conservation of isotopic spin in the interaction of nucleons (neutrons n, protons p) and antinucleons (antiprotons $\bar{p}$, antineutrons $\bar{n}$). Let us consider collisions in which mesons do not occur:

1) $\bar{p}+p\rightarrow\bar{p}+p$ (elastic scattering of antiprotons by protons)

2) $\bar{p}+n\rightarrow\bar{p}+n$ (elastic scattering of antiprotons by neutrons)

3) $\bar{p}+p\rightarrow\bar{n}+n$ (conversion of a proton and antiproton into a neutron and antineutron)

4) $\bar{n}+n\rightarrow\bar{n}+n$ (elastic scattering of antineutrons by neutrons)

5) $\bar{n}+p\rightarrow\bar{n}+p$ (elastic scattering of antineutrons by protons)

6) $\bar{n}+n\rightarrow\bar{p}+p$ (conversion of an antineutron and neutron into an antiproton and proton).

From charge symmetry, if we neglect electromagnetic forces:

$$\sigma_1=\sigma_4;\ \sigma_2=\sigma_5;\ \sigma_3=\sigma_6.$$

Thus only processes 1,2 and 3 need be considered.

Keep in mind, that all the particles entering into the reactions have isotopic spin $T=\frac{1}{2}$ and the following isotopic spin projections, T_3:

p	n	$\bar{p}$	$\bar{n}$
$1/2$	$-1/2$	$-1/2$	$1/2$

The nucleon-antinucleon system has, in general, two isotopic states: $T=1$ and $T=0$. If we denote the scattering amplitudes in these states respectively by f and g, then it is easy to see that the differential cross sections of reactions 1-3 are expressed in terms of f and g as follows:

$$\sigma_1=\frac{1}{4}|f+g|^2;\quad \sigma_2=|f|^2;\quad \sigma_3=\frac{1}{4}|f-g|^2.$$

Note that f and g are complex functions of the initial and final momenta of the particles and their spins. Thus the three cross sections are expressed in terms of three independent quantities: the moduli of the amplitudes, $|f|$ and $|g|$, and their relative phase. It follows from this, that, in general, there are no equations linking these cross sections.

However, in the scattering of antinucleons by nucleons at high energies, one can consider that $|f-g|\ll|f|$. This has to do with the fact that σ_3 is the cross section of a peculiar inelastic process (double "overcharging"). Such an "inelastic" process must have a significantly smaller probability than that of "genuine" inelastic processes. Considering nucleons and antinucleons as "gray" bodies (in particular cases they will be black bodies) of radius $\rho\sim10^{-13}$ cm, one gets an elastic cross section (mainly of a diffraction type) of the order of the inelastic (i.e., of the order of the annihilation cross section). Therefore, from the fact that the process $\bar{p}+p\rightarrow\bar{n}+n$ embraces a small portion of all the inelastic processes, it follows that its cross section is small compared to the elastic scattering $\bar{p}+p\rightarrow\bar{p}+p$ ($\bar{p}+n\rightarrow\bar{p}+n$), but this means that the inequality $|f-g|\ll|f|$ is satisfied.

On the basis of this result, we obtain $\sigma_1=\sigma_2$, i.e., the differential cross sections of the elastic scattering of antiprotons by protons and by neutrons are equal. Applying this to the forward direction, 0°, and recalling the connection between the imaginary part of the scattering amplitude and the total cross section σ_t, we find

$$\sigma_t(\bar{p}+p)\simeq\sigma_t(\bar{p}+n).$$

Together with the equality of the elastic cross sections, this means that the total annihilation cross sections for the collision of high energy antiprotons (antineutrons) with protons and with neutrons are equal.

In conclusion, I thank L. D. Landau for an interesting discussion.

Translated by M. Rosen
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The Conservation of Isotopic Spin and the Cross Section of the Interaction of High-Energy π-Mesons and Nucleons with Nucleons

L. B. OKUN' AND I. IA. POMERANCHUK
Academy of Sciences, USSR

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IN reference 1, the consequences of the conservation of isotopic spin in the scattering of antinucleons by nucleons were considered. The fact was used that the charge exchange cross section for the collision of antinucleons with nucleons is much less than the cross section for the other inelastic processes. For the scattering of π-mesons and nucleons, there are analogous results, justified at least for those energies at which inelastic reactions (creation of mesons) occur with high probability.

