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ABSTRACT

Comments on proton capture reactions involving isobaric analogue states are summarized on the basis of experimental results.

АННОТАЦИЯ

Замечания к протонному захвату в случае аналоговых состояний суммированы на основе экспериментальных данных.

KIVONAT

A cikk az izobár analóg rezonanciáknak a különböző reakciócsatornákban tapasztalt viselkedését tárgyalja.

I. INTRODUCTION

It is not necessary to repeat all that is known about the nature of the isobaric analogue resonances IAR and the fine structure phenomena, instead we refer to the review articles[1,2] and to the theory of analogue fine structure[3,4]. What we would like to do is to emphasize the importance of those experimental investigations which study how a doorway state manifests itself in different reaction channels, what kind of correlations arise between the channels enhanced by the doorway state. IARs seem to be the best tools for such purposes. We agree with the comment of ref. 1 that the richest source for such studies is the proton capture reaction since each γ ray transition gives information on a different reaction channel. In that our work on IARs has mainly centred on their γ decay feature, we should like to make some comments based on our experiences and also on the measurements of others.

II. DIFFERENT TYPES OF COUPLING

It is discussed in ref. 3 that the relationship between and D_f reflects the doorway-hallway coupling that is responsible for the fine structure. When $\Gamma^{\downarrow} \gg D_f$ one can speak about strong coupling; with $\Gamma^{\downarrow} \ll D_f$ one can reach the weak coupling limit.

In the following, we speak about IARs in the region of the $1f_{7/2}$ - $2p_{3/2}$ shell nuclei, i.e. $40 < A < 70$, and let us take into consideration those regions of excitation energy in the nuclei where the average mean level distance for any spin and parity is about 1 keV (e.g. in the ^{57}Co nucleus at about 10 MeV, or in the ^{53}Mn nucleus at about 11 MeV energy of excitation - as has been found experimentally[5,6]).

Here in general there are no single resonances alone showing the characteristics of the isobaric analogue state, indicating a real weak coupling case, nor is there a well developed fine structure grouped around the energy corresponding to the position of a certain IAR giving evidence for strong coupling. In this mass number region IARs were found having several fragments spread over a certain energy region showing a picture which corresponds neither to the weak coupling nor to the strong coupling case (see e.g. refs. 1,7). It seems to us that the parameters $\Gamma^{\downarrow}$ and D_f are of the same order of magnitude.

As a consequence of this it is difficult here to find the real fragments of the isobaric analogue (even if studying different channels), to identify them as components of it, and subsequently to extract the parameters characterizing the fine structure distribution.

III. GAMMA EXCITATION FUNCTIONS AND BRANCHINGS OF IARs

The way Bilpuch and co-workers[1] have chosen as a means of finding and identifying the fragments of IARs is to measure first the proton elastic scattering excitation functions and then to fit them. After this the fragments were analysed in other channels such as (p,p'), (p,p'γ) and (p,γ) and correlations between the channels were deduced.

Our experimental method does not involve particle measurements. We have tried to find and to identify the components of the IAR with the help of differential type gamma excitation functions in the capture reactions[5,6]. The complete γ excitation functions show the strongest transition or transitions in the investigated energy region. Usually these are isospin allowed M1 or E1 type dipole γ transitions which selectively populate special final states (the gamma transition operator being a one body operator) choosing those with a simple structure similar to the IAR.

Here one should mention the question of the analogue to anti-analogue isovector M1 γ transitions. In this mass number region the only example of the strong, almost single particle type of M1 transitions occurred in the $^{59,61,63}Cu$ isotopes in the gamma decay of the $g_{9/2}$ IARs. The $g_{9/2}$ IAR in the $^{58}Ni(p,p)^{58}Ni$ and $^{58}Ni(p,\gamma)^{59}Cu$ reactions can be taken as a nice example of weak mixing having only two fragments and showing a strong M1 γ transition to the anti-analogue state[8]. The explanation for the single particle character of this decay can be that the anti-analogue state ($E_x(^{59}Cu) = 3.042$ MeV, $J^{\pi} = 9/2^+$) is not fragmented and has rather pure single particle nature-as the ($^3He,d$) reaction indicated. In the case of other IARs in the $1f_{7/2}-2p_{3/2}$ shell, e.g. $p_{3/2}$ IARs, strong M1 transitions were not found, probably because the corresponding anti-analogue states are not pure and they are strongly fragmented.

