объединенный
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дубна

E2-89-876

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INCLUSIVE CHARGE-EXCHANGE (p,n) REACTIONS ON NUCLEI IN THE Δ-ISOBAR EXCITATION REGION

Submitted to "Gross Properties of Nuclei and Nuclear Excitations International Workshop XVIII", Hirschegg, Kleinwalsertal, Austria, January 15-20, 1990

1989

Inclusive reactions of the type (e,e′), (p,p′), (π,π'),(p,n), (^{3}He,t), (^{6}Li,^{6}He),... provide a basic source of information on effective NN and NΔ interactions, reaction mechanisms, and on the nuclear structure at intermediate energies. Poor knowledge of spin and isospin components of NN and ΔN interactions resulted in a great amount of works [1-6] devoted to charge-exchange reactions.

The aim of this note is to investigate the A-dependence of integral cross sections of inclusive reactions $(p,n)_\Delta$ for $T_p>0.6$ GeV, on the basis of the effective-number approximation [7] developed for the analysis of the inclusive reactions of knock-out clusters (p,pX), which are analogous to process $(p,n)_\Delta$.

In this approximation, based on the condition of completeness of states of nondetected fragments, the cross section of reaction $A(p,n)_\Delta B$ may be represented in the following form:

$$\frac{d\sigma_{A(p,n)_\Delta B}}{d\Omega_n}=\int d\vec{Q}[\Phi_N^A(\vec{Q})]^2\ \frac{d\sigma_{p+p\to n+\Delta^{++}}(\vec{P}_i,\vec{Q})}{d\Omega_n}, \qquad (1)$$

where $[\Phi_N^A(\vec{Q})]^2$ is the momentum distribution of nucleons in a nucleus A participating in the charge-exchange reaction.

The effective number of protons (neutrons) participating in the process $(p,n)_\Delta$ is determined by the integral of the momentum distribution:

$$\tilde{N}_{p(n)}=\int d\vec{Q}|\Phi^A_{p(n)}(\vec{Q})|^2. \qquad (2)$$

A detailed analysis of the properties of effective numbers of nucleons and clusters was performed in review [7]. The presence of the momentum of an intranuclear nucleon $\vec{Q}$ among the arguments of the cross section of charge-exchange on a free nucleon $d\sigma_{p+p\to n+\Delta^{++}}(\vec{P}_i,\vec{Q})/d\Omega_n$ points to the necessity of inclusion of effects of going out of the mass shell. However, in the investigated region of energies $T_p>0.6$ GeV, the influence of the off-mass-shell effects may be neglected as the momentum of an incident nucleon $\vec{P}_i$ and a transferred momentum $\vec{q}$ obey the conditions $|\vec{P}_i|\gg P_F$ and $|\vec{q}|\gg P_F$, where P_F is the Fermi momentum. The point is that the strength of interaction depends on the momentum of an incident proton $\vec{P}_i$ and that of an intranuclear nucleon $\vec{Q}$: $(P_i^2+Q^2)^{1/2}$, so that the integral correction for the Fermi motion of nucleons and for their being bound does not exceed 3÷5%. Besides, the off-mass-shell effects slightly influence the A-dependence of the integral cross section of reaction $A(p,n)_\Delta B$ we are interested in. In this approximation (1) is factorized as follows [8,9]:

$$\frac{d\sigma_{A(p,n)_\Delta B}}{d\Omega_n} \tilde{=} \tilde{N} \frac{d\sigma_{p+p\to n+\Delta^{++}(\vec{P}_i)}}{d\Omega_n}\Big|_{free} \qquad (3)$$

and in the approximation of effective numbers the quantity $\tilde{N}$ is of a simple structure:

$$\tilde{N}=\int d\vec{Q}[\Phi^A_N(\vec{Q})]^2=(Z+\frac{N}{3})\int d\vec{r}\rho(\vec{r})f^2(b,z)\equiv(Z+\frac{N}{3})<f^2> . \qquad (4)$$

In formula (4) $<f^2>$ is the effective factor of absorption, $\rho(\vec{r})$ is the one-nucleon density and $f^2(b,z)$ is the Glauber factor of the absorption.

