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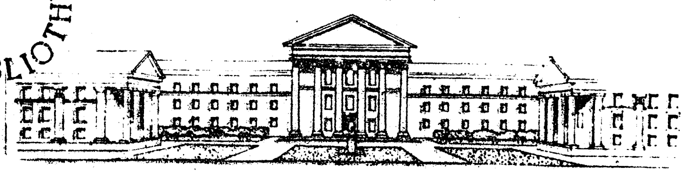



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# REAL-TO-IMAGINARY RATIO OF $\bar{p}p$ SCATTERING AMPLITUDE NEAR $\bar{n}n$ THRESHOLD



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A B S T R A C T

It is shown that due to large value and fast increasing of P-wave $\bar{p}p$-scattering amplitude and openning of $\bar{p}p \to \bar{n}n$ channel real-to-imaginary ratio Re/Im for $\bar{p}p$ forward scattering amdlitude should have a maximum in the incident antiproton momentum range between 0 and 200 MeV/c. The behaviour of Re/Im in this momentum range is predicted using two models: coupled channels and boundary condition of full absorption. The calculations are in agreement with present LEAR data.

After taking into operation Low Energy Antiproton Ring (LEAR) facility at CERN many new results concerned antiproton-nucleon and antiproton-nuclei interactions were obtained with high accuracy. For the first time at antiproton momentum range $K \simeq 200 \div 300$ MeV/c the real-to-imaginary ratio for the forward $\bar{p}p$-scattering amplitude was measured [1]. The value $\varepsilon = \mathrm{Re}\, f_{\bar{p}p}(0)/\mathrm{Im}\, f_{\bar{p}p}(0)$ is shown in Fig.1 (LEAR data). It is seen that there is a structure in $\varepsilon$ at the antiproton momentum K 200 MeV/c. If, besides that, take into account that $\mathrm{Re}/\mathrm{Im}\ (K = 0) = 2\Delta E/\Gamma \simeq -1 \div -2$ from atomic data on the shift of 1S-level for $\bar{p}p$-atom [2], where $\Delta$ E is a shift of 1S level, $\Gamma$ is a width of $K_\alpha$-line. Therefore, at the momentum range between 0 and 200 MeV/c the value $\varepsilon$ should have at least one additional zerow and goes down to negative values.

In this paper we would like to pay attention to the possibility of explanation for so unusual behaviour of ratio $\varepsilon$ = Re/Im connected with the vicinity of inelastic $\bar{p}p \to \bar{n}n$ channel (mass difference for channels $\bar{n}n$ and $\bar{p}p$ is $\Delta M = 2(m_n - m_p) = 2.6$ MeV what corresponds to the incident $\bar{p}$ momentum is equal to K = 98.8 MeV/c). First of all we explain qualitatively why inspite of relatively small contamination (charge exchange cross-section $\sigma^{ch}$ amounts not more than 20% to the elastic one at the momenta which are interested to us) openning of $\bar{p}p \to \bar{n}n$ channel can strong affected the behaviour of $\varepsilon$ .

## I. The physical reasons for the possibility of irregular behaviour of $\varepsilon$ near $\bar{n}n$ threshold

The point is that the value $\varepsilon$ is relatively small at low momentum: $\varepsilon$ is changed from -0.1 to +0.2 in the momentum interval 200 MeV/c $\lesssim K \lesssim$ 600 MeV/c. At the same momenta as it follows from phase analysis data[3] S- and P-waves contaminations are equal to each other. Let rewrite $\varepsilon$ in the following form:

$\varepsilon = \dfrac{Re^{S} + Re^{P}}{Im^{S+P}}$ , where S and P index correspond to S- and P-waves ( $Re^{S,P} \equiv Re\, f^{S,P}_{\bar{p}p}(0)$, $Im^{S+P} \equiv Im\, f^{S}_{\bar{p}p}(0) + Im\, f^{P}_{\bar{p}p}(0)$ ).

In this case a smallness of $\varepsilon$ could be explained by two different ways: (a) $Re^{S}/Im^{S+P} \ll 1$ and $Re^{P}/Im^{S+P} \ll 1$; (b) $Re^{S}/Im^{S+P} \sim Re^{P}/Im^{S+P}$ , but the signes of $Re^{S}$ and $Re^{P}$ are opposite. It seems to be more attractive the possibility (b), moreover it is physically well ground. Namely at zerow momentum $\varepsilon$ is negative (atomic data) and rather large by the absolute value. This means that we have $Re^{S}/Im^{S} \sim -1 \div -2$ and $|Im^{P}| \sim |Im^{S}|$ at the momentum $K \sim 200$ MeV/c, therefore there is only possibility (b) for explanation of the smallness of $\varepsilon$ . Hence, a smallness of $\varepsilon$ is explained by the rather peculiar compensation of large values - ratios $Re^{S}/Im^{S+P}$ and $Re^{P}/Im^{S+P}$ . In this case any small perturbation in one of the waves (S or P) could lead to relatively large change for $\varepsilon$ . Actually, let $\alpha$ and $\beta$ are a small mixtures in the real and imaginary parts of S-wave amplitude, correspondingly. Then a new value

