Letters to the Editor

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Deuterium Total Cross Sections for Positive and Negative Pions*

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RECENT communications from this laboratory report total cross sections of hydrogen for positive and negative pions.[1-3] In these experiments scintillation counters were used to measure the transmission of hydrogen in the several pion beams of the large Chicago cyclotron. In the present experiment similar techniques were used to compare the transmission of H_2O and D_2O cells for charged pions. The immediate result, which we call $(\sigma_D-\sigma_H)'$, is the difference between the cross sections of deuterium and hydrogen for those events which produce no ionizing particles within the angular acceptance of the last counter.

One type of cell for either H_2O or D_2O was 2 inches long, and a second type was 4 inches long. For each pair of cells the numbers of atoms/cm² were very nearly the same, so that the energy loss, Coulomb scattering, and nuclear events due to oxygen were very nearly the same. The difference between the $\frac{1}{2}(H_2O)$ and $\frac{1}{2}(D_2O)$ cross sections observed is then $(\sigma_D-\sigma_H)'$.

Table I presents the preliminary results. The solid angle is that of the last counter averaged over the absorber; hence it measures the "poorness" of the geometry. The energy band column lists the mean energy of the pions in the absorber, plus or minus half their energy spread. The energy spread is partly due to the spread in energy of the entering beam (±3 Mev), but mostly due to the energy loss in the absorber. This information comes partly from magnetic analysis of the beam, partly from range curves, and from calculations of the energy loss in the sample. The $(\sigma_D-\sigma_H)'$ entries have been corrected for the muon and electron contents of the beams, which in most channels is about 5 percent. The quoted error in $(\sigma_D-\sigma_H)'$ includes either the statistical or the consistency rms errors of the counts (whichever was greater), uncertainties in the corrections of the counting rates for chance coincidences (less the 1 percent), and uncertainties in the muon-electron correction (∼2 percent).

TABLE I. Cross sections of deuterium and hydrogen for π^+ and π^- at several energies.

Solid angle steradians	Energy band Mev	Observed $(\sigma_D-\sigma_H)'$ 10^{-27} cm² π^-	Corrected $(\sigma_D-\sigma_H)$ 10^{-27} cm² π^-	σ_H 10^{-27} cm² π^+	σ_D 10^{-27} cm² π^-
0.63	79±10	31±10	34±10	48±10	54±13
0.63	109±15	66± 4	72± 5	80±10	103±10
0.088	115± 9	87± 7	88± 7	95±15	124±11
0.63	115± 9	77±18	84±18		
0.43	127±15	77± 7	84± 8	125±15	129±11
0.63	133± 9	66±13	76±15	135±15	128±16
0.088	164± 9	135±13	139±13		198±12
0.63	164± 9	119±11	128±14		
0.088	179± 9	170±10	172±10		234±12
0.63	179± 9	146± 9	163±12		
0.43	209±15	109±24	131±25		192±26
		π^+	π^+	π^-	π^+
0.43	72±17	24± 6	24± 6	15± 8	60± 9
0.63	79±10	30±13	31±13	20± 8	79±15
0.43	109±15	28±12	29±12	31± 9	109±16
0.43	127±15	25±15	26±15	45±10	151±21

It is desirable to correct the D−H difference for those specifically nuclear events which scatter particles into the last counter. For the purposes of this correction (which is of the order of 10 percent) we have taken $\sigma_D-\sigma_H$ for π^- equal to $\sigma_H(\pi^+)$. The correction was computed using the measured hydrogen cross sections[1,2] and assuming that the scattering is isotropic. Where $\sigma_H(\pi^+)$ was not available, we have taken $\sigma_H(\pi^+)=3\sigma_H(\pi^-)$ (see reference 3). For π^+ the corresponding corrections are much smaller because of the importance of the charge exchange process.[3] The fourth column of Table I gives the corrected $\sigma_D-\sigma_H$. Values from different geometries are seen to agree within the experimental error. Justification of the assumption of the equivalence of $\sigma_D-\sigma_H$ for $\pi^\pm$ and σ_H for $\pi^\mp$ is seen from a comparison of columns 4 and 5 in Table I. There is some indication of deviations at the higher energies.

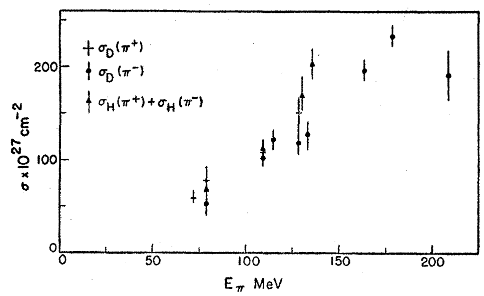

FIG. 1. Total cross sections of deuterium for positive and negative pions.

Adding σ_H to $\sigma_D-\sigma_H$, we obtain σ_D, as exhibited in column 6 of Table I and in Fig. 1. Within the experimental errors σ_D is the same for pions of either sign. This has also been observed at 60 Mev by the Columbia workers.[4] This equality is predicted by the principle of charge symmetry, which requires for the free neutron and proton

$$\sigma_N(\pi^+)=\sigma_H(\pi^-),\ \sigma_H(\pi^+)=\sigma_N(\pi^-).$$

For comparison, we have also plotted the sum $\sigma_H(\pi^+)+\sigma_H(\pi^-)$ in Fig. 1. It will be seen that σ_D does not differ greatly from this sum, in accordance with the idea that the neutron and the proton in the deuteron scatter pions fairly independently.

At energies above 115 Mev there is some indication that σ_D is less than $\sigma_H(\pi^+)+\sigma_H(\pi^-)$. From such an effect it may be possible to obtain information about the relative phase of the scattering from neutrons and protons. We hope to extend our study of this effect in the near future.

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[1] Anderson, Fermi, Long, Martin, and Nagle, Phys. Rev. **85**, 934 (1952).
[2] Anderson, Fermi, Long, and Nagle, Phys. Rev. **85**, 936 (1952).
[3] Fermi, Anderson, Lundby, Nagle, and Yodh, Phys. Rev. **85**, 935 (1952).
[4] Isaacs, Sachs, and Steinberger, Phys. Rev. **85**, 802 (1952).

Gamma-Gamma Angular Correlation in Pd^{106}

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SINCE the initial experiments of Brady and Deutsch,[1] the angular correlation of gamma-rays in Pd^{106} has constituted a puzzling discrepancy between experiment and theory. The shape of their correlation curve suggested spin assignments of 0-2-0 which yield a ratio of 2 for $W(\pi)/W(\frac{1}{2}\pi)$, while their measured ratio was about 1.5.

The angular correlation of the Pd^{106} gamma-rays from an aqueous ruthenium chloride source has been reinvestigated using NaI scintillation spectrometers with a resolution of 10 percent at 661 kev. The observed gamma-spectrum was in good agreement