# DIRECT DETERMINATION OF THE ALIGNMENT OF PROJECTILE FRAGMENTS FROM A $\beta$-ANISOTROPY LEVEL MIXING RESONANCE (LMR) MEASUREMENT * **

N. Coulier[a], G. Neyens[a], S. Ternier[a], K. Vyvey[a], S. Michiels[a], R. Coussement[a], D.L. Balabanski[b], J.M. Casandjian[c], M. Chartier[c], M.D. Cortina-Gil[c], M. Lewitowicz[c], W. Mittig[c], A.N. Ostrowski[c], P. Roussel-Chomaz[c], N. Alamanos[d] and A. Lépine-Szily[e]

[a]Instituut voor Kern- en Stralingsfysica, University of Leuven, Celestijnenlaan 200 D, B-3001 Leuven, Belgium.
[b]Faculty of Physics, St. Kliment Ohridsky University of Sofia, J. Bourchier Str. 5, BG-1164 Sofia, Bulgaria.
[c]Grand Accélérateur National d'Ions Lourds, B.P. 5027, F-14021 Caen Cedex, France
[d]Dapnia/SPhN, Batiment 703, Orme de Merisiers, C.E. Saclay, F-91191 Gif-sur-Yvette Cedex, France
[e]Institute of Physics, University of São Paulo, C.P. 66318, 05389-970, São Paulo, Brasil

*(Received December 10, 1996)*

Using the Level Mixing Resonance (LMR) interaction, which converts alignment into polarization, the nuclear spin aligment of $^{12}$B produced in two different fragmentation reactions at intermediate energy (respectively $^{13}$C onto a $^{12}$C target and $^{22}$Ne onto a $^{9}$Be target) was determined by measuring the $\beta$-anisotropy. The nuclear spin alignment of $^{18}$N fragments, produced in the $^{22}$Ne reaction was measured for different selections in the longitudinal fragment momentum distribution. In the same measurement the ratio of the quadrupole frequency to the magnetic moment $\frac{\nu_Q}{\mu}$ of neutron rich $^{18}$N fragments implanted in Mg was found to be an order of magnitude larger compared to simple shell model calculations.

PACS numbers: 23.20. En, 24.70. +s, 21.10. Ky, 27.20.+n

---

* Presented at the XXXI Zakopane School of Physics, Zakopane, Poland, September 3–11, 1996.

** This work is partially financed with grants for N.C. and S.T. from the Flemish Institute for Promotion of the Scientific and Technological Research in the Industry (I.W.T.), and by the Belgian National Science Foundation (N.F.W.O.) of which G.N. is a post-doctoral researcher. D.L.B. was supported in part by the Bulgarian National Science Foundation under Research Contract No.$\phi$-301.

## 1. Introduction

High- and intermediate-energy projectile fragmentation reactions have recently proved to be a powerful mechanism to produce light nuclei far from stability which can be separated by large recoil separators. Spin aligned fragments produced in such a reaction open a scope of possibilities for spectroscopic studies. The Level Mixing Resonance (LMR) [1] method, formerly used to measure the quadrupole frequency of long-lived low-spin states which decay by $\gamma$-radiation [2, 3], has recently been extended for $\beta$-decaying nuclei produced and aligned in a fragmentation reaction [4]. With the LMR method both the initial alignment and the quadrupole frequency of the fragments are measured at the same time. The first LMR measurements were performed at the SPEG [5] and LISE3 [6] spectrometers at GANIL. Because all the spectroscopic parameters of $^{12}$B $\left(I^\pi = 1^+,\, T_{\frac{1}{2}} = 20.20\text{ ms},\, Q_\beta = 13.4\right.$ MeV, $\left.\mu = 1.003\,\mu_N,\, \nu_Q = 46.5\text{ kHz [7, 8]}\right)$ and its implantation behaviour in a Mg hcp-single crystal are known, this is a good candidate for a first LMR measurement. The only unknown parameter in this measurement is the initial alignment of the $^{12}$B nuclei produced in a fragmentation proces. In the case of $^{18}$N $\left(I^\pi = 1^-,\, T_{\frac{1}{2}} = 624(12)\text{ ms},\, Q_\beta = 9.4(4)\text{ MeV [9]}\right)$ the magnetic and the quadrupole moment are not known. From a level mixing resonance we can extract the ratio $\frac{\nu_Q}{\mu}$ and the initial alignment of the $^{18}$N as independent fit parameters.

