NEUTRON-PROTON AND NEUTRON-DEUTERON TOTAL CROSS SECTIONS AT 4.0 AND 5.7 GeV/*c**

E. F. PARKER, H. R. GUSTAFSON‡, L. W. JONES, M. J. LONGO,
P. V. RAMANA MURTHY‡‡ and F. E. RINGIA
Randall Laboratory of Physics, University of Michigan, Ann Arbor, Michigan 48104

and

B. CORK
Argonne National Laboratory, Argonne, Illinois 60439

Received 14 January 1970

The np and nd total cross sections have been measured directly with a neutron beam with momenta of 4.0 ± 0.6 and 5.7 ± 0.6 GeV/*c*. The data are compared with the previous nucleon-nucleon and nucleon-deuteron results, and the deuteron screening term was also evaluated. The measured total cross section are 43.1 ± 0.6 and 80.3 ± 1.9 mb at 4.0 GeV/*c* and 42.5 ± 0.6 and 77.8 ± 1.3 mb at 5.7 GeV/*c*.

The np and nd total cross sections have been measured directly with a neutron beam for incident neutron momenta of 4.0 ± 0.6 GeV/*c* and 5.7 ± 0.6 GeV/*c*. The experiment was performed at the Bevatron of the Lawrence Radiation Laboratory. This data together with that from a previous AGS experiment [1] show that between 4 and 27 GeV/*c* the np total cross section has about the same magnitude as the pp total cross section but may vary more rapidly with energy. Data on n-nucleus total cross sections are presented in an accompanying letter.

This experiment employed the standard good-geometry transmission technique. A well-collimated neutron beam passed through a liquid hydrogen (or deuterium) target, and the fraction of the beam transmitted was measured by a total absorption spectrometer (TAS) [2]. Relatively good neutron energy resolution was obtained by accepting only the largest pulses from the TAS, thus heavily biasing accepted events towards the high end of the spectrum. As is well known the efficiency of the neutron detector does not affect the measured total cross sections.

* Work supported by the Office of Naval Research Contract NONR 1224 (23), the National Science Foundation Grant GP 9428 and the U.S. Atomic Energy Commission.

‡ Supported by a fellowship from the Institute of Science and Technology, University of Michigan, Ann Arbor, Michigan.

‡‡ Now at the Tata Institute of Fundamental Research, Bombay, India.

The experimental arrangement is shown in

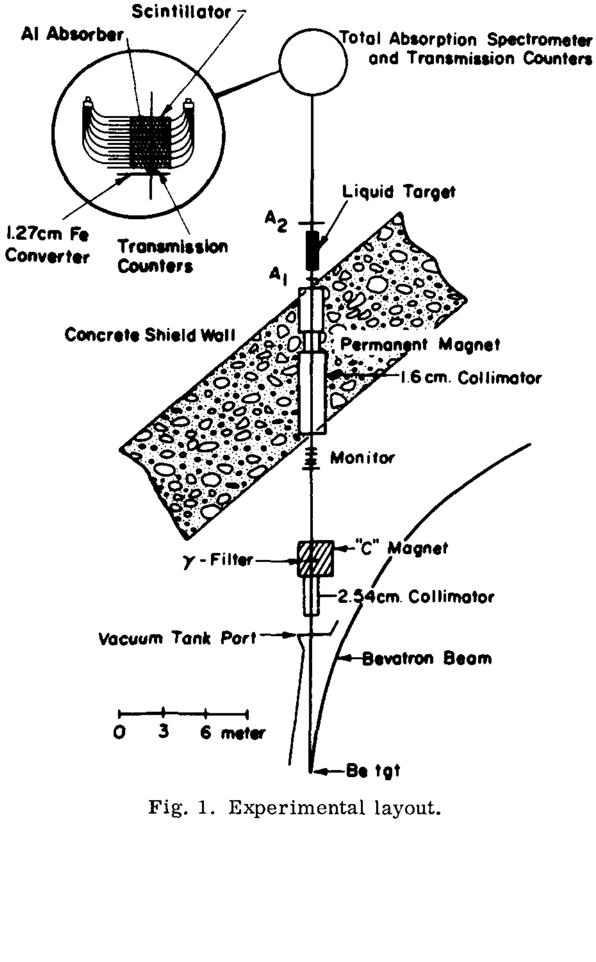

Fig. 1. Experimental layout.

