NEUTRON-NUCLEUS TOTAL CROSS SECTIONS AT 5.7 GeV/c *

E. F. PARKER, T. DOBROWOLSKI‡, H. R. GUSTAFSON‡‡, L. W. JONES, M. J. LONGO, 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 neutron total cross sections for He, Be, C, Al, Fe, Cu, Cd, W, Pb and U have been measured to an accuracy of 2 % at 5.7 ± 0.6 GeV/c. The total cross section versus atomic weight data was fit to an absorbing uniform grey sphere optical model. The best fit parameters are $R = a_0 A^{1/3}$ where a_0 = 1.27 ±0.01 fm, and a nucleon mean free path in nuclear matter of 3.0 ±0.2 fm. The energy dependence of the nucleon-nucleus total cross sections is discussed in terms of the nucleon-nucleon total cross sections and a screening term.

The "good geometry" beam attenation technique has been employed to measure the neutron-nucleons total cross section for He, Be, C, Al, Fe, Cu, Cd, W, Pb and U at 5.7 ± 0.6 GeV/c using a neutron beam from the Bevatron at the Lawrence Radiation Laboratory. The experimental arrangement, which has been described in the previous letter [1], contained a total absorption spectrometer (TAS) for neutron energy selection. The energy resolution of the TAS and the strongly peaked neutron spectrum resulted in an effective spectrum having roughly a triangular shape with a mean momentum of 5.7 GeV/c and FWHM of 1.2 GeV/c. The He measurement was made with liquid helium in the 1. 2 m target flask described in ref. 1, while the other measurements were made using solid targets having attenuations ranging from 20% to 40%.

The attenuation cross sections for the four transmission counters had to be corrested for a rate effect caused by pulse pileup in the TAS. This correction amounted to about 2% in most cases. It was necessary to correct the He cross section data for He gas in the target flask during the target empty runs, which resulted in 0.8% ± 0.4% correction for the He data.

The total cross sections were obtained by extrapolating the attenuation cross sections to zero solid angle. Because of the very small solid angles subtended by the transmission counters [1] the extrapolation to zero represents a small correction, ranging from 1% for He to 4.5% for Pb for the smallest counter. Three extrapolation techniques were tried. The first assumed the attenuation cross section was a linear function of the solid angles subtended by the transmission counters. The second method assumed that the difference between the attenuation cross section and the total cross section is due to small angle scattering and that dσ/dΩ is adequately represented by the expression for scattering from a totally absorbing disc, i. e.,

$$\sigma_T = \sigma_a(i) + \left(\frac{k\sigma_t}{4\pi}\right)^2 \int \left[\left\{ \frac{2J_1(kR\theta)}{kR\theta} \right\}^2 f_i(\theta) + \eta \right] d\Omega \quad (1)$$

where $\sigma_a(i)$ is the attenuation cross section and $f_i(\theta)$ is the geometrical response function of the ith transmission counter, R is the nuclear radius, and the η term takes into account inelastic scattering which is assumed isotropic over the small range of angles involved ($\theta < 0.75^o$). The third approach was to make a least squares fit to the data to a polynomial in the four-momentum transfer squared, t, i.e.,

$$\sigma_a(i) = \sigma \;+ a|t| + b|t|^2 + c|t|^3 \; . \quad (2)$$

* Work supported by the Office of Naval Research Contract NONR 1224 (23), the National Science Foundation Grant GP9428, and the U. S. Atomic Energy Commission.
‡ National Science Foundation Senior Foreign Scientist Fellow.
‡‡ Supported by a fellowship from the Institute of Science and Technology, University of Michigan, Ann. Arbor, Michigan 48104

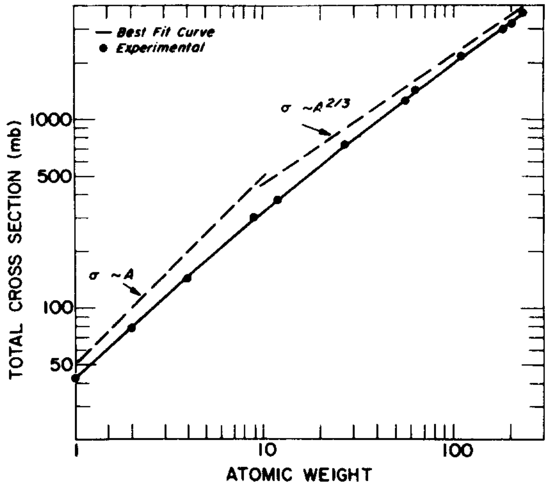

Fig. 1. Total cross section versus atomic weight.

