0.56×10^{-3}. Finally, a fit has been obtained,[10] including the $\Sigma^-\to\Lambda e^-\bar{\nu}$ data of Barash et al.[7] which were not used in the earlier fits; this fit predicts 0.62×10^{-3} for the $\Xi^-\to\Lambda$ fraction, again using no input value.

The experimental branching fraction for $\Xi^-\to\Lambda e^-\bar{\nu}$ is therefore consistent with the Cabibbo theory and with data for other baryon leptonic decays.

Improved upper limits for other unusual decay modes of Ξ^- and Ξ^0 will be presented in a later paper along with a detailed analysis of the normal $\Xi\to\Lambda\pi$ decay.

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NEUTRON-PROTON AND NEUTRON-DEUTERON TOTAL CROSS SECTIONS FROM 14 TO 27 GeV/c*

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The first direct measurements of neutron-proton and neutron-deuteron total cross sections in the momentum range 14 to 27 GeV/c are presented. The np total cross section apparently becomes less than the pp total cross section in this momentum region. Our results show no evidence for a rapid vanishing of the Glauber screening correction as predicted by Abers et al. on the basis of Regge theory.

In this Letter we present the results of the first direct measurements of neutron total cross sections in the 14 to 27 GeV/c region. Previous measurements[1,2] in this momentum region have been obtained by means of a comparison of pd and pp cross sections with the use of the Glauber corrections.[3] Direct measurements of neutron cross sections through a good geometry attenuation experiment with a neutron beam affords an opportunity to check the validity of the Glauber correction in the nucleon-nucleon system, to obtain the cross sections without the uncertainties such a correction introduces, and to investigate more directly the momentum dependence of $\sigma_T(np)-\sigma_T(pp)$. The data presented here also extend to somewhat higher momenta than previous measurements.

The experiment was performed at the Brookhaven alternating-gradient synchrotron (AGS) following an experiment to measure np elastic-scattering differential cross sections. A neutral beam was taken off at an angle of 1° from a beryllium target in the circulating beam of the AGS. Charged particles were removed by sweeping magnets. The beam was collimated by a series of collimators; the defining collimator was a 2.5-cm aperture located 35 m from the AGS target. The last collimator was followed by a sweeping magnet. Gamma contamination in the neutron beam was reduced by means of lead converters in the beam ahead of the sweeping magnets with a total of five radiation lengths. When the beam entered the hydrogen target, it had a diameter of 3.2 cm, a maximum divergence of 0.3 mrad, and had little or no halo. Since the AGS target was effectively a point source, the edges of the beam were very sharply defined. With 5×10^{10} protons per pulse hitting the Be target, there were approximately 10^6 neutrons per pulse in the beam. The momentum spectrum of the neutrons as determined from the preliminary results of the *np* elastic scattering experiment in the same beam[4] is consistent with the spectrum of inelastic protons obtained in a similar charged beam by Anderson et al.[5] Contamination of the beam by antineutrons and neutral kaons was negligible at the energies studied.

Before entering the hydrogen target, the neutrons passed through a 1.6-mm anti counter to insure that the incoming particle was neutral. An anti counter before the neutron detector (Fig. 1) insured that the outgoing particle was also neutral. A 2.5-radiation-length converter following the target removed most of the gammas formed in inelastic events. The detector was located 28.2 m downstream from the center of the target. The neutron detector, shown schematically in Fig. 1, was an "ionization calorimeter" or "total absorption spectrometer" as is frequently used in cosmic-ray research.[6] The calorimeter worked as follows. The neutrons interacted in a 5-cm-thick piece of iron. In order to help insure that the neutron deposited most of its energy in the calorimeter, a pulse three times larger than that from a minimum ionizing particle was required from counter S_1 following the iron. Two counters S_2 and S_3, 7.0 cm and 12.1 cm in diameter, respectively, defined the solid angles subtended by the calorimeter. Coincidences with each of these counters were scaled separately to allow the measured cross sections to be extrapolated to "zero solid angle". Following these counters were steel slabs interspersed with scintillation counters (T_1 through T_5). These counters thus sampled the ionization produced by the neutron-induced cascade in the steel. The dimensions of the calorimeter were such that essentially all of the energy of the incident neutron was contained. The voltages on the counters T_1 through T_5 were adjusted to give equal pulse heights when single minimum ionizing particles passed through them. The pulses from these counters were added, and the amplitude of the summed pulse was roughly proportional to the neutron momentum. A 28-GeV/*c* neutron gave a pulse ≈40 times that from a muon traversing the detector. The discriminator threshold was adjusted so that most of the counts were from neutrons near the high end of the momentum spectrum. The effective momentum resolution of the spectrometer was greatly improved by taking advantage of the sharp cutoff on the high end of the spectrum just below the proton momentum in the AGS.

