and calibrating the split-pole spectrograph.

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HIGH-PRECISION MEASUREMENT OF THE TOTAL n-p SCATTERING CROSS SECTION IN THE ENERGY RANGE 0.7-32 MeV

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The total n-p cross section has been measured using the neutron time-of-flight spectrometer at the Karlsruhe isochronous cyclotron. The measurements span the energy range from 0.7 to 32 MeV with statistical accuracy which varies from 0.2 to 1.0% and an energy resolution of 0.7 keV at 0.7 MeV and 200 keV at 30 MeV. No evidence was found for the recently reported oscillations in the total n-p scattering cross section.

It was recently reported[1] that the total n-p scattering cross section shows small but statistically significant oscillations as a function of energy. These oscillations were attributed to the manifestation of the charge-exchange process in neutron-proton scattering.[2] In this paper we describe a new precision measurement of the total n-p cross section performed with the high-resolution time-of-flight spectrometer[3] at the Karlsruhe isochronous cyclotron (KIC). The objectives of this investigation were to search for the reported structure and to provide additional high-precision data in the region 1-30 MeV.

The total n-p cross section was determined by transmission measurements using high-purity polyethylene and H_2O samples. The polyethylene samples were provided by Badische Anilin & Soda Fabrik, Ludwigshafen. Graphite samples with the same number of carbon atoms per cm^2 were placed in the open beam position to eliminate the effects of neutron interactions with the carbon. The oxygen cross section previously measured with our spectrometer was subtracted from the observed H_2O cross section. Normalization difficulties for the sample-in and sample-out measurements were eliminated by alternating the sample in the neutron beam on a 250-sec cycle. The polyethylene samples had thicknesses of 1.2167 and 0.192 95 hydrogen atoms/b and the H_2O sample had a thickness of 0.647 06 atoms/b. The hydrogen concentrations were calculated from measured densities and carbon-to-hydrogen ratios. The ratios were determined by chemical analysis. The flight path was 57.399 m and the neutron detector was a proton-recoil liquid scintillator NE 213, 9 cm diam and 1 cm thick. The time-of-flight spectrum was accumulated in 8000 data channels of a LABEN UC-KB digital time analyzer. The channel width was ~1 nsec, which, folded with a 1.5-nsec neutron burst and 1.8-nsec overall electronic resolution, was equivalent to an energy resolution of 0.72 keV at 0.7 MeV and 200 keV at 30 MeV. Since the cross section was found to be smoothly varying with energy, some channel grouping was employed after the measurements to further improve counting statistics. The LABEN time analyzer can accept up to four counts in the 8-μsec clock run-down period without counting loss. Residual dead-time effects were accouted for in the final cross-section calculation.

The total n-p scattering cross section from 0.7

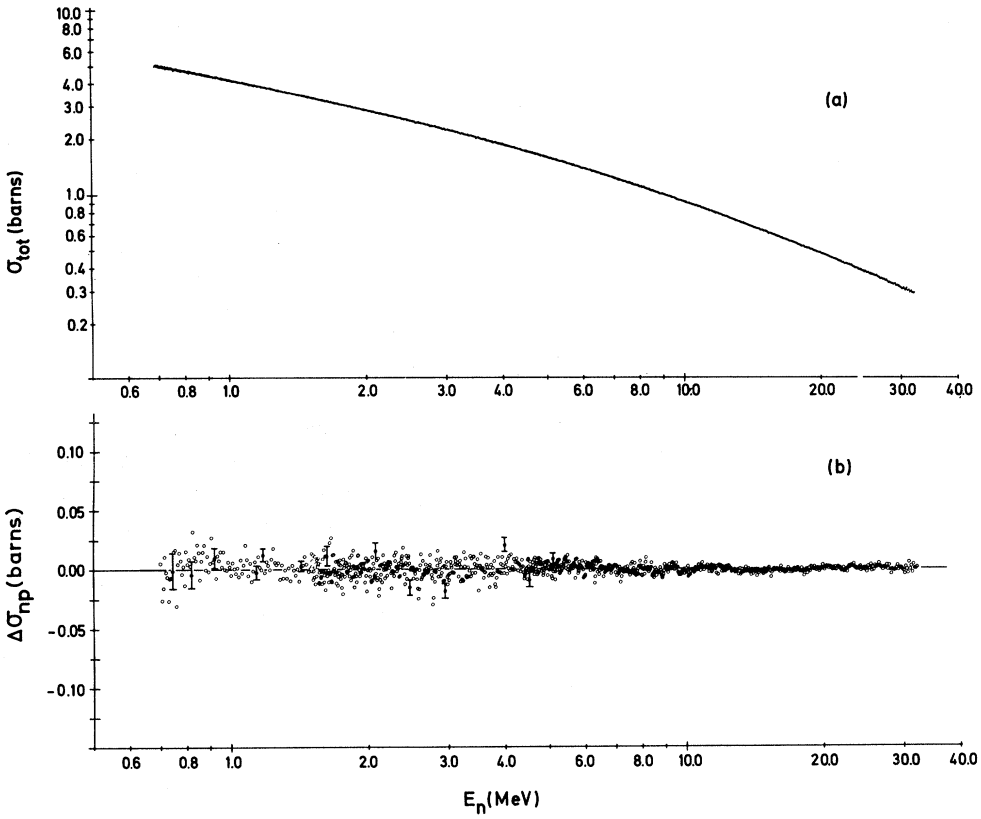

FIG. 1. (a) The n-p cross section in the energy range 0.7-32 MeV. (b) The difference $\Delta\sigma_{np}$ between experimental and theoretical n-p cross sections. The expression for σ_{np}(theo) was derived by fitting the Gammel formula to our data in the entire energy range shown. Error bars representing statistical uncertainties are shown on some of the points.

