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[10]According to the observations of Faire and Champion, the recombination coefficient for electrons and nitrogen ions is constant for nitrogen pressures from 0.011 mm Hg to 4 mm Hg. It is difficult to understand this result since the present measurements yield more than an order-of-magnitude change in the relative concentrations of the various nitrogen ions over the same pressure range.
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PHOTOPRODUCTION OF SINGLE NEUTRAL PIONS FROM HYDROGEN AT 60° IN THE 600-1100 Mev REGION

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In a recent experiment Cortellessa and Reale[1] measured the differential cross section for the process $\gamma + p \rightarrow \pi^0 + p$ in the neighborhood of the second resonance at a center-of-mass angle for the neutral pion of 57°. Their results, obtained with a proton telescope in coincidence with a lead glass Čerenkov counter used to detect one of the π^0 decay photons, are considerably different from those which had been reported previously. Earlier data were obtained by Vette[2] using a proton magnetic spectrometer, by Stein and Rogers[3] and Worlock[4] using proton telescopes, and by DeWire, Jackson, and Littauer[5] using a proton telescope plus Čerenkov gamma-ray counter. Some of the difference can be attributed to the better resolution of Cortellessa and Reale which was ±30 Mev in incident photon energy, about half that of the previous experiments. However, even taking into account this difference in resolution, a serious disagreement exists between the experiment of Cortellessa and Reale and the earlier ones in that Cortellessa and Reale obtain values for the cross section which are, in general, considerably lower than those previously obtained. Furthermore, Cortellessa and Reale find a sharp peak in the cross section at a photon energy 700 Mev, which is about 50 Mev lower than the energy corresponding to the "second resonance" peak observed in π-nucleon scattering.[6] Although the excitation curve at any given angle need not have a maximum at the same energy as the total cross section, the angular distributions for π^0 photoproduction do not seem to be changing rapidly in this region, so that one might expect the peak at 57° to be characteristic of the total cross section and to be centered closer to 750 Mev than 700 Mev as measured by Cortellessa and Reale. (The fact that π^+ photoproduction shows a peak at 700 Mev is probably the result of an interference effect with the meson current term which does not appear in π^0 photoproduction.[7])

Intrigued by this apparent discrepancy and by the interesting shape of the curve reported by Cortellessa and Reale, we have measured the π^0 cross section in this region and extended the measurements through the third resonance using the bremsstrahlung beam of the Caltech Synchrotron. The measurements were made by counting recoil protons alone and also by counting proton–gamma-ray coincidences. The protons were detected by a wedge-shaped, uniform field, magnetic spectrometer and associated counters.[8] They were identified both by a time-of-flight measurement and by the pulse heights in three scintillation counters located at the magnet focus. Decay photons from the π^0's were detected in two different ways. One was by a large lead glass Čerenkov counter (30 cm high, 36 cm wide, and 36 cm deep) placed in the π^0 flight direction with the front edge 65 cm from the liquid hydrogen target. The second was by using a 1.18-cm lead converter and a scintillation counter (16 cm×20 cm) placed 60 cm from the target directly in front of the Čerenkov counter. Coincidences between the scintillator and the Čerenkov counter were then used to measure gamma rays in the smaller solid angle subtended by the lead converter. An anticoincidence counter was not used to eliminate charged particles since it was found that such a counter accidentally vetoed some π^0 events because of the numerous low-energy charged particles present. A separate measurement was made of the number of "gamma-ray" counts produced by charged particles. We did not limit the active part of the Čerenkov counter with an absorbing aperture since such an aperture would not have been well defined without an anticoincidence counter. Since the counter subtended such a large solid angle, very few of the π^0-decay γ rays passed near its edge, and edge effects were thus quite small.

For the backward proton center-of-mass angle under investigation, it was difficult to obtain good photon energy resolution. Although we reduced the proton momentum acceptance interval to half that used by Vette, the resolution was decreased by only 20% because the angular acceptance of the magnet (±1°) contributed a great deal to the spreading of the resolution. Sizable contributions were also made by multiple scattering in the target and by slowing down in the hydrogen. Typical values of the resolution, $R(k)$ (full width at half maximum), of the experiment are: $R(585)=70$, $R(780)=83$, $R(1073)=112$ Mev.

Three different counting rates were monitored and each was used separately to calculate the cross section: (1) the recoil protons alone; (2) protons in coincidence with the Čerenkov counter; (3) protons in coincidence with both the Čerenkov counter and the scintillation counter in front of the Čerenkov counter. The geometric efficiencies of the γ-ray counters were calculated using a Monte Carlo program. The Čerenkov counter was calculated to be 90% efficient at $k=585$ Mev, increasing to 100% at $k=731$. The geometric efficiency of the scintillation counter ranged from 52% at $k=585$ Mev to 92% at $k=926$. The conversion efficiency of the 1.18 cm of lead in front of the scintillation counter was estimated to be 80%.

