ANGULAR DISTRIBUTIONS OF PIONS PRODUCED IN NUCLEON-NUCLEON COLLISIONS AND THE ISOTOPIC INVARIANCE HYPOTHESIS

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The angular distribution of π^0 mesons produced in neutron-proton collisions at ≈600 MeV is measured and compared with previously obtained angular distributions of π mesons for the purpose of testing the isotopic invariance hypothesis.

1. INTRODUCTION

IN earlier work[1] we showed that a discrepancy can exist between the angular distributions of neutral[1,2] and charged[3-6] pions produced in nucleon-nucleon collisions, thus violating the hypothesis of isotopic spin conservation. According to this hypothesis the combined (normalized according to the cross sections) angular distributions of π^0 mesons and of $\pi^\pm$ mesons produced in p-p and p-n collisions should be identical:

$$f^{\pi^0}_{pp+pn}(\theta) = f^{\pi\pm}_{pp+pn}(\theta). \qquad (1)$$

The distribution $f^{\pi^0}_{pp+pn}(\theta)$ is nearly isotropic at energies ≈650 MeV,[1,2] whereas $f^{\pi}_{pp+pn}(\theta)$ exhibits considerable anisotropy[3-6] resulting from the large anisotropy of π^+ mesons produced in p-p collisions.[3] However, as indicated in [1], this difference has not been firmly established experimentally. On the one hand, the π^+ angular distribution $f^{\pi^+}_{pp}(\theta)$ could actually be more isotropic than that reported in [3]; this is indicated in [7]. On the other hand, the π^0 angular distribution could be somewhat different from that reported in [1], where we studied collisions between protons and bound neutrons in deuterium. Interference is possible between nucleonic states of a deuteron, resulting in a π^0 distribution different from that arising in collisions between protons and free nucleons.[1)]

In order to resolve the second of these uncertainties we investigated accurately the angular distribution of π^0 mesons produced in free n-p collisions:

$$n + p \rightarrow \pi^0 + \begin{cases} n + p \\ d \end{cases}. \qquad (2)$$

For this purpose we used a neutron beam, having a broad energy spectrum [9] from the synchrocyclotron at the Laboratory for Nuclear Problems of the Joint Institute for Nuclear Problems. Figure 1 shows the effective spectrum of incident neutrons in reaction (2) obtained through multiplication of the cross section for (2)[1] by the neutron spectrum.[9] In these investigations we made use of experimental data accumulated in experiments with proton beams.[1,2] This was essential because of the relatively low intensity of neutron beams, which therefore do not yield accurate measurements of γ-telescope efficiency, solid angles, and various corrections. The lack of these measurements would make it impossible to obtain any precise data regarding π^0 angular distributions.

2. EXPERIMENTAL RESULTS

The angular distribution of π^0 mesons was in-

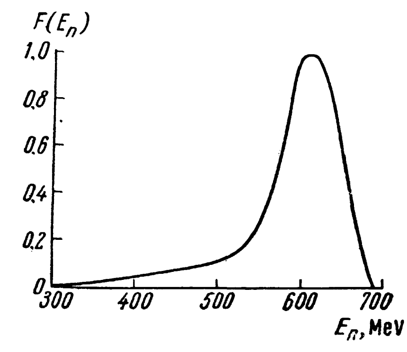

FIG. 1. Effective neutron energy spectrum for reaction (2).

1)As shown earlier,[8] in the given energy region the effect of the nucleonic bond in the deuteron on the total cross sections (integrated over θ) for meson production involves mainly a change in the cross sections due to intranuclear nucleon motion. This motion causes a small change in the velocity of the c.m. system for the angular distributions, which can be calculated from the known nucleon momentum distribution in the deuteron.[8]

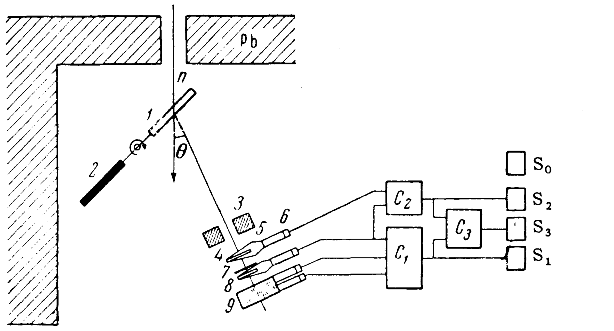

FIG. 2. Experimental arrangement. n – neutron beam; 1, 2 – polyethylene and graphite targets; 3 – lead diaphragm; 4 – scintillation counter for anticoincidences; 5 – hollow light guide; 6 – photomultiplier FÉU-33; 7 – lead converter; 8 – scintillation counter; 9 – Cerenkov counter with Plexiglas radiator; C_1, C_2 – coincidence circuits; C_3 – anticoincidence circuit; S_0 – S_3 – scalers (S_0 registered the neutron beam intensity).

vestigated by registering γ quanta from the decay of π^0 mesons produced by a neutron beam passing through the target. The experimental arrangement is shown in Fig. 2. The γ telescope, used in conjunction with a lead converter, consisted of scintillation counters and a Cerenkov counter. An important characteristic of the γ telescope was the combination of a low γ-energy threshold and low sensitivity to charged particles and neutrons. The latter property enabled measurements of γ yields at small angles θ, where the scattered-neutron background is especially large.

