PHOTOPRODUCTION OF PIONS FROM COMPLEX NUCLEI

A. S. BELOUSOV, V. M. POPOVA, N. G. SEMASHKO, E. V. SHITOV,
E. I. TAMM, V. I. VEKSLER and F. R. IAGUDINA

Lebedev Institute of Physics, USSR Academy of Sciences, Moscow

(presented by A. S. Belousov)

Introduction

In order to get an insight into the mechanism of meson photoproduction from nuclei, experiments on the dependence of pion photoproduction cross-section on atomic number of the nuclei, A, have been made in the USSR Academy of Sciences, Lebedev Institute of Physics, synchrotron laboratory.

It was shown previously in Panofsky, Steinberger and Steller's [1]—and also Littauer and Walker's [2] experiments, where the targets of different elements were irradiated by 320-Mev bremsstrahlung spectrum that the pion photoproduction cross-section per nucleus increased as a function of $A^{2/3}$ with increase in the atomic number A. This result is generally interpreted as the reabsorption of the meson produced inside the nucleus by nucleons (followed by the production of a star); then the nucleus surface alone proved to be effective in yielding mesons. In these experiments, however, the mesons detected had energies between 60 to 100 Mev and, therefore, the cross-section of their inelastic interaction with the nucleus is equal to the geometrical cross-section. The mean free path of a meson in nuclear matter depending greatly on the meson energy [3] (increasing as its energy decreases), it seemed to be possible by investigating the photoproduction of relatively low energy pions ($\sim$ 20 Mev), for which the nucleus must be to a considerable extent transparent, to obtain an unambiguous answer as to where the mesons are produced in the nucleus. If the pion photoproduction occurs only at the surface of the nucleus, the energy spectrum variation of the meson detected should not affect the dependence of the meson yield per nucleus on the atomic number A. But the meson production from the core of a nucleus and subsequent reabsorption of mesons produced in the interior of the nucleus by the same nucleus should lead to a dependence of the cross-section as a function of the atomic number on the meson energy.

The experiments for studying the dependence of the pion photoproduction on atomic number were made by A. S. Belousov, E. V. Shitov, and E. I. Tamm with neutral π mesons and by V. M. Popova, N. G. Semashko, V. I. Veksler and F. R. Iagudina with slow negative π mesons, the results of the latter work being preliminary ones.

a) π° *mesons*

The study of the photoproduction of π° mesons from nuclei has the advantage that in this case there is no Coulomb interaction which complicates the interpretation of experimental results on the photoproduction of charged mesons.

In the present experiments the π° mesons were detected by one of the decay gamma-rays by a telescope of scintillation counters arranged at an angle of 90° to the beam of gamma-rays (see fig. 1). The measurements were made for two values of the maximum energy of the bremsstrahlung E_{γ}^{m} –265 Mev, and 200 Mev; in order to reduce the background of accidental coincidences, the intensity pulse of the accelerator was extended in time to 3000 microseconds and 1000 microseconds respectively.

The results of the measurements given in fig. 2 show that the cross-section of π° meson production for a nucleus of atomic number A is proportional to $A^{2/3}$ with an accuracy of 3 per cent at a maximum beam energy of 260 Mev. At a maximum beam energy of 200 Mev, this cross-section is also proportional to $A^{2/3}$ within the error

