TOTAL HADRONIC (γ, p) AND (γ, d) CROSS SECTIONS FROM 4 TO 18 GeV*

D. O. Caldwell, V. B. Elings, W. P. Hesse, R. J. Morrison, F. V. Murphy, and B. W. Worster
Physics Department, University of California, Santa Barbara, California 93106

and

D. E. Yount†
Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305

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Photoabsorption cross sections in hydrogen and deuterium have been measured from 3.7 to 17.9 GeV. The energy dependences are similar to those of strong-interaction total cross sections, as expected from the vector-meson–dominance model. The magnitude of $\sigma_T(\gamma p)$ can be compared with data from $\gamma p \to \rho^0 p$ to determine a γ-p coupling constant, $\gamma_\rho^2/4\pi = 0.37 \pm 0.03$. This value disagrees with that obtained on the ρ mass shell, and hence there is only qualitative agreement with the vector-meson–dominance model.

The total cross sections of hadrons on nucleons have provided important information about both the strong interactions and the particles involved. Similar data for photon-nucleon total cross sections has been lacking, however, because the interesting hadronic final states are two orders of magnitude less frequent than the background electromagnetic states. This problem has been overcome in the experiment reported here to the extent that total cross sections with systematic errors less than 2% have been obtained for photoabsorption in hydrogen and deuterium over the energy range 3.7 to 17.9 GeV. The magnitude and energy dependence of the resulting (γ, p) cross sections provide a check of vector-meson dominance. The following paper[1] describes the evaluation of the (γ, n) cross section from the hydrogen and deuterium measurements and gives an interpretation of the data in terms of a Regge-pole model.

Previously we have reported[2] the dependence of the high-energy (7 to 18 GeV) photoabsorption cross sections on the size of the target nucleus, which showed that the photon does not behave in a purely electromagnetic manner, but rather is absorbed more like a strongly interacting particle in passing through a nucleus. Since the experimental arrangement has been described,[2] we shall give here only a brief outline of the setup used at the Stanford Linear Accelerator Center and discuss in addition those features of the experiment and its analysis which are particularly pertinent to obtaining reliable low-energy data.

The experiment was performed with tagged photons. The tagged portion of the bremsstrahlung beam, which was produced by positrons of energy E_0, included four energy bins between $0.74E_0$ and $0.94E_0$. As shown in Fig. 1, wide-angle photons were vetoed by the shower counter A_0, while a photon passing through the target also went through central holes in the hadron detectors $S2a$ and $S2b$ and produced a large pulse in the total-absorption anticounter, $S1$. The major background, pair production, had the same signature as a noninteracting photon, since pairs had a sufficiently small angle (typically 0.2 mrad or less) to pass through the $S2$ holes. Hadronic interactions were identified by a signal from one of the tagging channels in coincidence with a signal from the hadron detectors $S2$, with no large coincidence pulse from $S1$. The $S2$ counters, each a four-layer sandwich of 2.5-cm lead followed by scintillator, were required to give either a four-fold coincidence (from $S2a$ or $S2b$) or a total pulse height indicating an energy deposition of at least 1 GeV. These criteria insured a high efficiency for the detection of both charged and neutral pions, while greatly reducing the accidental coincidences caused by background electromagnetic events.

To permit checks on the efficiency for detecting hadronic events and rejecting background events, records were made on magnetic tape of events satisfying looser criteria: a tagging sig-

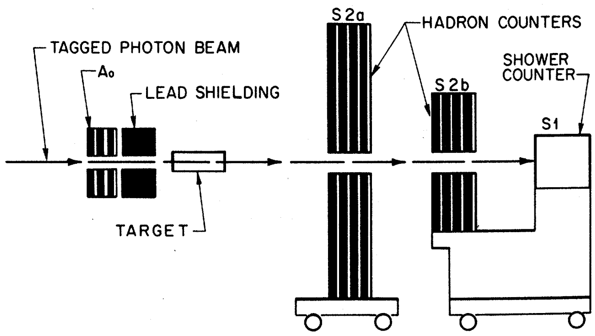

FIG. 1. Schematic diagram of the detectors used in this experiment.