In ref.[9] it is shown that $\tilde{N}^{exp}(\theta_n)$ within experimental errors does not depend on θ_n. Thus, the angular dependences of cross sections $d\sigma^{exp}[A(p,n)_\Delta B]/d\Omega_n$ testify, generally speaking, in favour of the DWIA or approximation of effective numbers. Physically, this means that the process takes place on the nucleus periphery, i.e.in the region where the density of nucleons is small, and consequently, all NN and ΔN interactions in the nucleus are close to free interactions.

More complicated is the A-dependence of cross sections. In Table 1 we list the results of data processing performed in ref. [4] (T_p=1 GeV, θ_n=4°). From the Table it is seen that $\tilde{N}^{exp}$ systematically exceed $\tilde{N}^T$ by about a factor 1.5, which clearly points to the insufficiency of the approximation of effective numbers for the description of integral cross section of the reaction $A(p,n)_\Delta B$.

That situation may be qualitatively understood if we consider the A-dependence of the quantities $\Delta\tilde{N}=\tilde{N}^{exp}-\tilde{N}^T$. As follows from Table 1, the quantities $\Delta\tilde{N}$ grow, on the whole, according to the law A^α, where α=0.6÷ 0.8. If we assume that the effect of going off mass shell in the cross section $d\sigma[p+p\to n+\Delta^{++}]/d\Omega_n$ is not very

large, we may consider expression (3) to be valid for description of the part of the cross section of reaction $(p,n)_\Delta$ where a realistic Δ^{++} or a Δ^+ isobar is generated(see diagram 1). By definition, diagram 1 contains only the direct charge exchange process. However, within the developed formalism, the cross section includes both the direct and exchange terms. The latter physically corresponds to excitation of the Δ-isobar in an incident particle and plays an important role. A similar comment can be made for diagram 2 discussed below.

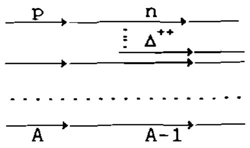

Diagram 1. This process will for brefity be denoted by $(p,n)^{\pi N}_\Delta$ with the emphasis on reality, principal observability of a produced Δ-isobar whose de-excitation occurs through decay into a pion and a nucleon.

According to refs. [9,10] the observed cross section may be represent by a sum:

$$d\sigma[A(p,n)_\Delta B]/d\Omega_n=d^{(1)}\sigma[A(p,n)_\Delta B]/d\Omega_n+d^{(2)}[A(p,n)_\Delta B]/d\Omega_n, \qquad (5)$$

the first term corresponds to the approximation of effective numbers (3) ; the second term can be connected with the process of exchange of virtual mesons, in which a virtual Δ-isobar also takes place (see diagram 2).

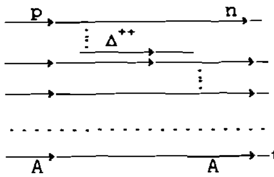

Diagram 2. In ref. [6] the process described by diagram 2 is called the mesonless Δ-isobar de-excitation. We shall denote this process by $(p,n)^{NN}_\Delta$, thus underlying that a virtual Δ-isobar is discharged through the charge exchange on one of the intranuclear nucleons.

In ref.[9] it has been shown that cross section for the reaction $(p,n)^{NN}_\Delta$ may also be written in a factorized form:

$$\frac{d\sigma^{(2)}_{A(p,n)_\Delta B}}{d\Omega_n} \tilde{=} \Delta\tilde{N} \frac{d\sigma_{p+p\to n+\Delta^{++}(\vec{P}_i)}}{d\Omega_n}\Big|_{free} . \qquad (6)$$

The relations (3) and (6) indicate that the angular spectra of neutrons from the charge-exchange channel $(p,n)^{NN}_\Delta$ coincide in form with analogous spectra of neutrons from the charge-exchange channel $(p,n)^{\pi N}_\Delta$. This result allows us to understand the experimental data from ref. [4], and it also points to the impossibility of principle of separation of the contribution from the channel $\Delta \to \pi N$ to the cross section of the charge-exchange reaction from the contribution of the channel $\Delta N \to NN$ on the basis of merely angular spectra of neutrons.