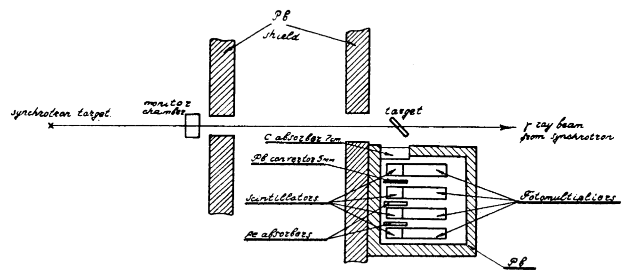

Fig. 1. Experimental arrangement for the detection of π^{0} mesons

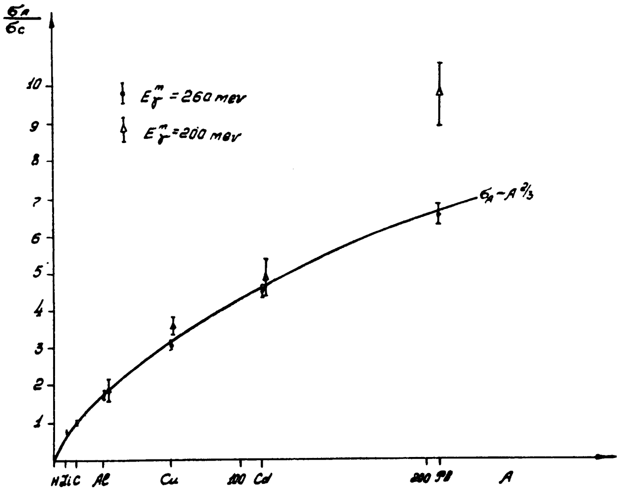

Fig. 2. Cross-section for π° photoproduction as a function of the atomic number A

of 10 per cent. An exception is Pb, for which in the latter case a cross-section greater than what one would expect from the dependence of $A^{2/3}$ was obtained. This may be due to the contribution of Thomson scattering of gamma-rays by nuclei, the cross-section of which depends very greatly on the atomic number of the target matter :

$$\sigma_T \sim \frac{Z^4}{A^2}.$$

It proved impossible to measure the Z-dependence of π° meson photoproduction at energies close to threshold by detecting one of the decay gamma-rays, due to the large contribution introduced by Thomson scattering of gamma-ray by nuclei.

The results obtained show that the nature of the dependence (upon the atomic number A) of the cross-section of π° meson production from nuclei does not change with the maximum energy variation of the gamma-rays from 265 Mev to 200 Mev, despite the fact that in this case the peak energy of meson spectrum is displaced from 65 Mev to 20 Mev.

It will be remembered that Panofsky, Steinberger, and Steller [1]) obtained the same dependence by irradiating the target with 310 Mev bremsstrahlung spectrum and by detecting the π° mesons at an angle of 45° to the beam. In this case the peak meson energy must be at about 100 Mev.

b) π^- *mesons*

π^- mesons produced by irradiating thin targets with 265 Mev bremsstrahlung were detected by photoplates of the NIKFI «K» type at an angle of 80° ± 20° to the beam. The whole arrangement was placed in the vacuum chamber. A clearing magnet removed all possible charged particles from the beam incident on the target.

The relative cross-sections of π^- mesons production from Be, C, Al and Cu were obtained in the energy range from 0 to (3.4 ± 0.1) Mev. The error in the determination of the mesons energy is chiefly due to the energy loss during their passage through the target.

The results were compared with theoretical curves for 2 Mev π^- mesons calculated by A. M. Baldin and A. I. Lebedev. The data are given in fig. 3, where the statistical errors only are shown (the total error is not more than 12 per cent, for aluminium it is slightly higher). Here, curve A corresponds to the effect of pure Coulomb interaction, the nucleus being assumed to be a point nucleus. Allowing for the finite size of the nucleus reduces the Coulomb interaction and leads to a reduction in the yields of slow mesons, which is especially considerable for nuclei with large Z's. In the case of light nuclei, this correction is rather small, but for small Z's account must be taken of the weak nuclear interaction (which for Z < 10 exceeds the Coulomb interaction). Both these effects were taken into consideration in the calculations (curves B and C).