The total cross section values yielded by these three extrapolation methods were averaged to obtain the final cross sections, and the spread among the methods, which was typically ±0.3%, was taken as a measure of the uncertainty in the extrapolation. In all cases this uncertainty was small compared with the statistical uncertainty of the data.

Fig. 1 is a plot of total cross sections versus atomic weight. The continuous line is a least squares fit to the data using a parametrization given by Sievers [2]; i.e.,

$$\sigma_t = 2\pi\left[R^2 - \tfrac{1}{2}x_0^2\{1 - (2R/x_0 + 1)\exp(-2R/x_0)\}\right], \quad (3)$$

where x_0 is the mean free path of a nucleon in nuclear material, and $R = a_0 A^{1/3}$. This equation results from assuming that the nuclear interaction is purely absorptive and that the partial wave amplitude appearing in the large l_{max} integral approximation for the scattering amplitude can be written as

$$a(b) = 1 - \exp\left[-2(R^2 - b^2)^{\frac{1}{2}}/x_0\right] , \quad (4)$$

where b is the impact parameter. The best fit values for a_0 and x_0 are $a_0 = 1.27 \pm 0.01$ fm and $x_0 = 3.0 \pm 0.2$ fm. This a_0 value agrees quite well with values obtained from electron scattering [3].

Fig. 2 shows the available nucleon-nucleus total cross section data above 1 GeV/c for C, Al, Cu and Pb. The early results of Atkinson et al. [5] and Pantuyev et al. [6] are inconsistent with the rest of the available data and have not been included.

Our results can best compared with the earlier results by means of the "shadowing" or multiple-scattering correction factor, $\delta(A)$ defined from

$$\sigma_{xA} = [(A-Z)\sigma_{xn} + Z\sigma_{xp}][1 - \delta(A)] , \quad (5)$$

where σ_{xn} and σ_{xp} are the nucleon-nucleon total

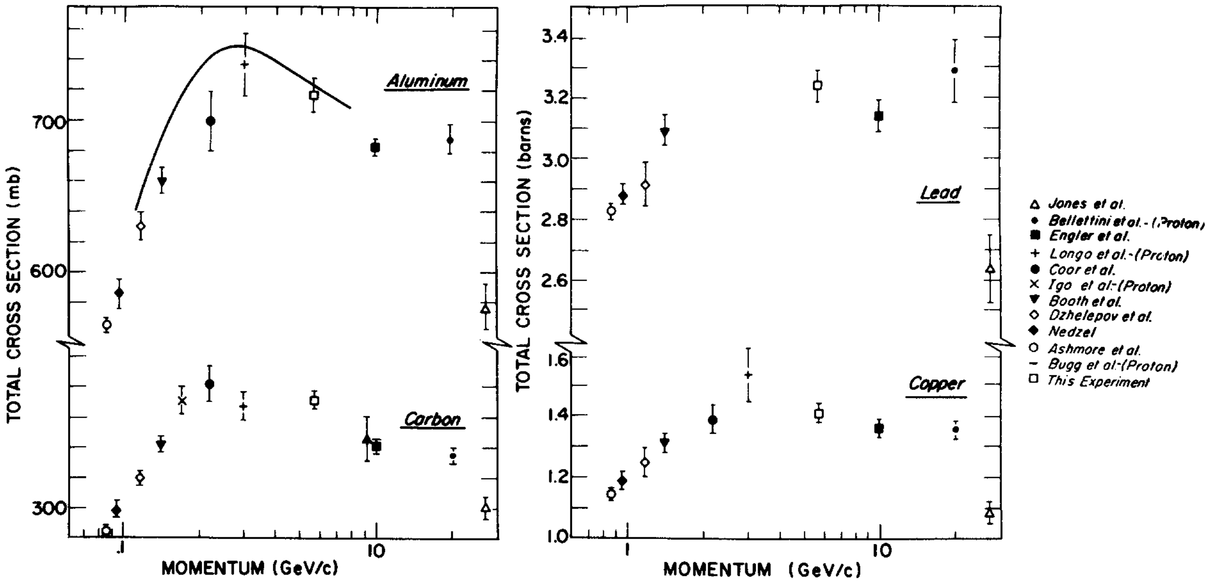

Fig. 2. Aluminium carbon, copper and lead total cross sections from this experiment and ref. 4.

