TOTAL CROSS SECTION FOR PHOTOPRODUCTION OF HADRONS ON HYDROGEN AND DEUTERIUM BETWEEN 1.0 AND 6.4 GeV

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The total cross section for hadron production by photons on hydrogen $\sigma(\gamma p)$ and deuterium $\sigma(\gamma d)$ has been measured for beam energies from 1.0 to 6.4 GeV. The cross section on neutrons is determined from the D_2 and H_2 data using a Glauber correction.

Several recent experiments [1-6], gave for the first time results on the total photoproduction cross section on hydrogen $\sigma(\gamma p)$ from threshold up to 18 GeV, and in one case [6] also on deuterium. We describe here a counter experiment that gives new accurate results on hydrogen and deuterium in the energy range from 1.0 to 6.4 GeV. Special attention was paid to the determination of $\sigma(\gamma n)$. The cross section on neutrons, and its energy dependence, as compared to $\sigma(\gamma p)$. Preliminary results have been reported at the conferences in Lund, Boulder and Liverpool [7].

The experiment was performed at the 7.5 GeV electron synchrotron DESY. A tagged photon beam hit a liquid $H_2(D_2)$-target. A set of scintillation counters covering almost 4π solid angle was used to detect the reaction products. The separation between hadronic and electromagnetic final states was achieved by using their different angular distributions.

Beam and tagging system. The source of tagged photons was a positron beam incident on a thin radiator (Au, 2% rad. length). The positron beam, obtained by converting a photon beam from a synchrotron internal target, was momentum-analyzed with 3 bending-magnets and two lead-slits to get a momentum resolution of $\Delta p/p \lesssim \pm 0.5\%$, free of low energy positrons. The intensity of the beam was typically 5×10^5 e^+/sec, its size at the $H_2(D_2)$-target 11×8 mm^2.

Positrons which lost energy in the radiator due to bremsstrahlung were bent out and detected in an array of scintillation counters, the tagging-system (fig. 1). It consisted of 12 energy-defining counters, each arranged to have $\frac{1}{3}$ overlap with both neighbouring counters, backed by 6 larger counters to suppress background. The energy resolution was limited to ± 50 MeV by the infinite width of the counters and was independent of the e^+-energy. The total energy range covered by the tagging counters was 2.0 GeV. Tagged photons were defined by a twofold coincidence between the smaller energy-defining counters and the corresponding backcounters (TAG). The photon flux was measured by requiring a coincidence with a sandwich shower counter (S) located at the end of the experiment (TAG · S) (fig. 1). The flux was varied in the range from 10^3 to 6×10^3 γ/sec.

To get a clean TAG-signal a number of veto counters (V_{1-7}) was used. $V_{1,2}$ rejected background outside the beam, V_{3-6} multiple processes in the radiator and V_7 a halo of photons around the beam just in front of the liquid $H_2(D_2)$-target. In addition to being vetoed in V_7 the particles in the halo were stopped in a lead shield between V_7 and the $H_2(D_2)$-target. This shield also prevented backward particles from hadronic reactions in the target from being vetoed by V_7. Due to these veto counters more than 95% of the TAG-counts were accompanied by high energy photons