fig. 1. The neutron beam was taken off at an angle of 2.5^{o} from an internal beryllium target in the Bevatron. Measurements of the neutron spectrum in a similar beam demonstrated that the spectrum peaks strongly at high energies cutting off rather sharply at the accelerator energy [3]. Chearged particles were swept out of the beam by the magnetic field of the Bevatron and by two sweeping magnets in the beam line. Photons were effectively eliminated by a 7.5 cm lead filter. Relative beam intensity was monitored by a monitor telescope, consisting of an anticounter followed by a polyethylene converter and three scintillation counters, placed in the neutron beam just ahead of the defining collimator.

The beam at the hydrogen target was approximately 3 cm in diameter with a negligible halo. The target consisted of a 1.2 m long, 7.5 cm diameter mylar vessel which could be filled with either hydrogen or deuterium. Anticounters preceding and following the target vetoed charged particles.

The neutron detector consisted of a 1.25 cm iron converter plate followed by four transmission counters which subtended solid angles of 2.6×10^{-5}, 7.1×10^{-5}, 2.3×10^{-4} and 6.8×10^{-4} sr from the center of the target. The transmission counters were followed by the total absorption spectrometer, a series of 14 sheets of plastic scintillator interspersed with 3.2 cm thick aluminium plates. The total thickness of the TAS was 130 g/cm^2 or about 2 collosion lengths. The light from alternate scintillators was summed optically and brought to two 5" diameter RCA 4522 photomultiplier tubes (see inset in fig. 1). The output of each of these tubes was added to give a pulse whose amplitude was approximately proportional to the neutron energy. The discriminator on the TAS output was set to accept only the largest 10% of the pulses, thus heavily biasing the response in favor of the highest energy neutrons. This together with the strong peaking of the neutron spectrum on the high end yielded an overall response similar to that shown at the bottom of fig. 2 for the 5.7 GeV/c point. The sharp cutoff on the high end is set by the proton energy in the Bevatron, 4.6 GeV/c for the 4.0 GeV/c point and 6.3 GeV/c for the 5.7 GeV/c point.

The energy resolution of the TAS was calculated from the pulse-height distributions obtained at different Bevatron energies together with available data on the neutron spectrum [3].

Coincidences between the TAS and each of the four transmission counters were scaled separately. Attenuation cross sections for each counter were obtained from the ratio of rates with target empty and target full. A typical data point represents data from a series of 50 target empty-target full cycles. The statistical uncertainty in the measured cross sections was less than 1%. Total cross sections were obtained by extrapolating the measured attenution cross sections to zero solid angle. Three extrapolation methods were used, and the total cross sections from all three were in very good agreement. The uncertainty in the extrapolation was about 0.2% of the cross section.

A correction of approximately 2% was made for rate effects caused by pulse pileup in the TAS. A correction of $0.8 \pm 0.4\%$ was made for gas remaining in the empty target. The temperature of both the liquid hydrogen an liquid deuterium was determined by liquid hydrogen boiling in the target reservoir at one atmosphere. This gave a hydrogen density of 0.0707 ± 0.0001 g/cm^3 and a deuterium density of 0.1708 ± 0.0003 g/cm^3 [4]. The resulting total cross sections are given in table 1.

The existing data on np, nd, and pd total cross sections are summarized in figs. 2 and 3. Our results for σ_{np} are somewhat higher than those of Engler et al. [1, 5, 6] at similar energies. This may be partially due to the larger spread in neutron momenta accepted in the latter experiment so that the relatively narrow peak in the cross section near 4 GeV/c was not resolved. Their nd data also appears somewhat