With the aid of the differential type excitation function it was possible to find the fragments of the $g_{9/2}$ IAR in the ^{57}Co and ^{53}Mn nuclei[5,6]. The fragments of these two $g_{9/2}$ IARs decay to the ground states of the nuclei with a high branching ratio. This E1 type γ transition dominates their gamma spectra. In the ^{57}Co nucleus we have found weak component of the $g_{9/2}$ anti-analogue state as well, however the transition probability of that isovector M1 transition which populates this state was rather low. In the ^{53}Mn nucleus, from the γ spectra we have had no indication for the $g_{9/2}$ anti-analogue state. In both cases the very strong E1 ground state gamma transition indicated the position of the IAR fragments and helped us to identify them. This would other-wise have been almost impossible by measuring and fitting proton elastic scattering excitation functions having $\ell = 4$ orbital angular momentum of the protons.

At this point we should emphasize the importance of the structure of the final states, since they help one to identify the analogue fragments and understand their structure. It is no use looking for gamma transitions going to any kind of final state because it may be that they are not related to the IAR just because of their structure.

From the excitation functions of the different gamma transitions present in the spectra we were able to learn that some bunches of gammas showed resonance behaviour at a certain bombarding energy and they really belong to a common resonance - as their angular distributions proved. Some other gammas were present only as background(because of the experimental resolution), and they did not show resonances at these energies. In this way the determination of the real branching (based on excitation functions) was possible[5]. This is a very important question as was pointed out by P.M. Endt[9] several years ago.

IV. CORRELATION BETWEEN DIFFERENT REACTION CHANNELS

To determine the partial width correlations between different channels let us follow Lane[10]. If we have a common doorway for channels c and c', the decay amplitudes of a state λ (the λ -th fragment of our IAR) to channels c and c' are as follows

$$\gamma_{\lambda c} = \langle\lambda|d\rangle \gamma_{dc} \qquad (1)$$

and

$$\gamma_{\lambda c'} = \langle\lambda|d\rangle \gamma_{dc'}, \qquad (2)$$

where $\langle\lambda|d\rangle$ is the probability of finding the doorway state $|d\rangle$ (at present the IAR) in the compound state $|\lambda\rangle$, γ_{dc} and $\gamma_{dc'}$ are the decay amplitudes of the doorway state to the corresponding channels. The same is valid for the case of more than two channels.

In the framework of this picture how can one interpret the experimental results available up till now?

It seems to be clearly established that one cannot expect a one-to-one correlation between the fragments appearing in different channels. If the factor $\langle\lambda|d\rangle$ (which produces the correlation between the channels) is very small for a certain fragment, it can happen that the decay amplitude of this state $\gamma_{\lambda c}$ will be too small for observation with the actual experimental resolution, and we do not find the fragment even if γ_{dc} is not equal to zero for this channel. The stronger fragments will of course appear and in spite of the missing fragments a correlation between the two channels can be found.

As an example of this, fig.1 shows the fragments of the $g_{9/2}$ IAR in the ^{53}Mn nucleus found in the (p,γ_0) and $(p,p'\gamma)$ channels; see also ref. 1 for further examples.

V. STRUCTURE OF THE FINAL STATES

An isobaric analogue state can be a common doorway as we have already seen not only for the (p,p_0) and (p,p') channels but at the same time for some of the gamma decay channels. This is entirely determined by the structure of the final state in that channel. A fragment of the isobaric analogue state will populate by γ decay those final states which have very similar structure to that of the IAR fragment.

The purer the analogue state in isospin and structure the cleaner the final state selection. When we have more components of analogue resonance indicating the mixing, we can expect that the γ transitions populate more complicated final states which can also be fed from other resonances not belonging to the components of the analogue state. In such cases the excitation function of the γ transitions will show a quite different picture from the distribution of the fragments of the IAR. See, for example, figs. 34 and 35 of ref. 1 and other similar examples when the integral type γ excitation functions are compared with the elastic proton excitation functions. One can see that the total γ excitation functions have many more peaks than the number of the possible fragments of the IAR found in the proton elastic scattering. These peaks probably correspond to a type of resonance other than the analogue.

