Q, Mev	Scattering angle in lab system									l	R, f
	32°49′	48°28′	63°04′	76°54′	90°24′	109°10′	124°13′	138°17′	151°57′		
0.000	850.20	302.30	177.00	109.20	60.50	38.50	44.50	65.00	64 20	—	—
—0.840	4.75	7.87	7.85	7.47	6.55	4.35	—	2.52	2.0	2	5.6
—1.014	6.93	9.55	10.30	10.10	8.88	7.80	7.00	6.34	—	2	5.6
—2.216	10.40	12.95	14.30	16.00	17.70	15.35	10.60	9.75	8.15	3	5.6
—2.743	8.45	11.20	12.55	13.35	13.05	12.30	11.60	10.50	7.36	2	5.0
—3.000	12.20	14.60	17.80	19.90	20.50	16.70	14.05	10.20	9.75	2	5.0

The angular distributions of all the particle groups (in the center-of-mass system) have the characteristic features peculiar to direct interaction angular distributions. The total scattering cross section for the six levels is about 700 mb, which is larger than the cross section for compound nucleus formation (about 600 mb). This leads to the conclusion that direct interaction makes a substantial contribution in 6.6-Mev scattering. The orbital angular momenta, l, transferred to the nucleus, determined by comparison with direct interaction theory,[5] are given in the table together with the corresponding values of the interaction radius R (in 10^{-13} cm).

In conclusion, the authors express their gratitude to Z. F. Kalacheva, I. V. Kretov, G. S. Tyurikov, N. S. Kirpichev, and M. Kh. Listov for aid in this work, and also to the crew of the cyclotron, particularly Yu. A. Vorob'ev, A. A. Danilov, V. P. Khlapov, and E. Kir'yanov, for assuring proper operation of the accelerator.

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Translated by M. Bolsterli

A METHOD FOR THE MEASUREMENT OF PHOTOPRODUCTION OF π^+ MESONS ON HYDROGEN CLOSE TO THRESHOLD

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Submitted to JETP editor January 4, 1961

J. Exptl. Theoret. Phys. (U.S.S.R.) **40**, 974-976 (March, 1961)

WHEN combining the experimental data on the photoproduction of π^+ mesons close to threshold[1] one finds that the square of the matrix element increases as the photon energy decreases. However, very close to threshold the accuracy of the measurements is not good enough to draw definite conclusions.[2]

The absence of good data on the photoproduction cross section close to threshold is due to the large experimental difficulties. Very close to threshold (152 – 160 Mev) one cannot use liquid or gas targets because of the energy loss of the mesons in the target and because of the large background. In this energy region one has to use thin polyethylene targets.[3] However, one then has to perform $CH_2 - C$ difference experiments, which for large yields from carbon decreases the statistical accuracy of the results.

We shall describe a method which allows to circumvent these difficulties and we shall give results of an experimental demonstration of its feasibility. The method is based on the kinematical difference between photoproduction on hydrogen and on carbon, in particular on the difference in the thresholds. The following reactions have the lowest thresholds:

$$\gamma + {}_6C^{12} \to \pi^+ + {}_5B^{12}, \tag{1}$$

$$\gamma + {}_6C^{12} \to \pi^+ + n + {}_5B^{11} \tag{2}$$

$$\gamma + {}_6C^{12} \to \pi^+ + n + n + {}_5B^{10}. \tag{3}$$

The thresholds for these reactions are respectively

154.5, 157.7, and 169.1 Mev. The π^+ production threshold on hydrogen is 151.3 Mev.

In Fig. 1 the photon energy has been plotted as a function of the meson energy for different directions of the outgoing π^+ meson both for production on hydrogen and by reaction (1). As can be seen from the thresholds the curves for reactions (2) and (3) will be still higher.

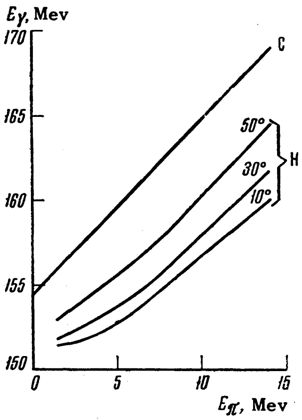

FIG. 1. Dependence of the photon energy on the meson energy at different angles of the outgoing meson.

From Fig. 1 one sees that for a given meson energy and a small angle one can choose such a maximum photon energy in the bremsstrahlung spectrum, $E_{\gamma max}$, that no photoproduction from carbon is possible. For example, for $E_{\gamma max}$ = 158 Mev mesons with 3 Mev at an angle 30° will have been produced exclusively on hydrogen by photons with an energy 153 Mev. However, under these conditions only the very tip of the bremsstrahlung spectrum will be utilized. One therefore should increase the photon energy $E_{\gamma max}$ as far as possible to increase the yield from hydrogen while keeping the background of mesons from carbon sufficiently low. Fortunately the photoproduction from nuclei is a single nucleon process.[4,5] Thus reaction (1) is a partial and unlikely process of reaction (2). Accordingly quite a high energy $E_{\gamma max}$ can be chosen.

In order to verify these considerations an experiment has been performed. The apparatus is shown schematically in Fig. 2.

