CERN LIBRARIES, GENEVA

SCAN-9601207

500 606

IPNO DRE 95-20

**DECAY OF THE ISOVECTOR GIANT RESONANCES EXCITED IN
CHARGE EXCHANGE REACTIONS.**

I. LHENRY

Institut de Physique Nucléaire, IN2P3-CNRS,
Université Paris-Sud, 91406 Orsay Cedex, France

*Invited talk given at the Groningen Nuclear Physics Conference on
Giant Resonances, June 1995*

Decay of the Isovector Giant Resonances excited in Charge Exchange Reactions.

I. Lhenry

Institut de Physique Nucléaire, 91406 Orsay, France

Abstract : Isovector Resonances are studied through the ($^{13}\text{C}, ^{13}\text{N}-n$) reaction at 60A.MeV incident energy on ^{208}Pb and ^{58}Ni targets. Neutron decay of the resonances observed in these reactions has been measured in coincidence with the ^{13}N ejectile. The measured neutron multiplicity has been used to deduce the contribution of fast processes like Pick-Up Break-Up and Quasi-Free Charge Exchange to the singles spectrum. The analysis of the neutron decay of the observed resonances revealed a direct branch to well defined final states in the residual nuclei, ^{207}Tl and ^{57}Co . In the case of isovector resonances in ^{58}Co , an angular distribution of this direct branch has been extracted. The strong anisotropy observed for this distribution does not appear compatible with the decay of a pure monopole state.

1. INTRODUCTION

The use of heavy ions in charge exchange reactions has prompted the study of isovector resonances in nuclei. Heavy ions projectiles at intermediate energy offer a large range of probes with different spin and isospin and allow to study those resonances in good conditions of selectivity and with suitable energy resolution. In particular, charge exchange reactions at energy higher than 100A.MeV select exclusively the $\Delta S=1$ part of the interaction. Recent progress has been made concerning the properties of the spin-isospin modes and in particular the Gamow-Teller Resonance [1].

Very little is known for the non-spin isovector modes, except of course for the well established Isovector Giant Dipole Resonance (GDR) and Isobaric Analog State (IAS). In order to selectively excite isovector electric resonances, one has to work either with pions [2] or with (n,p) type reactions at energy lower than 100A.MeV and with a projectile-ejectile combination allowing $\Delta S=0$ transitions. In a number of experiments realized under these conditions with various projectiles and targets, broad resonance-like structures are strongly excited [3,4]. Due to the strong selectivity and the fact that the detection was close to zero degrees, favouring low momentum transfers, the structures have been tentatively attributed to the excitation of the Isovector Giant Monopole Resonance. However, no signature of the multipolarity could be given for these states. In addition, there are some discrepancies in the positions and widths of the

resonances in the different experiments in particular in the case of the lead target. Table 1 shows the different parameters for the resonances measured in these experiments.

Table 1

Excitation energy (in the recoil nucleus and in the analog nucleus) and width of the structure (presumably IVGMR) observed in ($^{13}\text{C},^{13}\text{N}$) reaction compared to excitation energy and width of the IVGMR analog state measured in the (π^-, π^0) reaction.

Targets $T_z=T_0$	$(^{13}\text{C},^{13}\text{N})^{\text{a)}$			$(\pi^-, \pi^0)^{\text{b)}$		
	E_x^{res}	E_x^{analog}	Γ	E_x^{res}	E_x^{analog}	Γ
^{60}Ni	22.1 ± 0.8	33.2 ± 0.8	8.1 ± 1.0	22.4 ± 1.7	33.5 ± 1.7	14.7 ± 2.1
^{90}Zr	18.7 ± 2.1	31.8 ± 2.1	4.6 ± 0.8	19.7 ± 2.0	32.8 ± 2.0	15.0 ± 2.1
^{120}Sn	14.7 ± 1.1	33.0 ± 1.1	4.1 ± 0.8	16.0 ± 2.6	34.3 ± 2.6	9.2 ± 2.6
^{208}Pb	16.5 ± 0.6	39.4 ± 0.6	3.1 ± 0.5	7.0 ± 2.8	29.9 ± 2.8	11.6 ± 7.1

a) Ref [4]. b) Ref [2]

Theoretical calculations using Random Phase Approximation [5] are also available. For the lead, they provide values for the mean energy of the IVGMR intermediate between the two experiments' results. In Table 2 are presented the values calculated by Auerbach et al. for the IVGMR, the GDR and the Isovector Giant Quadrupole Resonance (IVGQR).