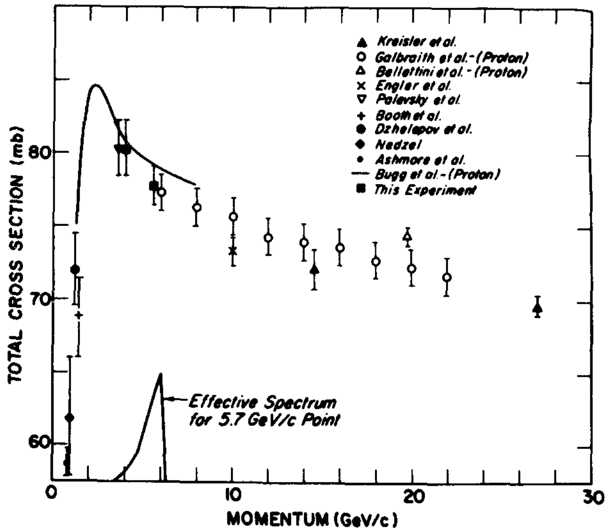

Fig. 2. nd and pd total cross sections from this experiment and data in ref. 5. The lower curve shows the effective neutron spectrum for the 5.7 GeV/c point.

Table 1
np and nd total cross sections and the deuteron screening term at 4.0 and 5.7 GeV/c.

Momentum (GeV/c)	total cross sections (mb) np	total cross sections (mb) nd	$\langle r^{-2}\rangle(1-\alpha_{np}\alpha_{pn})/4\pi$ (mb^{-1}) $\times 10^2$
4.0	43.1 ± 0.6	80.3 ± 1.9	3.4 ± 1.4
5.7	42.5 ± 0.6	77.8 ± 1.3	4.0 ± 1.0

low relative to the pd data of Galbraith et al. (fig. 2) [7]. Our 5.7 GeV/c nd data agree well with the 6 GeV/c pd data of Galbraith et al. [7] and our 4 GeV/c nd data agree with the 4 GeV/c data of Bugg et al. [6].

The Glauber [9] screening term for the deuteron was experimentally evaluated using the neutron data from this experiment and the proton data of Bugg et al. [6]. The screening term, $\langle r^{-2}\rangle(1-\alpha_{np}\alpha_{pp})/4\pi$, is defined by the following equation

$$\langle r^{-2}\rangle(1-\alpha_{np}\alpha_{pp})\,\sigma_{np}\sigma_{pp}/4\pi = \sigma_{pp}+\sigma_{np}-\sigma_{nd}$$

where the α's are the ratio of the real to the imaginary part of the forward scattering amplitude and $\langle r^{-2}\rangle$ is essentially the mean inverse square separation of the nucleons in the deuteron. The resulting values are given in table 1. Since the Glauber term is independent of particle type and momentum above 2 GeV/c [10] these values can be compared with the value

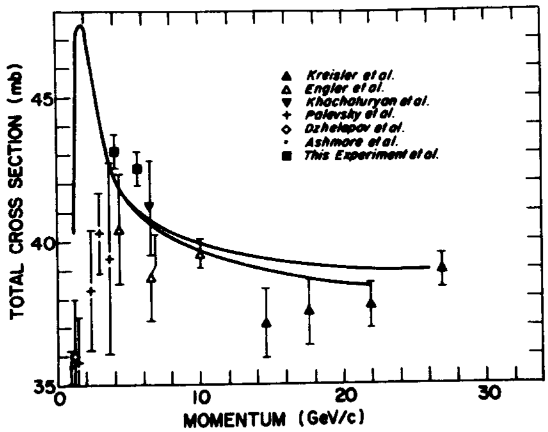

Fig. 3. np total cross section from this experiment and the data in ref. 5. The solid line is the pp total cross section. The pp data below 6 GeV/c are those of Bugg et al. [6] and above 6 GeV/c are those of Galbraith et al. [7] (lower curve) and Foley et al. [8] (upper curve).

0.042 ± 0.003 mb^{-1} and 0.239 ± 0.0014 mb^{-1} obtained from pion data by Galbraith et al. [7] and Baker et al. [11] respectively. Calculated values of the Glauber term range from about 0.025 to 0.035 mb^{-1} depending upon the wave function assumed for the deuteron [6, 10].