$$\tilde{\varepsilon} = \frac{\tilde{Re}}{\tilde{Im}} = \frac{\overset{s}{Re} + \alpha \overset{s}{Re} - \overset{p}{Re}}{\overline{Im}^{s+p} + \beta \overline{Im}^{s+p}} \simeq \frac{\overset{s}{Re} - \overset{p}{Re}}{\overline{Im}^{s+p}} + \alpha \frac{\overset{s}{Re}}{\overline{Im}^{s+p}} = \varepsilon + \alpha \frac{\overset{s}{Re}}{\overline{Im}^{s+p}}$$

If $\alpha \sim \varepsilon$ and $\overset{s}{Re} \gtrsim \overline{Im}^{s+p}$ (case (b) ), then $|\tilde{\varepsilon}| \gtrsim 2|\varepsilon|$. Note that in realistic models (which shall be considired below) we have $|\overset{s}{Re} / \overline{Im}^{s+p}| \lesssim$ 1 (coupled channel model[4]) and $|\overset{s}{Re} / \overline{Im}^{s+p}| \sim 2$ " (boundary condition model[5]). Thus the value $\varepsilon$ turns to be very sensitive to any small mixture in one of the waves which breaks a compensation for the real parts of S- and P-waves contaminations in $\bar{p}p$ scattering amplitude.

In this situation openning of $\bar{p}p$ — $\bar{n}n$ channel could affect really on $\varepsilon$ behaviour at the momentum range $0 \lesssim K \lesssim 300$ MeV/c. The channel $\bar{p}p$ — $\bar{n}n$ is revealed only in S-wave of $\bar{p}p$-scattering near $\bar{n}n$ threshold ($K \sim 100$ MeV/c). At the momenta more than $K \gtrsim 200$ MeV/c the factor $(K_o R)^2$ containing in the mixture to P-wave amplitude will be not so small ( $K_o R \sim 0.5 \div 0.7$ for R = = 1 fm, $K_o$ is a relative momentum in $\bar{n}n$ channel) and a compensation of S- and P-waves amplitudes should restore. If we take into account that $\overset{s}{Re} < 0$ (as it follows from atomic data) i.e. $\overset{p}{Re} > 0$, then it is clear that due to these effect a maximum in $\varepsilon$ at the momentum $K \lesssim 200$ MeV/c sфhould appear. Such behaviour of $\varepsilon$ as it is seen from Fig.1 is probably observed in the experiment.

## 2. Quantitative estimations

It is clear that for exact calculation of Re/Im at low momentum one needs to solve the coupled channel problem: $\bar{p}p$, $\bar{n}n$ and $n\pi$ or two channels ($\bar{p}p$ and $\bar{n}n$) with boundary condition taking into account the mass difference for proton and neutron. This task is rather complicated. Here we use by approximate formulaes which are satisfactory for $K_0 R \ll 1$.

In this case S-martix element for $\bar{p}p$-scattering near $\bar{n}n$ threshold could be written in the following form:/6/

for S-wave

$$S_0 = \frac{e^{2i\delta_0}(1-\gamma_0)}{2iK}, \tag{1}$$

where factor $\gamma_0 = \frac{1}{2}|m_0|^2 K_0$; $\gamma_0$ is expressed using charge exchange cross-sections $\sigma_s^{ch}$ in S-wave:

$$\sigma_s^{ch} = \frac{\pi}{K}|m_0|^2 K_0 = \frac{2\pi}{K}\gamma_0 \tag{2}$$

For P-wave

$$S_1 = \frac{e^{2i\delta_1}(1-\gamma_1)}{2iK},$$

where factor $\gamma_1 = \gamma_0 (K_0 R)^2$.

In this formulaes $\delta_0$ and $\delta_1$ are the phases in S- and P-waves for $\bar{p}p$- scattering without $\bar{n}n$ channel ( $\delta_0$ and $\delta_1$ are different for the states with definite $J$ , $S$ and $T$ , where $J$

is total angular momentum, S is total spin, T is isospin).