The efficiency of neutron registration was determined experimentally by positioning the γ telescope in the path of a beam of neutrons and γ quanta in the ratio 10 : 1. Different converters were used to measure the dependence of the telescope counting rate on the thickness of the lead absorber, which was positioned with good geometry in front of the telescope (Fig. 3). The relative γ-ray content of the beam decreased rapidly with increasing absorber thickness; at the greatest thickness the telescope registered practically only neutrons. The neutron efficiency of the telescope was then determined by extrapolation. On the basis of these measurements only very small corrections for neutron scattering were required. The γ-ray efficiency of the γ telescope was determined experimentally within about 2% by the procedure described in [2,10].

The yields of γ quanta produced in n-p collisions were determined by the difference method; targets made of polyethylene (CH_2) and of light graphite were bombarded. (We used the same targets as in [2].) The measurements were performed in two stages: first we obtained the angular distribution $f^{\gamma}_{nC}(\theta)$ of γ quanta produced in collisions between neutrons and carbon nuclei; secondly, the difference method was applied to the differential cross-section ratio for hydrogen and carbon, $\sigma'_{np}(\theta) = (d\sigma^{\gamma}_{np})/d\Omega)(d\sigma^{\gamma}_{nC}/d\Omega)^{-1}$, measured at 10 angles.

The available experimental angular distributions $f^{\gamma}_{pC}(\theta)$ obtained previously with a proton beam of different energy,[2] enabled a calculation of $f^{\gamma}_{nC}(\theta)$, since charge symmetry gives

$$f^{\gamma}_{nC}(\theta) = f^{\gamma}_{pC}(\theta). \qquad (3)$$

In order to check for the absence of systematic errors we measured the γ yields from carbon at several angles. Equation (3) was found to be fulfilled (Fig. 4) for $f^{\gamma}_{nC}(\theta)$ as measured and as calculated from the proton-beam data.

The determination of the relative cross sections $\sigma'_{np}(\theta)$ required laborious prolonged experimental runs because of the low neutron intensity and the necessity of an exact experimental determination of corrections for the difference between the γ spectra produced in n-p and n-C collisions. Our values of $\sigma'_{np}(\theta)$ in the accompanying table and the distribution $f^{\gamma}_{nC}(\theta)$ in Fig. 4 were used to obtain $f^{\gamma}_{np}(\theta)$, which is shown in Fig. 5.

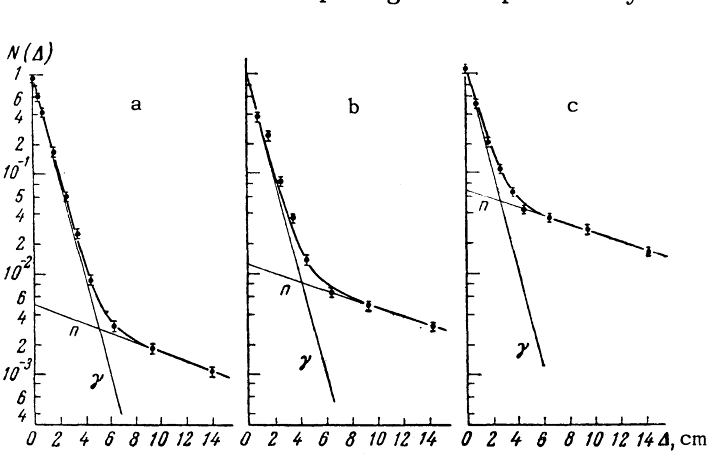

FIG. 3. Counting rate N of γ telescope in path of beam of neutrons and γ quanta as a function of lead absorber thickness Δ. a – measurements with lead converter thickness d = 2 mm; b – the same for d = 10 mm; c – measurements with graphite converter thickness d = 15 mm. The straight lines labeled γ and n represent γ-quantum and neutron absorption in lead. The heavy curve represents the addition of these straight lines.

