PHYSICAL REVIEW C **83**, 061304(R) (2011)

Collectivity in ^{41}S

Z. M. Wang,[1,*,†] R. Chapman,[1] F. Haas,[2] X. Liang,[1] F. Azaiez,[3] B. R. Behera,[4] M. Burns,[1] L. Corradi,[4] D. Curien,[2] A. N. Deacon,[5] Zs. Dombrádi,[6] E. Farnea,[7] E. Fioretto,[4] A. Gadea,[4] A. Hodsdon,[1] F. Ibrahim,[3] A. Jungclaus,[8] K. Keyes,[1] V. Kumar,[1] A. Latina,[4] N. Mărginean,[4,9] G. Montagnoli,[7] D. R. Napoli,[4] J. Ollier,[1,10] D. O'Donnell,[1,11] A. Papenberg,[1] G. Pollarolo,[12] M.-D. Salsac,[13] F. Scarlassara,[7] J. F. Smith,[1] K. M. Spohr,[1] M. Stanoiu,[9] A. M. Stefanini,[4] S. Szilner,[4,14] M. Trotta,[4] and D. Verney[3]

[1]*School of Engineering, University of the West of Scotland, Paisley, PA1 2BE, United Kingdom and the Scottish Universities Physics Alliance (SUPA)*
[2]*IPHC, CNRS-IN2P3 and Université de Strasbourg, F-67037 Strasbourg Cedex 2, France*
[3]*IPN, CNRS-IN2P3 and Université Paris-Sud, F-91406 Orsay Cedex, France*
[4]*INFN, Laboratori Nazionali di Legnaro, I-35020 Legnaro, Padova, Italy*
[5]*Schuster Laboratory, University of Manchester, Manchester, M13 9PL, United Kingdom*
[6]*ATOMKI, P.O. Box 51, H-4001 Debrecen, Hungary*
[7]*INFN-Sezione di Padova and Dipartimento di Fisica, Università di Padova, I35131 Padova, Italy*
[8]*Instituto de Estructura de la Materia, CSIC, E-28006 Madrid, Spain*
[9]*Horia Hulubei National Institute of Physics and Nuclear Engineering, Strasse Atomistilor 407, P. O. BOX MG-6, Bucharest, Romania*
[10]*STFC Daresbury Laboratory, Warrington, WA4 4AD, United Kingdom*
[11]*Department of Physics, University of Liverpool, Liverpool, L69 7ZE, United Kingdom*
[12]*Dipartimento di Fisica Teorica, Universitá di Torino, and INFN-Sezione di Torino, Via P. Giuria 1, I-10125 Torino, Italy*
[13]*CEA-Saclay, Service de Physique Nucléaire, 91191 Gif-sur-Yvette, France*
[14]*Ruder Bošković Institute, Zagreb, Croatia*

(Received 30 November 2010; published 27 June 2011)

Yrast states in the neutron-rich ^{41}S nucleus have been studied using binary grazing reactions produced by the interaction of a 215-MeV beam of ^{36}S ions with a thin ^{208}Pb target. The magnetic spectrometer, PRISMA, and the γ-ray array, CLARA, were used in the measurements. γ-ray transitions of energy 449 and 638 keV were observed. Results from published intermediate-energy Coulomb excitation measurements in combination with those from the present work have led to the construction of a new ^{41}S level scheme. Proposed J^{π} values are based on experimental observation and on model-dependent arguments. The level scheme and published electromagnetic transition probabilities are discussed within the context of state-of-art shell-model calculations using the SDPF-U effective interaction. In contrast with the excellent agreement observed in earlier published work, here there are significant discrepancies between experiment and the results of shell-model calculations.

DOI: 10.1103/PhysRevC.83.061304 PACS number(s): 23.20.Lv, 21.10.Re, 25.70.Lm, 27.40.+z

