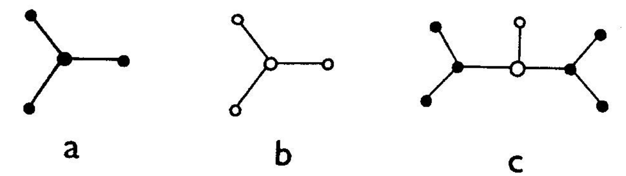

Fig. 1. The colour wave function of nucleon (a), antinucleon (b) and of exotic baryon (c) consisting of four quarks and one antiquark.

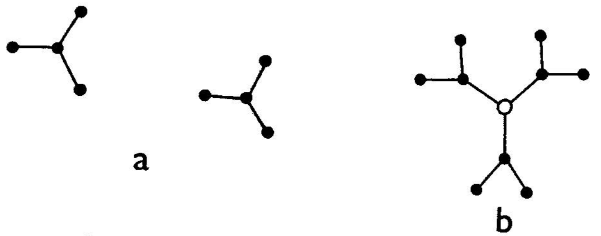

Fig. 2. The deuteron colour wave function in the usual (a) and the tight (b) configurations.

The antibaryon wave function is made from antiquarks and an antistring junction in a similar way. In this model the exotic baryon wave function consists of four quarks and one antiquark and is drawn in fig. 1c. There are two string junctions and one antistring junction in an exotic baryon wave function. When the string junction and the antistring junction are annihilated, the exotic baryon decays to an ordinary baryon and a meson. For instance, the charge 3 state E_{55}^{+++} decays to Δ^{++} and the π^+ meson. As far as the nucleus wave function is concerned it is easy to see that in this model besides the usual state in which the deuteron consists of two colourless nucleons (fig. 2a) there is a state with the colour wave function shown in fig. 2b. It is natural to suppose that the size of this six-quark state is of the order of a usual nucleon size and then this state can be joined to a usual deuteron wave function at distances of the order of a nucleon radius. Since the deuteron has a large radius, the admixture of a six-quark state W_d in the deuteron is small.

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In the static approximation the energy of a deuteron six-quark state is equal to the energy of the usual state*). In this approximation the introduction of additional string junctions into the hadron wave function does not change the energy.

Such a multiquark wave function can be constructed for other nuclei. The wave function of a nine-quark state for ^{3}He nucleus is shown in fig. 3a. The radius of ^{3}He is smaller than the deuteron radius and that is why the probability $W_{^3\mathrm{He}}$ to find the ^{3}He nucleus in a nine-quark configuration is larger than W_d and is equal to a few percent [11, 12].

If now during the antiproton interaction with the ^{3}He nucleus the antiproton antistring junction will be annihilated with an additional string junction of a nine-quark wave function, then at a small antiproton energy in the final state there will be two exotic baryons and one meson, as it is shown in fig. 3b.

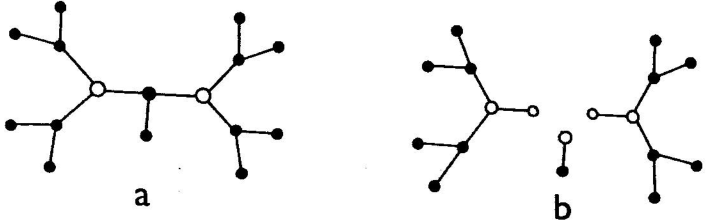

Fig. 3. The ^{3}He colour wave function in a tight configuration (a) and the final state after the string junctions annihilation in a $\bar{p}^3$He interaction (b).

If the E_{55} mass is about 1.5 GeV, such a reaction can take place with stopped antiprotons. It is easy to estimate the cros-section σ_{2E} of the reaction $\bar{p}^3\mathrm{He} \to 2E_{55}\pi$:

$$\sigma_{2E} = \sigma^{an}_{j\bar{j}} W_{^3\mathrm{He}} C, \qquad (2)$$

here C is the Clebsh-Gordon coefficient for some specific channel (for the case of an $E^{++}_{55}E^{--}_{55}\pi^0$, production $C = 17/84$) and $\sigma^{an}_{j\bar{j}}$ is the junction annihilation cross-section.

