Excitation of anomalous-parity nuclear levels by nucleons of medium and high energy, and models of nucleon-nucleon amplitudes

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Attention is called to the fact that processes involving excitation of anomalous-parity nuclear levels by nucleons can be used to determine the spin-dependent terms in the *NN*-scattering amplitude at high energies. The necessary nuclear parameters can be determined in the energy region where the *NN* amplitudes are well known.

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Excitations of anomalous-parity (AP) nuclear levels (the transitions $0^+ \rightarrow 1^+$, 2^-, 3^+, etc.) are connected with spin flips of the nucleons in the nucleus in the course of the interaction (see, e.g., [1]). The purpose of the present study is to demonstrate that an investigation of such processes can be used to determine the spin-dependent *NN*-scattering amplitudes in the region of medium and high energies, where these amplitudes are not very well known. The idea is the following. In this energy region, the process of excitation of the nuclear level can be described within the framework of the Glauber theory[2] or within the framework of the approximation of single inelastic scattering,[3] which is not equivalent to the DWBA. The cross section for the excitation of the AP level is expressed in this case in terms of the amplitudes of the *NN* scattering, which describe the spin flip, the absorption factor, and the nuclear parameters (the form factors of the transition). The nuclear form factor can be determined in the energy region where the *NN*-scattering amplitudes are well known. The use of this form factor at other energy values makes it possible to determine from the experimental data a certain combination of spin-dependent *NN* amplitudes. The information on other combinations of the amplitudes can be obtained either by studying other transitions or by studying the same transition for different nuclei (it is important in this case that the absorption, generally speaking, suppresses in different manners the amplitudes corresponding to different projections of the final-nucleus spin on any chosen direction).

The method considered can be simultaneously used to check on the models of the nuclear wave functions. It is important here (see[1]) that for the AP levels the transition form factors extracted from the hadron data differs from the electromagnetic form factor (it contains a different combination of longitudinal and transverse components. Consequently, the hadronic data contain additional information on the nuclear structure, information that cannot be obtained solely on the basis of electron data. (We recall that for normal-parity level there exists a model-independent connection between the hadronic electron data.[3])

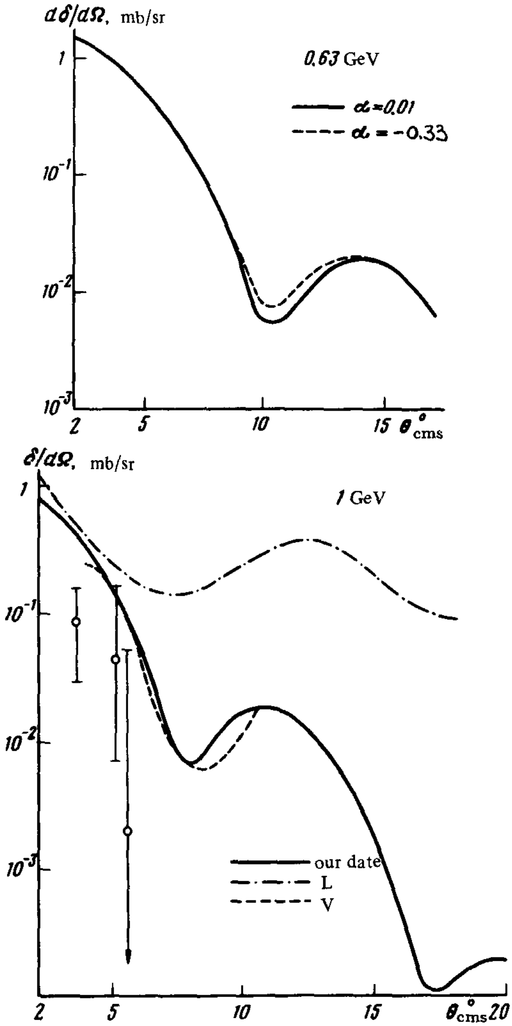
In this article we consider by way of example the cross section for the excitation of the level 1^+ (15.1 MeV) with isospin $T=1$ in ^{12}C by protons of energy 0.63 and 1.04 GeV. To calculate the cross section we use the single-inelastic-collision approximation, which was used successfully by many workers for the description of anomalous-parity level excitation cross sections. In this approximation, the amplitude of the inelastic nucleon-nucleon scattering is expressed in terms of the transition form factor $F_{21}(q)$, the spin-dependent NN amplitudes, and the elastic nucleon-nucleus scattering amplitude (see[1-4]). The form factor of the $0^+ \to 1^+$ (15.1 MeV) transition was obtained by Lee and McManus[4] on the basis of the Gillet and Vinh Mau particle-hole model[5] ($F_{21}^{G}(q)$). In the description of the data on the excitation of the 1^+ level by 156-MeV protons, Lee and McManus used NN amplitudes from[6]. It turned out that to obtain agreement with the experimental data the theoretical curve must be divided by 3.3. Taking into account later data and calculations with more modern NN amplitudes at 156 MeV,[7] the value of this factor is approximately 4.[8] We note that approximately the same normalization factor is needed for the description of the electron data with the form factor F_{21}^{G}.[9] Taking this into account, we use as the transition form factor the quantity NF_{21}^{G}, where F_{21}^{G} is the form factor of Gille and Vinh Mau,[5] and $N^2 = 0.25$.