## 2. Experimental method

The Level Mixing Resonance (LMR) method [1, 4] is a method which uses a combined magnetic dipole and electric quadrupole interaction to determine the alignment of a nuclear spin ensemble and to study the quadrupole moment of their nuclear state. In the level mixing region, due to a combined magnetic dipole and electric quadrupole interaction, a resonant change of alignment (A) into polarization (P) takes place. This change only occurs when a small angle $\beta$ has been put between the direction of the external magnetic field (B) (magnetic interaction) and the axis of the Electric Field Gradient (EFG) (quadrupole interaction). The exchange in orientation induces a $\beta$-anisotropy, which changes resonantly as a function of the strength of the applied magnetic field. From the position of the resonance, the ratio of the quadrupole frequency to the magnetic moment can be determined very accurately. At the same time we can extract the initial alignment of the projectile fragments from the amplitude of the resonance if the radiation parameter $A_1$ is known.

In all the experiments the fragments emitted in the forward direction (at zero degrees with respect to the primary beam direction) were selected because they are expected to have an amount of spin alignment [10, 11]. The $^{12}$B and $^{18}$N fragments were implanted in a Mg single crystal which provides the EFG. The crystal is positioned between two coils which produces the magnetic field. To measure the $\beta$-anisotropy two scintillation detectors, one at 0° and one at 180° with respect to the magnetic field direction, are placed close to the Mg crystal.

## 3. Results and discussion

The polarization measured as a function of the magnetic field for $^{12}$B is shown in Fig. 1a for the $^{13}$C fragmentation reaction and in Fig. 1b for the

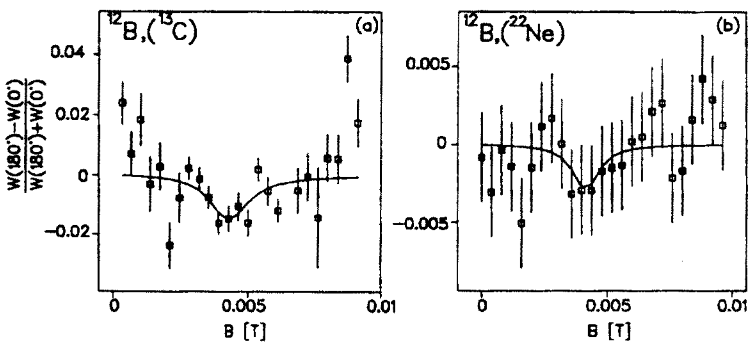


Fig. 1. Polarization as a function of the applied magnetic field in the case of $^{12}$B produced in a fragmentation reaction of $^{13}$C(75 MeV/n) onto a $^{12}$C target (35mg/cm$^2$) (a) and $^{22}$Ne (60 MeV/n) onto a $^9$Be target (185.5 mg/cm$^2$) (b).

$^{22}$Ne fragmentation reaction. We see that in both cases the resonance occurs at the expected magnetic field of 4.6 mT but in the $^{13}$C-reaction an alignment of 4.7(1.6)% and in the $^{22}$Ne-reaction an alignment of only 0.9(0.7)% was found. As expected the alignment decreases drastically if the fragment nuclei differ by many nucleons from the primary beam nuclei. The resonant change of the $\beta$-anisotropy as a function of the external magnetic field of the $^{18}$N fragments, selected from the center of the momentum distribution is shown in Fig. 2a, and selected from the high energy wing of the momentum distribution in Fig. 2b. The nuclear spin alignment found after a selection of fragments in the center of the momentum distribution is found to be 14.4(1.5)%. Selecting the $^{18}$N fragments from the high energy wing of the momentum distribution gives us a nuclear spin alignment of only

