lead foil stack (Fig. 3) it was found that nuclei with a half-life of 2 — 3 minutes have a long range, as well as the N^{13}. The two-minute activity was also distinguished during measurements of the cross section for N^{13} formation in Al and Ni, and the ratio of the two-minute activity yield to the N^{13} activity yield did not vary with energy. This indicates that the cross sections for the formation of both products have the same energy dependence. We believe that this two-minute activity can be assigned to O^{15}, which is formed when N^{14} captures a proton from the target nucleus, according to the scheme

$$A_Z(N^{14}, O^{15})\, A-1_{Z-1}.$$

The cross section of this reaction is estimated to be for Al 40 ± 10% and for Ni 17 ± 5% of the cross section for loss of a neutron.

In conclusion we consider it our pleasant duty to thank Academician I. V. Kurchatov for several useful comments during discussions of this work. We also thank the cyclotron crew, directed by Iu. M. Pustovoit, for their excellent work and V. M. Strutinskii for theoretical calculations of several observed effects.

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PRODUCTION OF NEGATIVE π MESONS BY 660-Mev PROTONS ON NUCLEI OF VARIOUS ELEMENTS

A. G. MESHKOVSKII, IA. IA. SHALAMOV, and V. A. SHEBANOV

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The energy spectra and cross sections $d\sigma^-/d\Omega$ for π^--meson production have been measured at an angle of 45° with respect to the proton beam for Li, Be, Al and Cu. The differential cross sections $d^2\sigma^-/d\Omega dE$ for 157 Mev π^--mesons were measured for Ag and Pb. A conclusion is reached concerning the dependence of the cross section for π^--meson production on atomic weight for elements lying between Li and Pb. A comparison is made with similar results obtained for π^0 and π^+ mesons in other works.

THE dependence of π-meson yield on the number of nucleons in the nucleus has been investigated at various angles for neutral π mesons[1,2] and at an angle of 45° for positive π mesons,[3] the π mesons being produced by 660-Mev protons on nuclei of various elements. In the present work, carried out at the

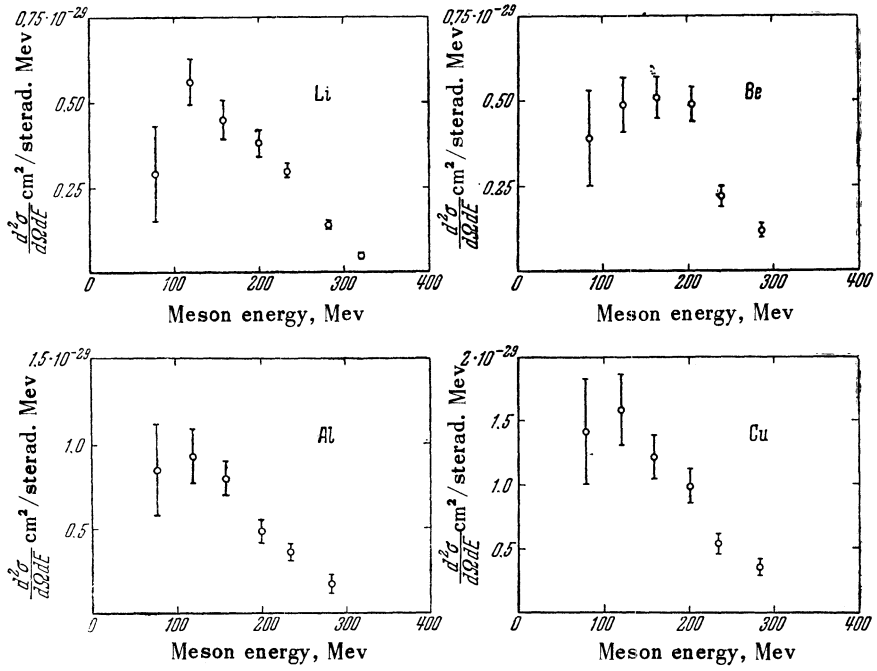

FIG. 1. Spectra of π^--meson production

synchrocyclotron of the Joint Institute for Nuclear Research, using methods described earlier,[3-5] we studied π-meson production at an angle of 45° with respect to the beam of 660 Mev protons on various elements.

The energy spectra of π^- mesons produced by targets of Li, Be, Al and Cu are shown in Fig. 1. Integration of the spectra, i.e., the differential cross sections $d\sigma^-/d\Omega$ in $cm^2\,sterad^{-1}$ for π^--meson production, calculated per nucleus, yielded the results given below. The quantity $d\sigma^-/d\Omega$ for carbon was measured earlier.[5] π^--meson yields from Ag and Pb were measured at only one meson energy, 157 ± 5 Mev. The quantity $d^2\sigma^-/d\Omega dE$ was (1.38 ± 0.22) $\times 10^{-29}\,cm^2\,sterad^{-1}\,mev^{-1}$ for Ag, and (2.01 ± 0.40) $\times 10^{-29}\,cm^2\,sterad^{-1}\,mev^{-1}$ for Pb.

Element	Li	Be	C	Al	Cu
$d\sigma^-/d\Omega \cdot 10^{27}$	0.93±0.14	1.00±0.15	1.00±0.13	1.64±0.26	2.82±0.43

As was shown earlier,[3] the spectra of π^+ mesons produced at an angle of 45° by 660-Mev protons on elements from Li to Cu are similar to one another. An approximate similarity of the spectra for π^- mesons was also observed in the present work, as may be seen if all the spectra shown in Fig. 1, as well as the spectrum for carbon,[5] are reduced to one scale. Using the apparent similarity of the π^- meson spectra, and the measured values of the quantity $d^2\sigma^-/d\Omega dE$ for Ag and Pg, we can calculate tentative values of the cross sections $d\sigma^-/d\Omega$ for these elements, if we assume that the form of the spectra does not change very much as we go to the heavier elements. In this connection, the cross section $d\sigma^-/d\Omega$ is (2.87 ± 0.88) $\times 10^{-27}\,cm^2\,sterad^{-1}$ for Ag, and (4.18 ± 1.16) $\times 10^{-27}\,cm^2\,sterad^{-1}$ for Pb.