However, the correlation between different gamma channels or between a certain γ and the elastic proton channel has a definite interest, but it seems to us that to look for a correlation between the total gamma channel and elastic proton channel has not too much meaning, unless the total gamma decay is dominated strongly by a single transition which itself correlates with the elastic channel. This seems to be supported with regard to the decay of the $p_{1/2}$ analogue in the ^{45}Sc nucleus[11], where anticorrelation was found between the elastic and the total gamma ray channel.

The fact that the final state selection reflects the structure of the fragment of the IAR is true not only for the γ

channels but for the (p,p') or (p,p'γ) channels as well, since the transition operator here is also a one body operator. When the IAR appears in the (p,p'_{2^+}) or $(p,p'_{2^+}\gamma)$ channel this indicates a component in the wave function of the fragments that is characterized by an excited core ($J_c^{\pi} = 2^+$). However, the distribution of this excited core component is not necessarily the same as that of the fragments in the elastic channel. One can find either more or less resonances in the elastic channel depending on the structure of the fragments.

The importance of the final state structure is clearly seen in those cases when just because of the large overlap between the entrance channel and the final system the fragments of the IAR were found not in the proton elastic scattering excitation functions but in the excitation function of the E1 ground state γ transition or in that of some isovector M1 (analogue to anti-analogue) γ transition.

VI. THE SPREADING WIDTHS

In connection with the above, we should like to comment on the question of the spreading widths of IARs.

It is known that the total width of a doorway state is composed of two parts

$$\Gamma_d = \Gamma^{\uparrow} + \Gamma^{\downarrow} , \qquad (3)$$

where $\Gamma^{\uparrow}$ stands for the proton escape width (decay amplitude to the entrance channel) in the case of IARs, and $\Gamma^{\downarrow}$ is the damping or spreading width of the IAR which measures the coupling between the doorway and the neighbouring complicated states, that is

$$\Gamma^{\downarrow} = 2\pi \left\langle \frac{V_{fa}^2}{D_f} \right\rangle , \qquad (4)$$

as defined in ref. 4 where V_{fa} is the matrix element of this coupling, D_f is the mean level distance for the actual states. In order to determine $\Gamma^{\downarrow}$ (see fig. 2) for a channel c one should take the distribution of the $\gamma_{\lambda c}$ partial widths which appear in this channel and fit it with a theoretical distribution function[6].

In ref. 1 the authors pointed out that the spreading of the $p_{3/2}$ IAR in the $^{48}Ti(p,p_0)^{48}Ti$ and in $^{48}Ti(p,p')^{48}Ti^*$ was very different, being 1.5 keV for the elastic and 8.5 keV for the inelastic channel. It seems to be similar to our case (see fig. 1) and we should like to suggest an explanation on the basis of the above mentioned structure considerations. We do not have the same number of fragments in different channels because of the absence of the one-to-one correlation between the fragments which might result in different spreading widths. In this way the spreading width determined for a certain channel is not necessarily equal with that deduced from another channel.

Consequently we should treat the channels separately collecting the appeared fragments channel by channel, and trying to analyse them according to a suitable fine structure theory (see e.g. ref. 12).

VII. CONCLUSION

Our purpose in this paper has not been to give a detailed experimental or theoretical treatment of line broadening but solely to comment on IARs based on our own experiments and on those of others.

We consider that the experiences gained from studying IARs in different channels is likely to be very useful in the future as an aid, for example, in investigating the intermediate resonances found in heavy ion reactions.