Introduction. The isotopes of Mg, Si, S, and Ar, which lie at the $N = 20$ and 28 shell closures, have been the subject of much experimental and theoretical activity. The $N = 20$ isotopes exhibit rapid changes in nuclear structure; thus the first 2^+ state of "semi-magic" $^{32}_{12}$Mg$_{20}$ has a low energy and a large quadrupole deformation [1–3] with large $2p$-$2h$ configurations in its wave function [4–12], while the recently observed 0^+ state at 1058 keV is believed to be spherical [13]. On the other hand, $^{34}_{14}$Si$_{20}$, two protons removed, has a spherical ground state with a $2p$-$2h$ intruder 0^+ state, yet unobserved, at a predicted excitation energy of 3.0 MeV in the work of Caurier *et al.* [10], and at about 2 MeV in the work of Otsuka *et al.* [8] and of Ibbotson *et al.* [14]. The large energy gap between the proton $1d_{3/2}$ and $2s_{1/2}$ orbitals leads to $^{36}_{16}$S$_{20}$ having the characteristics of a doubly magic nucleus; nevertheless $2p$-$2h$ configurations also play an important role in reproducing the spectrum of ^{36}S excited states in shell-model calculations [15]. Similarly, there is evidence that the size of the $N = 28$ shell gap is reduced south of doubly magic $^{48}_{20}$Ca. $^{42}_{14}$Si$_{28}$ has a low 2_1^+ energy [16], consistent with shell quenching and there is evidence for shape coexistence in $^{44}_{16}$S$_{28}$ [17]. In $^{46}_{18}$Ar$_{28}$, the suggested 0_2^+ state at 2710 keV is expected to have a $2p$-$2h$ configuration [18].

Turning now to the isotopes of sulfur, the measured $B(E2; 0^+_{\rm g.s.} \rightarrow 2_1^+)$ values for the even-A isotopes show an increase in quadrupole deformation with increasing neutron number, reaching a maximum at $N = 26$, $^{42}_{16}$S$_{26}$ [19,20]. This has been attributed to the decrease in the energy separation of the proton $1d_{3/2}$ and $2s_{1/2}$ states with increasing neutron number, which is a result of the monopole component of the tensor interaction [21,22] between neutrons in the $1f_{7/2}$ shell and protons in the $1d_{3/2}$ shell. A pseudo-SU(3) symmetry results [23]. In addition, as neutrons are added to the $1f_{7/2}$ shell, there is a tendency for the nucleus to adopt a quadrupole

*Present address: Department of Chemistry, Simon Fraser University, Burnaby, British Columbia, Canada V5A 1S6; TRIUMF, 4004 Wesbrook Mall, Vancouver, British Columbia, Canada V6T 2A3.
†zmwang@triumf.ca

deformation in order to remove the degeneracy associated with the filling of the $1f_{7/2}$ shell. This is the nuclear analog of the Jahn-Teller effect [24,25].

It is within the above context of a rich and varied nuclear landscape that we have recently been studying the spectroscopy of neutron-rich Si, P, S, and Cl isotopes using binary grazing reactions [15,26–30]. There is, in addition, a paucity of experimental information for neutron-rich nuclei lying between $N = 20$ and 28. Here, we focus on the low-lying yrast structure of ^{41}S.

Excited states of $^{41}_{16}S_{25}$ have previously been studied in β decay [31] and in β-delayed neutron decay [32]. The adopted level scheme [33] is based on intermediate-energy Coulomb excitation of 47.4 A MeV ^{41}S nuclei, produced in the fragmentation of a ^{48}Ca beam at the National Superconducting Cyclotron Laboratory at Michigan State University (MSU) [34]. γ-ray transitions were observed at energies of 449(8) and 904(16) keV with $B(E2\uparrow)$ values of 167(65) and 232(56) $e^2 fm^4$, respectively.

Binary grazing reactions with stable neutron-rich beams and heavy targets can be used to populate yrast and near yrast states of moderately neutron-rich nuclei [35–37] and, in general, as a consequence of the reaction mechanism, experiments using such reactions provide more detailed spectroscopy, to spins of the order of 30 $\hbar$ in heavy binary partners [38,39] and around 6 $\hbar$ [29] in the mass range of interest here, than is currently possible using intermediate-energy Coulomb excitation. In the latter process, the few states that are normally populated are those which are connected directly to the ground state by $E2$ transitions.

Here, the yrast decay sequence of ^{41}S, populated in binary grazing reactions, has been studied. We have exploited the combination of a large acceptance magnetic spectrometer, PRISMA [40], and a high-granularity and high-efficiency γ-ray detection array, CLARA [41], which allows good reaction channel selection and precise Doppler correction of γ-ray energy spectra.