Table 2

Theoretical predictions for excitation energy of the IVGMR, the GDR and the IVGQR by Auerbach et al. [5]

Targets	IVGMR		GDR		IVGQR	
	E_x^{res}	E_x^{analog}	E_x^{res}	E_x^{analog}	E_x^{res}	E_x^{analog}
^{60}Ni	23.1	34.2	9.1	20.2	21.8	32.9
^{90}Zr	20.6	33.7	5.9	19.0	17.3	30.4
^{120}Sn	17.0	35.3	1.1	19.4	12.6	30.9
^{208}Pb	11.3	34.2	1.9	24.8	7.1	30.

As it has been yet impossible to clearly identify the isovector structures observed in these inclusive experiments, we proposed to use coincidence techniques to measure their multipolarities. Indeed, exclusive experiments are a powerful tool to study giant resonances. First, the investigation of the particle decay of the excited recoil nucleus allows in many cases to separate the processes due to projectile excitation from the direct charge exchange process [6]. It is thus possible in these cases to eliminate an important part of the physical background on which are riding the resonances observed in the energy spectra. Moreover, the decay analysis is crucial to obtain information about the microscopic structure of the resonances. For example, the proton decay study of the GTR allowed to obtain

partial escape widths for the neutron-hole states in the residual nucleus [7], which are in agreement with the latest theoretical predictions by Colo et al. [8]. Finally, as shown in reference [9], the angular distribution of the particle emitted by the recoil nucleus can be characteristic of the multipolarity of the excited mode.

The purpose of our work is to investigate the neutron decay of the structures observed in the ($^{13}\text{C}, ^{13}\text{N}$) reaction by Bérat et al [4] in order to infer their multipolarity. Indeed, if their monopole assignment is correct, the direct neutron decay will be isotropic.

2. EXPERIMENTAL METHOD

Two experiments were carried out at the GANIL accelerator facility using a ^{13}C beam at 60 A.MeV and targets of ^{208}Pb (2.2mg/cm²) then ^{58}Ni (5mg/cm²). The ($^{13}\text{C}, ^{13}\text{N}$) reaction was chosen for the reasons described above, i.e. a (n,p) type reaction allowing the $\Delta S=0$ transition. Moreover, the ^{13}N has no excited state below threshold which eliminates the possibility of mutual excitations. The 60A.MeV incident energy was chosen to be low enough to favour the non-spin modes and high enough to ensure the predominance of the one step process.

The standard detection of the SPEG [10] spectrometer was used in coincidence with the neutron array EDEN [11]. In order to perform zero degree measurements, the spectrometer was set at 1°, covering a horizontal angular domain between -1° and +3°. The vertical angular acceptance was $\pm 2^\circ$. Two drift chambers, located near the focal plane, allowed the trajectory reconstitution and gave access to the scattering angle and momenta of ejectiles. The particle identification was made through a time of flight measurement between a plastic scintillator placed at the end of detection and the cyclotron RF and through the energy loss in an ionization chamber. The energy resolution was 500 keV and the angular resolution was 0.2 °.

The neutrons emitted by the recoil nucleus were detected by the Eden array, a modular ensemble of 40 NE213 liquid scintillator cells. The cells were located around the target, at a distance of 1.75 meters. The chosen configuration consisted of groups of 3 to 6 detectors at 10 different angles located between 80° and 145°, relatively to the beam direction. The covered solid angle was 0.13π . The energy resolution of the detector is less than 50 keV for 1 MeV neutrons, about 500 keV for 5 MeV neutrons and 2 MeV for 15 MeV neutrons.

The detection efficiency was checked in both experiments by measuring the neutron decay of the GDR in ^{12}B excited by the ^{12}C (^{13}C , ^{13}N) reaction. The multiplicity of neutrons decaying from this mode is known to be close to 1. Thus the measurement of the experimental multiplicity in the region of the GDR is a good test of the efficiency of our detection system.

3. RESULTS OF EXPERIMENT WITH ^{208}Pb TARGET

3.1 Inclusive data

Figure 1 shows the angular dependence of the excitation energy spectrum in ^{208}Tl . A peak at 5.8 MeV and a large structure at 17 MeV can be clearly seen,

superimposed on a broad background. As will be discussed later, a large part of this background is due to fast processes.

Figure 1. Excitation energy spectrum of ^{208}Tl from the $^{208}\text{Pb}(^{13}\text{C}, ^{13}\text{N})^{208}\text{Tl}$ reaction at 60 A.MeV, for two angular regions.

