At large energies, when L is sufficiently large, $\Sigma'_m \approx \Sigma''_m \approx \Sigma_m$. If the angle ϑ_1 is small, then Σ_0 will be larger than Σ_1 and Σ_2 since the latter contain the associated Legendre polynomials. Therefore in practice one can always use the inequality (1). Let us write it out in more detail:

$$\sum_0^L (2l+1)[P_l(\cos\vartheta_1)]^2 \geqslant 4\pi\sigma(\vartheta_1)/\sigma_{el}. \qquad (1')$$

It is obvious that (1′) will begin to be valid only for $L \geq L_{min}$. In a quasiclassical approach one may associate with L_{min} a minimum interaction radius $R_{min} \approx L_{min}\lambda\!\!\!^{-}$.

As an example we discuss pp scattering at 8.5 Bev. According to Tsyganov et al.[1] we have in this case

$$\sigma_{el} = (8.6 \pm 0.8)\ \text{mb},$$
$$\sigma(2.5^\circ - 5.5^\circ) = 123 \pm 18\ \text{mb/sr}.$$

From the inequality (1′) we find $L_{min} = 16 \pm 3$. The optical model, when used to describe the same data, gives an effective L equal to 16. The corresponding interaction radius is $R \approx 1.6 \times 10^{-13}$ cm. It follows from our results that any other model will lead to the same or larger interaction radius.

The inequality (1′) may be viewed as a stronger version of the Rarita-Schwed[2] inequality:

$$(L+1)^2 \geqslant k^2\sigma_t^2 / 4\pi\sigma_{el}, \qquad (6)$$

which, as is easy to see, follows from (1′) for $\vartheta = 0$ in the case of a vanishing real part of the scattering amplitude. Thus, in the example considered above, the inequality (6) yields the weaker estimate $L_{min} = 8 \pm 1$ if $\sigma_t = (30 \pm 3)$ mb.

In conclusion we note that all our results hold as well for inelastic two-particle reactions of the type $\pi^- + p \rightarrow \Sigma^- + K^+$. In this case one should replace σ_{el} by the total cross section for the reaction under study.

The authors are indebted to L. G. Zastavenko for discussions.

[1] V. I. Veksler, Report at the International Conference on High Energy Physics, Kiev, 1959.

[2] W. Rarita and P. Schwed, Phys. Rev. **112**, 271 (1958).

Translated by A. M. Bincer

CREATION OF ANTIPROTONS IN INTERACTION OF NEGATIVE PIONS WITH NUCLEONS

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UP to now there apparently has been no observed case of direct production of antiprotons in πN interactions. We have found several cases of production of antiprotons by negative pions on nucleons, two of which are reported in this letter.

The work was carried out on the proton synchrotron of the Joint Institute for Nuclear Research with a propane bubble chamber[1] in a permanent magnetic field of 13,700 gauss.

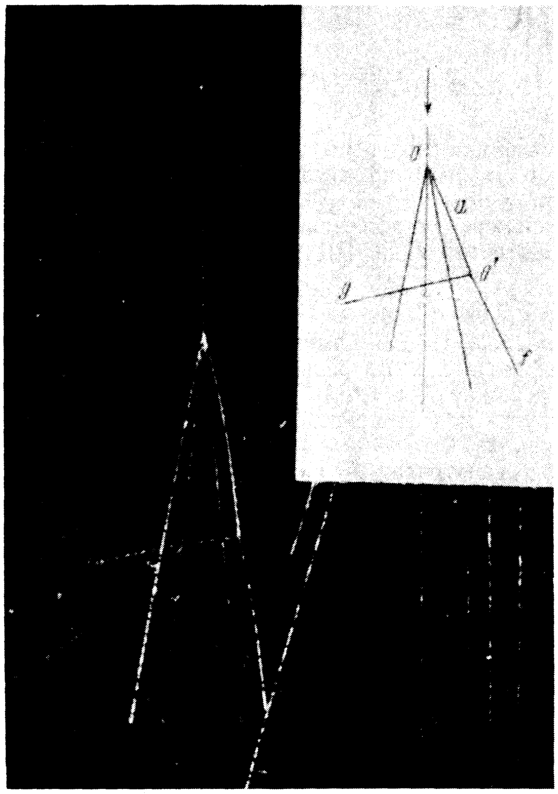

FIG. 1

Figure 1 shows a case where a primary negative pion with approximate energy 7 Bev crosses at the point O a star with four prongs. Prong a is determined unambiguously as an antiproton. The prong a experiences scattering by approximately 5°, 2.3 cm away from the point O, and travels another 3.3 cm before it is stopped at the point O′, where it is apparently annihilated, with the proton forming, in addition to neutral particles, two charged particles f^- and g^+. The momentum of the f particle is 138 ± 6 Mev/c, while that of the g particle is 170 ± 12 Mev/c. The angle between f and g is 126 ± 1°. It must be emphasized that the star O′ cannot be caused by any other process except annihilation.