The dependence of the π^--meson yield on the atomic weight is shown in Fig. 2. The abscissa represents $A^{2/3}$, and the ordinate represents the experimental values of $d\sigma^-/d\Omega$ in relative units. The differential cross sections for π^0- and π^+-meson production, measured at 33° and 45° respectively,[2,3] are also shown in the figure. All quantities are normalized to the values obtained for carbon. It is clear from Fig. 2 that the results obtained for π^- and π^0 mesons are very close to one another, but differ from the results for π^+ mesons. In particular, the relative yield of π^- and π^0 mesons is greater than that of π^+ mesons in the regions of small and large values of A.

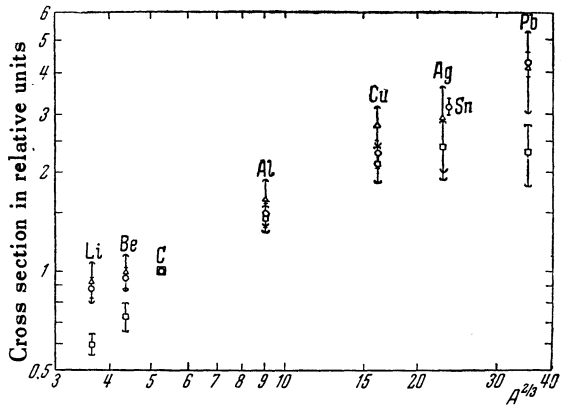

FIG. 2. Dependence of π-meson yield on atomic weight. ○ — π^0 mesons, △ — π^- mesons, □ — π^+ mesons.

To explain these experimental facts, it is necessary to take into account both the comparative effectiveness of π^+-, π^-- and π^0-meson creation on the nucleons of the nucleus, as well as the scattering of the produced π mesons by the nucleons. It can be shown, however, that in the region of π-meson energies investigated by us, the role of scattering is approximately the same for all π mesons, regardless of the sign of their charge.

A consequence of the hypothesis of isotopic invariance is that the cross sections of all possible reactions of the reactions of the interaction of π^+, π^-, and π^0 mesons with nucleons (without the production of other π mesons)

reduce to four independent cross sections, among which the relation[6]

$$\sigma_1(\pi^+p \to \pi^+p) + \sigma_2(\pi^-p \to \pi^-p) = \sigma_3(\pi^-p \to \pi^0n) + 2\sigma_4(\pi^0p \to \pi^0p). \quad (1)$$

exists. Moreover, in the energy region in which the interaction of π mesons with nucleons occurs mainly in the state with isotopic spin $3/2$, we have the well known relation

$$\sigma_1 : \sigma_3 : \sigma_2 = 9 : 2 : 1. \quad (2)$$

Now, let λ^0, λ^+ and λ^- denote the mean interaction lengths of π^0, π^+, and π^- mesons with nuclear matter. Then, considering the scattering of π mesons on nucleons of a nucleus to be the same as on free nucleons, and using relations (1) and (2), it is easy to show that

$$\lambda^0/\lambda^\pm = 1 \mp (N-Z)/2(N+Z) \approx 1.$$

Numerous experimental data, in particular, confirm that $\lambda^+ \approx \lambda^-$ in the energy region of 100 — 200 Mev.

Thus, to explain the dependence of the relative π-meson yield on atomic weight shown in Fig. 2, it is sufficient to consider only the comparative effectiveness of the creation of π^+, π^-, and π^0 mesons on nucleons of a nucleus, neglecting the possible insignificant difference in the cross sections of the interaction of π mesons of different signs with nuclear matter.

The production of π^- mesons by protons on nucleons occurs during single creation only in p-n collisions, according to the reaction $pn \to pp\pi^-$. The proximity of the results obtained for π^- and π^0 mesons may be explained by a preferred role for p-n collisions also in the case of π^0-meson production. In fact, experiment indicates[2] that $\sigma(pn \to \pi^0)/\sigma(pp \to \pi^0) \approx 2$ for collisions of 660-Mev protons with free nucleons. The significance of p-n collisions in the creation of π^0 mesons on the nucleons of a nucleus may become even stronger in the region of light nuclei (Li, Be) because of the relatively weak coupling of the neutrons in these nuclei. Finally, we must take into account the possible nonuniform distribution of neutrons and protons in the nucleus. Experiments on the scattering of high energy electrons lead to the extremely probable model of the nucleus in which there is a neutron excess on the surface of the nucleus.[7] On the other hand, because of the opacity of the nucleus, only some surface layer of the nucleus is effective for the creation of π mesons, which in connection with the above model of the nucleus must also strengthen the significance of p-n collisions. Thus, we are led to the conclusion that the identical character of the dependence of π^- and π^0 meson yield on atomic weight, established by the present experiments, may in fact be explained by the approximately identical role of p-n collisions in π^- and π^0 meson production.

In regard to π^+ mesons, we should note that they are produced preferentially in p-p collisions. This follows from the relation for the reactions on free nucleons $\sigma(pp \to \pi^+)/\sigma(pn \to \pi^+) \approx 3.5$, which may be evaluated from existing experimental data.[4,5] The excess of neutrons over protons in the regions of light and heavy nuclei may also explain the excess of the relative yields of π^- and π^0 mesons over the yield of π^+ mesons, which is observed in Fig. 2 for Li, Be, Cu, Ag and Pb.

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