Experiment. Yrast states of the $N = 25$ nucleus ^{41}S were populated using binary grazing reactions produced in the interaction of a 215-MeV beam of $^{36}S^{9+}$ ions, delivered by the Tandem-ALPI accelerator complex at the INFN Legnaro National Laboratory, Italy, with a thin ^{208}Pb target. The target, isotopically enriched to 99.7% in ^{208}Pb, was of thickness 300 μg cm^{-2} on a 20 μg cm^{-2} carbon backing. Projectile-like fragments produced during the reaction were analyzed with PRISMA [40], a large acceptance-angle magnetic spectrometer placed at 56° to the beam axis, and covering a range of angles including the grazing angle of the reaction (58°). γ rays from the deexcitation of both (projectile and ejectile) binary reaction products were detected using CLARA [41], an array of 25 escape-suppressed Ge clover detectors (22 Ge clover detectors were used during the present work). Gamma rays were detected in time coincidence with projectile-like fragments identified at the focal plane of the PRISMA spectrometer, thereby providing an unambiguous association of γ rays with each projectile-like binary fragment of a particular A and Z. CLARA was positioned in the hemisphere opposite to the PRISMA spectrometer and covering the azimuthal angles from 98° to 180° with respect to the entrance aperture of PRISMA. Doppler correction of γ-ray energies was performed on an event-by-event basis. Details of the experimental equipment used here have been given in earlier publications, e.g., Ref. [29]. Experimental data were accumulated during a six-day run with an average beam current of 60 *e*nA.

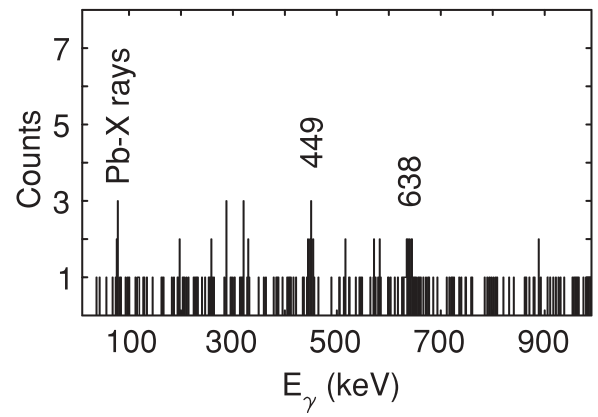

FIG. 1. γ-ray energy spectrum observed in coincidence with ^{41}S ions.

Results and Discussion. In the present experiment, a wide range of nuclear species, from Na ($Z = 11$) to Mn ($Z = 25$), was identified at the focal plane of PRISMA. Here, we focus on a discussion of ^{41}S. ^{41}S was weakly populated in the present study in a five-neutron transfer reaction. Only $\sim$ 100 coincidence events of ^{41}S ions and γ rays were obtained; this corresponds to about 5% of the total number of ^{41}S ions detected at the focal plane. Figure 1 presents the γ-ray energy spectrum measured in coincidence with ^{41}S ions identified at the focal plane of PRISMA. The γ-ray spectrum has two very weak photopeaks at energies of 449(2) and 638(2) keV, with areas of 11$\pm$5 and 14$\pm$5 counts, respectively. As noted earlier, the 449-keV γ-ray transition was previously identified by Ibbotson *et al.* [34].

In making assignments to the level scheme of ^{41}S, we have been guided by the observation that, in deep-inelastic processes, it is the yrast states that are predominantly populated [15,29,35,36,43]. The relative γ-ray intensities of the 449-keV and 638-keV transitions cannot be used to order the two γ-ray transitions within the level scheme, if they are in coincidence, since the relative transition intensities are the same, within experimental errors. In the present study, we follow the assignments based on the published Coulomb excitation experiment [34], i.e., the 449-keV γ ray corresponds to a transition to the ^{41}S ground state. The 904-keV γ-ray transition, observed in the Coulomb excitation experiment, was not observed in the present work; the low statistics of the ^{41}S reaction channel combined with the relatively low γ-ray detection efficiency at 904 keV might be the reason for the nonobservation. In addition, the 904-keV state will be relatively weakly populated in the present experiment if it is not yrast. The absence of a strong γ-ray photopeak at an energy of 638 keV in the γ-ray spectrum of Ibbotson *et al.* [34] indicates that this transition does not correspond to an $E2$ transition connected directly to the ground state of