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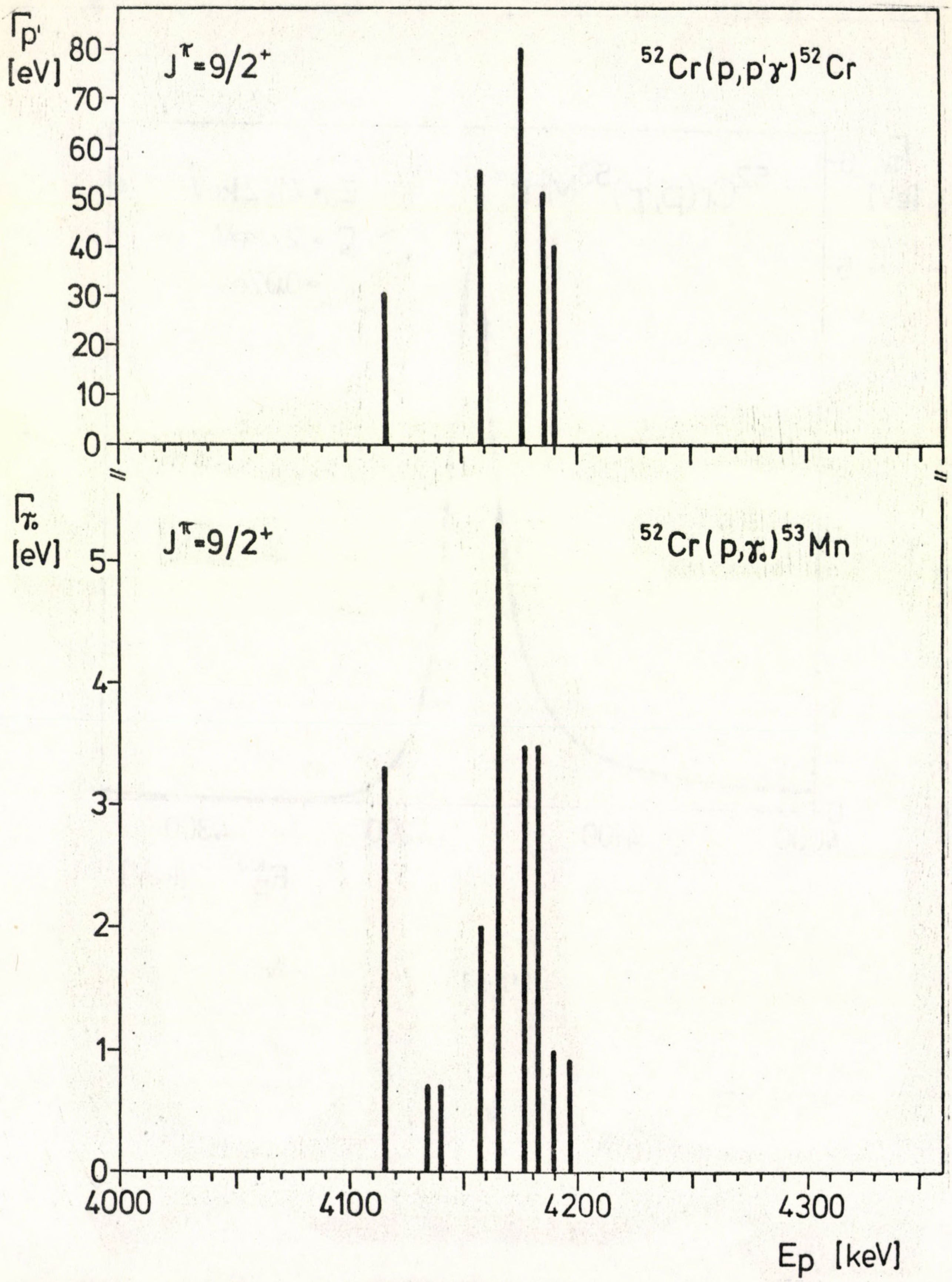
FIGURE CAPTIONS