It must be mentioned that the target in this experiment was contaminated by some carbon and that the charge exchange on ^{12}C leads to a strong excitation of the GDR that appears in the ^{208}Tl spectrum at 16 MeV, thus mixed up with the 17 MeV structure. This contamination has been estimated to be about 35 % of the cross section in the region of the resonance and its contribution has to be taken into account in all the following studies.

The structure is strongly forward peaked, which is in favour of a $L=0$ resonance. Unfortunately, its angular distribution does not display the diffractive pattern predicted by standard DWBA calculations [4,12]. More sophisticated DWBA calculations by Ichihara et al. are in progress [13] which will be compared to the available data.

3.2 Neutron multiplicity; contribution of fast processes

In this section we are going to show the importance of the decay study to estimate the contribution of the so-called fast processes to the inclusive energy

spectrum. Figure 2 shows the experimental neutron multiplicity function of excitation energy, i.e. at a given energy, the ratio :

$$\frac{\text{number of coincidences}}{\text{number of singles}} * \frac{1}{\text{efficiency}}$$

It is compared to the multiplicity predicted by a statistical calculation using the code CASCADE [14]. This code is based on the Hauser-Feshbach formalism. Transmission coefficients for neutrons have been evaluated using the optical potential of Rapaport. At low excitation energy (≤ 3 MeV), discrete states are taken into account by the calculation. Just above this energy region, the level density has been determined according to the standard parameters from Dilg et al. [15]. At very high excitation energy, the parameters are those predicted by the liquid drop model. The calculation presented in figure 2 was performed for a L=0 multipolarity. The calculations using L=1 or L=2 multipolarity gives very similar results.

Figure 2. Multiplicity calculated with the statistical code CASCADE (solid line) compared to the experimental multiplicity assuming that the complete singles spectrum arises from states excited by the charge exchange process.

An important discrepancy is observed between the two curves which can be explained by the presence of fast processes in the singles spectrum. Indeed, the experimental multiplicity determined as explained above implies that all events of the singles spectrum decay by the emission of statistical neutrons. But some fast processes can contribute to the singles spectrum and have a very directional neutron emission not seen by our detection system. The singles events coming from these processes would thus give no (or little) detectable decay and lower experimental multiplicity.

3.3 Decay analysis of ^{208}Tl

In the following, the analysis of the decay of ^{208}Tl will be described. The measurement of the emitted neutron energy, combined with the measurement of excitation energy of ^{208}Tl , allows to reconstruct the residual energy in ^{207}Tl after the decay i.e. in this case the energy of proton-hole states in ^{207}Tl . Figure 4 shows the final energy in ^{207}Tl , obtained after gating on three different energy regions in ^{208}Tl . Each spectrum is compared to the result of a statistical calculation obtained with the code CASCADE described above. The calculation was normalized in order to never overshoot the experimental cross section. The data not reproduced by the statistical calculation are attributed to a direct decay.

Figure 4. Final energy spectrum in ^{207}Tl for 3 excitation energy bins in ^{208}Tl (histogram for a, d and data points for b, c). The dashed lines show the result of the statistical calculation (code CASCADE). Spectra a, b and c correspond to the experimental range ($0 < \theta < 2.5^\circ$).

Figure 4.a shows the final state energy spectrum from the de-excitation of the 5.8 MeV state in ^{208}Tl . The decay to the proton-hole state at 1.5 MeV has a direct component but the statistics are too low to obtain a multipolarity assignment. Figure 4.b shows that above 25 MeV excitation energy in ^{208}Tl , the decay is almost exclusively statistical.

The decay of the structure at 17 MeV is shown in figure 4.c. It is mainly statistical but however 10 % of direct decay is evidenced, feeding a group of proton-hole states centered at 5.5 MeV and corresponding to the $2g_{7/2}$ proton-hole configuration [18]. Moreover, if we take into account the fact that the 17 MeV resonance disappears at angles larger than 1° , the subtraction of the decay spectrum measured for large scattering angles ($\theta > 1^\circ$) from the decay measured at small angles ($\theta < 1^\circ$) should eliminate a large part of the decay originating from the underlying continuum excited at this energy. Figure 4.d shows the subtracted final energy spectrum. The proportion of non-statistical decay is estimated to be 16%. This number needs to be corrected because the statistical decay is overestimated due to the above-mentioned carbon contaminant in the target. The final result for the direct decay of the 17 MeV resonance is $22 \pm 6\%$. Assuming that the 17 MeV structure is due to a single resonance with a 3 MeV width, the escape width would be 660 keV, that is much lower than the theoretical prediction by Colo et al. New calculations are in progress [19].

