NUCLEON-NUCLEON TOTAL CROSS SECTIONS BETWEEN 1 AND 8 GeV/c

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(Received 21 June 1965)

Measurements have been made of the two total cross sections, $\sigma(p\text{-}p)$ and $\sigma(p\text{-}d)$, over the laboratory momentum range 1.1 to 7.8 GeV/c, by the conventional attenuation technique. The cross sections have been measured with an average statistical accuracy of ±0.1%, and systematic errors of the same order. The cross sections are in general slowly varying functions of c.m. energy, but there is evidence for a small, broad structure centered on an energy of 2.75 GeV in $\sigma(p\text{-}p)$.

A proton beam was obtained by diffraction scattering from an internal target in Nimrod. The beam momentum was varied by operating the accelerator at different energies. The beam had a momentum spread of ±0.5%. Floating-wire and rotating-coil magnetometer measurements were used to calibrate the momentum with an absolute error of ±0.5%, and relative errors between momenta of ±0.2%. The purity of the beam was confirmed using time of flight and a Cherenkov counter.[1] The pion contamination was less than 1 part in 10^4.

Three identical target vessels were used; one contained liquid hydrogen, the second liquid deuterium, while the third was an evacuated dummy. The lengths of the targets were observed directly through windows in the vacuum tanks, and allowance was made for the curvatures of the end windows using the measured beam profiles. The temperatures and, hence, molar volumes of the target liquids were obtained from their vapor pressures.[2]

The transmission of the beam through a target was measured by six circular scintillation counters subtending linearly increasing solid angles at the target. These counters were mounted on a trolley running parallel to the beam line. Scattered particles were counted over a constant range of transverse momentum by keeping the distance between counters and target proportional to the beam momentum. Such a procedure meant that corrections for Coulomb effects varied little with momentum, and permitted a more systematic treatment of the data. To minimize effects due to Cherenkov light produced in the Perspex light guides of the counters by scattered particles, the guides of adjacent counters were arranged to be substantially nonoverlapping, and the outputs of such pairs were then taken together with the beam telescope, T, in threefold coincidence TS_iS_{i+1}, where $s = 1\text{-}5$. The efficiencies of the transmission counters were continuously monitored by means of a small counter covering the beam immediately behind them, and in coincidence with T.

At all but the lowest momenta, twofold accidentals were eliminated by pulse-height discrimination, using a $\frac{1}{2}$-in.-thick scintillator, in a way similar to that of Citron *et al.*[3]

At each momentum, the data were collected in five or six batches, which were tested for statistical consistency, and then corrected for Cherenkov effects, variations in detection efficiency, and, where necessary, random coincidences. Further small corrections (typically ~0.2%) were applied for multiple and single Coulomb scattering. The corrections were weighted averages over the beam profile or the counter surface, as appropriate.

In extrapolating the partial cross sections so determined to zero solid angle, a linear fit was found to be inadequate, and a quadratic extrapolation was used. For the deuterium data even this fit was not completely adequate, and this produces a contribution to the over-all systematic error in $\sigma(p\text{-}d)$. The over-all systematic error in the measurements is believed to be about ±0.3% for $\sigma(p\text{-}d)$ and ±0.5% for $\sigma(p\text{-}d)$.

A more complete account of the experimental arrangement and method, as well as the procedures employed in analyzing the data, will be published elsewhere.

Values of $\sigma(p\text{-}p)$ have been corrected for Coulomb nuclear interference using values of $\mathrm{Re}f(0)$ calculated by Söding,[4] and assuming an angular dependence $\exp(4.6t)$ for $\mathrm{Re}f(t)$, where t is the four-momentum transfer squared in $(\mathrm{GeV}/c)^2$. The Coulomb amplitude was taken from the Stanford data[5] to have an angular dependence $[K\exp(5.5t)]/t\beta$. This correction is large compared with our experimental errors; for example, it is 0.3 mb at 5 GeV/c. Ignorance of the angular dependence of $\mathrm{Re}f(t)$ introduces the largest systematic error in our results. However, since $\mathrm{Re}f(0)$ is a smooth and slowly varying function of momentum, this correction is unlikely to account for the structure seen in $\sigma(p\text{-}p)$.

