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MEASUREMENT, WITH A FREE NEUTRON BEAM, OF ABSOLUTE NEUTRON-PROTON
FORWARD ELASTIC SCATTERING DIFFERENTIAL CROSS SECTION AT
INTERMEDIATE ENERGIES

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Abstract :

The differential cross section in free np forward elastic scattering has been measured for incident neutron energies of 378, 481, 582, 683, 784, 884 and 1085 MeV and for momentum transfer $0.01 < |t| < 0.08$ (GeV/c)². The experiment used a recoil detector ionization chamber which served at the same time as a gas target. Special care has been taken to obtain a precise absolute normalization.

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The study of the elementary proton-proton interaction at intermediate energies, rather well known now after the extensive measurements of spin observables¹ these last years, has brought very interesting results, especially through Phase-Shift Analyses (P.S.A.)²⁻⁴ which have shown resonance-like behavior for the 3F_3 and 1D_2 waves in elastic scattering. It has often been suggested⁵ that this behavior is determined by the excitation of the Δ_{33} resonance which largely dominates the proton-proton interaction from 400 to 800 MeV. The situation is different for the neutron-proton interaction, which is isospin-mixed I=0,1 instead of I=1 only for p-p. Indeed, for the I=0 part, the excitation of the Δ is forbidden by isospin conservation. This means that other features could emerge in this I=0 component of the nucleon-nucleon interaction, while being invisible in the Δ -dominated I=1 p-p channel. It would thus be of great interest to undertake a detailed study of the n-p interaction in this energy domain, and also at higher energies, where the excitation of the I=1/2 N^{*} resonances is expected to play a role in both the I=0 and I=1 components of the N-N interaction.

Unfortunately, the experimental situation is much worse for the n-p interaction than for the p-p case. Data are scarce: the spin-averaged total cross section σ_t is known, but, for elastic scattering, the differential cross-section and analyzing power are poorly known (especially at small transfers) and very few spin observables have been measured. For inelastic channels, only a very limited set of data is available. Moreover, existing experiments have often been done by quasi-free scattering of neutrons bound inside a deuteron (beam or target) instead of using a free neutron beam. We have measured free $\bar{n}$ -p elastic differential cross sections and analyzing powers at small transfer, where, it must be noted, there was no previous data. Analyzing powers have already been published⁶. We present here cross sections

at incident energies $T_n = 378, 481, 582, 683, 784, 884, \text{ and } 1085 \text{ MeV}$. In the framework of the physical ideas explained above, we did this experiment to provide data for P.S.A.. It must be noted that our data are also essential to determine the free n-p amplitude, which is an important input in any microscopic calculation of nuclear reactions.

The experiment was performed at the SATURNE synchrotron at Saclay. The incident neutron beam was obtained by break-up of deuterons⁷ on a 20 cm thick Be target. This leads to a neutron energy width $\sigma = 25$ to 50 MeV between 378 and 1085 MeV. The beam was collimated in such a way that its diameter at the target did not exceed 2 cm. We used an intensity of about 10^5 neutrons/burst, with a frequency ranging from 0.7 burst/s at 378 MeV to 0.25 burst/s at 1085 MeV. In Fig. 1, which shows a schematic picture of the apparatus, one can see that the intensity of the beam was monitored by means of a double left-right telescope of plastic scintillators. To obtain the absolute cross sections presented here, we had to calibrate this monitor carefully. Not having the possibility with our apparatus to measure the charge exchange reaction $p(n,p)n$, which is one way⁷ to calibrate a neutron beam, we have used an original method. Having demonstrated that nuclear differential cross sections for n-⁴He and p-⁴He can be considered as equal within 1-2 percent in the range of small transfers⁸, we have used our detector IKAR to measure relative n-⁴He elastic scattering cross sections with our uncalibrated monitor. The comparison with the previously measured absolute p-⁴He elastic scattering cross sections⁹ has thus given an absolute calibration of our device.

Let us briefly recall here the principle of the experiment, of which a complete description will be given elsewhere. The chamber IKAR¹⁰ is filled with CH₄ gas at 14.2 atm, and serves as both target (hydrogen) and detector.

(For the monitor calibration measurement, He gas replaces CH₄.) IKAR has been used many times previously associated with an external trigger, for example in the measurement of p-p elastic differential cross sections¹¹. It is a ionization chamber with a cathode, a grounded grid and, for this experiment, five concentric anodes set perpendicular to the beam direction. For elastic scattering at small transfers, recoil protons are emitted at slightly less than 90°, and thus almost parallel to the anode plane. In the volume between the cathode and the grid, electrons created along the proton track migrate towards the grid under the action of an electric field parallel to the beam direction, and are collected by the anodes. The anode signals thus appear only after the electrons have drifted past the grid. The cathode signal appears immediately by induction and is used as a trigger, this auto-triggering mode of operation of IKAR being used for the first time. The time difference between the inner anode and cathode signals (8 μ s maximum) permits us to determine the Z-coordinate (parallel to the beam) of the interaction vertex in the grid-cathode space. Cuts are placed to eliminate tracks which are very close to either the grid (the signal induced on the cathode is too small) or the cathode (the recoil track can pass through the cathode and leave the active region). This eliminates dependence of the effective target thickness on recoil angle. The small differences between the times of the anodes are related to the recoil angle of the proton. For recoil protons which stop inside the active volume, the sum S of the amplitudes of the corresponding anode signals is related to the recoil energy T_r by the equation $T_r = E_0 + k \cdot S$. The (small) pedestal energy E_0 is due to the usual physical effect of quenching of the ionization occurring at the end of the recoil proton track, just before it stops. E_0 has been measured at LNPI (Gatchina) in a special experiment of p-p elastic scattering where both

