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DIRECT-SEMIDIRECT CAPTURE MODEL ANALYSIS OF THE REACTION $^{54,56}\mathrm{Fe}\,(p, \gamma_0)^{55,57}\,\mathrm{Co}$

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Yield curves and excitation energy dependence of gamma ray angular distribution coefficients a_2 for the $^{54,56}\mathrm{Fe}\,(p, \gamma_0)$ reactions were calculated from the direct-semidirect capture model taking the giant dipole resonance unsplit. From the agreement with the experimental data it follows that the energy dependence of angular distribution of γ-rays in these cases do not help in arguing that giant dipole resonances are isospin split.

1. *Introduction*

One of the goals of the investigation of photonuclear reactions is to study the isospin splitting of the giant dipole resonances (*GDR*). At least for some nuclei it was observed that in the energy region of *GDR*, where the levels of isospin $T_< = T_0 = 1/2\,(N - Z)$ are excited is well separated from the region where the levels of isospin $T_> = T_0 + 1$ dominate. The effective tool for this study is the analysis of the energy dependence of the strength of the deexcitation γ-rays following the particular photonuclear reaction. A rough guess of such splitting can be obtained also from the shape of *GDR*. In the analysis of the photonuclear reaction on ^{55,57}Co (through the inverse capture reaction (p, γ_0) there was an attempt to recognize the isospin splitting of *GDR* also from the energy dependence of the angular distribution of the reaction products$^{1)}$.

As the nuclei ^{55}Co and ^{57}Co have their ground state isospins 1/2 and 3/2 respectivelly, it follows from the isospin coupling considerations that in ^{55}Co the strength of the (γ, p) part of *GDR* is divided between $T_<$ and $T_>$ levels in the ratio$^{1)}$ 1 : 5 while for ^{57}Co this ratio is 1 : 1.5. This means that (γ, p) excitation function of ^{57}Co in the region of *GDR* should constitute two roughly equal parts having their isospins 3/2 and 5/2. This double bump like function should therefore be wider in ^{57}Co than in the ^{55}Co case, where practically only $T_> = 3/2$ states contribute. In this case the peak of the excitation function should appear at higher energy. Though it is not expected that the same consideration is valid also for ground state transition (γ, p_0), experimental excitation functions, qualitatively agree with above prediction.

It was systematically observed$^{2)}$ that the a_2 angular distribution coefficient from the Legendre polynomial expansion $\mathrm{d}\sigma/\mathrm{d}\Omega = A_0 (1 + \Sigma a_l P_l (\cos \vartheta))$, depends smoothly on the excitation energy through the whole region of *GDR*. The same behaviour of a_2 coefficient was, on the average, observed also in the cases considered here. It changes the sign in the region where $T_<$ and $T_>$ »resonances« overlap. Authors$^{1)}$ indicated that this change may be due to the isospin splitting of *GDR* in ^{55}Co and ^{57}Co.

For the reaction ^{55}Co (γ, p_0) this expectation is qualitatively supported by the results of the shell model calculation$^{3)}$. Using the effective shell model interaction, resulting from fitting several experimental bound state energies, the shell model states which dominantly contribute to the reaction (γ, p_0) were calculated. The result is that the $T_<$ and $T_>$ levels are grouped separately and that the excitation function and energy dependence of a_2 coefficient agree with the experimental data. The last two results were obtained after the spreading the shell model states for spreaing width.

In spite of this agreement the eventual conclusion, that the change of the sign of a_2 coefficient is due to the separation of $T_<$ and $T_>$ part of *GDR*, deserves additional analysis.

The aim of this contribution is to analyse the mentioned ^{55,57}Co (γ, p_0) reactions in the frame of the so called direct-semidirect (*DSD*) capture model$^{4)}$. This is an semimicroscopic model, which, besides the direct capture of nucleon to the single particle state, takes into account also the contribution of the capture process in which the *GDR* state is inelastically excited and capture gamma rays appear as a result of the deexcitation of this state. In the model the *GDR* state is, according to Steinwedel-Jensen, described as an oscillation of proton and neutron fluids within a fixed sphere. The position the width, and the strength of the *GDR*, which enter into the calculation, are taken from the experiment. The strength of the coupling of the incoming particle and dipole state vibrations is considered as a free parameter.

In this contribution the *DSD* model has been used to calculate the excitation functions and energy dependence of the a_2 coefficients for ^{54,56}Fe $(p, \gamma_0))$ reactions considering the *GDR* unsplit.

2. *Calculation*

Calculation was performed within the Potokar[5] approach to the *DSD* model in which the particle-vibration interaction function is complex. Scattering wave functions were calculated from optical model parameters of Rosen et al.[6]. The shape of the real part of this potential was used also for the calculation of the final state $f_{7/2}$ wave functions. The bound wave function was obtained by adjusting the proton binding energy to the experimental value.