Due to weak statistics, no significant angular distribution of direct neutrons could be obtained and thus the identification of the mode was not possible. But the feasibility of the experiment with this target was proven and the statistics necessary can be now estimated in order to obtain in the near future the angular distribution of this direct branch.

4. RESULTS OF EXPERIMENT WITH ^{58}Ni TARGET

The second experiment was performed with a ^{58}Ni target in the same conditions but with much better statistics.

4.1. Inclusive data

Figure 5 shows the angular dependence of the excitation energy spectrum for ^{58}Co . At low energy, a peak at 2 MeV, very forward peaked, is observed. The ground state is only weakly excited. At higher excitation energy, two structures, a few MeV wide, are superimposed on a large bell-shaped physical background. The first one is the well known GDR. It has two main components, one at 10.6 MeV and another at 13.0 MeV, both 2 MeV wide. The second structure at 24 MeV, was the one interpreted by Bérat et al. as the Isovector Giant Monopole Resonance. In contrast with the lead experiment, no strong angular dependence in the experimental angular domain can be observed. In this case, the very large background makes the extraction of the angular distribution very delicate. One needs to go through to the coincidence analysis to obtain more information about these structures.

$^{58}\text{Ni}(^{13}\text{C}, ^{13}\text{N})^{58}\text{Co}$ 60 A.MeV

Figure 5. Excitation energy spectrum of ^{58}Co from the $^{58}\text{Ni}(^{13}\text{C}, ^{13}\text{N})^{58}\text{Co}$ reaction at 60 A.MeV, for three angular regions.

4.2. Neutron multiplicity; contribution of fast processes

First, as in the lead case, it is important to have an estimation of the contribution of the background due to fast processes. Figure 6 shows the experimental multiplicity as a function of excitation energy, obtained by the same method as in 3.2. It is compared to the one given by the statistical code CASCADE assuming $L=0,1,2$ multiplicities [14].

Figure 6. Multiplicity calculated with the statistical code CASCADE (solid line) compared to the experimental multiplicity assuming that the complete singles spectrum arises from states excited by the charge exchange process.

In contrast with the lead, the experimental curve follows very well the statistical one until 20 MeV. Around 22 MeV, in the region of the structure, a direct decay (i.e. a region where the experimental multiplicity is not entirely reproduced by the calculation) is clearly seen in the data. Above 25 MeV, a discrepancy between the two curves can be seen, increasing with the excitation energy. This is clearly the sign of the contribution of a fast process, i.e. PUBU, in the single spectrum as described in 3.2. The same analysis as for the lead allowed to estimate this contribution. The deduced cross section due to such processes was extracted and fitted using the shapes calculated for the PUBU and the QFCE. As this background is very low below 25 MeV, and as the QFCE is calculated [17] to be maximal at 20 MeV, its contribution has to be negligible. The presence of this process would be only possible if the corresponding neutrons were seen by all our detectors which is highly improbable according to the kinematics. Moreover the probability for QFCE to occur is proportional to the number of protons and thus is lower for nickel than for lead. Figure 7 shows the total singles spectrum with the estimated contribution of PUBU.

Figure 7. Inclusive excitation energy spectrum in ^{58}Co (histogram). The solid line shows the contribution of Pick-Up Break-Up.

4.3. Decay analysis of ^{58}Co

Three excitation energy regions in ^{58}Co have been chosen for the decay study. First the final energy in the residual ^{57}Co corresponding to the region of the GDR (9.5 - 12.5 MeV) is shown figure 8.a. It is compared to the CASCADE calculation performed for a $L=1$ multipolarity. This comparison shows a direct decay of the GDR to the ground state of ^{57}Co i.e. to the $1f_{7/2}$ proton-hole state.

For the energy region between 45 and 55 MeV, the decay is very well reproduced by the statistical calculation (figure 8.b).

The region of the 24 MeV bump shows a dominant statistical decay but about 20% of direct decay is observed (figure 8.c). One may notice that this resonance feeds strongly the ground state of ^{57}Co . It is important to notice that the energy resolution of the 15 MeV neutrons populating the ground state is about 2 MeV. Despite this poor energy resolution, if the structure corresponds to a monopole resonance, the neutron angular distribution has to be isotropic independently of the final state reached in ^{57}Co .

