TOTAL CROSS-SECTIONS FOR n-p AND n-d SCATTERING AT 10 GeV/*c* NEUTRON MOMENTUM

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The total neutron cross-sections were measured with high precision for hydrogen and deuterium. At an average neutron momentum of 10 GeV/*c* we obtained $\sigma_T(np) = 39.5 \pm 0.5$ mb and $\sigma_T(nd) = 73.3 \pm 1.1$ mb. These values are in excellent agreement with p-p and p-d total cross sections. No energy dependence was found for n-p cross section between 4 and 10 GeV/*c*.

The fundamental nucleon-nucleon interaction can best be studied by p-p and n-p scattering.

Most of the information for neutron-proton total cross-sections has been obtained in the past from (pd) scattering by subtracting the (pp) contribution. However, in this procedure, screening corrections which have been calculated by Glauber [1] and by Harrington [2] have to be applied, and these introduce an element of uncertainty. These data indicate that the (np) total cross-section is higher than the (pp) cross-section in the energy range between 8 and 20 GeV. Recent measurements of neutron-proton total cross-sections at various neutron momenta between 14 and 27 GeV/*c* have been reported by Kreisler et al. [3]. These data show (np) cross-sections which are lower than the corresponding (pp) cross-sections at 14 GeV/*c* [4,5], and are then rising slowly to the corresponding (pp) value at about 27 GeV/*c*.

To solve this discrepancy the (np) total cross-section is determined in this experiment absolutely for a mean neutron momentum of 10 GeV/*c* with high precision. In addition, the energy dependence was measured with lower accuracy. The n-d total cross section was also measured at an average neutron momentum of 10 GeV/*c*. From a comparison with p-d data information on the screening correction can be obtained.

The measurements were carried out during the tests for a neutron-proton elastic scattering experiment at the CERN Proton Synchrotron. A neutron beam was installed under an angle of -2.7° with respect to the tangent at the internal Be target. The beam was constructed of a series of collimators and confined to a rectangular shape by the defining collimator at a distance of 29.5 m from the internal target. The aperture of this collimator was 12.94 mm horizontally by 28.42 mm vertically at the above distance, and it was tapered so that the walls aimed at the target position. The total number of neutrons was 30 000 per burst of 5×10^{11} protons. Gamma rays were attenuated very effectively by the vacuum pipe of the machine itself, and by an additional lead filter of 2.5 cm. Charged particles were removed by a sweeping magnet of 1.5 Wb/m bending strength. Contamination of neutral kaons was calculated to be $\sim 5\%$, in agreement with a survey done in a previous experiment in a similar geometric location [6]. A counter telescope looking at the internal target [7] was used as beam monitor which proved to be reliable.

Much effort was spent on performing the measurements with good geometry, including beam definition, and on correcting for small-angle scattering. Since the experiment was done on a parasitic basis, sufficient beam-time was available not only for obtaining good statistical accuracy but also for eliminating systematic errors. On the other hand, the primary proton energy was chosen by the main user and could not be changed deliberately.

The experimental set-up is shown schematically in fig. 1. The neutrons were converted by an

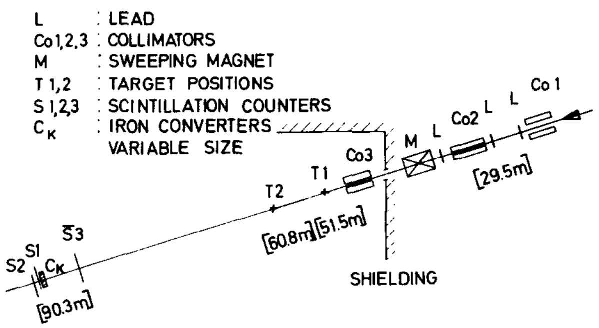

Fig. 1. Layout of the experimental arrangement at the CERN Proton Synchrotron. The distance from PS internal Be target are given in square brackets below the beam line.

Table 1a.
Relative (np) total cross-sections as obtained with the low intensity beam and different trigger conditions of the neutron detector

$\Delta\sigma_T/\sigma_T$ (4.3 - 6.5 GeV/c)	= (4.0 ± 6.0)%
$\Delta\sigma_T/\sigma_T$ (6.5 - 10.0 GeV/c)	= (1.8 ± 3.5)%

Table 1b.
(np) total cross-sections as obtained with the low intensity beam (systematic errors included)

Momentum [GeV/c]	T[mb]
4.3	40.4 ± 1.9
6.5	38.7 ± 1.5

iron slab of variable size (C1, ... , C5) and the shower detected by two scintillation counters, of 4 mm thickness, in coincidence. The sensitive area of the scintillation counters (S1, S2) could be varied and matched to the size of the iron converter by changing the amount of overlap between the two. The scintillation counter S3, placed 1.5 m upstream, served as an anticounter with which to remove charged particles from the scattered beam. No other anticounter was installed ahead of the targets, because it was found that more charged particles were produced with it than were present without it ($\leqslant$ 0.5%). The liquid hydrogen target (position T2) was 50.1 ± ± 0.3 cm long and 8.0 cm in diameter.

