Reaction $\bar{p}p \to \bar{\Lambda}\Lambda$ and anomalous contribution of the *P* wave in the $\bar{\Lambda}\Lambda$ system near the threshold

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The anomalously large *P*-wave intensification of the reaction $\bar{p}p \to \bar{\Lambda}\Lambda$ at energies near the threshold $\bar{\Lambda}\Lambda$, which was observed experimentally, can be explained theoretically by the existence of quasinuclear levels in the $\bar{\Lambda}\Lambda$ system.

A strong asymmetry in the angular distribution of $\bar{\Lambda}$ (Fig. 1) and in the behavior of k^3 (k is the relative momentum in the Λ and $\bar{\Lambda}$ c.m. frame) of the cross section for the reaction $\bar{p}p \to \bar{\Lambda}\Lambda$ (Fig. 2) at very small k, $k \approx 45$ MeV/c (consistent with the kinetic energy ϵ in the $\bar{\Lambda}\Lambda$ frame, $\epsilon \approx 2$ MeV) was recently detected in an experiment[1] carried out at the slow antiproton storage ring (LEAR) in CERN. These experimental data show that the role of the *P* wave in the orbital motion of $\bar{\Lambda}$ and Λ is considerable: It is comparable to the contribution of the *S* wave at the momenta k, where the expected contribution of the *P* wave to the cross section for the reaction $\bar{p}p \to \bar{\Lambda}\Lambda$ should not be greater, based on simple barrier-related estimates, than 1% of this cross section. If the $\bar{\Lambda}\Lambda$ interaction radius is calculated from these barrier estimates under the assumption that the *P* wave comprises just 10% of the indicated cross section, then this radius will be very large: 3 fm, which is equal to the radius of a ^{12}C nucleus. We recall in this connection that an analogous phenomenon (an anomalously large contribution of the *P* wave) was previously observed in the behavior of the cross sections for $\bar{p}p$ interaction near the $\bar{p}p$ threshold.[2] The available experimental data on the $\bar{p}p$ interaction near the threshold in this case were described in a realistic bound-channel model.[3] The use of this model to describe the experimental data has resulted in a prediction of a spectrum of rather narrow ($\Gamma \lesssim 50$–80 MeV) quasinuclear near-threshold *P* states in the $\bar{N}N$ system, whose existence accounts for the anomalously large *P*-wave contribution to the $\bar{p}p$ interaction near the threshold.

In the present letter we show that a nonrelativistic model of four bound channels can be used to describe the process $\bar{p}p \to \bar{\Lambda}\Lambda$ near the $\bar{\Lambda}\Lambda$ threshold. The channels 1 and 2 correspond to the $\bar{p}p$ and $\bar{\Lambda}\Lambda$ systems with a realistic OBEP-type interaction.[4] The potential cutoff $[V(r<r_c)=0]$ and the cutoff radius r_c were taken from Refs. 3 and 5. Channels 3 and 4 correspond to the annihilation interaction in the $\bar{p}p$ and $\bar{\Lambda}\Lambda$ systems, respectively. These channels were approximated by two noninteracting particles with masses equal to the ρ-meson and K^*-meson masses. The coupling between the $\bar{B}B$ ($B \equiv p,\Lambda$) channels and the annihilation channels was established by means of local Yukawa potentials; the constants in front of these potentials, which were taken from Ref. 3, were assumed to be the same for channels 3 and 4. (By analogy with the way in which the radius for the transition potential was chosen from the $\bar{p}p$ system in the case of a potential which couples channel 4 with the $\bar{\Lambda}\Lambda$ system, the corresponding annihilation radius was assumed to be $r_a = 1/2M_\Lambda \approx 0.09$ fm, where M_Λ is the mass

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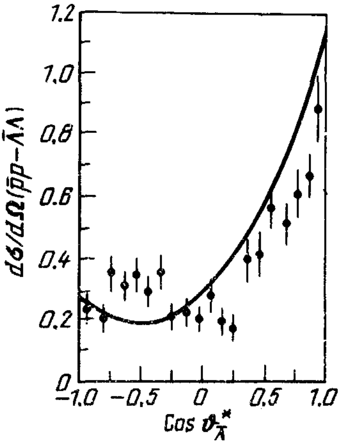

FIG. 1. Differential cross section of the reaction $\bar{p}p\to\bar{\Lambda}\Lambda$ plotted as a function of the cosine of the c.m. angle of emission of $\bar{\Lambda}$ at $\epsilon = 3.6$ MeV.

of a Λ hyperon.) There is no coupling among channels 3 and 4, $\bar{p}p$ and 4, and $\bar{\Lambda}\Lambda$ and 3 (the physical reason for this absence of coupling is that the contribution of strange particles to the $\bar{p}p$ annihilation is no greater than 10%,[6] whereas channels involving strange particles must be the dominant channels if $\bar{\Lambda}\Lambda$ annihilation is to occur). It can also be shown analytically that a strong interaction between the annihilation channels leads to a decrease in the annihilation cross section by a factor of N_B, where N_B is the number of baryons considered in the problem (this effect will be discussed in detail in another study). The coupling between the channels $\bar{p}p$ and $\bar{\Lambda}\Lambda$ is achieved by means of the potential $V(\bar{p}p\to\bar{\Lambda}\Lambda)$, which corresponds to the exchange between mesons K and K^* (the coupling constants were taken from Ref. 4). The cutoff radius of the potential $V(\bar{p}p\to\bar{\Lambda}\Lambda)$ is the only variable parameter of the model. To describe the experimental