nal accompanied by either (1) a hadronic signal in $S2$ or (2) the absence of a large pulse in $S1$. The pulse heights of the eight hadronic scintillators and of $S1$, the output of a time-to-amplitude converter for the hadronic signal in $S2$ relative to the tagging pulse, and the status of the coincidence circuits were then recorded. With this information it was possible to rerun the experiment on a computer under different conditions, such as requiring three-fold instead of four-fold $S2$ coincidences. In this way it was established that the hadron detector's efficiency was between (98.7 ± 1.0) % at 4 GeV and (99.6 ± 0.4) % at 18 GeV, a result which was consistent with prior tests showing that 2-GeV pions were detected by a four-layer, lead-scintillator sandwich with at least 99% efficiency.

The detection geometry was varied with energy to insure a high geometrical efficiency without picking up significant background from electromagnetic events. To check that the detector geometry was adequate, the $S2$ detector was divided into two parts, each mounted on its own cart so that the inner and outer acceptances could be varied separately. Measurements with $S2a$ in different positions established that at high energy the reaction products went sufficiently forward so that the $S2$ counters essentially always intercepted at least one hadron or a photon from a neutral pion. Above 5.8 GeV the only siginficant geometrical loss came from pion production through the central hole. The correction for this loss was calculated to be less than (1.0 ± 0.5) %.

At the lowest energy the wide-angle acceptance limit was more important and the total geometrical correction, calculated for known two-body processes,[3] was (3.0 ± 1.5) %. This correction was consistent with tests, made with a deuterium target, in which decreases in measured cross section of (1.7 ± 3.3) and (11.2 ± 2.7) % were observed as the outer solid-angle acceptance was reduced by factors of 1.7 and 2.8, respectively.

Another spurious energy-dependent effect could have arisen from electromagnetic contamination, particularly from electron Compton scattering and from pair production. To study this effect $S2b$ was moved downstream until these small-angle processes caused a significant increase in the measured rate. These increases were completely accounted for by asymmetric electron pairs, which produced a signal in $S2$ and a pulse in $S1$ just below the normal veto threshold, and by a Compton contribution which was calculated taking into account the target length and counter resolution. The analysis showed that with $S2a$ and $S2b$ at the normal data positions these effects were less than 0.15 ± 0.08 μb for all energies.

Table I. Total photoabsorption cross sections in hydrogen and deuterium for each tagging energy. Each separated group of four photon energies corresponds to one incident positron energy.

E_γ (GeV)	$\sigma_T(\gamma p)$ (μb)	$\sigma_T(\gamma d)$ (μb)
3.70	135.3±5.0	241.0± 8.9
3.95	142.7±5.2	255.2± 9.1
4.19	127.2±5.1	243.6± 9.2
4.43	136.0±5.8	247.2±10.0
4.71	127.2±4.4	244.9± 7.8
5.01	134.7±4.6	230.8± 7.8
5.32	121.9±4.5	239.0± 8.2
5.62	130.4±5.0	240.2± 9.1
5.98	121.1±4.1	250.5±10.8
6.37	129.1±4.3	235.2±10.8
6.76	120.6±4.3	238.5±11.0
7.16	118.6±4.5	230.9±11.6
7.68	123.8±4.1	217.3± 8.8
8.19	121.5±4.2	239.6± 9.4
8.69	119.2±4.3	244.9± 9.6
9.20	115.1±4.4	246.9±10.2
8.95	122.0±4.1	242.5± 6.7
9.54	123.0±4.3	218.4± 6.6
10.13	121.8±4.3	226.5± 6.7
10.71	111.8±4.8	220.8± 7.0
9.75	116.6±4.0	224.2± 9.5
10.39	127.7±4.4	237.3± 9.3
11.03	127.6±4.4	232.9± 9.4
11.67	121.9±4.5	210.5± 9.9
11.38	120.6±4.1	222.8± 7.1
12.12	115.0±4.1	222.6± 7.3
12.86	115.5±4.1	227.8± 7.3
13.61	117.1±4.4	219.9± 7.6
12.39	113.9±4.5	219.4± 4.7
13.02	110.0±4.5	226.8± 4.9
14.01	118.3±4.7	206.5± 4.8
14.82	112.3±5.0	220.9± 5.3
14.92	111.5±4.0	221.8± 4.1
15.65	113.8±4.4	210.0± 4.5
16.63	111.6±4.4	220.4± 4.5
17.87	114.5±5.0	210.3± 5.1