In all measurements the PS energy was 19.3 GeV. The neutron spectrum was determined independently with a total absorption spectrometer consisting of 56 cm Fe interspersed with 20 scintillator plates. The energy resolution was found to be ~ 45%. The neutron spectrum thus determined agreed with calculations for protons based on a statistical model by Hagedorn and Ranft [8].

To extend the measurements to lower energies, a separate experiment was made when only 3% of the beam intensity was available. During the acceleration cycle of the PS, the internal Be target was flipped twice, producing short bursts of 20 msec. The corresponding mean neutron momenta were 4.3 and 6.5 GeV/c. Since the measuring time was rather long, the results are subject to larger systematic uncertainties which, however, are included in the error.

A second method consisted of changing the trigger condition of the total absorption counter to a sixfold coincidence. According to the calibration, the threshold of the counter was then moved up to about 3 GeV/c neutrons, and it generally favoured neutrons of higher energy. The results for the different trigger conditions are given in table 1b. The results show no change of the total cross-section down to neutron momenta of 4 GeV/c (see table 1a).

For the main measurements with the full beam no statistically significant change was found in the ratio N_{full}/N_{empty} for different neutron converters. To corroborate this, a differential measurement was made with a small pencil-shaped (0.5 × 10.0 cm^2 area) scintillation counter with a 2 cm thick iron converter of the same shape in front of it. Within the statistical accuracy and the limitation of the reproducibility of the position of the counter, no significant contribution of small-angle scattered neutrons to the detected neutrons could be found.

From these measurements a total cross-section of (39.5 ± 0.5) mb was obtained for 10 GeV/c neutrons. The error includes systematic uncertainties. This value is in excellent agreement with results for the p-p total cross-section, which at the same momentum is (39.8 ± 0.4) mb [4,5]. Hence there is no indication for a cross-over of the two cross-sections (fig. 2).

Using the optical theoren $(\mathrm{d}\sigma/\mathrm{d}t)_{t=0} = (\sigma_T^2/16\pi)(1+\alpha^2)$ the total cross-section measurement yield information on the two isospin amplitudes for forward scattering. Assuming that the ratio α of real to imaginary part is approximately the same for p-p and n-p scattering the equality $\sigma_T^{np} \approx \sigma_T^{pp}$ implies $(\mathrm{d}\sigma/\mathrm{d}t)_{T=0}^{np} = (\mathrm{d}\sigma/\mathrm{d}t)_{t=0}^{pp}$. From the symmetries of the various amplitudes one has [12]

$$(\mathrm{d}\sigma/\mathrm{d}t)_{\theta=0}^{I=0} = 2[(\mathrm{d}\sigma/\mathrm{d}t)_{\theta=0}^{np} + (\mathrm{d}\sigma/\mathrm{d}t)_{\theta=\pi}^{np}] - (\mathrm{d}\sigma/\mathrm{d}t)_{\theta=0}^{pp}$$

$$(\mathrm{d}\sigma/\mathrm{d}t)_{\theta=0}^{I=1} = (\mathrm{d}\sigma/\mathrm{d}t)_{\theta=0}^{pp} .$$

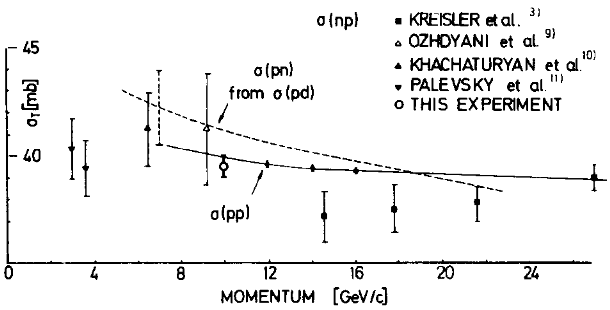

Fig. 2. (pp) and (np) total cross-sections at various incident momenta. The dashed line was fitted to (pn) cross-sections calculated from (pd) data taken from ref. 4. The solid line shows the results from (pp) measurements as taken from ref. 5. The accuracy of these data is represented by some typical errors. All other points are taken from direct (np) measurements.

Since $(d\sigma/dt)^{np}_{\theta=\pi} \lesssim \frac{1}{30}(d\sigma/dt)^{np}_{\theta=0}$ one infers from the measured total cross-section that the forward scattering cross-sections for isospin 0 and 1 differ less than about 2%.

For the n-d total cross-section a value (73.3 ± 1.1) mb was found at 10 GeV/c. This again is in very good agreement with the p-d cross section [4] (75.8 ± 1.3) mb.

From these values the screening correction can be evaluated from

$$\delta\sigma_{corr} = \sigma_T(pp) + \sigma_T(np) - \begin{cases} \sigma_T(nd) \\ \sigma_T(pd) \end{cases} .$$

One obtains at 10 GeV/c $\delta\sigma_{corr}$ = (6.0 ± 1.4) mb and (3.5 ± 1.5) mb for the (nd) and (pd) data, respectively. This correction is of the same magnitude as those found at other momenta [13].

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