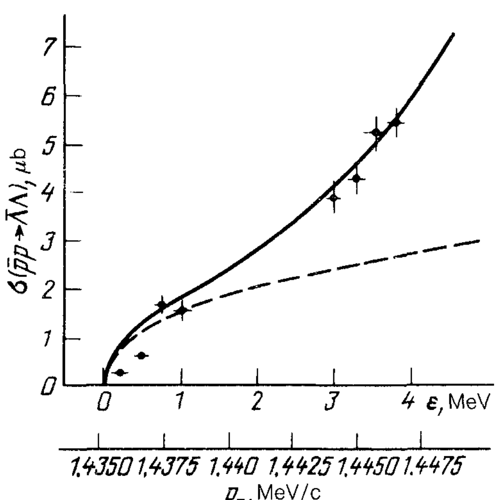

FIG. 2. Total cross section of the reaction $\bar{p}p\to\bar{\Lambda}\Lambda$ plotted as a function of the kinetic energy of $\bar{\Lambda}$ and Λ and as a function of the momentum of the incident antiproton in the laboratory frame. Solid curve—total cross section; dashed curve—S-wave contribution.

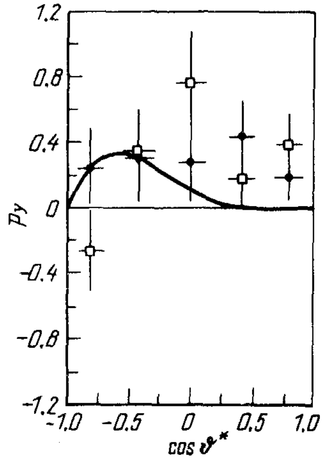

FIG. 3. Polarization of $\bar{\Lambda}$(□) and Λ(●) versus the cosine of the c.m. angle at $\epsilon = 3.6$ MeV.

data, we used the following values of the cutoff radii: $r_c(^1S_0) = r_c(^3S_1) = 1.0$ fm, $r_c(^3P_0) = r_c(^3P_2) = 1.3$ fm, $r_c(^1P_1) = 1.4$ fm, $r_c(^3P_1) = 1.5$ fm. Only the contribution from the S and P waves is taken into account in the calculations.

Figure 1 compares the calculated differential cross section for the reaction $\bar{p}p \to \bar{\Lambda}\Lambda$ with the experimental data when the kinetic energy of the system is $\epsilon = 3.6$ MeV. We see that the theoretical curve correctly conveys the principal qualitative feature: the sharp forward direction of the angular distribution of $\Lambda(\bar{\Lambda})$ due to the large P-wave contribution. A slight divergence of the theoretical curve from the experimental data at large angles ($\theta > 90°$) may be due to the D-wave contribution, which is ignored in these calculations. The solid curve in Fig. 2 shows the calculated total cross section of the reaction $\bar{p}p \to \bar{\Lambda}\Lambda$. The dashed curve corresponds to the S-wave contribution to the reaction cross section. At the momenta $k \approx 50$–60 MeV/c ($\epsilon \approx 3$–4 MeV) we see that the P wave accounts for approximately one-half of the indicated cross section.

A marked increase in the P-wave contribution in the $\bar{\Lambda}\Lambda$ system, which was measured experimentally and found by us, is caused by the same factors as those in the previously studied case[3] of $\bar{p}p$ interaction near the $\bar{N}N$ threshold. To resolve this problem, we studied the spectrum of P-wave quasinuclear resonances in the $\bar{\Lambda}\Lambda$ system. One of the P states, which contributes significantly to the P-wave part of the amplitude of the process $\bar{p}p \to \bar{\Lambda}\Lambda$, has the following parameters: mass—2237 MeV; total width—8 MeV; annihilation width—2.5 MeV; the ratio of the width along the $\bar{\Lambda}\Lambda$ channel to the total width—0.7; total moment—1; and (space- and charge-even) spin—1. The annihilation cross section for $\bar{\Lambda}\Lambda$, on the other hand, is the same as that for the $\bar{N}N$ channel. Figure 3 shows the $\Lambda(\bar{\Lambda})$ polarization in the reaction $\bar{p}p \to \bar{\Lambda}\Lambda$. The fact that polarization was observed experimentally is evidence in favor of the existence of triplet P states in the $\bar{\Lambda}\Lambda$ system near the threshold. We notice that the total width of the P-wave resonance is small and that the $\bar{\Lambda}\Lambda$ channel elasticity is large. This means that the P-wave states may be seen as narrow states in the $K\bar{K} + n\pi$ systems.

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