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M1 TRANSITION FROM $g_{9/2}$ ANALOGUE TO ANTI-ANALOGUE STATE IN ^{59}Cu, ^{61}Cu, ^{63}Cu, ^{65}Ga AND ^{67}Ga NUCLEI

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ABSTRACT

$g_{9/2}$ analogue resonances have been found in the $^{58,60,62}Ni\ (p,\gamma)\ ^{59,61,63}Cu$ and $^{64,66}Zn\ (p,\gamma)\ ^{65,67}Ga$ reactions, with strong M1 transitions to the corresponding anti-analogue states.

KIVONAT

$g_{9/2}$ analóg rezonanciákat találtunk a $^{58,60,62}Ni\ (p,\gamma)\ ^{59,61,63}Cu$ és a $^{64,66}Zn\ (p,\gamma)\ ^{65,67}Ga$ magreakciókban, amelyek erős M1 átmenettel bomlanak a megfelelő antianalóg állapotokba.

РЕЗЮМЕ

Были найдены аналоговые резонансы $g_{9/2}$ в ядерных реакциях $^{58,60,62}Ni(p,\gamma)^{59,61,63}Cu$ и $^{64,66}Zn(p,\gamma)^{65,67}Ga$, которые распадаются переходом MI в соответствующие антианалоговые состояния.

M1 transitions from the isobaric resonances (IAR) to the anti-analogue states (AIAS) have recently received much attention from both experimental and theoretical points of view [1-9]. It has been pointed out that these transitions are strong in 2s-1d shell nuclei and are hindered by several orders of magnitude in the lower part of the 1f-2p shell. In a previous article [10] some preliminary results were published on the ^{58}Ni (p,γ)^{59}Cu reaction which indicated that the IAR to AIAS M1 transition strength rises to the order of the single particle strength again. In order to collect more detailed information on the general behaviour of these transitions we have extended our investigations to (p,γ) reactions of other even-even nuclei of the upper part of the 1f-2p shell, namely to the ^{58,60,62}Ni (p,γ) ^{59,61,63}Cu and ^{64,66}Zn (p,γ) ^{65,67}Ga reactions.

The experiments were performed with the 4 MeV Van de Graaff accelerator of the Central Research Institute for Physics. The Zn targets were evaporated from natural metallic zinc, the ^{58,60,62}Ni targets, enriched to 97.6, 95.1 and 90.6 %, respectively, were electroplated onto thick gold backings. The total (beam+target) energy resolution of the system was about 3 keV in every case. A 7.5 x 7.5 cm^2 NaI(Tℓ) scintillation detector was used for the simultaneous measurement of the excitation functions for γ-rays of energy

(i) $E_\gamma > E_1 - 200$ keV
(ii) $E_\gamma > E_2 + 300$ keV
(iii) $E_2 + 300 > E_\gamma > E_2 - 1300$ keV,

where E_1 is the energy of the first excited state of the target nucleus and E_2 is the expected energy of the IAR-AIAS transition. The excitation functions were measured in 2.5 keV steps over a region of about 150 keV around the expected position of the IAR-s. The detailed γ-spectra were taken by a 30 cm^3 Ge(Li) detector.

Since all the excitation functions, including those of type (iii) showed very complex structure except for those of the ^{58}Ni (p,γ) ^{59}Cu reaction (see Fig. 1 of ref. [10]), it was necessary to measure the γ-spectra of each resonance found in the covered bombarding energy region in order to get further arguments for identification of IAR-s beyond their position. In each nucleus studied here resonances were found whose spectra were markedly different from those of the others. This means that only these resonances decay to the low-lying $g_{9/2}$ state, and furthermore these transitions are the strongest primary ones in the spectra. In the final nuclei there is only one known $g_{9/2}$ state which is a candidate to be the AIAS. In order to check the M1 character of these transitions the asymmetry parameter I_{90°/I_{0° was determined for the Cu isotopes. The obtained values are in agreement with the mainly M1 $(9/2^+ \rightarrow 9/2^+)$ character expected. On the basis of the above observations the resonances of special properties were identified as members of the IAR of the first $g_{9/2}$ state in the target + neutron system.

The results are summarized in Table 1. It can be seen that the IAR-s are very close to the expected positions calculated from the Q_n and the estimated [22] Coulomb-energy shift values. While in ^{59}Cu and ^{67}Ga only one resonance seems to possess the IAR strength, in the other nuclei the IAR shows fine structure splitting spread over a region of several ten keV. In Table 1 can be found the estimated and measured Coulomb-energy shifts together with the deduced symmetry potential values. The Coulomb shifts are in good agreement with other experimental results [11,12]. The V_1 symmetry potential strengths derived from the energy splitting of the isospin doublets [3] are reasonable. The acceptable values of the symmetry potential are consistent with the assumption that the AIAS strength is mainly concentrated in the only known low-lying $g_{9/2}$ state of the final nuclei.