The temperature of the 1-m liquid target was monitored by two platinum resistors. We have assigned to the relative densities of hydrogen and deuterium a ±0.5% error, which is partially due to the difference in densities between ortho- and parahydrogen.

Corrections for attenuation of the photon beam in the target and empty target subtractions were typically (4.5 ± 0.06) % and 10.0 ± 0.8 μb, respectively. The procedure for subtracting accidental coincidences between tagging and hadron-detec-

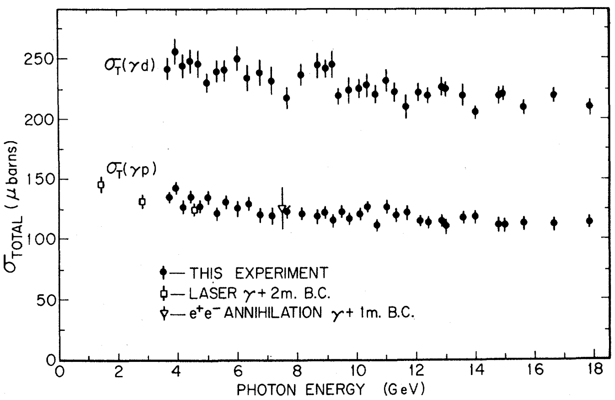

FIG. 2. Total photoabsorption cross sections in hydrogen and deuterium as a function of photon energy.

tor signals has been described in the previous paper.[2] This correction increased from typically 3 ± 1 to 7 ± 3 μb in going from the lowest to highest photon energy.

The values for $\sigma_T(\gamma p)$ and $\sigma_T(\gamma d)$ and their errors are given in Table I and shown in Fig. 2. The errors include those assigned to all of the systematic corrections discussed above, typically ±1%, as well as those due to statistics, typically ±3.3%. Not included is a ±1.1% normalization error due to the uncertainty in accidental vetoes in $S1$ and in the number of target nucleons. Also shown in Fig. 2 are previously published measurements.[4,5]

While the energy dependence shown in Fig. 2 is reminiscent of pion-nucleon total cross sections, as would be expected from the vector-meson-dominance model (VDM),[6] a more quantitative test of VDM can be made by comparing $\sigma_T(\gamma p)$ with hydrogen ρ-photoproduction data. In this model the photon is pictured as a coherent superposition of vector mesons, mostly ρ, so that the Compton scattering and ρ-production amplitudes are proportional. The optical theorem then leads to the relation

$$\sigma_T(\gamma p) = \sigma(\varphi, \omega) + \left[\frac{4\pi\alpha}{1+\eta^2}\frac{4\pi}{\gamma_\rho^2}\frac{d\sigma}{dt}(\gamma p \to \rho p)\Big|_{t=0}\right]^{1/2}, \qquad (1)$$

