Estimate of the absolute value of the cross section for inelastic double charge exchange on nuclei

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The influence of the instability of the isobar on the absolute value of the cross section and on the character of the distribution with respect to the missing mass (relative to the emitted pion) is estimated at different momentum transfers for the double-charge-exchange mechanism that includes the production of the virtual isobar Δ(1236).

Reactions of the type $(\pi^{\pm}, \pi^{\mp})$ on nuclei at high energies are of interest because they permit observation of the picture of the motion of the complex singularity of the triangular diagram corresponding to the isobar mechanism of inelastic double charge exchange (Fig. a).[1-3] If only the final pion is registered experimentally, then the position of the maximum in the distribution with respect to the missing mass (relative to the pion) varies with the square of the momentum transferred from the initial pion to the final one. For a reliable observation of the mechanism corresponding to Fig. a, it is important to observe not only the picture of the moving singularity, but also to be assured that the absolute value of the cross section agrees with the theoretical expectations, particularly since considerable background effects are possible.

The isobar mechanism was investigated in detail in[2]. The formulas obtained in that reference, however, call for further "decoding," since they contain the "total cross section" of the isobar on the nucleus 1, designated σ_{12}, which was defined formally by standard formulas in terms of the matrix element of the reaction

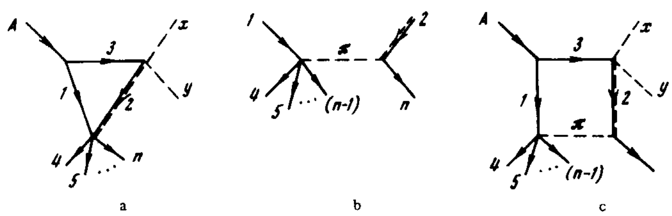
$$1 + 2 \to 4 + 5 + \ldots + n\,. \tag{1}$$

The quantity σ_{12} does not have a simple physical meaning, for example, it cannot be stated that it is of the order of or less than the geometric cross section of the nucleus. The point is that an isobar with momentum on the order of 500 MeV/c traverses prior to decay only a fraction of a Fermi unit, and the nucleus one interacts mainly with the nucleon and pion produced by the decay of this isobar. Of particular importance is the interaction of the pion, since its energy lies in the resonant region, where the πN-scattering cross section is large. This circumstance corresponds to the fact that the amplitude of the reaction (1) (Fig. b) has a pole singularity at those values of the kinematic variables which can actually be obtained by integration with respect to the momenta of the virtual particles in the diagram of Fig. c (this diagram is obtained from Fig. a by substitution of Fig. b in the lower vertex). Thus, to estimate the absolute value of the double charge exchange cross section it is necessary to know the value of σ_{12} or, to the contrary, to be able to tell which value of σ_{12} can be expected from the reduction of the experimental data by the formulas of[2].

A rigorous calculation of the diagram of Fig. c encounters serious technical difficulties. We confine ourselves here therefore to an approximate estimate. The two most important aspects are the replacement of the pion propagator by a certain effective value, and the determination of the limits of that region of variation of the momentum $\mathbf{p}_n$ (of the particle n) which makes the main contribution to the double charge exchange cross section. We consider first the case when the momentum transfer in the vertex $3 + x \to 2 + z$ is small, smaller than or of the order of the characteristic momentum p_0 determined by the form factor A of the nucleus. Let the $\mathbf{p}_n$ be such that the pion propagator passes through zero when the momentum of particle 1 (the integration is carried out with respect to this momentum) is smaller than p_0, and the form factor A of the nucleus still does not suppress the integrand. Then the pion propagator can be replaced effectively by the quantity q_0^2, where q_0 is of the order of p_0 (in fact, it is apparently somewhat smaller). This follows from dimensionality considerations and can be verified with simple examples, say with diagrams corresponding to the interaction in the final states. The matrix element M_{12} of the reaction (1) is then expressed simply in terms of the matrix element M' of the reaction $1 + \pi \to 4 + \ldots + (n-1)$ (we denote the cross section of this reaction by σ_0) and the elements M_Δ of the $\Delta \to \pi + n$ decay:

$$M_{12} = \frac{2\mu M' M_\Delta}{k_\pi^2 - \mu^2 - i\eta} \to \frac{2\mu M' M_\Delta}{q_0^2} \tag{2}$$

where μ is the pion mass. Formula (2) enables us to express σ_{12} in terms of σ_0. The main contribution is made by the region of the momenta of the particle n such that $(k_{\rm res} - p_0) < |\mathbf{p}_n| < (k_{\rm res} + p_0)$, where $k_{\rm res}$ is the momentum of the nucleon produced in the decay of the free isobar. When $\mathbf{p}_n$ is outside this interval, the integrand is strongly suppressed by the nuclear form factor. Within the framework of the assumptions made above, we find that



Diagrams corresponding to the isobar mechanism of double charge exchange. Dashed lines—pions, solid line with the dashes corresponds to the isobar.

$$\frac{\sigma_{12}}{\sigma_0} \sim \frac{m_\Delta^2 \Gamma (k_{res} + p_0)^3}{\pi m q_0^5}, \qquad (3)$$

where m_Δ and Γ are the mass and width of the isobar, and m is the nucleon mass. If we substitute the values $k_{res} = 230$ MeV/c, $p_0 = 150$ MeV/c, and $q_0 = 100$ MeV/c, then we obtain

$$\sigma_{12} \sim 300 \sigma_0 \qquad (4)$$

Of course, the foregoing estimate is quite crude. It can be stated on this basis, however, that the "cross section" for the interaction of the isobar with the nucleus 1, which is obtained by reducing the data on inelastic double charge exchange by the formulas of[2], should exceed by several dozen or by several hundred times the total cross section of the interaction of the pion with the nucleus 1, which is of the order of the geometric dimensions of the nucleus in the resonant energy region. This is the main result of the present paper. To obtain nontrivial information on the interaction of the isobar with the nucleus it is necessary to separate experimentally such final states in which an isobar is present. Additional investigations show that the obtained estimate can hardly be significantly altered by going over to momentum transfers on the order of 400–500 MeV/c from the initial pion to the final one.

An important requirement, for the foregoing arguments is that the kinematics of the process be such that the propagator of the pion passed through zero at $p_1 \lesssim p_0$. This corresponds precisely to the region of the maximum in the distribution with respect to the missing mass (relative to the pion) at different momentum transfers. It can be assumed that allowance for the nonconstancy of the matrix element of the process (1) has little effect on the form of the corresponding relations obtained in[2] in the region of the peak, but alters strongly the curves far from the maxima.

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