Values of $\sigma(p\text{-}d)$ have been corrected for Coulomb nuclear interference in the same fashion as $\sigma(p\text{-}p)$. However, in the absence of any data on the real part of the $n\text{-}p$ scattering amplitude, it has not been possible to put in any correction for it.

The cross section $\sigma(p\text{-}n)$ has been obtained from $\sigma(p\text{-}d)$ to $\sigma(p\text{-}p)$ by applying the Glauber correction[6] for the mutual shielding of the neutron and proton in the deuteron. A value of $\langle r^{-2}\rangle = 0.0239\ \mathrm{mb}^{-1}$ was used in this correction.[7] This value is used in preference to that of Galbraith *et al.*,[8] since it yields a cross section $\sigma(p\text{-}n)$ in much better agreement with the values of $\sigma(n\text{-}p)$ measured using neutron beams incident on hydrogen by Friedes *et al.*[9] and Khatchaturyan and Pantuev.[10] In the first approximation, the Glauber correction affects only the absolute scale of $\sigma(p\text{-}n)$ and $\sigma(T=0)$, to the extent of about 3 and 6 mb, respectively; an error in its magnitude is unlikely to affect the shapes of these cross sections appreciably.

The cross sections $\sigma(I=1)$ and $\sigma(I=0)$ are plotted as a function of the c.m. energy in Fig. 1. Previous results have been omitted for the sake of clarity. The dashed curve in Fig. 1(b) is that obtained from the experimental results (full curve) by unfolding the Fermi motion using a Hulthén wave function. In general, the new measurements of $\sigma(p\text{-}p)$ agree with previous ones within statistics, although the range

