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THE INFLUENCE OF ABSORPTION ON POSSIBLE
NUCLEON - ANTINUCLEON RESONANCES AND BOUND STATES

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ABSTRACT

We study analytically the effect of an absorptive potential on bound states and resonances in the NN system. We show that these states are destroyed by moderate absorption. Thus, only NN channels which are weakly absorptive can exhibit resonant behaviour.

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Investigation of the $N\bar{N}$ system, using one-boson exchange potentials (OBEP) which fit NN scattering ¹⁾, has led to the prediction of many bound states and resonances ^{2),3)}. So far experiments have only provided us with one bump in low-energy $p\bar{p}$ cross-sections ⁴⁾⁻⁶⁾. In view of the OBEP results, it is important to ask why many resonances have not been observed.

One possible answer is that in the real $N\bar{N}$ system annihilation dominates the low-energy scattering phenomena ($\sigma_{\text{tot}}:\sigma_{\text{ann}}:\sigma_{\text{el}} = 3:2:1$) ⁷⁾. Indeed Byran and Phillips ⁸⁾ have shown that the (pre-resonance) $N\bar{N}$ data ^{5),7)} could be satisfactorily explained by OBEP plus a strong, short-range absorptive potential. The latter simulates the effect of annihilation. This point has recently been the object of an extensive numerical investigation by Myhrer and Gersten ⁹⁾.

One purpose of the present analytic investigation is to gain some physical insight into the numerical results of Myhrer and Gersten ⁹⁾. After showing that our model is realistic enough to reproduce the behaviour of their ⁹⁾ Argand plots when the strength of the absorptive potential is increased, we also show that it is transparent enough for one to understand what is happening. Specifically, we study the effect that a short-range absorptive interaction has on a resonance pole. As a bonus, with small changes in the parameters, we can also study the behaviour of a bound state pole when absorption is introduced.

A typical resonance found by Myhrer and Gersten with the real $N\bar{N}$ OBEP ^{8),10)} occurs in p wave at 17 MeV with a (elastic) width of 10 MeV. We assume a two-term separable potential (for p wave) of the form

$$V(p, p') = P_1(\hat{p} \cdot \hat{p}') [\lambda_1 v(p) v(p') + \lambda_2 g(p) g(p')] \quad (1)$$

with

$$v(p) = p / (p^2 + \beta^2) \quad , \quad g(p) = p / (p^2 + \gamma^2) \quad (2)$$

With this potential we adjust λ_1 and β (with $\lambda_2 = 0$) to reproduce the position and width of the p wave resonance quoted above ($\lambda_1 = -113.04$ and $\beta = 4.59 \text{ fm}^{-1}$) ^{*}). The second term represents here the short-range $p\bar{p}$ annihilation. We fix $\gamma = 10 \text{ fm}^{-1}$ to be approximately twice the nucleon mass, and we use λ_2 as a negative, imaginary parameter to be varied.

^{*}) We note that in a resonant channel the separable approximation should be a good representation ¹¹⁾.

Our primary motivation was to understand the movement of existing resonances as λ_2 is increased from zero. However, the existence of $p\bar{p}$ bound states [from the real OBEP ^{2),3)}] raises another interesting question. What will happen to a bound state pole as we increase the strength of an absorptive potential? Naively, one might expect that a short-range, absorptive potential would deplete the bound state wave function at short distances, and would therefore act like a repulsive potential reducing the binding energy. In the second part of this investigation we adjust λ_1 (with $\beta = 4.59 \text{ fm}^{-1}$ and $\lambda_2 = 0$) to give a bound state at 9.1 MeV ($\lambda_1 = -116.87$). We study how this bound state pole moves in the complex energy plane as we increase the strength λ_2 of the absorptive potential.

Figure 1 shows the Argand diagram for the results of Myhrer and Gersten ⁹⁾ in the resonant 3P_1 $p\bar{p}$ channel, compared with our separable potential results, as the strength of the absorptive potential is varied in both. Clearly, we could choose λ_2 to reproduce the results of Ref. 9). However, no attempt is made to fit, we simply show the structural similarity in the two cases, particularly for $k^2 < 1 \text{ fm}^{-2}$. Now it is a simple matter to solve analytically for the resonance poles in the scattering amplitude in the separable potential model. In Fig. 2 we show the behaviour of the resonance pole in the complex E plane as λ_2 increases. When we increase the absorption, the resonance pole moves away from the physical region (for $\lambda_2 \simeq -12i$ it moves into the third quadrant on the second Riemann sheet). This means that even for relatively small ratios of the absorptive to real parts of the potential, we no longer have a resonance. In view of this result we can readily understand the lack of resonances found by Ref. 9) using a complex potential for $p\bar{p}$. Even if the real $p\bar{p}$ potential produces a resonance in a given (LSJT) channel, an absorptive potential of moderate strength in the same channel is sufficient to move that resonance far away from the physical region.

The effect of absorption on the bound state pole is also rather interesting. As we increase λ_2 the bound state pole moves rather quickly into the third and then fourth quadrant on the 1st Riemann sheet, see Fig. 2. This behaviour is similar to what one expected from the simple argument presented earlier. Nevertheless, there is an important difference of principle between this effective repulsion and the introduction of real, short-range repulsion. In the latter case the pole moves along the negative real axis to become a true resonance (a pole in the 4th quadrant of E_{II}). However, in the former case, the bound state pole moves into the 4th quadrant of E_I - as far as possible from the physical region. That is, we expect such states to have no effect on $N\bar{N}$ scattering.

To summarize our results we assume that it is reasonable to simulate annihilation in the $p\bar{p}$ system by using a short-range, imaginary potential. We find that a small absorptive potential can destroy $N\bar{N}$ resonances and bound states predicted by the OBEP by moving the corresponding resonance - and bound state poles away from the physical region. Thus, it will only be possible to observe a $N\bar{N}$ resonance or bound state of definite LSJT, if for some reason (e.g., selection rules) the absorptive potential is very weak in this particular $N\bar{N}$ channel.

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FIGURE CAPTIONS

Fig. 1 : The behaviour of a p wave NN amplitude for various strengths of the absorptive potential. Solid curves labelled a, b, and c are for the Bryan-Phillips case with W_0 equals 0.0, 0.5 and 2.0 GeV [see Ref. 9)]. The dashed curves labelled α and β are for our separable potential with $\lambda_2 = -1.26$ and -12.60 . The numbers on the curves are momenta squared (in fm^{-2}).

Fig. 2 : This figure shows the movements of the bound state pole on the first Riemann sheet and the resonance pole on the second sheet, as λ_2 is increased. Each curve starts at the position of the pole for $\lambda_2 = 0.0$. The energy $E = k^2$ is in units of fm^{-2} .

FIG. 3

FIG. 1

FIG. 2