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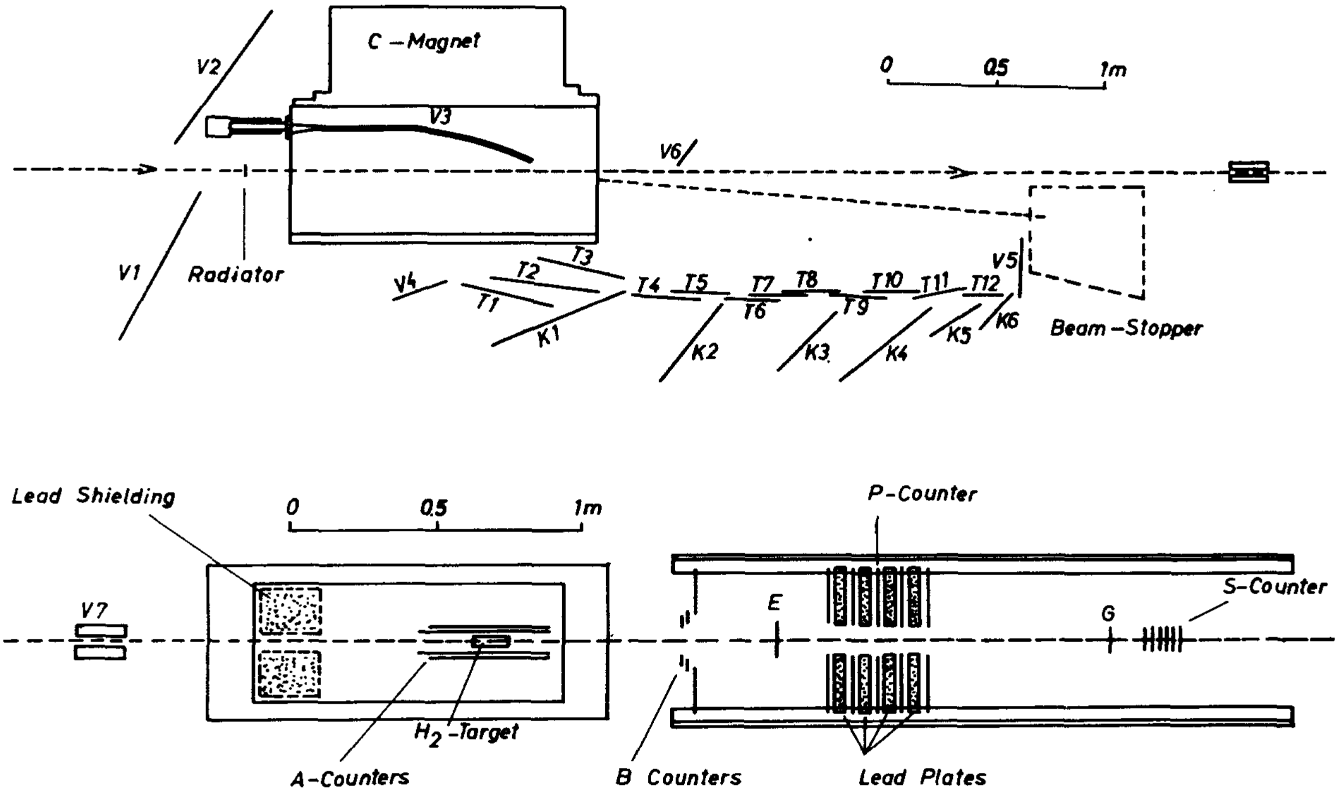

Fig. 1. The experimental setup. It shows the tagging system (counters T_i and K_i), the veto counters (V_i), the hadron counters A, B, and P, the pair counters E and G, and the shower counter S.

Target. The target cell for the liquid hydrogen or deuterium was made entirely from 0.1 mm thick "H-film" measuring 12 cm in length and 5 cm in diameter. The target density was kept constant by holding the liquid at its boiling point under constant pressure. Four corrections were made which reduced the effective target length by 3% : 1.) the ortho-para composition of hydrogen, 2.) the flow of bubbles through the target due to the boiling process, 3.) the remaining gas in the target cell (in the case of empty target runs), 4.) a reduction in target length due to the spherical shape at both ends of the target cell and the finite width of the beam. The final errors in the target constants, due to the uncertainties in density and length, are ± 1.6% and ± 1.2% for hydrogen and deuterium, respectively.

Detection system. A set of scintillation counters was used to detect charged particles from the target (fig. 1). Most hadronic reactions were seen by the A-counters, which consisted of half cylinders surrounding the target. The B-counters covered the forward angular range from 2^o to 10^o and were arranged as overlapping rings so as to give the angular distribution of forward produced particles. For both A and B counters a coincidence signal from an additional backcounter was always required. A lead scintillator sandwich counter P (10 rad. lengths lead in total) was used for detecting possible hadronic events with no count in the A, B counters but a large pulse in P indicating photons from π^0 decays. Counters G and E were used to monitor electron pairs from the target. To suppress purely electromagnetic reactions, the S-counter, covering the small forward cone ($\pm 1^o$), was operated in anticoincidence with the hadronic counters A and B.

Data runs. Data were taken for positron energies of 3, 4, 5, 6 and 7 GeV. At each energy, runs with full and empty target for two different distances of the B- and P- counters from the $H_2(D_2)$-target were made. The positions of G and S were kept fixed. The photon flux (TAG · S), the electron pairs (TAG · E · G · S) and hadronic reactions (TAG · (A or B or P) · $\bar{S}$) were measured simultaneously. A small computer (PDP 8) connected to an IBM 360/75 was used for data storage and monitoring the experiment on-line. A complete analysis was performed off-line.

Results. Table 1 summarizes our results for $\sigma_{tot}(\gamma p)$ and $\sigma_{tot}(\gamma d)$ as a function of the photon

Table 1.
Total cross section for photoproduction of hadrons on protons $\sigma(\gamma p)$, deuterium $\sigma(\gamma d)$, and neutrons $\sigma(\gamma n)$ as functions of photon energy E_γ. The factor $1/(1-x)$ represents the Glauber correction.