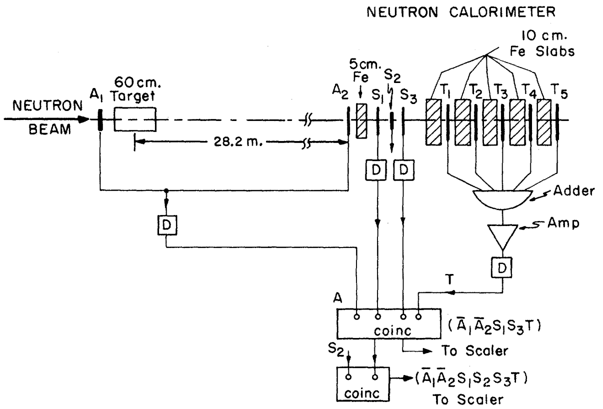

FIG. 1. Schematic representation of the experimental apparatus.

The momentum resolution of the detector was studied by setting the discriminator threshold and then varying the AGS beam momentum. The effective momentum response of the detector could then be unfolded from the observed counting rate versus AGS beam momentum after making reasonable assumptions concerning the shape of the neutron momentum spectrum. The estimated momentum response for a typical point is shown in Fig. 2. Because of uncertainties in the neutron spectrum and the shape of the detector response, the mean neutron momentum is uncertain by ±0.5 GeV/*c*.

The neutron flux was monitored by two independent counter telescopes, consisting of an anti counter followed by a block of polyethylene and then a two-fold telescope. These were placed in the neutron beam upstream of the hydrogen target and both tracked well during the course of the experiment.

The cross sections were calculated from the measured ratios of neutron counts to monitor

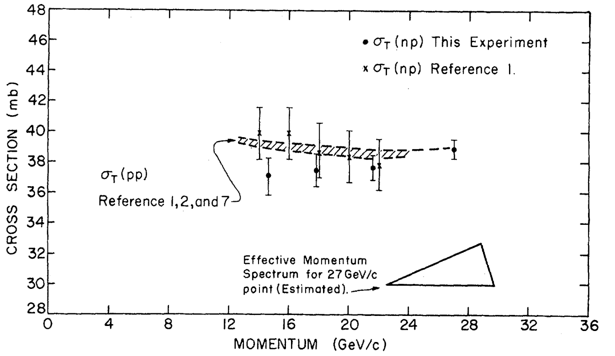

FIG. 2. Neutron-proton total cross sections. The data of Ref. 1 have been lowered by 0.34 mb. The cross-hatched area shows spread in the data points in the *pp* cross sections. The inset shows our estimated effective momentum spectrum for a typical point. This momentum spread is comparable in width with that from *pd*-*pp* subtraction experiments.

counts with the target empty and full using the formula

$$\sigma = \frac{1}{nx} \ln \frac{(N/M)_{\text{empty}}}{(N/M)_{\text{full}}},$$

where n is the number of scatterers per unit length and x is the length of the target. The length of the target was found to be 62.28 ± 0.16 cm. The density of the liquid in the target depends slightly on the boiling temperature. This was determined by measuring the pressures in the reservoir. In this manner, the densities of the liquids during data runs was found to be 0.0691 ± 0.0005 g/cm^3 for hydrogen and 0.168 ± 0.002 g/cm^3 for deuterium. In addition, n had to be corrected for the densities of the residual gases in the empty target which were found to be 0.00172 ± 0.0001 g/cm^3 for hydrogen and 0.0015 ± 0.0001 g/cm^3 for deuterium.

Measurements were taken with the AGS proton beam momentum at 29.4, 25.9, 22.4, and 18.9 GeV/c. In addition, the AGS ran at 14.9 GeV/c so that the momentum resolution at 18.9 GeV/c could be ascertained. At each momentum, from 6 to 45 measurements of the cross section were made, depending on running time available. Each measurement generally consisted of a cycle of two runs with target empty, four runs with target full, followed by two runs with target empty. The results of all measurements at each momentum were averaged.