forward and recoil protons were detected. The coefficient k is determined from range-energy tables using information from recoil protons which stop at the limits between two anodes. Protons of energy greater than 15 Mev leave the chamber, so we compute their total energy T_r from their energy loss in the gas. Correlations between the amplitudes of the anode signals allow us to know whether the proton stopped inside the chamber or not, and permit identification of the recoiling particle as a proton. Correlations between amplitudes and times (i.e. between T_r and θ_r) allow separation of free elastic scattering events from the quasi-free scattering off protons in CH_4 . The forward neutron detectors visible in fig. 1, needed for the analyzing power measurements⁶, were not used in obtaining the results presented here.

Having obtained, for each good elastic scattering event, the transfer $-t$ by the formula (valid for elastic scattering) $-t = 2mT_r$, we can extract the absolute differential cross-section. Our results are presented in Fig. 2, where the (small) errors bars are statistical only. The other main sources of error are the background subtraction and monitor calibration. The uncertainty in background subtraction causes a 2.5% uncertainty in the measured n-p yields. The absolute monitor calibration, as stated above, is done by comparing n-⁴He yields with previously measured⁹ absolute p-⁴He cross sections. The experimental differences between the two measurements have been well studied and are not expected to introduce large uncertainties. We estimate the uncertainty in beam normalization to be between 2.5% and 6%, depending on energy. Including other small uncertainties in the determination of efficiencies, target thickness, etc., we obtain overall normalization uncertainties of the cross-sections presented in Fig. 2 of 4 to 7 percent, depending on the energy.

In Fig. 2, we also present the results of the Phase-Shift Analyses made by Arndt² and Bystricky et al.³ before the inclusion of our normalized data. For Bystricky et al., a preliminary unnormalized version of our data was included in the fit, which somewhat constrains the slope. In these analyses, the normalization of $d\sigma/dt$ is mainly governed by the size of the n-p total cross-section σ_t , which is well-known. This means that the agreement of our data with the P.S.A. predictions indicates a good experimental consistency between our normalization and those of the experiments giving σ_t . It must be noted, however, that our results at 378 Mev are higher than those predicted by more than the experimental error.

In high energy physics, the Regge pole theory¹⁴ predicts an exponential behavior of the elastic p-p cross section angular distribution at small transfers. Experimental results show that it is still true at our energies, and one usually parametrizes the cross section using the slope parameter b of the diffraction cone:

$$d\sigma/dt \propto e^{-bt}$$

For the present experiment, fits for b have been done for $0.01 < |t| < 0.08$ (Gev/c)². For fits made with different t ranges, b remains approximately the same, provided that the range is not so small that the fit is dominated by experimental fluctuations. Fig. 3 shows the variation with incident neutron energy of b for the differential cross-sections presented in Fig. 2, together with the corresponding variation of the same quantity for the p-p system.

It is interesting to see in Fig. 3 that the slope parameter b does not differ significantly in the p-p and n-p cases. This means that the I=0 component, which makes the difference between the p-p and n-p interactions, is negligible, or has the same behavior as the I=1 component for this

observable. However, more experimental studies are needed, especially at energies around 1 GeV or above, where the excitation of N^* resonances becomes possible, and can contribute in both $I=0$ and $I=1$ terms.

Further investigations on the inclusion of our data in P.S.A. are in progress.

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References

1. F. Lehar, J. Phys. Soc. Jpn. **55** Suppl., 284 (1986)
2. R.A. Arndt et al., Phys. Rev. **D28**, 97 (1983)
R.A. Arndt et al., Phys. Rev. **D35**, 128 (1987)
3. J. Bystriicky, C. Lechanolne-LeLuc, and F. Lehar, Jour. de Phys. **48**, 199 (1987)
4. Y. Higuchi, N. Hoshizaki et al., "1983 INS Symposium", Tokyo 1983
5. See Particle Data Group, "Review of Particle Properties," Phys. Lett. **170B**, 337 (1986) and references therein
6. G.A. Korolev et al., Phys. Lett. **165B**, 262 (1985)
7. G. Bizard et al., Nucl. Instr. Meth. **111**, 451 (1973)
8. Y. Terrien and F. Wellers, Jour. de Phys. **46**, 1873 (1985)
9. G.N. Velichko et al., Yad. Fiz. **42**, 1325 (1985) [Sov. J. Nucl. Phys. **42**, 837 (1985)]
10. A.A. Vorobyov et al., Nucl. Instr. Meth. **119**, 509 (1974)
11. A.V. Dobrovolsky et al., Nucl. Phys. **B214**, 1 (1983)
12. A.J. Bersbach et al., Phys. Rev. **D13**, 535 (1976)
13. R. Carlini et al., Phys. Rev. Lett. **41**, 1341 (1978)
14. See, for example, Martin L. Perl, High Energy Hadron Physics (Wiley, New York, 1974) Chap. 17

Figure captions

1. Schematic picture of the experimental set-up; A1, A2, R1-R3, and L1-L3 are scintillation counters.
2. Absolute differential cross section for n-p elastic scattering. The curves are from the phase shift analyses of refs. 2 and 3. The open points are from refs. 12 and 13.
3. Slope parameter b of the elastic scattering differential cross section versus energy.

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Fig. 1

Fig. 2

Fig. 3