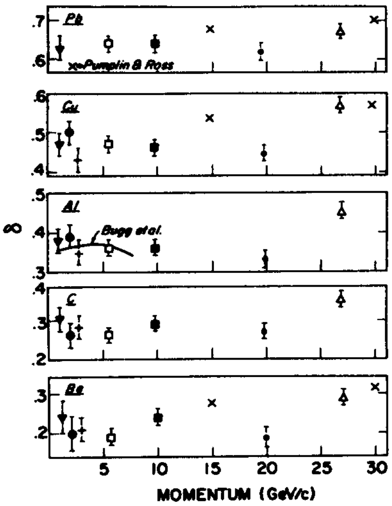

Fig. 3. δ(A) versus momentum for Be, C, Al, Cu and Pb. The data point symbols used in this figure are the same as those used in fig. 2.

cross sections, and $\sigma_{\chi A}$ is the nucleon-nucleus total cross section. This data are well represented by the empirical fit $\delta(A) = A^{0.26}$. Pumplin and Ross [7] have investigated the energy dependence of δ and conclude that above 5 to 10 GeV/c multiple-scattering effects associated with inelastic intermediate states of the nucleon produce a significant increase in the size of δ over that associated with purely elastic scattering. Fig. 3 shows the values of δ obtained from the nucleon-nucleon data presented in ref. 1. The values calculated by Pumplin and Ross are also included. If we assume that δ is constant below 10 GeV/c there is good agreement among the various experiments below 10 GeV/c. If we assume that δ increases above 10 GeV/c as predicted by Pumplin and Ross our results agree quite well with the 27 GeV/c results of Jones et al. However, if δ remains constant our results are in our results are in agreement with the 20 GeV/c results of Bellettini et al. More data above 10 GeV/c are needed to resolve this question.

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. E. F. Parker et al., Phys. Letters 31B (1970) 246.
2. P. Sievers, Externer Bericht 3/68-12, Institut für Experimentelle Kernphysik, Kernforschungszentrum, Karlsruhe, Karlsruhe (1968).
3. R. Herman and R. Hofstadter, High-energy electron scattering tables, (Stanford University Press, Stanford, Cal. 1960) p. 62.
4. V. P. Dzhelepov, V. I. Satarov and B. M. Golovin, Soviet Phys. JETP 2 (1956) 349.
N. E. Booth, G. W. Hutchinson and B. Ledley, Proc. Phys. Soc. (London) 71 (1958) 293.
D. V. Bugg, D. C. Salter, G. H. Stafford, R. F. George K. F. Riley and R. J. Tapper, Phys. Rev. 146 (1966) 980.
M. J. Longo and B. J. Moyer, Phys. Rev. 125 (1962) 701.
V. A. Nedzel, Phys. Rev. 94 (1954) 174.
A. Ashmore, R. G. Jarvis, D. S. Mather and S. K. Sen, Proc. Soc. (London) A70 (1957) 745.
T. Coor, D. A. Hill, W. F. Hornyak, L. W. Smith and G. Snow, Phys. Rev. 98 (1955) 1369.
J. Engler, K. Horn, J. König, F. Mönning, P. Schludecker, H. Schopper, P. Sievers, H. Ullrich and K. Runge, Phys. Letters 28B (1964) 64.
G. Bellettini, G. Cocconi, A. N. Diddens, E. Lillethun, G. Matthiae, J. P. Scanlon and A. M. Wetherell, Nucl. Phys. 79 (1965) 609.
L. W. Jones, M. J. Longo, J. R. O'Fallon and M. N. Kreisler, Phys. Letters 27B (1968) 328.
G. J. Igo, J. L. Friedes, H. Palevsky, R. Sutter, G. Bennet, W. D. Simpson, D. M. Corley and R. L. Stearns, Nucl. Phys. B3 (1967) 181.
5. J. H. Atkinson, W. N. Hess, V. Perez-Mendez and R. Wallace, Phys. Rev. 123 (1961) 1850.
6. V. S. Pantuyev and M. N. Khachaturyan, Soviet Phys., JETP 15 (1962) 626.
7. J. Pumplin and M. Ross, Phys. Rev. Letters 21 (1968) 1778.

* * * * *