E_γ [GeV]	$\sigma_{tot}(\gamma p)$ [μb]	$\sigma_{tot}(\gamma d)$ [μb]	$\frac{\sigma_{tot}(\gamma d)}{1-x}$ [μb]	$\sigma_{tot}(\gamma n)$ [μb]
1.15	182.1 ± 7.8			
1.45	153.7 ± 6.3	294.3 ± 10.0	295.0 ± 10.1	141.3 ± 11.9
1.75	146.0 ± 6.4	285.7 ± 9.5	287.3 ± 9.5	141.3 ± 11.5
2.05	148.5 ± 6.7	268.1 ± 8.5	270.6 ± 8.5	122.1 ± 10.8
2.35	144.2 ± 8.0	266.7 ± 9.9	269.7 ± 9.9	125.5 ± 12.7
2.65	142.0 ± 9.5	268.2 ± 9.7	271.5 ± 9.7	129.5 ± 13.6
2.95	129.8 ± 6.9	266.8 ± 8.7	270.4 ± 8.7	140.5 ± 11.1
3.25	132.7 ± 6.0	252.9 ± 8.5	256.5 ± 8.5	123.7 ± 10.4
3.55	127.2 ± 6.2	243.9 ± 9.3	247.5 ± 9.3	120.2 ± 11.2
3.85	134.6 ± 6.4	248.2 ± 10.0	251.9 ± 10.0	117.3 ± 11.9
4.15	131.5 ± 6.6	245.7 ± 8.0	249.5 ± 8.0	117.9 ± 10.4
4.45	124.7 ± 5.8	236.7 ± 8.3	240.4 ± 8.3	115.7 ± 10.1
4.75	124.2 ± 5.4	238.1 ± 8.2	241.9 ± 8.2	117.7 ± 9.8
5.05	121.8 ± 4.5	248.4 ± 7.7	252.5 ± 7.7	130.7 ± 8.9
5.35	122.1 ± 6.0	234.5 ± 8.3	238.3 ± 8.3	116.3 ± 10.3
5.65	118.4 ± 5.0	232.1 ± 7.7	236.0 ± 7.7	117.7 ± 9.2
5.95	123.6 ± 5.5	225.1 ± 8.0	229.0 ± 8.0	105.3 ± 9.7
6.25	122.1 ± 5.6	227.6 ± 7.6	231.5 ± 7.6	109.4 ± 9.5

energy in 300 MeV intervals. The data were corrected for empty target contributions, accidental coincidences, contamination from electro-magnetic processes, and double bremsstrahlung in the radiator. The empty target rate was typically 25% and 12% of the full target rate for hydrogen and deuterium, respectively. The accidental coincidences were measured in three different ways: 1) by recording delayed hadronic triggers, 2) by setting the hadronic trigger with three different resolution times of 22, 25, and 32 nsec, respectively, and 3) by recording the time overlap spectrum of the trigger pulse. The cross sections obtained by using each of these three methods in the analysis were in good agreement with one another.

A contamination from electromagnetic processes was expected only at small production angles. This was observed as a rise in the cross section by including in the definition of hadronic reactions - (TAG · (A or B) · $\bar{S}$) - those B-counters which covered scattering angles below 4^o. As the cross section for angles greater than 4^o showed a rather flat behaviour, the hadronic cross section could be obtained by extrapolating to 0^o. The uncertainty in this procedure was estimated to be ± 2%. Events without a charged particle in the A or B counters (TAG · P · $\bar{S}$) gave a cross section of ≈ 0.5 ± 0.2 μb and were neglected.

The finite thickness of the radiator results in a nonnegligible contribution to the photon flux due to double bremsstrahlung. Hadronic events produced by one of these two photons were not counted as, in general, the second photon caused a veto from S. This effect was accounted for by an energy-dependent flux correction of 1.5% to 5.5% between 3 and 7 GeV, with an estimated uncertainty of ± 1%.

The final errors quoted in table 1 include the statistical error, the uncertainties in the target density, and the uncertainties in the corrections for electromagnetic processes and for double bremsstrahlung. The overall scale error of the hadronic cross section due to flux measurement and target density was checked by comparing the e^+e^--pair cross section, measured simultaneously in this experiment (TAG · G · E · S), with a recent very accurate calculation [8]. Table 2 shows our experimental and the theorerical pair cross sections. There is good agreement within the quoted experimental errors (typically ± 1.2%).

To get the cross section on neutrons one performs the subtraction $\sigma(\gamma n) = \sigma(\gamma d)/(1-x) - \sigma(\gamma p)$ where the factor $1/(1-x)$ represents the Glauber correction, and $\sigma(\gamma n)$, $\sigma(\gamma d)$, $\sigma(\gamma p)$ are the total cross sections on neutrons, deuterons, and protons, respectively. The main contribution to the shadow effect comes from elastic ρ^0-photoproduction. The values of x obtained from a calculation of G. Knies [9] can be taken from table 1, which shows $\sigma(\gamma d)/(1-x)$, $\sigma(\gamma d)$, $\sigma(\gamma p)$ and $\sigma(\gamma n)$

Table 2.
Total cross section for electron positron pair production on hydrogen $\sigma_{pair}(\gamma p)$ and deuterium $\sigma_{pair}(\gamma d)$ as functions of the photon energy E_γ. The theoretical values have been taken from ref. [8].

