SovietRxiv

Soviet-era science, translated into English

PHYSICS

P. E. NEMIROVSKII

1957

SovietRxiv

View the original and related papers at https://sovietrxiv.org/items/ru-195701.52715

Source: Math-Net.Ru and CyberLeninka. Machine translation. Verify with the original.

SovietRxiv

Abstract

Full Text

PHYSICS

P. E. NEMIROVSKII

ON THE QUESTION OF THE INTERACTION OF ANTIPROTONS WITH NUCLEI

(Presented by Academician I. V. Kurchatov, 3 XI 1956)

In a number of papers by Segrè' s group ([1], [2]) it has been shown that the cross sections for inelastic interaction of antiprotons with nuclei in the region of antiproton energies 300–500 MeV considerably exceed the cross sections for the interaction of nucleons with nuclei. Thus, for Cu at an energy of 450 MeV the experiment gives $\frac{\sigma_a}{\sigma_H} = 1.5 \pm 0.5$, or 1.2 barn ([1]), and according to other data $\frac{\sigma_a}{\sigma_p} = 2.02$ ([2]).

For lower energies and lighter nuclei this ratio may be larger (the effect was observed for Be and glass). If one considers a nucleus with a sharp edge, the effect cannot be explained, since the Cu nucleus is already almost black for nucleons. Therefore, to explain it, it is necessary to consider a nucleus with a diffuse edge.

The potential at the boundary of the nucleus must decrease gradually for two reasons. First, the interaction potential between a nucleon and an antinucleon has a finite radius. The dependence of the elementary interaction on distance is unknown; however, in any case, it must rapidly vanish for $r > 1.5 \cdot 10^{-13}$ cm (if one assumes that the interaction is carried by particles no lighter than π-mesons). This, apparently, is insufficient to explain the antinucleon cross sections (especially if the interaction potential has a Gaussian form). However, there is a second effect leading to diffuseness of the nuclear boundary. According to a number of experimental data (scattering of high-energy electrons, μ-mesonic atoms, etc.), the density of nuclear matter does not terminate discontinuously at the nuclear boundary, but decreases gradually. Williams ([3]) showed that such an assumption is in good agreement with data on the scattering of fast neutrons by nuclei.

Data on electron scattering by nuclei ([4]) show that the proton density decreases from 0.9 to 0.1 over a distance of order $2.4 + 0.3 \cdot 10^{-13}$ cm. In the present note it will be shown that the antiproton cross sections can be reasonably explained on the basis of the density behavior given above.

In what follows we shall assume that the interaction of an antinucleon with a nucleon is described by a δ-function, and shall take into account only the influence of the behavior of the nucleon density (the behavior of the neutron

SovietRxiv

and proton densities is assumed to be identical). The density ρ may be specified, for example, in the following three ways:

$$1) \quad \rho = \rho_0 \quad \text{for } r \le r_0^{(1)}, \qquad \rho = \rho_0 e^{-\frac{r-r_0}{a_1}} \quad \text{for } r \ge r_0^{(1)}; \tag{1}$$

$$2) \quad \rho = \frac{\rho_0}{1 + e^{\frac{r-r_0^{(2)}}{a_2}}}; \tag{2}$$

$$3) \quad \rho = \rho_0 \quad \text{for } r \le r_0^{(3)}, \qquad \rho = \rho_0 e^{-\frac{(r-r_0)^2}{a_3^2}} \quad \text{for } r \ge r_0^{(3)}. \tag{3}$$

For copper we take

$$a_1 = 0.7 \cdot 10^{-13} \text{ cm}, \qquad r_0^{(1)} = 4.1 \cdot 10^{-13} \text{ cm}$$

or

$$a_2 = 0.5 \cdot 10^{-13} \text{ cm}, \qquad r_0^{(2)} = 4.3 \cdot 10^{-13} \text{ cm}$$

and, finally,

$$a_3 = 2 \cdot 10^{-13} \text{ cm}, \qquad r_0^{(3)} = 2.8 \cdot 10^{-13} \text{ cm}.$$

All the indicated values of the parameters do not contradict the data on electron scattering.

It remains to find the absorption coefficient of nuclear matter $K = \rho_0 \bar{\sigma}$, corresponding to the experimental value of the absorption cross section.

The quantity $\bar{\sigma}$ is the cross section for the interaction of a nucleon and an antinucleon, averaged over protons and neutrons in the nucleus. The Pauli principle in this interaction may be disregarded, especially at $E = 300$–500 MeV (since it imposes no restrictions on annihilation, while the restrictions on scattering turn out to be twice as weak as for nucleon-nucleon collisions). Therefore $\bar{\sigma}$ should not differ greatly from the interaction cross section of free particles.

In the terms of geometrical optics, $2\int_0^\infty \rho\bar{\sigma}\, ds$ gives the attenuation of a beam of antiprotons passing at impact distance r, and the cross section is expressed as

$$\sigma_a = 2\pi \int_0^\infty r \left(1 - \exp\left[-2\int_0^\infty \rho(x)\bar{\sigma}\, ds\right]\right) dr, \tag{4}$$

SovietRxiv

where $x = \sqrt{r^2 + s^2}$.