where $d\sigma(\gamma p \to \rho p)/dt|_{t=0}$ is the ρ-photoproduction differential cross section at zero four-momentum transfer. The sum of contributions to the proton total photoabsorption cross section from the other vector mesons, $\sigma(\varphi, \omega)$, is evaluated from photoproduction data to be 18 ± 2 μb.[3] The ratio of real to imaginary parts of the ρ-production amplitude, η, is assumed to be −0.2, which is the value obtained for the forward Compton amplitude using dispersion relations.[7,8] Figure 3 shows a comparison of a fit to our values of $\sigma_T(\gamma p)$ and the right-hand side of Eq. (1), using recent ρ-photoproduction measurements[9,10] over the energy range of our data. A least-squares fit with the γ-ρ coupling constant, $\gamma_\rho^2/4\pi$, as a free parameter yields the value $\gamma_\rho^2/4\pi = 0.37 \pm 0.03$. Because the errors in the ρ-photoproduction data are mostly systematic, the χ^2 for this fit of 11.0 for 18 degrees of freedom has no absolute significance. However, the smallness of χ^2 indicates that which is also apparent from Fig. 3: The energy dependences of the two types of measurements are the same, in support of VDM. The error in the γ-ρ coupling constant presented here is estimated from the systematic errors. This value for the γ-ρ coupling constant replaces that given in our previous paper,[2] since it is based on data over a wider energy range. This new determination is in excellent agreement with the value 0.38 ± 0.05, given by the variation of the total photoabsorption cross section with nuclear size.[2] However, both determinations of the γ-ρ coupling constant on the photon mass shell disagree quantitatively with the value obtained on the ρ mass shell using e^+-e^- colliding beams, $\gamma_\rho^2/4\pi = 0.50 \pm 0.03$.[11] Thus, while there is qualitative agreement with VDM, these results may indicate that the model is too simple.

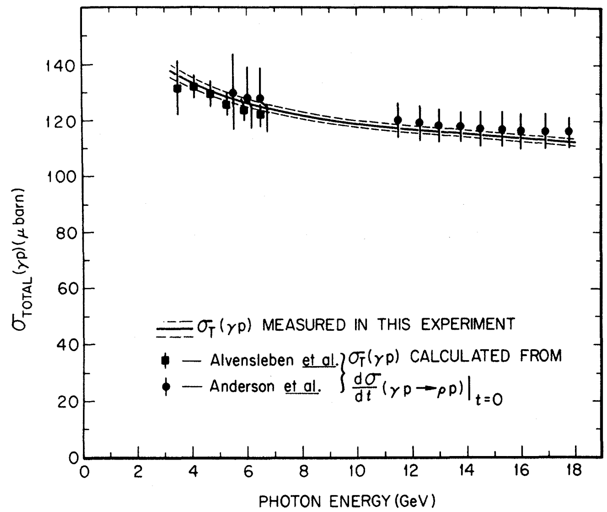

FIG. 3. Comparison of the best fit for proton total cross sections from this experiment with the total proton cross sections calculated from forward differential ρ-photoproduction data of Refs. 9 and 10 using Eq. (1) and assuming $\eta = -0.2$, $\sigma(\varphi, \omega) = 18 \pm 2$ μb, and $\gamma_\rho^2/4\pi = 0.37 \pm 0.03$.

The VDM also relates $\sigma_T(\gamma p)$ to the ρ-proton cross section $\sigma_T(\rho p)$ by the expression

$$\sigma_T(\gamma p) = \sigma(\varphi, \omega) + \tfrac{1}{4}\alpha(4\pi/\gamma_\rho^2)\sigma_T(\rho p), \tag{2}$$

which demonstrates the hadronlike behavior of $\sigma_T(\gamma p)$. Using $\gamma_\rho^2/4\pi = 0.37 \pm 0.03$ we find that $\sigma_T(\rho p)$ decreases from 23 ± 2 mb at 4 GeV to 19 ± 2 mb at 16 GeV. These values are somewhat lower than the quark-model predictions, which are the average of the π^+ and π^- cross sections. The mean $\sigma_T(\rho p)$ from this paper for the energy range 7-18 GeV is 20.2 ± 2.0 mb and is in good agreement with the value 20.4 ± 2.7 mb determined from our A dependence.[2]

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†Now at the Department of Physics and Astronomy, University of Hawaii, Honolulu, Haw. 96822.

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