The above-expounded formalism was applied to compute the cross section of the reaction A(p,n)B in a quasielastic region of excitation of a nucleus (i.e. in a high momentum region of the neutron spectrum in which an incident proton either knocks out a neutron or suffers a charge-exchange on neutrons without excitation of the Δ-isobar). From Tab. 1 it is seen that also in this region of excitation of a nucleus, the proposed approach describes the A-dependence of the integral cross section of reactions A(p,n)B with a reasonable accuracy.

And finally, in Fig. 1 we present the energy spectrum of neutrons $d\sigma[{}^{12}C(p,n)_\Delta]/d\Omega_n dT_n$ at T_p=1 GeV. The experimental data [4] at $\theta_n=4^o$ are denoted by triangles, a dashed curve is the contribution of diagram 1; dotted, diagram 2; and a solid curve is their sum. The theoretical spectra were calculated for $\theta_n=0^o$. As follows from our analysis, the channel described by diagram 2 improves the fit to the data in the Δ-region which coincides with the conclusions of ref. [10] devoted to $(e,e')_\Delta$.

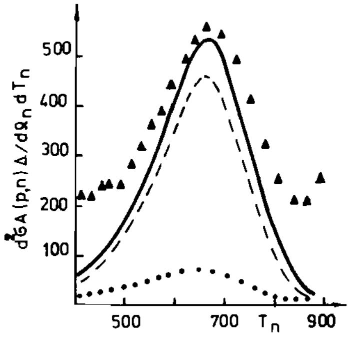

Fig.1

Our summary of this work is as follows:

1. The process of charge-exchange with excitation of the Δ-isobar is shown to be peripherical. An important role of the channel $\Delta N \to NN$ of charge-exchange in reactions $A(p,n)_\Delta B$ is demonstrated.

2. The differential cross sections of charge-exchange on nuclei, $A(p,n)_\Delta B$ (A(p,n)B)), are found to be proportional to the cross section of the corresponding process on a free proton (deuteron), and proportionality factors turn out to equal the effective numbers $\tilde{N}$ and do not depend on θ_n. It is shown that the angular distribution $d\sigma[A(p,n)_\Delta B]/d\Omega_n$ in the energy region $|\vec{P}_i| \gg P_F$ is in form the same for the processes $(p,n)_\Delta^{\pi N}$ and $(p,n)_\Delta^{NN}$.

Table 1. The A-dependence of cross sections and effective numbers $\tilde{N}$ for reaction $A(p,n)_\Delta B$ at T_p=1 GeV at $\theta_n=4^o$ [4] and $\hat{N}_{CEX}$ for reaction A(p,n)B in the quasielastic region.

Target	A	Z	$\frac{d\sigma[A(p,n)_\Delta B]^{exp}}{d\Omega_n}$	$\tilde{N}^{exp}$	$\tilde{N}^T$	$\Delta\tilde{N}=\tilde{N}^{exp}-\tilde{N}^T$	$\hat{N}^{exp}_{CEX}$	$\hat{N}^T_{CEX}$
^{12}C	12	6	162,3∓4,8	3,8	3,0	0,84	2,23	1,80
^{16}O	16	8	220,6∓11,0	5,2	3,2	2,02	2,72	1,88
^{27}Al	27	13	255,8∓7,5	6,0	4,8	1,15	3,22	3,02
^{40}Ca	40	20	331,5∓23,2	7,8	5,9	1,86	3,39	3,41
^{116}Sn	116	50	554,7∓28,0	13,0	8,1	4,86	6,62	5,53
Pb	208	82	588,4∓23,8	13,8	9,3	4,51	9,79	6,92

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Received by Publishing Department
on December 29, 1989.