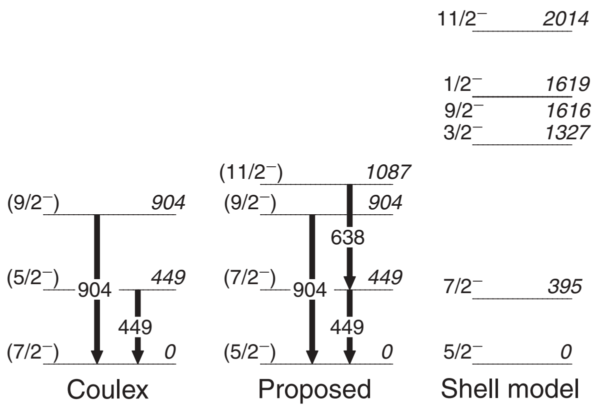

FIG. 2. A comparison of the published level scheme, the proposed ^{41}S level scheme based on the intermediate-energy Coulomb excitation measurement [34] and the present experiment, and the result of the $0\hbar\omega$ *sd*-*pf* shell-model calculation with the latest SDPF-U effective interaction [42]. See text for details.

^{41}S. Although Coulomb excitation populates states primarily through $E2$ excitation from the nuclear ground state, $E1$ or $M1$ excitation is also possible. Ibbotson *et al.* [34] have argued that any strong same-parity transitions observed in their study of ^{41}S can reasonably be assumed to result from $E2$ excitations and that, since $E1$ strengths are generally of the order of 10^{-4} W.u., no strong $E1$ excitations will be observed. However, the possibility of $E1$ excitations cannot entirely be ruled out. So, while we are unable to dismiss the possibility that the 638-keV transition is connected directly to the ground state of ^{41}S, it is much more likely that it corresponds to the deexcitation of an yrast state at 1087 keV which decays to the 449-keV first excited state. The proposed ^{41}S level scheme, based on the above considerations, is presented in the second column of Fig. 2. In constructing the level scheme, we have relied on the results of the Coulomb excitation experiment to order the 449- and 638-keV transitions.

In a simple shell-model picture, five neutrons occupy the $1f_{7/2}$ shell in the ^{41}S ground state with a J^π value of $7/2^-$. The ground state of ^{41}S was indeed assigned a J^π value of $(7/2^-)$ in the MSU work [34], based on this expectation. On the other hand, the results of $0\hbar\omega$ shell-model calculations give a ground state J^π value of $5/2^-$. The shell-model calculations presented here have been performed using the ANTOINE code [44,45] with the most recent *sd*-*pf* residual interaction (SDPF-U) [42]; the full *sd*(*fp*) valence space has been used for protons (neutrons). We note that the $N = 25$ isotone, $^{43}_{18}\mathrm{Ar}_{25}$, has an established ground-state J value of 5/2 [46]. Here, we have adopted a ground-state J^π value of $5/2^-$ for ^{41}S, as shown in the level scheme of Fig. 2. This assignment is based on a model-dependent argument.

The proposed level scheme of ^{41}S is based on experimental observations and on reaction population characteristics and the proposed J^π assignments are aided by model-dependent arguments. A comparison of the level scheme, column 2 of Fig. 2, with the results of shell-model calculations, column 3 of Fig. 2, would suggest an association of the first excited state at an energy of 449 keV with the $J^\pi = 7/2^-$ shell-model state at 395 keV. We propose here that the two close-lying states

TABLE I. A comparison of level energies and $B(E2)$ values [34] with the results of shell-model (SM) calculations for the ^{41}S nucleus. See text for details.

E_f (Exp) keV	E_f (SM) keV	$J_i \to J_f$ $\hbar$	$B(E2)$ (SM) $e^2 fm^4$	$B(E2)$ (Exp) $e^2 fm^4$
449	395	$5/2^- \to 7/2^-$	180	167(65)
904	1616	$7/2^- \to 9/2^-$	116	
		$5/2^- \to 9/2^-$	76	232(56)
1087	2014	$9/2^- \to 11/2^-$	86	
		$7/2^- \to 11/2^-$	127	

at excitation energies of 904 and 1087 keV are counterparts of the shell-model yrast states with $J^\pi = 9/2^-$ and $11/2^-$ at excitation energies of 1616 and 2014 keV, respectively. We would not expect to populate the experimental counterparts of the shell-model state with $J^\pi = 1/2^-$ at an excitation energy of 1619 keV and that at 1327 keV with $J^\pi = 3/2^-$, since the states are not yrast or "near yrast." The population characteristics of multinucleon transfer reactions would lend support to the 1087-keV level being the $J^\pi = 11/2^-$ member of the doublet. The proposed J^π assignments are not inconsistent with the results of the Coulomb excitation experiment. In particular, the direct population of the 904-keV state precludes a J^π assignment of $11/2^-$.