to 32 MeV is shown in Fig. 1. Between 4.5 and 32 MeV the data are shown with two-channel grouping of the original spectra; from 4.5 to 1.5 MeV and 1.5 to 0.7 MeV groups of four and 16 channels were taken, respectively. The total uncertainty in the absolute cross section is less than 2%. This value includes estimates of errors in the dead-time correction ($\leq$1.5%), uncertainty in the carbon compensation or oxygen cross-section subtraction (0.2-1.0%), and uncertainty in the various sample thicknesses (0.2%). The latter two uncertainties are small because independent measurements were made with two polyethylene samples and one H_2O sample. A systematic study of the energy dependence of the n-p total cross section was made by calculating the difference $\sigma_{np}(\text{expt})-\sigma_{np}(\text{theo})=\Delta\sigma_{np}$.

This quantity is shown in Fig. 1(b). The expression for σ_{np}(theo) was derived by least-squares fitting of the five-parameter equation given by Gammel[4] to our data. No periodic oscillations in the energy dependence of σ_{np} are apparent in Fig. 1, although Hrehuss and Czibók have reported oscillations of 50-150 mb in the energy range 0.8-5.2 MeV. The magnitude of $\Delta\sigma_{np}$ in Fig. 1(b) is typically $\pm$5 mb and all differences from zero appear to be statistical. We have made a statistical analysis of the deviations of $\Delta\sigma_{np}$ from zero. The analysis was a significance or t test of unpaired means. We have assumed that oscillations in the cross section are described by the term $K\sin^2(\frac{1}{2}\pi\alpha/E_n^{1/2})$, with $\alpha = 24.6$ MeV$^{1/2}$ as given by Hrehuss and Czibók. This equation predicts 25 fluctuations between 0.7 and 32 MeV. The amplitudes of the presumed oscillations in $\Delta\sigma_{np}$ have been represented by an average over the energy range ΔE_n, where the term $K\sin^2(\frac{1}{2}\pi\alpha/E_n^{1/2})$ exceeds 90% of its extreme values. The t test was applied to the deviations of these mean values from the average value of $\Delta\sigma_{np}$ over one full cycle. The t values and corresponding degrees of freedom are given in Table I. Clearly none of the deviations approach the 95% confidence level ($t\approx 2$). At a confidence level of 95% this analysis also yields values for the minimum detectable fluctuation ampli-

Table I. Statistical analysis of the total n-p cross section. The first column lists the energies of the oscillation peaks predicted by Hrehuss and Czibók, with $\alpha = 24.6$ MeV$^{1/2}$; K_{min} is the smallest oscillation detectable at the 95% confidence limit in our data. The third column contains the actual t values and corresponding degrees of freedom obtained from our analysis.

PREDICTED OSCILLATION E_n(MeV)		K_{min}(mb) 95 % CONFIDENCE	t-VALUE	NUMBER DEGREES FREEDOM
MAX.	MIN.			
	17.222	0.60	0.31	64
12.653		0.81	1.22	74
	9.687	1.24	0.39	59
7.654		1.35	1.30	67
	6.200	2.02	0.61	50
	4.305	3.11	0.30	37
3.699		3.64	0.81	32
	3.163	4.12	0.75	33
2.756		5.59	0.87	27
	2.422	4.69	1.33	27
2.145		5.10	0.58	26
	1.914	3.97	0.15	30
1.717		4.40	0.30	35
	1.550	4.72	0.46	30
1.406		4.96	0.66	35
	1.281	6.44	0.87	31
1.172		8.46	0.68	26
	1.076	7.86	0.90	30
0.992		9.40	0.99	31
	0.917	10.50	0.40	29
0.850		11.20	0.79	39
	0.791	15.50	0.45	30
0.737		17.20	0.60	32

tude K_{min} allowed by the statistics of our data. These values range from 0.6 mb at 17 MeV to 17 mb at 0.7 MeV and are about $\frac{1}{10}$ the size of the predicted oscillations. Therefore, at an energy of 17 MeV there is only a 5% probability that a peak 4.7 MeV wide has a peak amplitude higher than 0.6 mb.

We conclude that our data show no evidence for oscillations in the energy dependence of the n-p total cross section between 0.7 and 32 MeV.[5] With our counting statistics and energy resolution we should easily have observed fluctuations with amplitudes as small as 0.5% of the smoothly varying cross section.

We believe that the absolute cross section reported in this work is accurate within less than 2%. Our data compare very favorably with the recommended n-p scattering cross section[6] above 1.0 MeV. In the energy range 0.7-1.0 MeV a small but significant difference of about 2% exists between our data and the recommended curve. Our fitted curve is 100 mb lower at 0.7 MeV and this difference decreases to 1.0 MeV. We note however that below 1.0 MeV there have been only a few data points on which to base a recommended curve.

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THREE-FLUID HYDRODYNAMICAL MODEL AND THE PROTON DISTRIBUTION IN ^{208}Pb†

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A three-fluid hydrodynamical model for nuclei is proposed and it is shown that the observed rise in proton density near the surface of ^{208}Pb can be accounted for in this model.

Hofstadter[1] recently reported the proton distribution required to fit the electron-scattering data of ^{208}Pb. Assuming the modified Fermi distribution

$$\rho_p(r) = \rho_{p0}[1 + w(r/a)^2]\{1 + \exp[(r-a)/a]\}^{-1}, \quad (1)$$

he found $w = 0.32$ to give the best fit with the ex-