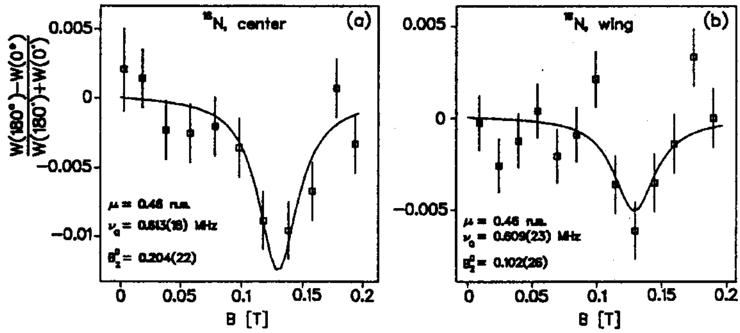


Fig. 2. Polarization as a function of the applied magnetic field in the case of $^{18}$N produced in a fragmentation reaction of $^{22}$Ne (60 MeV/n) onto a $^{9}$Be target (185.5 mg/cm$^2$) selecting the center (a) and selecting the upper wing of the momentum distribution (b).

7.2(1.6)%. In both measurement the position of the resonance was fitted to the ratio of the quadrupole frequency to the magnetic moment. This ratio was determined to be $1.328(33)\frac{MHz}{\mu_N}$. Shell model calculations for a pure $^{18}\mathrm{N}(\pi 0p_{\frac{1}{2}}^{-1}\nu 0d_{\frac{3}{2}})_{1^-}$ configuration [9–12] predict a ratio which is a factor of 10 smaller. The big difference can be explained by configuration mixing [13] and possibly a large deformation for the $^{18}$N ground state [14]. A measurement of $\mu$, combining LMR and $\beta$-NMR is planned for the future and will allow the determination of the quadrupole deformation.

## 4. Conclusions

The LMR-method looks a very promising method to study nuclear moments of $\beta$-decaying projectile fragments using the alignment produced by the reaction and without the need for a selection of a polarized fragment beam. The alignment induced by the fragmentation proces on the forward scattered fragments can be extracted directly from the measured $\beta$-anisotropy induced by the LMR interaction.

## REFERENCES

[1] R. Coussement *et al.*, *Hyperfine Interact.* **23**, 273 (1985).
[2] R. Coussement *et al.*, *Hyperfine Interact.* **35**, 993 (1987).

[3] G. Scheveneels *et al.*, *Hyperfine Interact.* **52**, 179 (1989).
[4] G. Neyens *et al.*, *Nucl. Instrum. Methods Phys. Res., Sect. A* **340**, 555 (1994).
[5] L. Bianchi *et al.*, *Nucl. Instrum. Methods Phys. Res., Sect. A* **276**, 509 (1989).
[6] J.P. Dufour *et al.*, *Nucl. Instrum. Methods Phys. Res.* **248**, 267 (1986).
[7] P. Raghavan, *At. Data and Nucl. Data Tables* **42**, 189 (1989).
[8] F.D. Correll *et al.*, *Hyperfine Interact.* **4**, 544 (1978).
[9] J.W. Ollness *et al.*, *Nucl. Phys.* **A373**, 13 (1982).
[10] K. Asahi *et al.*, *Phys. Lett* **B251**, 488 (1990).
[11] K. Asahi *et al.*, *Phys. Rev.* **C43**, 456 (1991).
[12] K.L.G. Heyde, *in The Nuclear Shell Model, 2nd. Edition*, Springer-Verlag, New York Berlin Heidelberg 1994.
[13] G. Neyens *et al.*, *Phys. Lett.* **B** (1996) in press.
[14] S.K. Patra, *Nucl. Phys.* **A559**, 173 (1992).