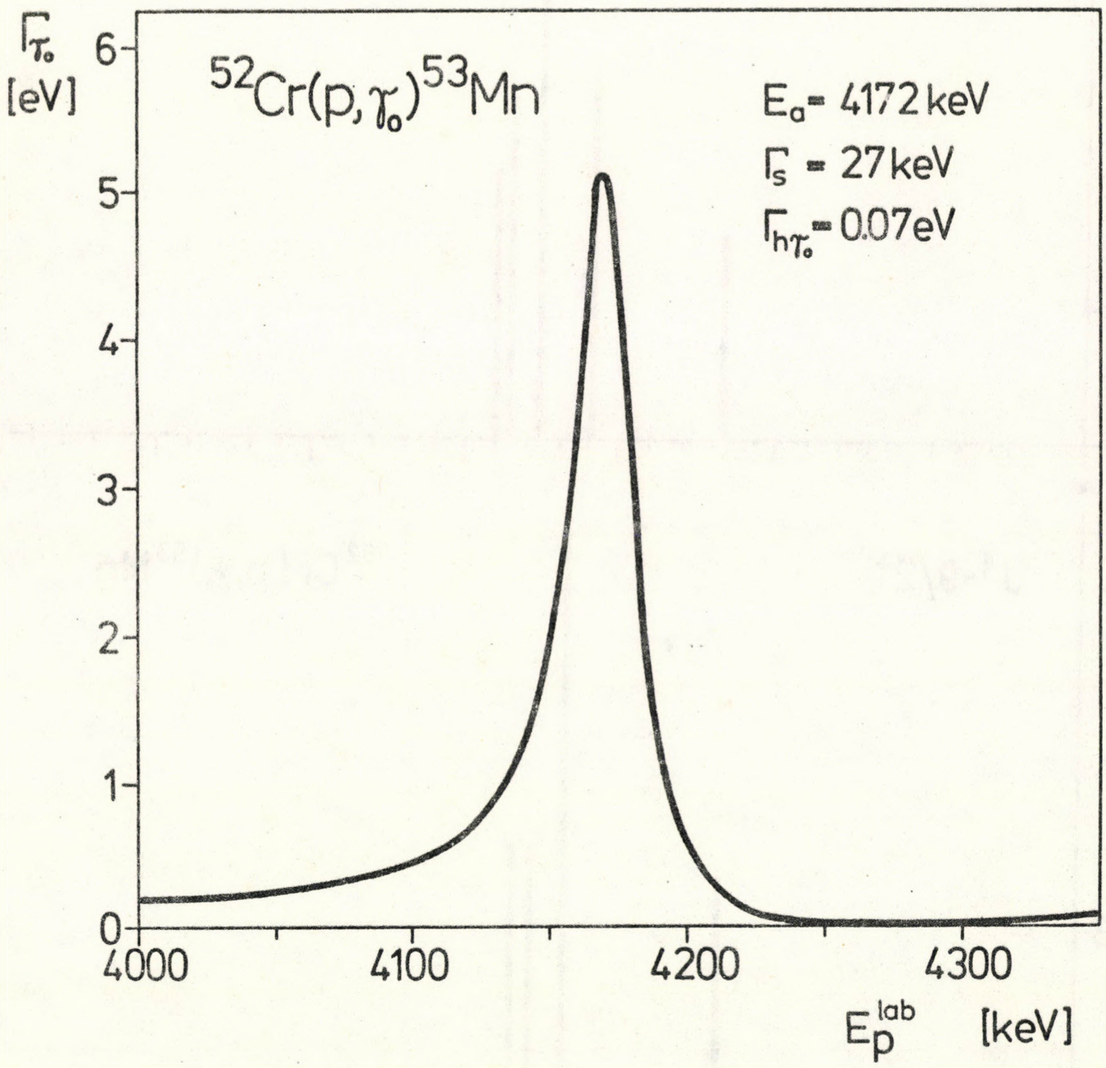
Fig. 1. The $g_{9/2}$ IAR fragments in the $^{52}Cr(p,p'\gamma_{2^+})^{52}Cr$ and $^{52}Cr(p,\gamma_0)^{53}Mn$ reactions for detailed treatment see ref. 6 .

Fig. 2. The distribution function of the Γ_{γ_0} partial widths fitted to the fragments found experimentally in the $^{52}Cr(p,\gamma_0)^{53}Mn$ reaction (see fig. 1).



Γp'
[eV]
80
70
60
50
40
30
20
10
0
J^π=9/2^+
52Cr(p,p'γ)52Cr
Γγ0
[eV]
5
4
3
2
1
0
J^π=9/2^+
52Cr(p,γ0)53Mn
4000
4100
4200
4300
Ep [keV]

Fig. 1



Γ_{γ_0} [eV]
$^{52}Cr(p,\gamma_0)^{53}Mn$
E_a = 4172 keV
Γ_s = 27 keV
$\Gamma_{h\gamma_0}$ = 0.07 eV
0
1
2
3
4
5
6
4000
4100
4200
4300
E_p^{lab} [keV]

Fig. 2

Kiadja a Központi Fizikai Kutató Intézet
Felelős kiadó: Szegő Károly
Szakmai lektor: Lovas István
Nyelvi lektor: Harvey Shenker
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