It can be shown [10] that at a high energy the whole annihilation cross-section $\sigma^{an}_{\bar{p}p}$ is due to the junction annihilation because the processes with additional quark-antiquark annihilation vanish with energy more rapidly. At a low antiproton energy $\sigma^{an}_{j\bar{j}} < \sigma^{an}_{\bar{p}p}$.

The experimental data [13] show that in an annihilation at rest $\sigma^{an}_{\bar{p}p} = 2\sigma^{an}_{\bar{p}n}$. This means that at a low antiproton energy at the state with $I = 0$ there is some additional mechanism which is most probably due to the annihilation of junctions and all quarks and to the production of the pure gluon intermediate state (fig. 4a). Such an annihilation mechanism weakens with energy very rapidly (approximately as $s^{-1.5}$) and can be only in a $\bar{p}p$ but not in a $\bar{p}n$ channel. Diagrams with the annihilation of junctions and one or two additional quarks (fig. 4b, c) lead to the equality $\sigma^{an}_{\bar{p}p} = 5/4\,\sigma^{an}_{\bar{p}n}$ in contradiction with [13].

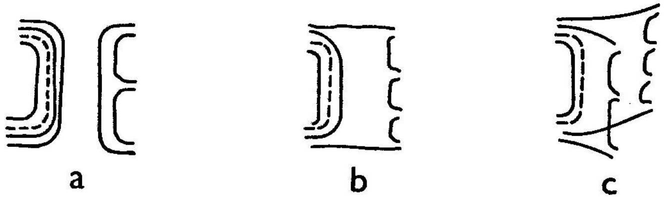

Fig. 4. The processes of annihilation of string junctions and three quark pairs (a), of string junctions and two quark pairs (b) and of string junctions and one quark pair (c).

So in annihilation at rest $\sigma^{an}_{j\bar{j}} \leqslant 1/2\sigma^{an}_{\bar{p}p}$. If one takes in agreement with [11, 12] the value 0.05 for $W_{^3\mathrm{He}}$ then for the cross-section of $E^{++}_{55}E^{--}_{55}\pi^0$ production in $\bar{p}^3$He annihilation we obtain the value ($\sigma^{an}_{j\bar{j}}$ was chosen as $1/2\sigma^{an}_{\bar{p}p}$)

$$\sigma_{2E} = 5 \times 10^{-3}\,\sigma^{an}_{\bar{p}p}. \qquad (3)$$

The same calculations can be carried out for the $\bar{p}^4$He annihilation. In this case there are three exotic baryons E_{55} in the final state, for, instance, there can be the state $E^{++}_{55}E^{--}_{55}E^{0}_{55}$. If the mass of the exotic baryon is equal to 1.5 GeV, this reaction can also proceed with stopped antiprotons and at $W_{4\mathrm{He}} = 0.12$ [14] and $\sigma^{an}_{j\bar{j}} = 1/2\sigma^{an}_{\bar{p}p}$

$$\sigma_{3E} = 5 \times 10^{-3}\,\sigma^{an}_{\bar{p}p} \qquad (4)$$

The cross-sections σ_{2E} and σ_{3E} are high enough to enable the detection of the exotic baryons in experiments on LEAR.

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*) Let the quark mass be equal to m_q, the string junction mass be equal to m_j and the binding energy of the string be equal to $-E_S$. Then in the static limit the baryon mass will be equal to $m_B = 3(m_q - E_S) + m_j$. It is easy to see that at $m_j = 3/2E_S$ the baryon mass is equal to $m_B = 3m^*_q$, where $m_q = m^*_q + 1/2E_S$ and the masses of all multiquark configurations in the nucleus will be equal to $M_A = 3Am^*_q$. This is the mass of nucleus consisting of A nucleons. Within this limit the mass of the exotic baryon is equal to $M_E = 5m^*_q$.

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