Let us consider the possible reactions:

1. $K^- + p \to \Lambda^0 + \pi^+ + \pi^-$ (for the free and bound proton);
2. $K^- \to \pi^- + \pi^0 + \pi_0$;
3. $K^- \to \pi^- + \pi^0$;
4. $\bar{p} + p \to \pi^+ + \pi^- + (n\pi^0)$.

1. The $\pi^\pm$ mesons (f and g) cannot be produced by reaction 1, from energy considerations. This conclusion is not changed if it is assumed that the K^- mesons interact in flight, because the angle between a and f at O is greater than 90°, and the angle between a and g is close to 90°.

2. Reaction 2 is also impossible from energy considerations, even if it is assumed that one of the γ quanta from the π^0-meson decay produces immediately a positron, and the electron receives no energy at all.

3. If it is assumed, on the other hand, that reaction (3) takes place, then the negative pion should have a momentum of 205 Mev/c; measurements yield 130 ± 6 Mev/c. Furthermore, the positive g particle should be a positron and carry away the total momentum of the γ quantum, on the order of 100 Mev/c. Actually the measurements show the particle to have a momentum of 170 ± 12 Mev/c.

4. Only the last possibility remains: g and f are positive and negative pions respectively, created simultaneously with the other neutral particles during the act of annihilation.

Figure 2 shows the second case of creation of a slow antiproton by a negative pion of energy 8 Bev. The negative pion interacts with the carbon nucleus and produces at the point O a three-pronged star. Particle a, which has a negative charge, covers 12.9 cm in the chamber and is stopped at the point O′, where it is annihilated with the nucleon in the carbon nucleus, forming a star of seven prongs, three of which have minimum ionization.

Track b, one of the three prongs with minimum ionization, formed by the positive particle, has a momentum of 566 ± 34 Mev/c, i.e., it is a positive pion. This fact confirms that the a particle is an antiproton (or, less probably, $\bar{\Sigma}^+$), since no other known particle can produce a pion with so large a momentum when stopped. The momenta of the other prongs of this star cannot be measured with reliable accuracy, since they have a very small length in the chamber and all go outside the working volume.

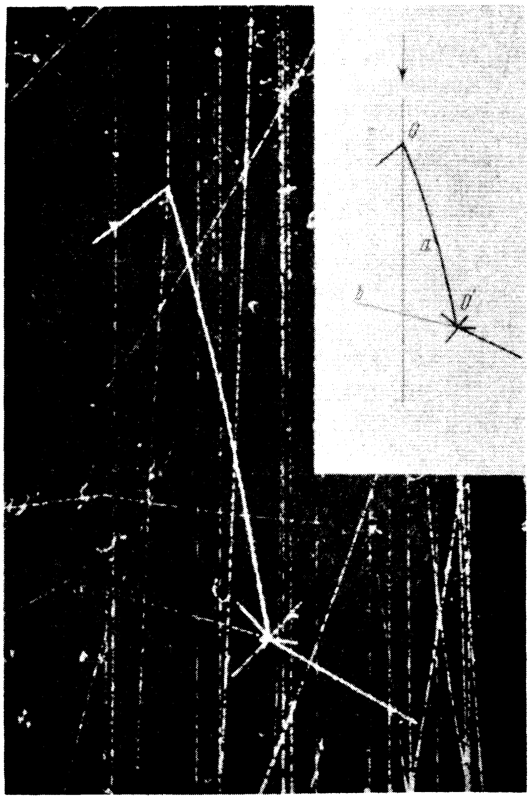

FIG. 2

The mechanism of production of these two antiprotons, and also several cases of production of antiprotons with momenta greater than 1.5 Bev/c, will be described in detail in another article.

An estimate of the cross section for the production of antiprotons by negative pions with energies 7 — 8 Bev in propane gives a lower value of 10^{-30} cm^2 per nucleon.

[1] Wang, Solov'ev, and Shkobin, Приборы и техника эксперимента (Intruments and Measurement Engineering) No. 1, 41 (1959).

Translated by J. G. Adashko
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