As can be seen in fig. 3 the data suggest that the np cross section oscillates around the pp cross section with crossing points at about 3.5, 10 and 27 GeV/c. This would indicate that the pure nucleon-nucleon $I = 1$ total cross section is larger than the $I = 0$ cross section above 10 GeV/c, in contrast to the situation for the K-nucleon and antinucleon-nucleon systems [7]. However, the statistical significance of any difference between the np and pp cross section is marginal.

The authors would like to express their appreciation to W. Hartsough and the operating crew at the Bevatron, to B. Edwards and E. McLaughlin of the LRL Mechanical Engineering Group, and to C. Cork, O. Haas and S. Wilson for their most valuable assistance.

References

1. M. N. Kreisler, L. W. Jones, M. J. Longo and J. R. O'Fallon, Phys. Rev. Letters 20 (1968) 468.
2. L. W. Jones, Proc. Intern. Conf. on Nuclear electronic, Versailles, (Sept. 1968).
V. S. Murzin, Progress in elementary particles and cosmic ray physics, (North-Holland Publishing Co. Amsterdam, The Netherlands, 1967), Vol. IX, p. 245.
M. N. Kreisler, S. L. A. C. Report # 66, Stanford Linear Accelerator Center, Stanford University, Stanford, Cal. (1966).
4. R. J. Corruccini, Pure and Applied Cryogenics, Vol. 5 (Pergamon Press, Oxford, 1966) p. 80.
E. C. Kerr, J. Am.Chem. Soc. 74 (1952) 824.
5. V. P. Dzhelepov, V. I. Satarov and B. M. Golovin, Soviet Phys., JETP 2 (1956) 349.
N. E. Booth, G. W. Hutchin and B. Ledley, Proc. Phys. Soc. (London) 71 (1958) 293.
H. Palevsky, J. L. Friedes, R. J. Sutter, R. E. Chrien and H. R. Muether, Congr. Intern. de Physique nucléaire 1964 ed. Mme. P. Gugenberger (Editions du Centre National de la Recherche Scientific, Paris, 1964) Vol. II, p. 162.
V. A. Nedzel, Phys. Rev. 94 (1954) 174.
A. Ashmore, R. G. Jarvis, D. S. Mather and S. K. Sen, Proc. Phys. Soc. (London) A70 (1957) 745.
M. N. Khachaturyan and V. S. Pantuyev, Phys. Letters 7 (1963) 80.
J. Engler, K. Horn, J. König, F. Mönnig, P. Schludecker, H. Schopper, P. Sievers, H. Ullrich and K. Runge, Phys. Letters 27B (1968) 599.
W. Galbraith, E. W. Jenkins, T. F. Kycia, B. A. Leontic R. H. Phillips, A. L. Read and R. Rubinstein, Phys. Rev. 138 (1965) 913.

K. J. Foley, R. S. Jones, S. J. Lindenbaum, W. A. Love, S. Ozaki, E. D. Platner, C. A. Quarles and E. H. Willen, Phys. Rev. Letters 19 (1967) 857.
6. D. B. Bugg, D. C. Salter, G. H. Stafford, R. F. George, K. F. Riley and R. J. Tapper, Phys. Rev. 146 (1966) 980.
7. W. Galbraith, E. W. Jenkins, T. F. Kycia, B. A. Leontic, R. H. Phillips, A. L. Read and R. Rubinstein, Phys. Rev. 138 (1965) 913.
8. K. J. Foley, R. S. Jones, S. J. Lindenbaum, W. A. Love, S. Ozaki, E. D. Platner, C. A. Quarles and E. H. Willen, Phys. Rev. Letters 19 (1967).
9. R. J. Glauber, Phys. Rev. 100 (1955) 242.
10. M. J. Longo, A comparison of experimental data on deuteron screening corrections with the Glauber calculation, submitted to the Fourteenth Intern. Conf. on High energy physics, Vienna, August, 1968. (unpublished).
11. W. F. Baker, E. W. Jenkins, T. F. Kycia, R. H. Phillips, A. L. Read, K. F. Riley and H. Ruderman, Proc. Sienna Intern. Conf. on Elementary particles, 1963, ed. G. Bernardini and G. P. Puppi (Societa Italiana di Fisica, Bologna, 1963).

* * * * *