Figure 9.a shows the angular distribution in the laboratory frame of the neutrons corresponding to the statistical decay of the 24 MeV structure, whereas Figure 9.b shows the distribution for the direct decay. The distribution of statistical decay is compatible with isotropy as it is expected. On the contrary, the direct decay has a very strong anisotropy which is in contradiction with the decay of a monopole mode. One has to be very cautious before reaching a final conclusion based on this observation.

Figure 8. Final energy spectrum in ^{57}Co for 3 excitation energy bins in ^{58}Co (histogram). The dashed lines show the result of the statistical calculation (code CASCADE).

Figure 9. Angular distribution of neutrons emitted by the recoil nucleus (^{58}Co) in the region of the 24 MeV structure. θ_{lab} is the angle of the neutron respectively to the beam in the laboratory frame.

The first point to check is that the laboratory to center of mass transformation will not distort the observed angular distribution. This effect has been evaluated through kinematics and was found to be smaller than the error bars. The second point is to ensure that the distribution is not contaminated by neutrons originating from the tail of QFCE process. The QFCE seems to be very unlikely as discussed above. Moreover the angular distribution given by simulations for this process would not predict the observed anisotropy. Analysis is still in progress concerning the interpretation of these results. It is clear that if no other processes pollute our decay data, the dominant monopole nature of the mode can be surely rejected. The next step will be to analyze the angular distribution and to deduce the multipolarity of the decaying resonance. Angular correlation calculations in the laboratory frame are in progress.

5. CONCLUSION

Neutron decay of the giant isovector resonances observed in ($^{13}\text{C},^{13}\text{N}$) reactions at 60 A.MeV, on ^{208}Pb and ^{58}Ni targets, has been measured. The purpose of the experiment was to extract from the direct branch of the neutron decay, an angular distribution that would allow to sign the multipolarity of these resonances.

In the case of the lead target, the statistics were too low to obtain a signature, but about 22% of direct decay was extracted, showing the feasibility of the experiment. The corresponding partial escape width, assuming an isolated resonance, was found to be 660 keV, which is much under the theoretical predictions given by the RPA calculations available.

In the case of the nickel target, 20% of direct decay were measured in the region of the 24 MeV structure, with statistics large enough to extract an angular correlation for this branch. This correlation is strongly anisotropic, which is incompatible with the decay of a monopole resonance. Before concluding firmly on this result, theoretical angular correlations calculated in the laboratory frame have to be made and compared to the experimental data. This should allow us to determine the multipolarity of the 24 MeV Isovector resonance in ^{58}Co .

I wish to acknowledge my colleagues from the IPN ORSAY: D. Beaumel, S. Fortier, S. Gales, H. Laurent, J. M. Maison, Y. Blumenfeld, J. Guillot, H. Langevin-Joliot, T. Suomijärvi and G. M. Crawley from MSU for their participation in the experiments and for numerous discussions.

REFERENCES

- [1] F. Osterfeld, Int. Rev. of Nucl. Phys. 7 (1991) 535 and ref. therein
- [2] A. Erell et al., Phys. Rev. C34 (1986)1822
- [3] T. D. Ford et al., Phys. Lett. B195 (1987)311
- [4] C. Bérat et al., Phys. Lett. B218 (1989) 299;
C. Bérat et al., Nucl. Phys. A555 (1993)455
- [5] N. Auerbach et A. Klein, Phys. Rev. C28 (1983) 2075

- [6] J. A. Scarpaci et al., Phys. Lett. B258 (1991),279
- [7] Fujiwara et al, proceedings of this conference
- [8] J. L. Colo et al., Phys. rev. C50 (1994) 1496
- [9] N. Sholz et al., Z Phys. A344 (1993)269
- [10] L. Bianchi et al., Nucl. Instrum. Meths. A236(1989) 509
- [11] H. Laurent et al., Nucl. Instrum. Meths. A276(1993) 517
- [12] I. Lhenry et al., Proceedings of Tours Symposium on Nuclear Physics II, Sept 1994, Tours, France, 512
- [13] T. Ichihara, Proceedings of the same conference
- [14] F. Pühlofer, Nucl. Phys. A280 (1977) 267
- [15] W. Dilg et al., Nucl. Phys. A217 (1973) 269
- [16] E. Adamides et al., Nucl. Phys. A475 (1987) 598
- [17] J. Jänecke et al., Phys. Rev. C48 (1993)2828
- [18] H. Langevin-Joliot et al., J. Phys. G10 (1984) 1435
- [19] J. L.Colo , private communication