As the initial formula for the inelastic scattering amplitude we use expression (1) of[4], which we correct to take relativistic kinematics into account. In addition, we take into account only the first-order approximations in the spin-dependent NN-scattering amplitudes, and neglect the spin terms in the elastic-scattering amplitude (we set $W_2(z)$ equal to zero in formulas (8) and (9) of[4]). The amplitude of the elastic scattering of a nucleon by a carbon nucleus then takes the following form in impact-parameter space:

$$1 - \Gamma(b) = 1 - \exp\left[-\frac{1}{2}\sigma(1 - i\alpha)T(b)\right],$$

$$T(b) = \frac{4}{\pi a_0^2}\exp\left[-\frac{b^2}{a_0^2}\left(\frac{5}{3} + \frac{4}{3}\frac{b^2}{a_0^2}\right)\right],$$

$$\sigma = \tfrac{1}{2}(\sigma_{pp} + \sigma_{pn}), \quad a_0 = 1.6\ \phi, \quad \alpha = (\alpha_{pp}\sigma_{pp} + \alpha_{pn}\sigma_{pn})/2\sigma,$$



FIGS. 1 and 2. Cross sections of the excitation of the level 1⁺ (15.1 MeV) in ^{12}C by protons of energy 0.63 and 1 GeV. Solid curves—results of calculation with NN-scattering amplitudes from[10] at 0.63 GeV and from[12] at 1 GeV. Curve V—Viollier's result,[14] curve L—Layly's result[15] divided by 4. The experimental data are from[13].

where α is the ratio of the real and imaginary parts of the NN-scattering amplitude averaged over the nucleon spin projections.

The results of the calculations of the cross section $(d\sigma/dr)_{cms}$ are shown in Figs. 1 and 2. At 0.63 GeV we used the amplitudes of Golovin and Rozanova[10] and the parameters $\alpha_{pp}=0.01$, $\alpha_{pn}=0.01$, $\sigma=38.4$ mb.[11] Inasmuch as the value α_{pn} at 0.63 GeV is not well known, we have also performed the calculations with $\alpha_{pp}=0.01$ and $\alpha_{pn}=-0.67$. The results differ by not more than 10% in the region of the minimum. At 1.04 GeV we used the amplitudes of Lambert and Feshbach[12] and the parameters $\alpha_{pp}=-0.05$, $\alpha_{pn}=-0.5$, $\sigma=43.95$ mb.[11] The results of the calculations at 1 GeV agree with the preliminary Saclay data.[13] This means that the Lambert-Feshbach set of amplitudes is a fair one, although the accuracy of the data does not permit a more accurate quantitative analysis.

At present there are also analogous calculations for 1 GeV, performed by Viollier[14] and Layly,[15] both of whom also used the Lambert-Feshbach *NN* amplitudes. Our calculations agree with Layly's result if his answer is divided by 4, since he assumed a unity normalization factor ($N^2=1$), but differ significantly from the results of Viollier, who used another value of the oscillator parameter in the form factor of Gillet and Vinh Mau, without bothering to reconcile the calculations with the data at 156 MeV.

As seen from Figs. 1 and 2, the cross section decreases by an approximate factor of 2 when the energy is increased from 0.63 to 1 GeV. The energy dependence of the cross section was determined fully by the energy dependence of the *NN*-scattering amplitudes. Refinement of the experimental data on the excitation cross section of the 1^+ level at 1 GeV and the performance of analogous measurements at other energies would be quite desirable. We note also that, as shown by very simple estimates,[1] the law governing the decrease of the cross section, which is determined by the decrease of the spin-dependent *NN* amplitudes, can change in the region 1.5—2 GeV because of a contribution from the two-step mechanism connected with two transitions with normal change of parity (e.g., $0^+ \to 1^- \to 1^+$). If this were actually to occur, the determination of the spin dependence of the *NN* amplitudes by this method would be more difficult, although the very investigation of the *AP* nuclear level excitation cross section in this region would be no less interesting.

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