The meson-nucleus repulsive potential taken according to the mesic atoms was considered equal to 4.8 Mev for the light nuclei. When calculating the curves B and C,

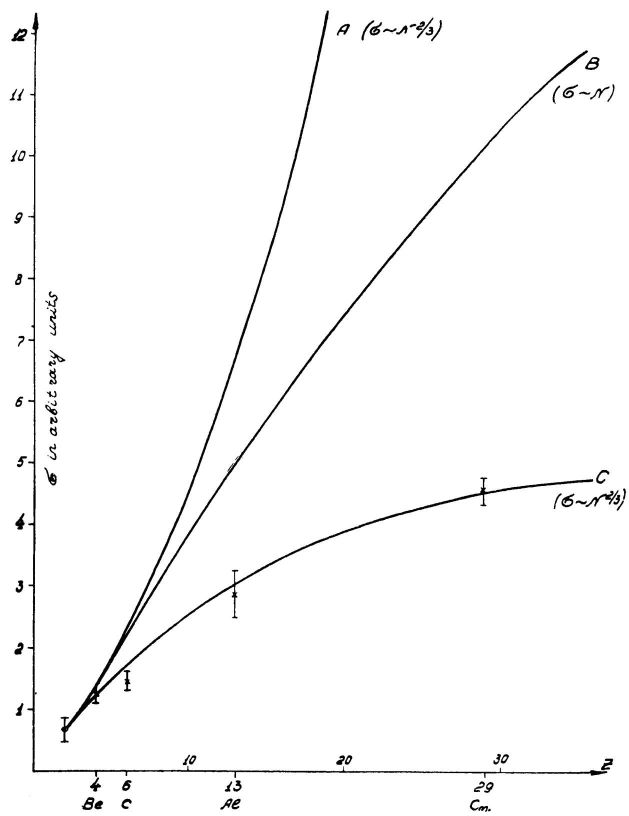

Fig. 3. Cross-section for π^- photoproduction as a function of atomic charge Z. The solid curves correspond to calculations by Baldin and Lebedev

the cross-section of pion photoproduction was assumed proportional to A and $A^{2/3}$ respectively. It may be seen that the experimental points lie close to the C curve, but not to the B curve, thus confirming the dependence of $A^{2/3}$ of the slow pion yield upon the atomic number.

It should be noted that the cross section for negative photomesons with an energy up to 4 Mev from D and also from lighter ($Z_{av}=7$) and heavier ($Z_{av}=41$) nuclei if photoemulsions (emulsions filled with D_2O being irradiated by 265 Mev bremsstrahlung) lie close to the same curve C [4,5].

c) *Conclusions*

1. Our results with respect to the π° mesons cannot be explained by the reabsorption of mesons produced inside the nuclei. As the energy of the mesons decreases, their mean free path in the nucleus increases; therefore, if the mesons were produced in the entire core of the nucleus, the π° meson production cross-section as a function of the atomic number would have to change appreciably with a decrease of the meson energy from 100 to 20 Mev. The fact that such a change is not observed, may be due to a certain process suppressing the production of mesons inside nuclei and leading to a surface production of mesons.

2. In the case of π^- mesons, the dependence of $A^{2/3}$ also suggests surface meson production because the nucleus is practically transparent for mesons of such small energies.

3. For large Z's the cross-section of slow π^- meson production decreases radically because of the Coulomb interaction weakening due to the finite size of the nucleus.

4. For small Z's the agreement with the theoretical curve shows that the cross-section of slow π meson production decreases due to repulsive interaction between the meson produced in the S-state and the nucleus. Thus, an investigation of the photoproduction of slow π^- mesons from complex nuclei (slow to the extent that their wavelength exceeds the dimensions of the nucleus, and they interact with all the nucleons of the nucleus) may give some information on meson-nucleon interaction in addition to data on mesic atoms.

LIST OF REFERENCES

1. Panofsky, W. K. H., Steinberger, J. N. and Steller, J. Further results on the production of neutral mesons by photons. Phys. Rev., *86*, p. 180-9, 1952.
2. Littauer, R. and Walker, D. Charged photomesons from various nuclei. Phys. Rev., *86*, p. 838-46, 1952.
3. Stork, D. H. Interaction of pions with complex nuclei. Phys. Rev., *93*, p. 868-80, 1954.
4. Gorghevskaia, E. G. and Panova, N. M. (private communication.)
5. Adamovitch, M. I. et al. (private communication.)