TABLE

^{55}Co	Ref.	^{57}Co	Ref.
$E_D = 19$ MeV	a	$E_D = 20$ MeV	a
$2\Gamma = 4.3$ MeV	a	$2\Gamma = 6.3$ MeV	a
$\sigma_{-1} = 42$ mb	b	$\sigma_{-1} = 43$ mb	b

a) extracted from Ref. 1.

b) extrapolation from Ref. 7.

Parameters of the ^{55,57}Co giant dipole resonances used in the *DSD* calculation.

The data about the position and the width of *GDR* in ^{55,57}Co are not available. Values presented in table were extracted from the excitation functions of Ref. 1. The values of $\sigma_{-1} = \int E^{-1}\,\sigma(E)\,\mathrm{d}E$ which enter into the calculation, have been obtained by the interpolation procedure from mass dependence of σ_{-1} presented in Fig. 3 of Ref. 7.

3. *Results*

a) *Excitation functions*

From the recent *DSD* analyses[7] it seems that the strength of particle-vibration coupling strengths V_1 and W_2 depend smoothly, on mass number. We therefore insisted to calculate both excitation functions using the same V_1 and W_2 parameters. Taking $V_1 = 70$ MeV and $W_1 = 90$ MeV, which are extrapolated values from recent analyses, we reproduced the ^{57}Co (γ, p_0) excitation function in the region of *GDR* satisfactorily good.

In the case of ^{55}Co (γ, p_0) reaction the calculated maximum cross section reaches only about 80% of the experimental value. To improve the agreement, the W_1 value should be increased to about 130 MeV. But, instead of doing that, we ascribe the disagreement i) to the already mentioned uncertain data about the *GDR*, and ii) to the uncertainity of the spectroscopic factors C^{2}S. As the final states are not pure, single particle states the model values mus* be multiplied by these factors, being 0.21 and 0.19 for ^{55}Co and ^{57}Co respectively. These values were taken from Nuclear data tables[8,9] and provide from the (^{3}He, *d*) reaction measurements. Experimental errors are not quoted but can easily exceed 10%, which is enough to cover the disagreement between the calculated and experimental maximum cross section in the ^{55}Co case.

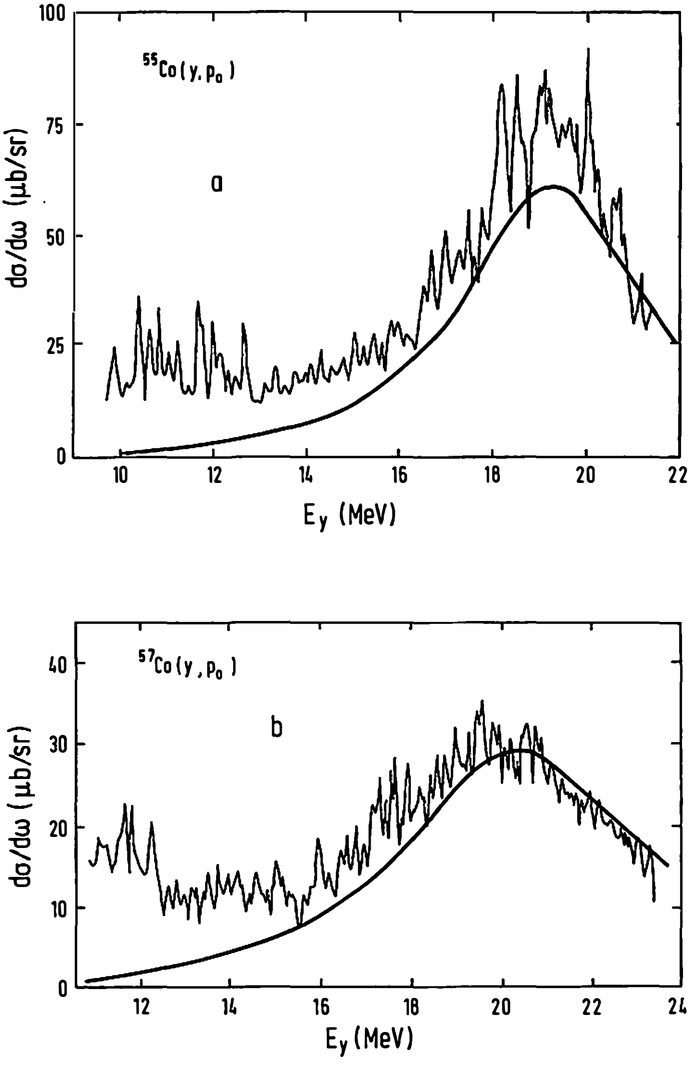

Fig. 1. Excitation function at 90° for the ^{55}Co(γ, p_0)^{54}Fe—a) and ^{57}Co (γ, p_0)^{56}Fe reaction — b) obtained from the inverse reaction by the principle of detailed balance: thin line — experiment, heavy line — *DSD* calculation.

b) *Angular distribution*

Experimental angular distribution data are given by the a_2 coefficients as a function of excitation energy. Experimentally it was observed that also some other coefficients are different from zero. Such coefficients were recently sucessufly calculated using the generalysed *DSD* model in which interference between the dipole and quadrupole amplitudes is considered. As the quadrupole contribution usually does not influence the a_2 value, we limit ourselves only to the dipole process.