We use the expressions given above for the density distribution to calculate the cross sections for collisions of nucleons with nuclei. In the present case the absorption coefficient is determined easily. The cross section for the interaction of a proton with nucleons, averaged over neutrons and protons, is equal to 28 mb at $E \sim 300$–500 MeV. If the Pauli principle is taken into account for an incident nucleon energy of 450 MeV, then the cross section for the interaction of intranuclear nucleons with the incident one should be taken as equal to 24 mb. The density of nuclear matter at the center of the nucleus, ρ_0, in case (1) is $1.30 \cdot 10^{38}$, in case (2) $1.25 \cdot 10^{38}$, and in case (3) $1.43 \cdot 10^{38}$. The absorption coefficient $K(0)$ is, respectively, $3.12 \cdot 10^{12}$, $3 \cdot 10^{12}$, $3.4 \cdot 10^{12}$.

Table 1

(1)	(1)	(2)	(2)	(3)	(3)
$K(0) \cdot 10^{-12}$	σ_a, barns	$K(0) \cdot 10^{-12}$	σ_a, barns	$K(0) \cdot 10^{-12}$	σ_a, barns
3.12	0.7	3.0	0.66	3.4	0.68
6.2	0.91	6.2	0.84	6.2	0.85
12.4	1.103	12.4	1.0	12.4	1.03
24.8	1.28	24.8	1.16	24.8	1.20

With such coefficients a nucleus with a rectangular edge is almost black (the absorption cross section is $\sim 0.82\pi R^2$). The results of calculating absorption cross sections for the three potentials at different $K(0)$ are given in Table 1. They are in satisfactory agreement with one another and with experiment. The calculations for Be are considerably less reliable; however, at $K(0) = 25 \cdot 10^{12}$ the cross section increases, compared with the nucleon one, by more than a factor of 2.

As is seen from the table, $\sigma_a = 1.20$ b is obtained in case (1) for $\bar{\sigma} = 150$ mb, in case (3) for $\bar{\sigma} = 175$ mb, and in case (2) for $\bar{\sigma} = 200$ mb. Thus, the collision cross sections of free antiprotons with nucleons in the indicated energy interval are approximately 0.15–0.20 b. However, the existence of such large cross sections does not require a substantial increase of the radius

interactions of nucleons and antinucleons compared with the radius of ordinary nuclear forces.

Let us consider the question of the influence of the range of action of nuclear forces on the absorption potential at the edge of the nucleus. A finite range of action of the forces can be introduced into the absorption coefficient by the formula:

$$K(x) = \int_V L\left(|x - x'|\right) \rho(x') \bar{\sigma}\, dx'. \tag{5}$$

SovietRxiv

If one takes $L(\xi) = \text{const}$ for $\xi \leqslant \xi_0$ and $L(\xi) = 0$ for $\xi > \xi_0$, then the integrals are easily evaluated. It turns out that, for a rectangular-well radius of $1 \cdot 10^{-13}$ cm, the dependence of the absorption coefficient on r changes very little. Moreover, if the value of the density at the center of the nucleus and the cross section of the elementary act are kept unchanged, then the absorption cross section by the nucleus (for $\bar{\sigma} = 200$ mb) changes by only 3%. If $\xi_0 = 2 \cdot 10^{-13}$ cm, then the absorption cross section in the case of the density behavior (1) and (2), for $\bar{\sigma} = 200$ mb, increases by 15%. Thus, the effect of the finite range of action of nuclear forces is small for the case of a diffuse boundary.

It should be noted that at lower energies there are other causes for an increase in the interaction of antinucleons with nuclei. First of all, these include Coulomb attraction, as a result of which the phases of waves with $l > kR$ are nonzero in the region of action of the nuclear forces. Furthermore, if the real part of the nuclear potential for antinucleons is considerably larger than for nucleons, then the refraction of antinucleon waves increases; however, this cannot have a very strong effect on the cross section if the absorption coefficient is large. The indicated effects may somewhat reduce the cross sections of the elementary acts obtained. Since the cross sections for the interaction of an antiproton with a neutron and with a proton may differ substantially, the comparison can be carried out only after measurements on the deuteron.

Received
16 X 1956

CITED LITERATURE

[1] O. Chamberlain, E. Segre et al., Phys. Rev., **102**, 1659 (1956). [2] J. M. Brabant, B. Cork et al., Phys. Rev., **102**, 1622 (1956). [3] R. W. Williams, Phys. Rev., **98**, 1387 (1955). [4] B. Hahn, D. G. Ravenhall, R. Hofstadter, Phys. Rev., **101**, 1131 (1956).

Note: Figure translations are in progress. See original paper for figures.

Source: Math-Net.Ru and CyberLeninka. Machine translation. Verify with the original.