In the concrete calculations we use two realistic models: coupled channel model (A) /4/ and boundary condition (B) /5/. The results of our calculations are presented in Fig.1 (curves A and B, correspondingly). It is seen that the ratio Re/Im has a maximum near $K \sim 200$ MeV/c the size of which depends very strongly on the model for $\bar{N}N$ interactions, i.e. a measurement of $\varepsilon$ at the momentum range $K = 0 \div 200$ MeV/c would be very useful for checking of different $\bar{N}N$ model. As it was said the changing of $\varepsilon$ from the value of the order of $\varepsilon \sim -1$ at zerow momenta up to $\varepsilon \sim 0$ at $K \sim 200$ MeV/c is due to very fast increasing of P-wave contamination, moreover $|R_e^s| \sim |R_e^p|$ at the momenta of incident antiprotons, where $KR \ll 1$. This phenomenon from our point of view notes on the existence of P-wave bound quasinuclear states in $\bar{N}N$ system /7/. In coupled channel model /4/ such P-states with the widths of the order of $10 \div 50$ MeV were obtained. As for the boundary condition model /5/ this question was not considered in details. Besides that a boundary condition should be complex (not pure imaginary as in /5/). The reason for this is unitarity (an annihilation acts not only as absorption but repulsion also).

## 3. Conclusion

In conclusion we have summerized our results:

(1) Taking into account $\bar{p}p$ — $\bar{n}n$ channel one can reproduce qualitatively the behaviour of $\varepsilon$ = Re/Im at the momentum range of incident antiprotons $K = 0 \div 500$ MeV/c.

(2) The value Re/Im should have a maximum at the momentum K ~ 200 MeV/c. This maximum is coused by fast increasing of P-wave $\bar{p}p$-scattering amplitude which leads to the compensation of $R_e^s$ and $R_e^p$ and to small value of $\varepsilon$ without $\bar{p}p$ —— $\bar{n}n$ channel.

(3) Fast increasing and large contamination of P-waves in $\bar{p}p$-scattering amplitude at low relative momenta note on the existence of bound quasinuclear type states in nucleon-antinucleon system.

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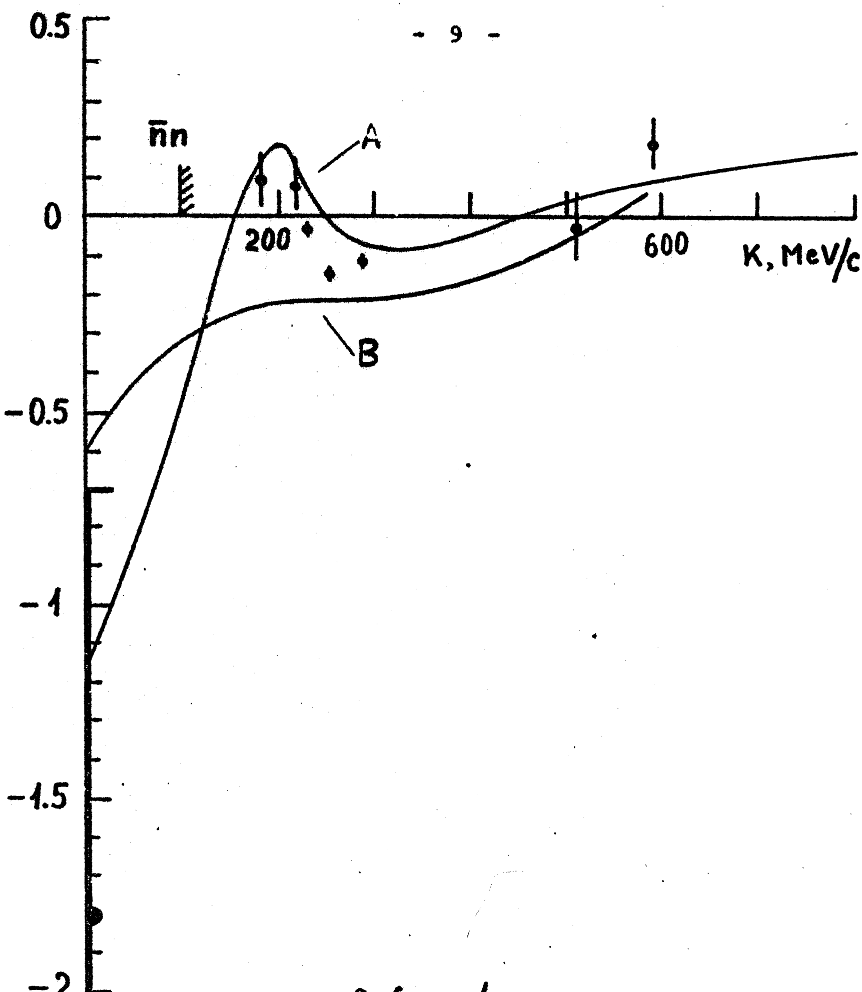


Fig. 1 The ratio $\mathcal{E} = Re\, f_{\bar{p}p}(0) / Im\, f_{\bar{p}p}(0)$ as a function of the momentum of incident antiproton. The experimental points are LEAR data /1/. The curves A and B correspond to the boundary condition model /5/ and coupled channel one /4/, correspondingly.

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