Results of the calculation are presented in Figs. 2a and 2b together with the experimental data. Values of a_2 coefficient are positive in the low energy region and change the sign at the E_{exe} = 17.5 MeV and 18.5 MeV for ^{55}Co (γ, p_0) and

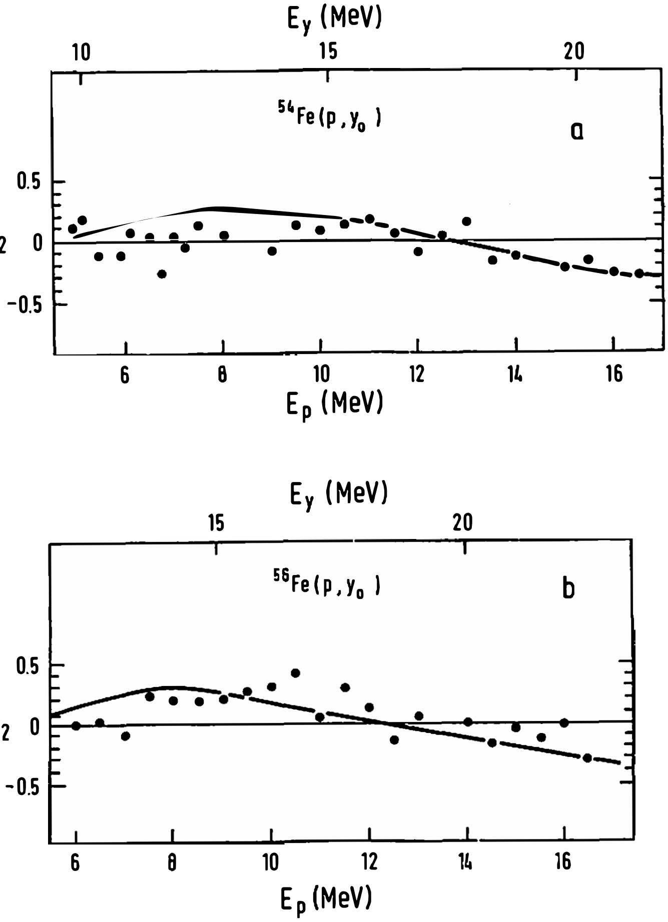

Fig. 2. Energy dependence of the a_2 Legendre polynomial expansion coefficient for the ^{55}Co ^{55}Co (γ, p_0)^{54}Fe reaction a) and ^{57}Co ($\gamma\, p$i(^{56}Fe reaction b): dots — experiment, solid line — *DSD* calculation.

^{57}Co (γ, p_0) reaction respectivelly. The experimental cross point and the high energy part is in the ^{55}Co case reproduced very well but somewhat less satisfactory for ^{57}Co isotope. The overall agreement, however, is certainly good enough that rules out the possibility to ascribe the change of the sign of the a_2 coefficient to the isospin splitting of *GDR-s*. In this connection it should be noted that a_2 values do not depend veiy much on the W_1 value. In the ^{57}Co case the change of W_1 from 60 MeV to 90 MeV results the increase of a_2 from $-$ 0.29 to $-$ 0.27 at fixed value of $V_1 = 70$ MeV and excitation energy of 22 MeV.

4. *Conclusion*

The experimentally observed energy dependence of the a_2 coefficient including the change of the sign is fairly well reproduced by the results of the calculation based on *DSD* capture model in which the *GDR* is considered unsplit. The observed change of the sign of the a_2 coefficients in the region between the supposed $T_<$ and $T_>$ parts of the *GDR* therefore cannot be used as an indication of the isospin splitting of the *GDR*.

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ANALIZA REAKCIJE ^{54,56}Fe $(p, \gamma_0)^{55,57}$Co Z DIREKTNO-SEMIDIREKTNIM MODELOM

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Krivulje pridelkov in energijska odvisnost koeficientov kotne porazdelitve, a_2, za reakciji ^{54,56}Fe (p, γ_0) smo izračunali na osnovi direktno-semidirektnega modela zajetja ob predpostavki, da dipolna veleresonanca ni razcepljena. Iz ujemanja z eksperimentalnimi podatki sledi, da iz energijske odvisnosti kotne porazdelitve žarkov γ v teh primerih ne moremo sklepati, da bi bili dipolni veleresonanci razcepljeni.