$\theta_{lab.}$, deg	$\theta_{c.m.}$, deg	$\sigma'_{np}(\theta)$	$\theta_{lab.}$, deg	$\theta_{c.m.}$, deg	$\sigma'_{np}(\theta)$
10	17.0	0.275±0.019	60	89.2	0.228±0.007
14	23.9	0.284±0.010	75	105.3	0.225±0.009
20	33.4	0.296±0.010	90	119.4	0.227±0.006
35	56.5	0.264±0.007	130	149.4	0.205±0.007
48	74.3	0.231±0.008	150	162.2	0.190±0.008

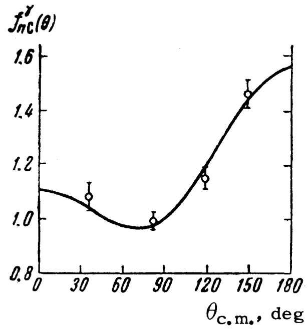

FIG. 4. Angular distribution of γ quanta from the decay of π^0 mesons produced in collisions of neutrons with carbon nuclei. The curve was calculated from data on p–C collisions in [2].

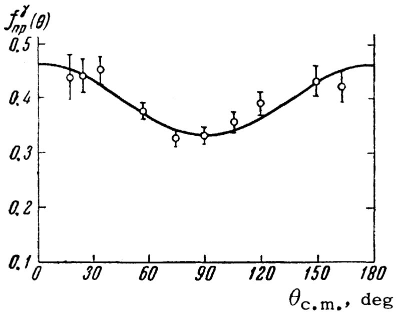

FIG. 5. Angular distribution of γ quanta from the decay of π^0 mesons produced in n-p collisions. The curve represents $f^{\gamma}_{np}(\theta) \approx 1/3 + 0.12 \cos^2\theta$ obtained by least squares.

3. DISCUSSION

The angular distribution $f^{\gamma}_{np}(\theta)$ should be symmetric about 90° in the c.m. system of colliding nucleons if isotopic spin is conserved. The distribution was actually found to be symmetric, having the small angular term $(0.002 \pm 0.011) \cos\theta$. This confirms the absence of any appreciable systematic errors in our procedure. A good fit of the experimental distribution $f^{\gamma}_{np}(\theta)$ is given by the second-degree polynomial

$$f^{\gamma}_{np}(\theta) \sim {}^1/_3 + (0.12 \pm 0.02) \cos\theta.$$

From this distribution combined with π energy spectra [3,5,7,11-13] we obtained the π^0 angular distribution by the procedure described in [2]:

$$f^{\pi^0}_{np}(\theta) \sim {}^1/_3 + (0.40 \pm 0.07) \cos^2\theta.$$

We now compare the foregoing distributions with the forms of $f_{pn}(\theta)$ previously obtained for bound neutrons.[1] Taking the neutron spectrum into account,[9] the γ angular distribution[1] is

$$\overline{f^{\gamma}_{pn}(\theta)} \sim {}^1/_3 + (0.13 \pm 0.02) \cos^2\theta,$$

which agrees with the present work. This proves the absence of any interference effects appreciably distorting the angular distribution of π^0 mesons produced in proton collisions with neutrons bound in deuterons. We have thus eliminated one of the conceivable explanations for the discrepancy, mentioned in the introduction, between the angular distributions of neutral and charged pions at ≈ 650 MeV. It therefore becomes very important to test another possible explanation associated with a refined angular distribution of π^+ mesons produced in p-p collisions at 650 MeV.

In conclusion we shall compare the available angular distributions of pions produced by nucleons at ≈ 600 MeV. For this purpose all known distributions are averaged, taking the spectrum in [9] into account. This enables an accurate determination of cross sections for nucleon scattering in the isotopic spin state T = 0 and a test of isotopic spin conservation.[14] The average angular distribution of neutral pions[2)] is found to be nearly isotropic:

$$\overline{f^{\pi^0}_{pp+np}(\theta)} \sim {}^1/_3 + (0.32 \pm 0.06) \cos^2\theta.$$

The distribution of charged pions, based on the data of several investigators,[3-6,13,15] is more anisotropic:

$$\overline{f^{\pi^\pm}_{pp+np}(\theta)} \sim {}^1/_3 + (0.59 \pm 0.12) \cos^2\theta,$$

so that we find a discrepancy similar to that noted in [1] at a somewhat higher energy (≈ 650 MeV). As in the latter case, the difference between the average angular distributions disappears if the data in [3] are replaced with the data in [7]:

$$\overline{f^{\pi^\pm}_{pp+np}(\theta)} \sim {}^1/_3 + (0.33 \pm 0.08) \cos^2\theta.$$

The discussed difference between the angular distributions of neutral and charged pions produced at 600—650 MeV could result from a violation of isotopic spin invariance at high energies. This question has become especially interesting in con-

[2)]The π^0 angular distributions averaged here are more anisotropic than those given in [1,2], where the transition from the γ angular distribution to the π^0 angular distribution was based on energy spectra that were subsequently found to be too hard. However, this discrepancy still lies within experimental error.

nection with the frequently advanced hypothesis [16] that ρ^0 mesons and ω^0 mesons are the same particle, in whose decay isotopic spin ceases to be a "good" quantum number.

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