The Γ_γ values determined for the IAR-AIAS M1 transitions from the measured yields are presented together with the single-particle estimations in Table 2 [3,14]. There are two theoretical Γ_γ values for each transition: one is calculated with the Schmidt g-factor, the other with the measured effective g-factor value [15,16]. The experimental Γ_γ radiation widths were derived on the assumption that $\Gamma_p \approx \Gamma_{total}$. This approximation is supported by the following reasoning. Since the neutron channel is closed in all cases, only the elastic (Γ_p), and inelastic proton width $(\Gamma_{p'})$ and Γ_γ could make an essential contribution to Γ_{total}. However, the measured γ-yield of the $(p,p'\gamma)$ reaction indicates that $\Gamma_{p'} \ll \Gamma_p$. The single particle estimations on the other hand, give values of about 100 eV and 10 eV for the proton widths of the $g_{9/2}$ IAR-s in Cu and Ga isotopes, respectively $\left(\Gamma_p^{IAR} = \frac{S}{2T_o + 1}\,\Gamma_{s.p.}\right)$, hence $\Gamma_\gamma \ll \Gamma_p$, and so the approach $\Gamma_p \approx \Gamma_{total}$ seems to be good.

Comparing the theoretical and experimental Γ_γ values of Fig. 1 and Table 2, it is clearly seen that the IAR-AIAS transition strength is high again in the nuclei with a closed $f_{7/2}$ shell, although the deviation from the single particle estimation increases with the mass number, i.e. with increasing number of nucleons outside the double-closed core. S. Maripuu [5] and M. Hirata [8] have made theoretical calculations to explain the strong hindrance of the IAR-AIAS M1 transition in the lower part of the 1f-2p shell. According to these models the anti-analogue configuration is expected to mix with different core-polarized configurations in which the active nucleons of the double-closed inert part of the core are coupled to a spin J_c different from zero. The admixture of such components can strongly reduce the M1-transition probability. These core-polarized states probably do not play a very important role in the nuclei just above the closed $f_{7/2}$ shell, an assumption supported by the strong reappearance of the IAR-AIAS transitions. On the other hand, the influence of the core-polarized states can keep growing in importance with increasing number of nucleons outside the double-closed inert part of the core, and this is a possible explanation of the decrease of the M1 transition probability. Unfortunately, there is no direct experimental evidence yet, for the existence of core-polarized states in these nuclei, although their presence is indicated by the relatively low values of the spectroscopic factors of AIAS-s measured in proton transfer reactions [17 - 20]. It would be desirable to search for the core-polarized states and to perform shell model calculations according to [5, 8] for this nuclear region.

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FIGURE CAPTION

Fig. 1. Analogue to anti-analogue M1 transition strengths in Weisskopf units. Squares indicate $f_{7/2} \rightarrow f_{7/2}$ transitions; circles $p_{3/2} \rightarrow p_{3/2}$ transitions; triangles $g_{9/2} \rightarrow g_{9/2}$ transitions. The open signs are experimental values [1,2,4,5,9,13,21]; filled signs are values for single-particle transitions with a spinless core calculated with Schmidt g-factors [3].

Table 1

Summary of experimental results

Target	Parent state		AIAS		$E^{Lab}_{p,res.}$	E^{*}_{IAR}	$\Delta E_C^{th.}$	$\Delta E_C^{exp.}$	V_1	$\frac{\Gamma_p \Gamma_\gamma}{\Gamma_{total}}$	$\frac{I_{90^o}}{I_{0^o}}$
	E (keV)	(2J+1)S	E (keV)	$(2J+1)C^2S$	(keV)[a]	(keV)	(keV)[b]	(keV)	(MeV)	(eV)	
^{58}Ni	3071	10.6	3030	3	3538	6898	9441	9408	149	1.0 ±0.09	0.56±0.06
^{60}Ni	2133	8.45	2711	1.4	3719	8458	9326	9326	138	0.82±0.08	0.72±0.08
					3725	8466		9334		0.61±0.07	0.75±0.08
					3735	8476		9346		0.32±0.04	0.56±0.09
^{62}Ni	1299	6.1	2509	2.9	3751	9817	9213	9233	130	0.1 ±0.04	–
					3774	9839		9256		0.21±0.05	–
					3786	9851		9268		0.45±0.05	0.6 ± 0.1
					3790	9855		9272		0.66±0.06	0.6 ± 0.1
					3806	9871		9288		0.24±0.04	0.5 ± 0.15
^{64}Zn	1064	7.8	2034	4	2926	6828	9823	9806	123	0.29±0.05	–
					2937	6839		9817		0.2 ±0.05	–
^{66}Zn	602	8.4	2063	4.62	3335	8550	9712	9729	122	0.32±0.06	–

a/ Error of these values ± 4 keV

b/ see ref. [22]

