

Potential resonances in the elastic scattering of antiprotons by nuclei

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(Submitted 4 March 1982)

Pis'ma Zh. Eksp. Teor. Fiz. **35**, No. 10, 441–443 (20 May 1982)

Potential resonances in antiproton–nucleus scattering are studied. Calculations are carried out for ^{12}C , ^{16}O , ^{40}Ca , and ^{208}Pb . There is a resonance structure in the strength function for large-angle elastic scattering. The effect is highly sensitive to the parameters chosen for the potential. The resonance cross section falls off with increasing A .

PACS numbers: 25.40.Cm, 27.20. + n, 27.40. + z, 27.80. + w

We have carried out a detailed study of the potential resonances which Auerbach *et al.*¹ recently predicted in large-angle elastic antiproton–nucleus scattering. Interest in resonance phenomena in antiproton–nucleus interactions stems from Shapiro's predictions^{2,3} of possible resonances in the $N\bar{N}$ system and their manifestations in the scattering of antiprotons by nuclei.

There are several features which distinguish antiproton–nucleus interactions from proton–nucleus interactions and which can give rise to potential resonances at comparatively high energies of the incident particles, $E > 10$ MeV. The feature of primary interest here is the anomalously large depth of the optical potential $U(r) = V(r) + iW(r)$ for antiprotons. The meson structure of the real part of this potential was studied in Ref. 4 (see also Ref. 5), where $V(r)$ was constructed by convolving the $N\bar{N}$ potentials for single-boson exchange with the nucleon density distribution in the nucleus. The calculations in Ref. 4 showed that $V(r)$ has a depth of 500–600 MeV [the average value $V(0) = -550$ MeV is used in the calculations reported in the present paper], and the spin-orbit interaction is about 30 times weaker than in the nucleon–nucleus interaction. For this reason, we have not considered spin-orbit coupling in the present study. Since the radius of the $N\bar{N}$ interaction in the meson theory of nuclear forces is determined by the Compton wavelength of the exchange mesons, the shape parameters of the real part of the optical potential (the radius R and the diffuseness a) differ from the corresponding parameters for the nucleon distribution. In particular, we have $R_V = R + \Delta$, where the average value $\Delta = 0.17 F$ was used in the present study for all nuclei.

Because of the annihilation interaction of antiprotons with nucleons of the nucleus, the imaginary part of the optical potential, $W(r)$ may also have a large depth. At present, $W(0)$ has not been determined reliably; study of the widths of antiprotonic atoms yields values in the range⁶ 100–200 MeV. Since the radius of the annihilation interaction is short (on the order of $1/M$, where M is the nucleon mass), it may be expected that the radius R_W and the diffuseness a_W of the imaginary part of the optical potential will be the same as for the nuclear density distribution. In the present study we carried out calculations for the nuclei ^{12}C , ^{16}O , ^{40}Ca , ^{90}Zr , and ^{208}Pb . The scattering cross section was

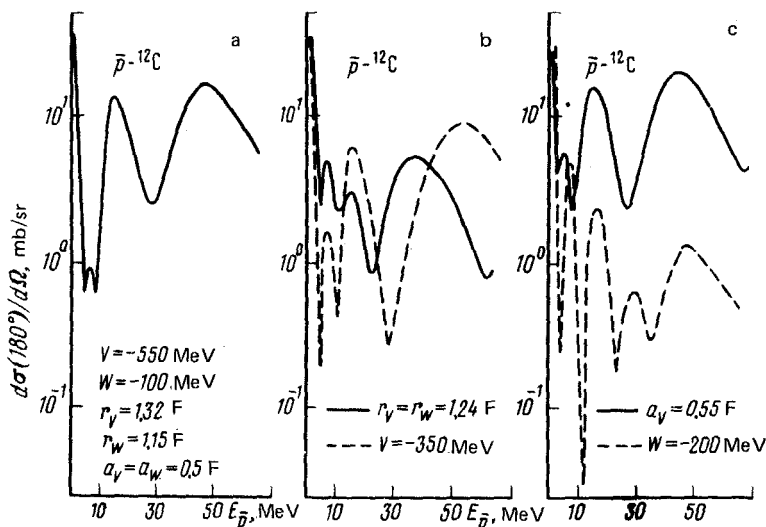


FIG. 1. Calculated strength function for elastic scattering of antiprotons through 180° by the ^{12}C nucleus. In parts b and c, only those parameters which were varied from their values for part a are listed.

calculated by the partial-wave method (the program⁷ used by us can carry out the summation up to $l \leq 200$). The optical potential is chosen in the form

$$U(r) = V \left[1 + \exp \left\{ \frac{r - r_V A^{1/3}}{a_V} \right\} \right]^{-1} + iW \left[1 + \exp \left\{ \frac{r - r_W A^{1/3}}{a_W} \right\} \right]^{-1}.$$

The calculated results are shown in Figs. 1-3, along with all the parameters used.

