Photoproduction of π^+ Mesons from Hydrogen Near Threshold*

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An experiment has been undertaken with the purpose of investigating, in detail, the photoproduction of π^+ mesons from hydrogen near the meson threshold.

The procedure was to use Ilford G-5 nuclear emulsions as detectors of mesons produced in a liquid hydrogen target by the x-ray beam of the Illinois 300-Mev betatron. Figure 1 shows a schematic diagram of the experimental setup. The target proper was a vertical cylinder $1\frac{1}{4}$ in. in diameter. In the region of the x-ray beam, the cylinder walls were 0.0005-in. brass. These walls contributed to a total meson background which was less than 5 percent. Outside the vacuum shell, plate holders constructed of light materials were distributed. Plates were mounted so that mesons from the target came through 0.017-in. aluminum windows in the vacuum shell, and entered at a glancing angle of about 5°. The low-energy limit for meson detection in the plates was taken to be 5 Mev. This corresponds to a 9–10 Mev meson produced in the target. Particles whose tracks were observed in the emulsions were identified by measuring the relative grain density and angular deviations of the tracks. The energy of each meson identified by this procedure was taken to be the mean of the two energies thus obtained. Energies of stopping mesons were calculated from their ranges. Scattering and grain counting calibrations were established for each plate from measurements made on stopping mesons.

Plates were exposed at laboratory angles ranging from 30° to 150°. Three independent types of exposures were made during the course of the experiment. Most runs were made with no absorber in front of the plates; some were made with absorbers, and finally some pellicles were exposed. These were immersed in a sea of emulsion so arranged as to constitute detectors in an infinite homogeneous medium.

In the analysis of the plates, surface scanning was employed. For the pellicles, volume scanning for $\pi-\mu$ decays was used. The three different methods were used as a check on inefficiencies inherent in the various scannings. Consistent results have been obtained for all mesons having more than twice minimum grain density on fully developed plates.

Energy measurements made on individual tracks by scattering and grain count usually differed by less than 5 Mev. Each calculated meson energy is believed to have less than 10 percent probable error.

The differential cross sections per unit solid angle in the center-of-mass system, measured at 175, 185, and 195 Mev photon energy in the laboratory system are shown in Table I listed under the center-of-mass angles at which they were obtained. The indicated errors are statistical.

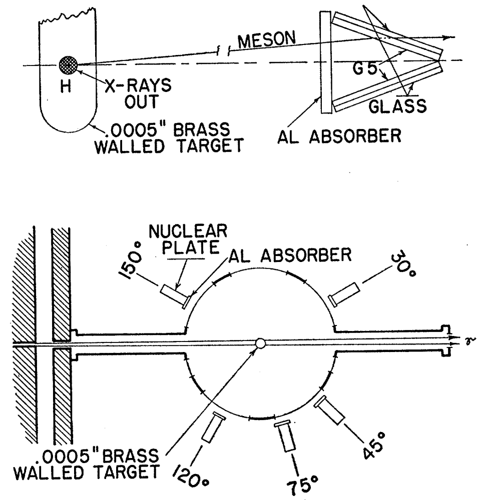

Fig. 1. Schematic diagram of liquid target and nuclear emulsion detectors.

Previous results[1–3] at higher energies, considered in the light of current theoretical proposals,[4,5] may be interpreted as a combination of S and P wave emission of the mesons. It is clear from the data in Table I that at these low energies an interpretation of the results can be given in terms of a predominant S wave. This aspect of the angular distribution is further borne out by a rough check of the momentum dependence of the cross sections at 90° as shown in Table II. It is apparent here that the momentum dependence is very closely linear and therefore is consistent with the S-wave interpretation.

A more detailed discussion of these results will soon be forthcoming.

Table I. Cross section as a function of lab energy and c.m. angle.

	$(d\sigma/d\Omega^*)\times10^{29}$					
E_γ, Mev\Θ	40°	59°	93°	123°	148°	159°
175		0.61±0.07	0.64±0.04	0.64±0.07		
185	0.60±0.14	0.63±0.15	0.69±0.08	0.74±0.06	0.85±0.13	0.82±0.08
195	0.79±0.17		0.90±0.07	1.09±0.1	0.99±0.14	0.90±0.12

Table II. Cross section *vs* lab energy and meson c.m. momentum.