	Theory	Experiment	
E_γ[GeV]	$\sigma_{pair}(\gamma p)$[mb]	$\sigma_{pair}(\gamma p)$[mb]	$\sigma_{pair}(\gamma d)$[mb]
1.46	18.9	18.91 ± 0.20	18.89 ± 0.18
1.98	19.2	19.06 ± 0.33	19.70 ± 0.23
2.55	19.5	19.61 ± 0.28	19.62 ± 0.26
2.99	19.7	19.57 ± 0.30	20.60 ± 0.19
3.46	19.8	19.70 ± 0.24	19.97 ± 0.23
3.98	19.9	20.02 ± 0.30	20.49 ± 0.21
4.55	19.9	20.19 ± 0.33	20.34 ± 0.25
4.99	20.0	19.58 ± 0.18	20.28 ± 0.15
5.46	20.1	19.90 ± 0.25	20.25 ± 0.15
5.98	20.1	20.17 ± 0.21	20.34 ± 0.20
6.55	20.2	20.50 ± 0.24	20.76 ± 0.18

as functions of the photon energy.

Discussion. Fig. 2 shows the cross section $\sigma(\gamma p)$ from this experiment together with values from other experiments [1-6]. Considering the completely different methods applied, the agreement is quite good, although two values from ref. [1] at 2 and 3 GeV are rather low and the data from small angle e^-p- scattering [4,5] seem to be systematically higher by ≈ 8% than those from the other experiments. But in both cases we think this is not unreasonable in view of the large systematic corrections that had to be applied.

Fig. 2 shows $\sigma(\gamma d)$ and $\sigma(\gamma n)$ as functions of the photon-energy, including the data from ref. [6]. The neutron cross section is seen to be systematically lower than the proton cross section, the latter being indicated by the solid line. The difference $\sigma(\gamma p) - \sigma(\gamma n)$ averaged over the energy range 3 to 6.4 GeV is 8.6 ± 3.5 μb. If confirmed by future experiments this indicates $I = 1$ exchange contributions to forward Compton scattering at these energies.

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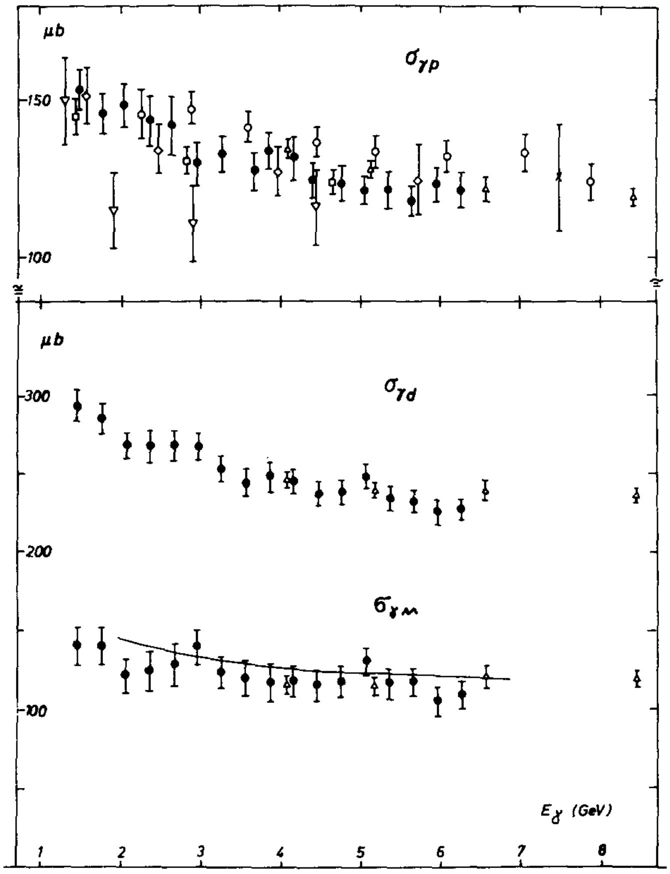

Fig. 2. Total cross section $\sigma(\gamma p)$, $\sigma(\gamma d)$ and $\sigma(\gamma n)$ versus E_γ, the photon energy. The data points are taken from the following experiments: ∇[1], ⧗[2], □[3], ○[4], ◇[5], △[6], ○ (this experiment). The solid line indicates the behaviour of $\sigma(\gamma p)$, according to $\sigma(\gamma p) = 95 + 64/E_\gamma^{1/2}$

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