In the scattering of protons, the following reactions are possible:

1) $p+p \rightarrow p+p$ (elastic scattering of protons by protons)

2) $p+n \rightarrow p+n$ elastic scattering of protons by neutrons)

3) $p+n \rightarrow n+p$ (exchange scattering of protons by neutrons).

The neutron scattering reactions can be written analogously.

The differential cross sections of these reactions can be written in terms of the scattering amplitudes of the states with $T=1$ and $T=0$, as follows:

$$\sigma_1 = |f|^2, \quad \sigma_2 = {}^1/_4\,|f+g|^2, \quad \sigma_3 = {}^1/_4\,|f-g|^2.$$

It is known that at low energies($\sim 10^8$ ev) $|f| \gg |g|$, which leads, in particular, to a significant exchange scattering cross section at these energies ($\sigma_2 \approx \sigma_3$). At high energies ($\lesssim 10^9$ ev) exchange scattering $p+n \to n+p$ constitutes a small part of all the inelastic processes, so that, at such energies, π-meson creation reaction processes occur with high probability. In these circumstances, the total cross sections of the elastic and the inelastic processes are approximately equal; this is connected with the fact that we are dealing with scattering from "gray", "semi-transparent" bodies, where, within very wide limits of variation of opacity, elastic scattering has, in the main, a diffraction character. Therefore, the cross section σ_3 must be small as compared with σ_1 and σ_2. From this we find that $|f\text{-}g| \ll |f|$, i.e.,

$$\sigma_1 \approx \sigma_2; \quad \sigma_3 \approx 0.$$

Using the connection between the elastic and the total cross sections, we find that the total cross sections for the scattering of protons and neutrons from protons (neutrons) are equal to each other:

$$\sigma_t(p+n) = \sigma_t(p+p).$$

This also implies the equality of the corresponding inelastic cross sections.

In an analogous manner, one can also consider the scattering of high energy π-mesons by nucleons. The following elastic scattering and charge exchange reactions for π-mesons on protons are possible:

1) $\pi^+ + p \rightarrow \pi^+ + p$;

2) $\pi^0 + p \rightarrow \pi^0 + p$;

3) $\pi^0 + p \rightarrow \pi^+ + n$;

4) $\pi^- + p \rightarrow \pi^- + p$;

5) $\pi^- + p \rightarrow \pi^0 + n$.

The reactions with neutrons can be written analogously. All these reactions go through channels with isotopic spin $T=3/2$ or $T=1/2$. Their differential cross sections, expressed in terms of f and g, corresponding to $T=3/2$ and $T=1/2$, are:

$$\sigma_1 = |f|^2; \quad \sigma_2 = {}^1/_9\,|2f+g|^2;$$

$$\sigma_3 = \sigma_5 = {}^2/_9\,|f-g|^2;$$

$$\sigma_4 = {}^1/_9\,|f+2g|^2.$$

It is known that at low energies ($\sim 10^8$ ev) the scattering cross sections for π^-- and π^+-mesons on protons are substantially different.

At high energies ($\gtrsim 10^9$ ev) the charge exchange cross section of $\pi^- + p \to \pi^0 + n$ must be small compared to the total cross section of the inelastic processes, and, therefore, as compared with the cross section of the elastic processes. As in the scattering of nucleons, this is connected with the fact that, at these energies, inelastic processes occur intensively, and we are dealing with scattering from a very "gray" body, where elastic scattering has, in the main, a diffraction character and is equal to the inelastic in order of magnitude. From this it follows that $|f\text{-}g| << |$, i.e., $f \approx g$. Therefore:[2]

$$\sigma_1 \approx \sigma_2 \approx \sigma_4 \approx |f|^2; \quad \sigma_3 = \sigma_5 \approx 0.$$

Thus, at high energies, the differential cross sections for the elastic scattering of π^+-, π^--, π^0-mesons from protons (neutrons) are equal to each other. Considering the forward direction, 0°, we obtain for the total cross section:

$$\sigma_t(\pi^+ + p) \approx \sigma_t(\pi^- + p) \approx \sigma_t(\pi^0 + p).$$

This also implies that the corresponding total inelastic cross sections are equal to each other.

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[1] I. Ia. Pomeranchuk, J. Exptl. Theoret. Phys.(U.S.S.R.) 30, 424 (1956); Soviet Phys. 3, 305 (1956).

[2] K. M. Watson, Phys. Rev. 85, 852, (1952).

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