E_γ	$\frac{d\sigma}{d\Omega^*}$	$\frac{d\sigma}{d\Omega^*}\left(\frac{m_0c^2}{pc}\right)$	$\frac{d\sigma}{d\Omega^*}\left(\frac{m_0c^2}{pc}\right)^3$
165	0.48×10^{-29}	1.35×10^{-29}	10.8×10^{-29}
175	0.64×10^{-29}	1.31×10^{-29}	5.45×10^{-29}
185	0.69×10^{-29}	1.16×10^{-29}	3.24×10^{-29}

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Nuclide V^{53}†

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A search for the nuclide V^{53} was made by bombarding separated Cr^{53} as Cr_2O_3 with neutrons in the pile at Oak Ridge for 16 hours. The isotopic composition of the separated Cr^{53} was as follows: Cr^{54}, 1.7 percent; Cr^{53}, 92.1 percent; Cr^{52}, 5.7 percent; Cr^{50}, 0.5 percent. The nuclear reaction expected was $Cr^{53}(n,p)V^{53}$.

The sample was dissolved in concentrated HCl and 4 mg of vanadium carrier added. The solution was evaporated nearly to dryness and 10 ml of 4 percent H_2SO_4 added. This solution was then cooled in an ice bath and 5 drops of 6 percent cupferron reagent was then added to precipitate the vanadium. The precipitate was centrifuged and washed with 4 percent H_2SO_4.

The vanadium precipitate was then mounted in planchet and counted. Absorption curves taken at two-day intervals indicate a beta with an energy of 0.56±0.1 Mev.[1]

Gamma-ray spectra of the vanadium precipitate were obtained using a sweep-type differential and integral discriminator, similar to the one already described by Fairstein.[2]

Measurements from the decay curve and from the gamma-ray spectra indicate the half-life of V^{53} to be 23±1 hours.

The number of gamma rays shown by the gamma-ray spectra data indicate a complex decay scheme for V^{53}.

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Work is continuing on this nuclide.

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[1] An isotope of vanadium with a 23-hour half-life and ~0.6-Mev β^- has been observed by L. Hsiao and R. B. Duffield (private communication from R. B. Duffield).

[2] E. Fairstein, Rev. Sci. Instr. 22, 76 (1951).

Spins of the Lowest States of the K^{40}, P^{32}, and Al^{28} Nuclei

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COMPOUND nucleus theories as well as stripping theories of nuclear reactions predict the differential cross section at a given reaction angle to vary with the spin I of the final nuclear state. Because there are as a rule other unknown parameters and because of the approximate nature of the theories, a predicted spin dependence is in general of little value for determining the spins of nuclear states. In certain special cases, however, the dependence might be useful, namely for levels that are members of closely spaced (j,j) multiplets where the only parameter differing appreciably from state to state is the resultant spin. The simplest cases are perhaps those stripping processes in which the captured particle can be assumed to go directly into a vacant "orbit" without appreciably agitating the target "core."

In stripping theories the cross section is expressed as a sum over all channels allowed by conservation rules of angular momentum and parity. In the simple cases mentioned above, however, the shell model (insofar as it is valid) requires that the captured particle brings with it the right orbital angular momentum $l\hbar$ and has the right spin direction. In that case the number of open channels are the same as the number of degeneracies of the final state or $(2I+1)$. When the energy separations between multiplet states are small, the variation in yield from state to state will be determined mainly by this factor. Because the states considered all have the same l value for the captured particle, the angular distributions are the same or very nearly so.

The compound nucleus theory of Wolfenstein[1] gives predictions about angular distributions and about the variation of the average cross section with spin of the final state, among other things. The experimental relative (d,p) yields considered in this letter have been measured at a reaction angle $\theta_{lab}=90$ degrees, with incident deuteron energies from 2 to 5 Mev and emerging proton energies above 7 Mev. From Wolfenstein's work it may be inferred that it is a fairly good approximation for these cases to assume a $(2I+1)$ dependence also for the part of the cross section that is due to compound nucleus formation.