The correction to the measured cross sections due to the finite solid angle subtended by the neutron detector was quite small and was made by extrapolating the cross sections measured with counters S_2 and S_3 linearly to zero solid angle. The corrections to the cross sections measured with the smaller counter were typically 0.20 ± 0.05 mb for hydrogen and 0.60 ± 0.05 mb for deuterium. It was also found that the cross sections measured were slightly dependent on the flux of neutrons in the beam because of pile-up effects in the neutron detector. Typically, a factor of two increase in the neutron flux from $\approx 10^5$ neutrons per pulse to 2×10^5 neutrons per pulse caused a 2% change in the apparent measured cross sections. This effect was corrected for experimentally by running at various fluxes and extrapolating the cross sections to zero flux. The quoted errors reflect the maximum uncertainty in this correction and the uncertainty in the solid angle correction, as well as statistical uncertainties.

In Fig. 2 and Table I we present our results for $\sigma_T(np)$ and $\sigma_T(nd)$, as well as some previous results obtained with proton beams.[1,2,7] The data of Galbraith et al.[1] for $\sigma_T(np)$ have been lowered by 0.34 mb since in applying the Glauber correction to their data, they neglected a contribution due to the real part of the forward-scattering amplitude. Data now available[7,8] show $\alpha_{np} \approx \alpha_{pp} \approx -0.26$ which would decrease the Glauber correction by ≈ 0.34 mb.

We make the following observations about the data:

(1) The *np* cross sections below 22 GeV/c are generally consistent with those measured using a *pd*-*pp* subtraction with the Glauber correction.

(2) We see no evidence for a rapid vanishing of the Glauber screening correction at these energies, as predicted by Abers et al. on the basis of Regge theory.[9] At 3 GeV/c the experimentally determined screening correction, $\sigma_T(pp) + \sigma_T(np) - \sigma_T(pd)$, is 1.3 ± 1.4 mb if we use $\sigma_T(pp)$ and $\sigma_T(pd)$ from Bugg et al.[10] and $\sigma_T(np)$ from Palevsky et al.[11] At 6.5 GeV/c the screening correction is 3.0 ± 1.7 mb.[10,12] Using our results together with those of Foley

Table I. Neutron total cross sections.

Momentum (GeV/c)	$\sigma_T(np)$ (mb)	$\sigma_T(nd)$ (mb)
14.6	37.1 ± 1.2	72.2 ± 1.5
17.8	37.5 ± 1.2	
21.6	37.7 ± 0.8	
27.0	38.9 ± 0.6	69.7 ± 0.7

et al.[7] and Galbraith et al.,[1] we obtain a correction of 2.5 ± 1.8 mb at 14.6 GeV/c, 3.9 ± 1.7 mb at 17.8 GeV/c, and 5.0 ± 1.5 mb at 21.6 GeV/c. Similarly, we can evaluate $\sigma_T(pp)+\sigma_T(np)-\sigma_T(nd)$ from our data and those of Ref. 7. At 14.6 GeV/c we obtain 4.3 ± 1.9 mb and at 27.0 GeV/c, 8.1 ± 0.9 mb. The data are therefore more consistent with a rising screening correction, and even allowing for large systematic errors, a falloff faster than about $E_{\text{lab}}^{-1/2}$ seems to be excluded.[13]

(3) Our result for $\sigma_T(nd)$ at 14.6 GeV/c is completely consistent with the result of Galbraith et al.[1] for $\sigma_T(pd)$ at 14 GeV/c (74.0 ± 1.3 mb) as expected from charge symmetry. This also shows $\sigma_T(nn)$ is equal to $\sigma_T(pp)$ within errors.

(4) The np total cross section apparently becomes less than the pp total cross section in this energy region. Although the errors are sizeable, all three of our low-energy points are below the pp cross sections. In view of the fact that our results for the deuteron measurements are consistent with $\sigma_T(pd)$ from Galbraith et al.,[1] it does not appear that the difference can be due to systematic errors. It should be noted that the corrected data of Galbraith et al.[1] for the $\sigma_T(np)$ agree with the results within the uncertainty of their Glauber correction (1 to 2 mb).

The highest energy point (our most carefully measured point) seems to indicate that the cross sections converge again near 27 GeV/c. As $\sigma_T(np)-\sigma_T(pp)$ is expected to go to zero at asymptotic energies, these results would indicate that this energy region is not yet asymptotic.

We would like to thank the staff at the AGS for all their assistance during this run. In particular, A. Maschke is to be thanked for his help in operating the machine at lower energies. We would also like to thank B. Gibbard, J. Cox, S. Wilson, O. Haas, W. Toner, and G. DeMeester for their help with the computer.

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