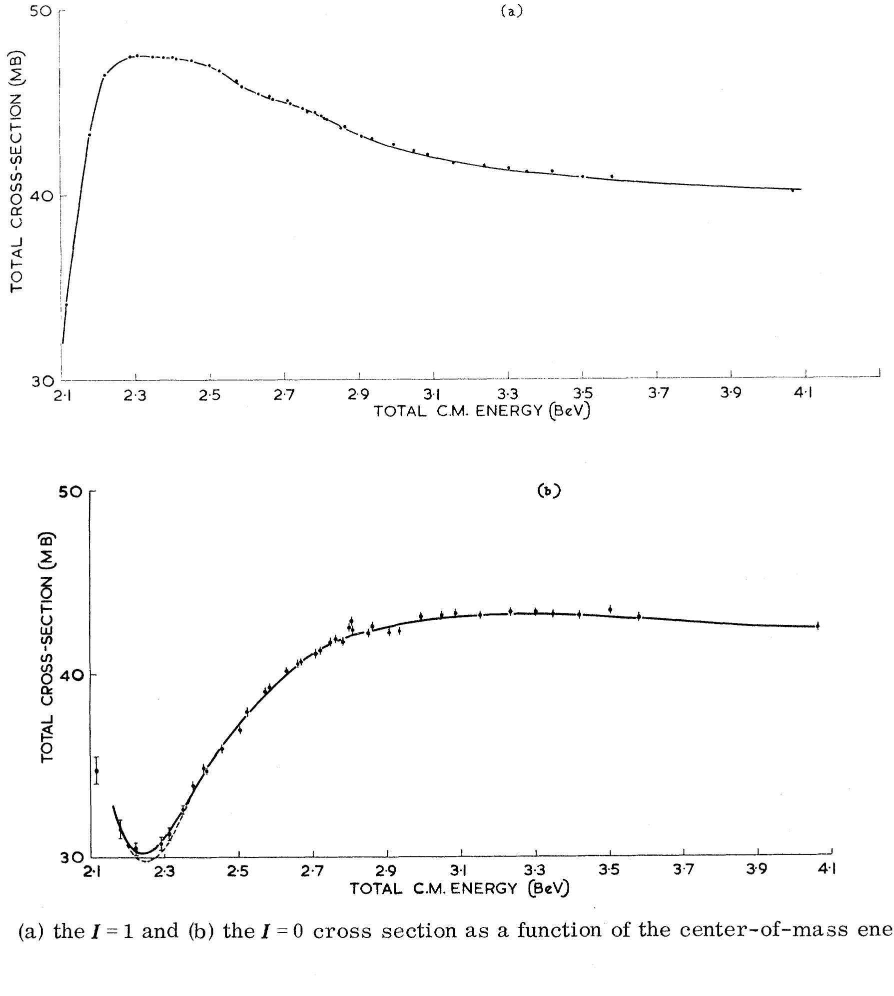

FIG. 1. (a) the $I=1$ and (b) the $I=0$ cross section as a function of the center-of-mass energy.

2.1 to 2.3 GeV, the energy scale of the present experiment, is systematically 30 MeV lower than that of Dzhelepov, Moskalev, and Medved'.[11] Because of the large systematic and statistical uncertainties in many of the previously measured values of $\sigma(p\text{-}n)$, and uncertainty in the Glauber correction parameter, a corresponding comparison is not instructive.

There is significant structure in the $I=1$ cross section between 2.6 and 2.9 GeV. This is shown on an expanded scale in Fig. 2. In the $I=0$ state, the cross section begins rising sharply at 2.3 GeV, but thereafter there is no significant small-scale structure at higher energies. However, we remark that any structure in $\sigma(I=0)$ comparable in magnitude to that in $\sigma(I=1)$ around 2.75 GeV would not be visible in this experiment, because of the Fermi motion of the neutron inside the deuteron.

It is well known[12] that the large rise in $\sigma(I=1)$ in the energy range 2.1 to 2.3 GeV is due to a rapid increase in the cross section for producing $N^*(1238)$. Likewise, the additional structure in $\sigma(I=1)$ around 2.75 GeV might well be due to $N^*(1688)$ production, for which the threshold is at 2.63 GeV. Indeed, it is remarkable that $N^*(1512)$ and $N^*(1688)$ production are so inconspicuous in the total cross section compared with the 25 mb rise associated with $N^*(1238)$ production. The rise in $\sigma(I=0)$ above 2.3 GeV is presumably due to inelastic processes such as $N^*(1512)$ production, double $N^*(1238)$ production, and production of $N^*(1420)$, if this exists.

The "woolly cusp" mechanism of Nauenberg and Pais[13] might contribute to the dip in $\sigma(I=1)$ at 2.63 GeV, which is the threshold for $N^*(1688)$ production.

Dyson and Xuong[14] have speculated on the existence of an $I=1$ dibaryon resonance, and the observed structure at 2.75 GeV could be fitted into their scheme. At this energy $\pi\lambda^2=1.24$ mb, so this would have to be a very inelastic resonance. The total cross section alone does not allow any more positive statement to be made.

We wish to acknowledge the generous assistance and cooperation of the operating staff of Nimrod and the High-Energy Physics-Engineering Group of the Rutherford Laboratory in the carrying out of this experiment. The technical help given by G. T. J. Arnison and R. Mackenzie is also gratefully acknowledged. We are particularly grateful to Miss K. M. Knight for invaluable assistance in the early stages of setting up this experiment.

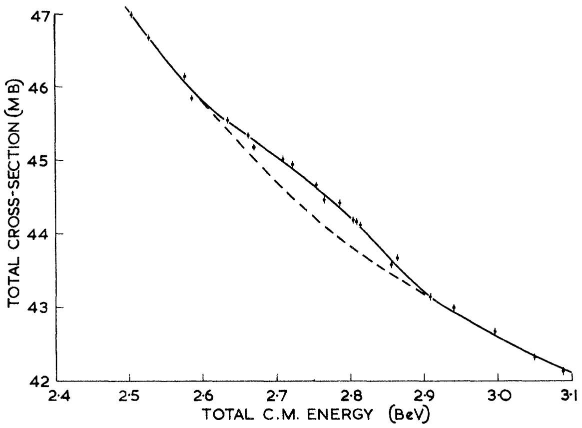

FIG. 2. A portion of $\sigma(I=1)$ on an expanded scale. The dotted curve is an estimate of the background.

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