Various experimental data concerning the lowest states of K^{40}, P^{32}, and Al^{28} have been collected in Table I. The combinations of odd-proton and odd-neutron states expected to yield the lowest levels are given in column 2. Two possible configurations are given for Al^{28}. Apparent disagreement between experimental data prevents one at the moment from deciding between the alternatives. The lowest states observed[2-4] (column 3) are tentatively assumed to be members of the (j,j) multiplets in column 2. (These assumptions are not very well founded, especially for the two higher levels in K^{40}.)

Results from the stripping analysis[5-8] of angular distribution data are quoted in column 4 for the unresolved P^{32} and Al^{28} doublets. As judged from available experimental data, small contributions from larger orbital angular momentum values (e.g., $l_n=2$) cannot be entirely excluded in the Al^{28} case. Spin values compatible with the measured l_n values are given in column 5 and other restrictions on the spins in column 6 [from β decays and (n,γ) measurements]. Suggested final spin assignments for the various levels are presented in column 7. They are based on all available data and also on relative yields. The relative yields expected when employing the $(2I+1)$ rule are given in column 8 (I_0=ground-state spin). These figures should be compared with the experimental values in column 9.

For the $P^{31}(d,p)P^{32}$ stripping process also, $l_n=0$ is allowed for the ground state by ordinary conservation rules. The fact that only $l_n=2$ occurs is a great tribute to the shell model[7,9] and it proves that one of the basic ideas behind the $(2I+1)$ rule is correct. This rule is further based on the assumption that in stripping processes only one spin direction is allowed for the incident particle when forming a specific state. The ordinary law of conservation of angular momentum very often allows different numbers of incident spin directions (1 or 2) for different members of the same multiplet (l_n given). An approximate validity of the $(2I+1)$ rule in such cases for pure stripping would further strengthen the view that shell-model considerations should be taken into account when describing these processes. The measured (d,p) yields referred to

TABLE I. Suggested spin assignments for the lowest states of K^{40}, P^{32}, and Al^{28}, partly based on the assumption that the (d,p) yield is proportional to $(2I+1)$.

Nucl.	Assumed config. of multiplet	Exc. energy Mev	Stripping data l_n	Stripping data I	Other spin data	Final spin assign.	$\frac{(2I+1)}{(2I_0+1)}$	Exper. yield ratio
K^{40}	$(d_{3/2},f_{7/2})$	0			4	4^-	1	1
		0.032[a]			$\lesssim 3$[f]	3^-	0.78	0.8[i]
		0.800[a]			$\lesssim 3$[f]	2^-	0.56	0.6[i]
		0.893[a]			$\gtrsim 4$[f]	5^-	1.22	1.1[i]
P^{32}	$(s_{1/2},d_{3/2})$	0	2[d]	1, 2, (3)	0, 1[g]	1^+	1	1
		0.077[b]	2[d]	1, 2, (3)		2^+	1.67	1.5[j]
Al^{28}	$(d_{5/2},s_{1/2})$ or $(d_{5/2},d_{5/2})$	0	0[e]	2, 3	2, 3[g]	3^+ or 2^+	1	1
		0.031[c]	0[e]?	2, 3	1[h]	2^+ or 1^+	0.71 (0.60)	0.63[k]

[a] See reference 2. [b] See reference 3. [c] See reference 4. [d] See references 6 and 7. [e] See references 5, 6, and 8. [f] From $K^{39}(n,\gamma)K^{40}$ yields. See reference 2 and G. A. Bartholomew and B. B. Kinsey, Can. J. Phys. **31**, 927 (1953). [g] From β decay. Further references given in Hollander, Perlman, and Seaborg, Revs. Modern Phys. **25**, 469 (1953). [h] From β decay of Mg^{28}. Also $\Delta I \lesssim 1$ between states. See A. H. Wapstra and A. L. Veenendaal, Phys. Rev. **91**, 426 (1953). [i] Taken out of Fig. 1 in reference 2. $E_d=5$ Mev. [j] Average for $E_d=1.8$ and 2 Mev. See reference 3. [k] Average for $E_d=1.5$, 1.8, 2.1, and 5.2 Mev. Author's results and W. W. Buechner (private communication).