A polyethylene target of 0.0173 g/cm^2 was placed in the photon beam of the synchrotron of the Physics Institute of the Academy of Sciences. The energy was $E_{\gamma max}$ = 175 Mev. Mesons of energy 0.5 to 5.5 Mev emitted at 30° in the lab system* were counted. Nuclear NIKFI-K emulsions 400μ thick were used as the detector. Target and emulsions were placed in a vacuum chamber. The energy loss for mesons of average energy in the target was ~ 0.1 Mev.

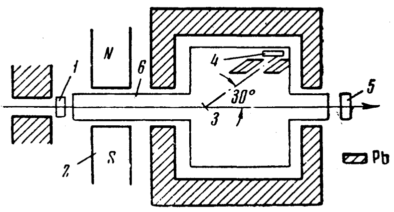

FIG. 2. Experimental setup. 1, 5 – ionization chambers, 2 – magnet, 3 – target, 4 – nuclear emulsion, 6 – vacuum chamber.

In such an experimental arrangement in the nuclear emulsions both positive mesons from hydrogen and carbon and negative mesons from carbon will be seen. The π^- mesons are created in carbon in reactions similar to those of the π^+ mesons, namely:

$$\gamma + {}_6C^{12} \rightarrow \pi^- + {}_7N^{12}, \quad (1a)$$

$$\gamma + {}_6C^{12} \rightarrow \pi^- + p + {}_6C^{11}. \quad (2a)$$

The thresholds for these reactions are 157.8 and 158.9 Mev respectively.

The contribution of π^+ mesons from carbon can be easily estimated from the number of observed π^- mesons since the π^+/π^- photoproduction ratio in carbon is known for the energy range of interest[6] and equals 2.7 ± 0.4.† This allows one to avoid the necessity of performing the rather tedious work of determining the yield of π^+ mesons from carbon.

The experimental results are:

$E_{\gamma\ max}$, Mev:	175	250
$\pi^-(CH_2)/\pi^+(CH_2)$:	0.22±0.06	0.55±0.14
$\pi^+(CH_2)/\pi^+(H_2)$:	1.09±0.03	1.26±0.05

It follows from these data that the relative yield of π^+ mesons from carbon is (9 ± 3)% of that from hydrogen. For comparison purposes the analogous quantities are given also for $E_{\gamma max}$ = 250 Mev. Thus one sees clearly that the proposed method allows to decrease the π^+-meson background from the carbon in the polyethylene target considerably and to increase the statistical accuracy of the experimental results obtained in a given running time.

In addition, our experimental data allow a determination of the most probable type of the reaction.

We now shall compare the experimental ratio $\pi^-(C)/\pi^+(H_2)$ with a calculation for $E_{\gamma max}$ = 250 Mev which is based on the assumption that the total meson yield from carbon is due to the reactions (1) and (2). In the determination of this ratio for reaction (2) the distribution of nucleon momenta in the nucleus was taken into account.[7] We obtain:

	Experiment	Calculation	
		Reaction (1)	Reaction (2)
$\pi^-(C)/\pi^+(H_2)$:	0.24 ± 0.07	0.67 ± 0.17	0.34 ± 0.09

One can see from this that the results of the present experiment support the supposition on the one nucleon mechanism of π-meson production in nuclei.

It should be mentioned that the suggested method will be even more effective for the measurement of the photoproduction of π mesons from deuterons close to threshold using heavy polyethylene.

In conclusion the authors express their gratefulness to Professor P. A. Cerenkov for his interest in the work.

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*At the energy $E_{\gamma max}$ = 175 Mev mesons at this angle can be produced only in reactions (1) and (2).

†Comparing the thresholds for π^+ and π^- production one can easily see that the ratio π^-/π^+ at $E_{\gamma max}$ = 175 Mev is practically the same as that found at $E_{\gamma max}$ = 250 Mev.[6]

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Translated by M. Danos
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A NOTE ON THE ANISOTROPY IN THE ANGULAR DISTRIBUTION OF PARTICLES FROM NUCLEAR INTERACTIONS AT 10^{12} ev.

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Submitted to JETP editor January 7, 1961

J. Exptl. Theoret. Phys. (U.S.S.R.) **40**, 976-977 (March, 1961)

In the work of Gierula et al.[1] it was shown that the angular distribution of secondary particles from nuclear interactions with primary energy > 10^{12} ev has a significant anisotropy and that besides the anisotropy, characterized by $\sigma > 0.6$, there is a structure with two maxima. This result was confirmed in reference 2.*

We would like to point out that the interactions produced by charged particles (p) have, on the average, a greater anisotropy than those with neutral (n) primaries. We show in the figure the distribution of values of $\log(\gamma_c \tan\theta_L)$ separately for the groups with p primaries (solid curve) and n primaries (dashed curve). The first group includes 19 cases with $\langle\gamma_c\rangle = 54$, predominantly from the literature. In the n interactions there are 13 cases with $\langle\gamma_c\rangle = 44$. We determined the anisotropy with the aid of σ as in reference 1; for the group p we have $\sigma = 0.82$, and for the n distribution we obtained $\sigma = 0.64$.