Empty-target backgrounds of protons alone were approximately 30% of the full target counting rate. However, the Čerenkov counter coincidence requirement reduced this background to about 4%, and thus improved the counting statistics by a factor of about 1.5. Requiring both the scintillation and Čerenkov counters led to poorer statistics due to the lower efficiency for detecting the π^0 decay photons.

The set of points shown in Fig. 1 was run by varying the bremsstrahlung end point, E_0, with fixed kinematic settings of the spectrometer and counters corresponding to a photon energy, k, of 800 Mev for single π^0 photoproduction. This

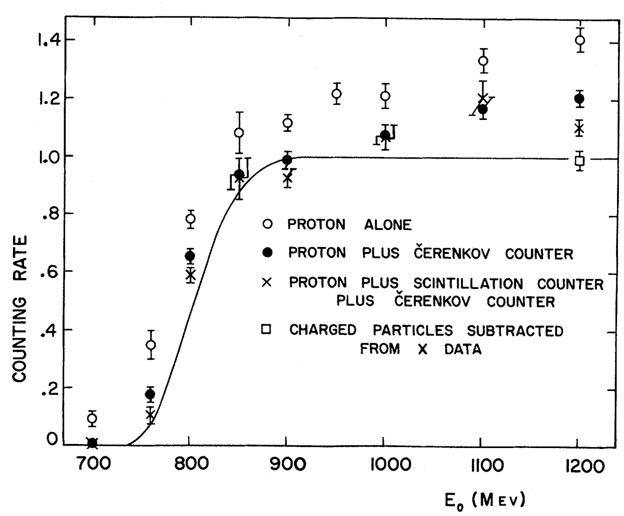

FIG. 1. Number of counts per equivalent quantum as a function of bremsstrahlung end point, E_0, with fixed kinematic settings of the spectrometer and counters corresponding to $k=800$ Mev and $\theta=60°$ c.m. for the reaction $\gamma+p\rightarrow\pi^0+p$. Folding the resolution given by the Monte Carlo program together with the bremsstrahlung spectrum as measured by J. Boyden [Ph.D. thesis, California Institute of Technology, 1961 (unpublished)] and the cross section as measured by this experiment gives the solid line. The errors shown are those of the counting statistics only. For a given E_0 the errors for the three methods used are not independent.

gave a check on the resolution, on the correlation between k as determined by the magnet system and E_0 as determined by magnetic field measurements of the synchrotron, and on the contribution from pion pairs. A comparison of the proton plus Čerenkov counter data with the calculated curve of Fig. 1 shows a discrepancy between k and E_0 of 17 ± 3 Mev. Measurements at other points have indicated a similar displacement. This small discrepancy is not yet understood. The rate of rise of the experimental points for $E_0 \leq 900$ Mev agrees quite closely with that of the curve verifying the resolution calculations. The rise above $E_0 = 900$ is presumably due to pion pairs. Near the threshold for pion pairs (about 950 Mev for the equipment set at $k = 800$ Mev) the π's come out in such a direction that most of them pass through the Čerenkov counter. To measure the charged particle contribution to the counting rate at higher E_0, the front scintillation counter pulse heights were examined at $E_0 = 1200$ Mev and also at 900 Mev where it was assumed that no charged particles were counted. Charged particles gave a minimum-ionizing pulse whereas the showers produced in the lead converter by the π^0 decay photons in general gave at least twice-minimum-ionizing pulses. Subtracting the charged particle contribution at 1200 Mev estimated in this way gave the point shown in Fig. 1, indicating that within the statistical accuracy of this measurement, all of the rise above 900 Mev may be ascribed to charged particles, presumably pions, counting in the Čerenkov counter.

Figure 1 also shows the extent to which cross sections obtained from the three different counting rates described above agree with each other. The counting rates of protons alone, properly normalized, were consistently higher than those with a gamma-ray coincidence. Furthermore, at $E_0 = 700$ Mev, which is below the limit of the resolution function, the proton counting rate (with empty target background subtracted) did not vanish. This indicates a background from hydrogen produced by lower energy photons. A mass-spectrograph analysis of the hydrogen showed no impurity which could account for the background. The mechanism producing these protons is not fully understood. Some of the protons probably come from particles, photoproduced by the beam, which scatter in the hydrogen (for example, $\gamma + p \rightarrow \pi^+ + n$ followed by $n + p \rightarrow n + p$). Calculations are being made to determine whether such scattering can completely explain the effect. The proton plus converted γ-ray results tend to be lower than the proton plus Čerenkov results; more detailed calculations of the lead conversion efficiency may clear up this slight discrepancy. For these reasons, the proton plus Čerenkov data are considered to be the most precise and accurate of the three sets of data.

