INTRODUCTION

The study of the elastic $np \rightarrow np(pn)$ scattering processes has been the subject of many papers, both theoretical and experimental [1–7 and references therein]. These papers present experimental data in the form of tables of differential cross sections of elastic scattering in relation to different kinematical variables, as well as a comparison with the existing models. The amplitudes of exchange processes of elastic scattering may be presented in different ways. One of the approaches to the problem is to consider the emergence of forces between the nucleons as a result of an exchange of charged or neutral virtual mesons.

An attempt to describe the process of elastic $np$ scattering by a single-pion exchange was satisfactory only at initial energies of up to 100 MeV, when the differential cross section from the cosine of the scattering angle in the c.m.s. is symmetric [7]. Asymmetry increases more and more sharply in distributions at large energies, and the single-pion exchange model no longer describes the experimental data.

The elastic scattering without charge exchange at initial energies above 10 GeV and a scattering angle close to zero is conventionally represented as a process of exchanging a pomeron having vacuum quantum numbers. At lower energies and larger angles, however, theoreticians propose that the contribution of other, heavier, mesons should be taken into account [1]. For instance, paper [3] suggests considering up to five poles: the exchange of a pion; an $\rho$ meson; and other, heavier, mesons.

There is little experimental material in the range from 1 to 10 GeV, and this range is almost never discussed in reviews.

In the present paper we analyze the experimental differential cross sections of the processes of elastic $np$ scattering, both without ($\cos \Theta_p^* < 0$) and with charge exchange ($\cos \Theta_p^* > 0$), in the reaction $np \rightarrow np(pn)$ at initial neutron momenta $P_0 = 1.43, 2.23,$ and 5.20 GeV/c.

Using this analysis as a basis, we suggest a pole model which takes account of charged- and neutral-boson ($\pi$- and $\rho$-meson) exchange and also includes the peripheral exchange mechanism of the pomeron-exchange type. The model allows one to calculate the differential cross sections of elastic $np$ interactions in relation to $\sqrt{s}$ in the energy range of $\approx 1–10$ GeV, as well as to determine the cross sections and other parameters of elastic $np$ scattering.

1. EXPERIMENTAL MATERIAL

1.1. Conditions for Obtaining Experimental Material

The Laboratory of High Energy Physics (LHEP) of the Joint Institute for Nuclear Research (JINR) is the unique laboratory that provides $np$-interaction data for several neutron-beam momenta in the range 1–5 GeV/c. These data have been obtained at the irradiation of JINR LHEP’s 1-m hydrogen bubble chamber (HBC) [8] with quasi-monochromatic neutron beams. The neutron beam was generated upon stripping of accelerated deuterons on a 1-cm Al target placed inside the JINR Synchrophasotron vacuum chamber. The neutrons left the accelerator at 0° to the deuteron beam direction. The neutron beam passed about 12 m in the accelerator magnetic field, which allowed the beam to be cleaned from charged particles. At a distance of $\sim 130$ m from the aluminum target HBC was inserted into a magnetic field with a strength...
of 1.7 T. The neutron beam was formed by collimators and then entered a chamber with parameters $\Delta P_n/P_n \sim 2.5\%$, $\Delta \Omega_n = 10^{-7}$ without admixtures of charged particles and $\gamma$-quanta. The neutron channel and irradiation conditions are outlined in [9–11].

In each run of irradiation, the parameters of the beam of incident neutrons in the HBC were determined using three- and five-pronged stars from which events free of neutral particles were selected. The selection procedure is described in [9–11]. The values of incident-neutron momenta determined in this way were further used in the separation of different channels of $np$ interactions.

More than 1.5 million events were collected during several runs of irradiation at different momenta of incident neutrons. The precision of measurement of the particle momenta in the chamber was 2–3%; the angles were measured to an accuracy of 0.5°. As a result, the values of the transferred momenta squared are determined with a precision of 3–4%.

The procedure based on the analysis of the quantity $\chi^2$ for each event was used to select reactions without neutral particles and with one neutral particle. In addition, a visual estimation of ionization was used to identify tracks of positively charged particles and events selection according to the criterion $\Delta P_n/P_0 \leq 3\%$, where $P_n$ is the total momentum of all charged particles and $\Delta P_0$ is the total momentum error [9–11].

1.2. Selection of Elastic np-Scattering Events

One-pronged events at incident-neutron momenta of 1.43 and 2.23 GeV/c were selected in all the available films in the HBC effective volume.

In photo frames obtained during irradiation with a momentum of 5.20 GeV/c, when viewed sequentially, there were also selected one-pronged events occurring all over the effective volume of the HBC. After some statistics had been collected and analyzed, it was decided to select only stars generated at an angle of 20° to the neutron beam direction. Events related to the elastic charge-exchange interaction (the reaction $np \rightarrow pn$) focus in this angle. The statistics added in such a manner allowed the parameters of the elastic charge-exchange interaction to be determined more accurately.

The reaction of elastic interaction was separated using the $\chi^2$ method [13] with one degree of freedom (1C fit) with $\chi^2 < 30$, which exceeded the 99.9% CL. The selected events are attributed to elastic $np$ interactions (EL group); the other, including various inelastic channels, are attributed to the INEL group. The distributions of missing masses for the selected events at $P_0 = 1.43, 2.23,$ and 5.20 GeV/c have full widths of 20, 30, and 40 MeV/c², respectively, the maximum at a neutron mass to an accuracy of 0.1 MeV/c², and are symmetric about the central value (from here on, $P_n$ is the momentum of incident neutron). The distribution of $\chi^2$ values for the selected events coincides with the standard distribution of $\chi^2$ with one degree of freedom. Admixtures of the other reaction channels in the EL group are almost absent at such a selection of events.

The separation of events related to the elastic interaction channel only by the missing mass method applied in most investigations does not permit one to get rid of an admixture of inelastic channels, which increases with increasing a momentum of primary beam. Figure 1 shows distributions of missing masses at $P_0 = 1.43, 2.23,$ and 5.20 GeV/c for the events of

![Fig. 1. Distributions of missing masses at $P_0 = (a) 1.43$, (b) 2.23, and (c) 5.20 GeV/c. The light bins are events identified by kinematic fit as elastic; the dark bins are the other events.](image-url)