The strength function for 180° scattering (Figs. 1 and 2) was calculated for antiproton energies $E < 100$ MeV, which correspond to momentum transfers $q < 5 \text{ F}^{-1}$, which are typical of optical-potential depths of 500-600 MeV. At higher energies of the incident antiprotons, it is apparently necessary to consider two-body, short-range correlations in a study of back scattering. It can be seen from these results that the strength function has a characteristic resonance structure. Analysis of the angular distributions at the resonance energies of the antiprotons reveals a significant increase (by about an order of magnitude) in the cross section for large-angle scattering. This circumstance distinguishes the resonance scattering from an ordinary diffraction pattern.

The basic reason for the appearance of resonances is the strong attraction in the real part of the optical potential, which results in the capture of the antiprotons and their orbiting around the nucleus, followed by a decay of the resonant system. It can be seen in Fig. 1 that the resonance effect is intensified if $R_V > R_W$ or $a_V > a_W$. Under these conditions, an antiproton "pocket" appears.¹ At the same time, an increase in the depth of the imaginary part of the optical potential from 100 to 200 MeV reduces the cross section for back scattering by about an order of magnitude, although the resonance pattern is retained. As Auerbach *et al.* pointed out,¹ erasure of the resonances would require $R_V < R_W$, $a_V < a_W$, and very strong absorption.

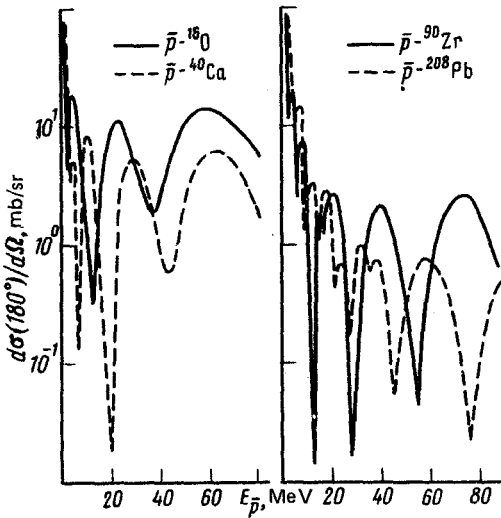


FIG. 2. Strength function for elastic scattering of antiprotons through 180° by the nuclei ^{16}O , ^{40}Ca , ^{90}Zr , and ^{208}Pb . The parameters used for the optical potential in these calculations are given in Fig. 1a.

The calculations show that for the values used here for the parameters of the optical potential the strength function for back scattering is of a resonance nature for all the nuclei considered, but its magnitude falls off with increasing number of nucleons in the nucleus. This A dependence reflects the behavior of the nuclear form factors $F(q)$ at large momentum transfer: For a stepped distribution of the matter in the nucleus, the ratio of the form factors for two nuclei is inversely proportional to the ratio of the square radii of these nuclei.

Since elastic back scattering is determined by the high-momentum components of the nuclear form factor, even at comparatively low energies of the incident antiprotons, a relativistic description of this process would be more justified.

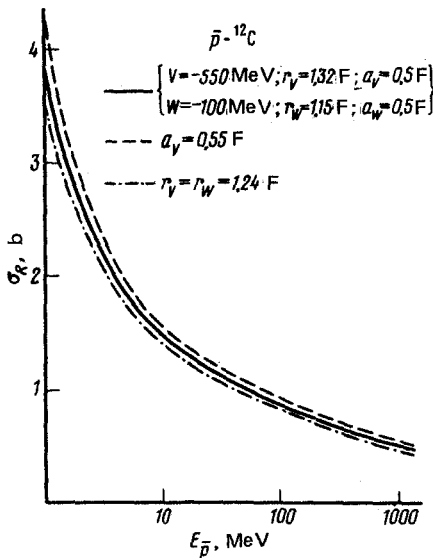


FIG. 3. Calculated total reaction cross section for scattering of antiprotons by the ^{12}C nucleus.

We also calculated the total reaction cross sections σ_R as a function of the antiproton energy (Fig. 3). This cross section changes only slightly upon variation of the parameters of the optical potential. On the other hand, the resonance structure in the strength function for the 180° scattering depends on the choice of the parameters V , W , r_V , r_W , a_V , and a_W ; the strength of the spin-orbit interaction of antiprotons with nuclei determines¹ the polarization of the backward-emitted antiprotons.

In summary, this experimental study of large-angle elastic scattering of antiprotons yields realistic values for the parameters of the optical potential. These results are important for understanding of the interaction of antiprotons with nuclei.

We wish to thank A. B. Gridnev for useful discussions.

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