Table 2

Experimental and theoretical Γ_γ values in W.u. for the M1 $(9/2^+ \rightarrow 9/2^+)$ IAR – AIAS transitions*

	^{59}Cu	^{61}Cu	^{63}Cu	^{65}Ga	^{67}Ga
Experimental	0.83	0.44	0.2	0.21	0.06
Theoretical, calculated with Schmidt g-factors	2.7	1.9	1.5	1.9	1.5
Theoretical, calculated with effective g-factors	1.7	1.2	0.93	1.2	0.93

* The experimental values are summed up for the members of the fine structure splitting.

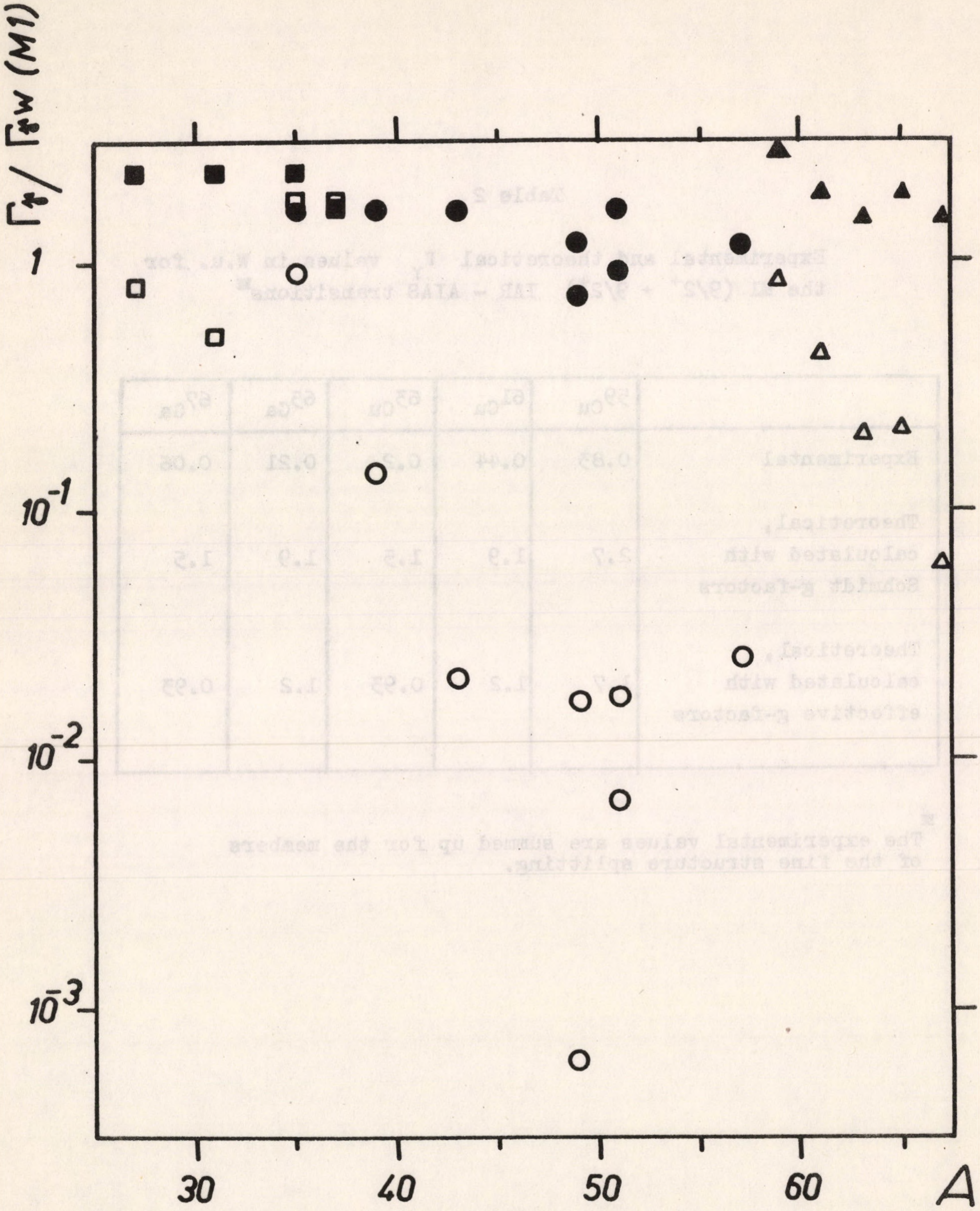

Fig. 1.

Kiadja a Központi Fizikai Kutató Intézet
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