The results of the experiment are shown in Fig. 2. Assuming a systematic error in the proton magnetic spectrometer settings of the magnitude indicated by the discrepancy shown in Fig. 1, the points were plotted at energies of approximately 2% lower than those given by the magnet settings. Empty-target backgrounds have been subtracted, and the data have been corrected for the absorption and scattering of the protons in the magnet system and for the Čerenkov geometric efficiency. Pulse-height spectra from the Čerenkov counter were measured and indicated no loss of efficiency from the electronic bias. The experiment was run with $E_0 = k + 100$ Mev, so that pion pairs were kinematically excluded and no correction was necessary. Due to the similarity of kinematics, elastic scattering of photons by protons (proton Compton effect) could not be excluded. Measurements[9] have shown this effect to be of the order of 3% of the single π^0 production. For $585 \leq k \leq 878$ Mev the points in Fig. 2 were obtained from the proton plus Čerenkov data. Above 900 Mev the Čerenkov counter was not used and the results were obtained using protons only. As a correction for the proton background from lower energy photons and processes other than π^0 production, a fixed amount, 0.31 μb/sr, was subtracted from these results (0.31 μb/sr is the average difference between the results from protons alone and the proton plus Čerenkov results; this difference was remarkably constant over the range in which the Čerenkov counter was used). Our results, while agreeing substantially with the early experiments[2-5] as typically represented by that of DeWire *et al.*, present a much clearer picture of the second resonance. These results disagree with those of Cortellessa and Reale. The third resonance appears to be much less prominent than the second resonance and has a width comparable with that of the second resonance. The widths are not well determined because of our wide energy resolution.

Using protons alone, data are being obtained at c.m. angles 90° and 120°. The results obtained thus far show a shape at 90° similar to the one at 60°, largely agreeing with the values obtained by the early experiments once the difference in reso-

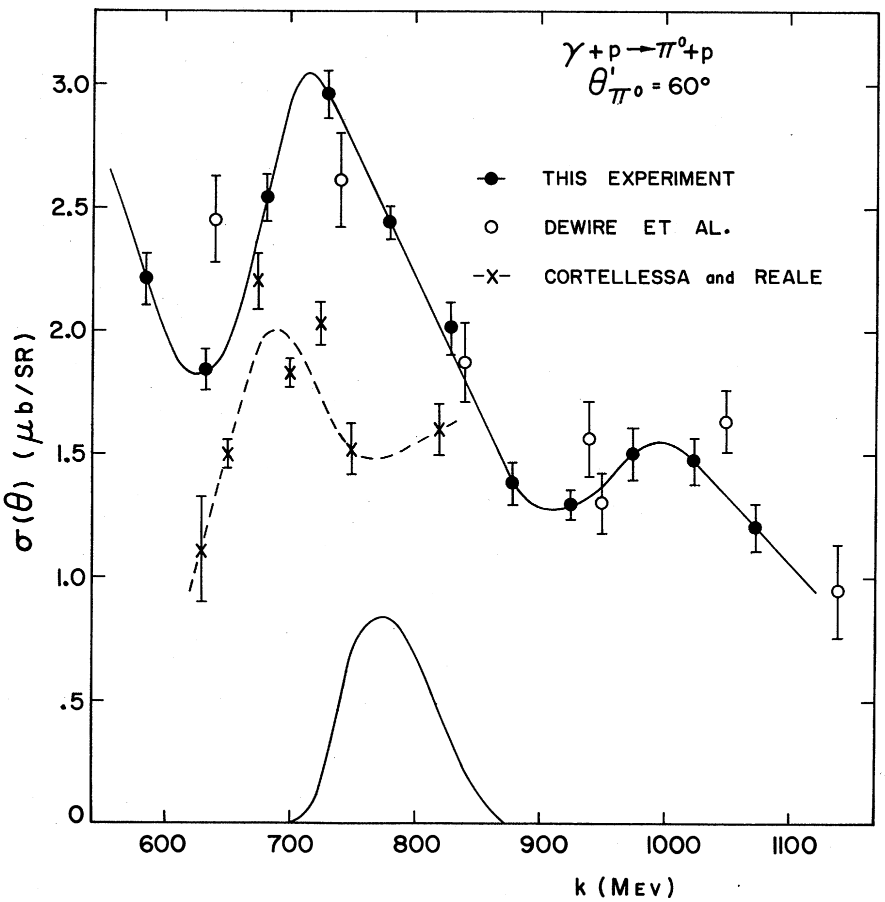

FIG. 2. Differential cross section at $\theta_\pi = 60°$ c.m. as determined by this experiment (solid circles and line) as a function of photon energy, k. The resolution at $k = 780$ Mev is shown at the bottom of the graph. Also shown are the cross sections obtained by Cortellessa and Reale[1] interpolated to $\theta = 60°$ (crosses and dashed line) and those of DeWire et al.[5] (open circles).

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