Table I presents a comparison of level energies and $B(E2)$ values with the results of shell-model calculations. The shell model reproduces the $B(E2)$ value of the $5/2^-$ to $7/2^-$ transition very well, but fails to reproduce the large experimental $B(E2)$ value of the $5/2^-$ to $9/2^-$ transition. While the $7/2^-$ state has been reproduced rather well in the shell-model calculation, this is not the case for the $9/2^-$ and the $11/2^-$ states. In addition, the shell-model calculation does not reproduce the observed collectivity of the $9/2^- \to 5/2^-$ $E2$ transition, which is based on the work of Ibbotson [34]. The lack of collectivity in the shell model could explain qualitatively why the $J^\pi = 9/2^-$ and $11/2^-$ states are too high in energy in the shell-model calculations. As proposed in the MSU paper, the $5/2^-$, $7/2^-$, $9/2^-$, and $11/2^-$ states seem to form a band (prolate) with interband $E2$ transitions of ~ 15 W.u., which is relatively strong. The evidence presented here, which is based on the intermediate-energy Coulomb excitation experiment [34] and on the present work, would therefore appear to indicate that the shell-model calculations exhibit a lack of collectivity compared with experimental observation.

Conclusions. Results from the present experiment together with published data from an intermediate-energy Coulomb excitation experiment have been used in the construction of a level scheme. The revised ^{41}S level scheme presented here is a reasonable interpretation of the available experimental and theoretical information. Proposed J^π assignments are based on a comparison of the level scheme with the results of shell-model calculations and on the population characteristics of the two reaction processes discussed here. The experimental yrast level energies and $B(E2)$ values are compared with the results of *sd*-*pf* $0\hbar\omega$ shell-model calculations with the latest

SDPF-U effective interaction. There is a discrepancy between the experimental observations and the results of shell-model predictions in terms of excitation energies and $B(E2)$ values, apart from the lowest transition. This is a very surprising result since it is in contrast with the good level of agreement observed in earlier published studies in this mass region, which would suggest that the model is robust. For even-Z isotopes with $12 \leqslant Z \leqslant 18$, comparisons with experimental 2^+ energies and $B(E2)$ values for the neutron-rich isotopes of Mg, Si [42], S [29, 47,48], and Ar [49,50] result in overall good agreement. For odd-Z nuclei, good agreement has been observed with the yrast level schemes of ^{37}P [28] and ^{38}Cl [30], with the g factor of the ^{44}Cl ground state [51], and the $1/2^+$ - $3/2^+$ energy splitting in the isotopes of K, Cl, and P [42]. The shell-model calculations performed here also show that, in ^{41}S, $\pi(2s_{1/2})^1(1d_{3/2})^1$ and $\pi(2s_{1/2})^0(1d_{3/2})^2$ configurations play an important role in a description of the observed states and measured $B(E2)$ values. However, in ^{41}S, the origins of the enhanced collectivity are, at the present time, not understood and this presents a challenge to the shell model, which is not reflected in the shell-model description of collectivity in the even-A neutron-rich isotopes of sulfur [19,20,29,42]. In view of this surprising discrepancy between experiment and the shell model, there is clearly a need for additional experimental investigations of the level structure of ^{41}S in order to verify the results of the present work and those of Ibbotson *et al.* [34].

This work was supported in part by the EPSRC (UK) and by the European Union under Contract No. RII3-CT-2004-506065. Five of us (D.O., M.B., A.H., K.K., and A.P.) acknowledge financial support from the EPSRC. Z.M.W. acknowledges support from ORSAS and from the University of the West of Scotland. A.N.D. acknowledges support from STFC. A.J. acknowledges financial support from the Spanish Ministerio de Ciencia e Innovación under Contracts No. FPA2007-66069 and No. FPA2009-13377-C02-02. Zs.D. acknowledges the financial support from OTKA Project No. K68801. The contribution of the accelerator and target-fabrication staff at the INFN Legnaro National Laboratory is gratefully acknowledged. The authors would like to thank Frederic Nowacki for extended discussions in relation to collectivity in the neutron-rich isotopes of sulfur and, in particular, ^{41}S.

[1] T. Motobayashi *et al.*, Phys. Lett. B **346**, 9 (1995).
[2] B. V. Pritychenko *et al.*, Phys. Lett. B **461**, 322 (1999).
[3] V. Chiste *et al.*, Phys. Lett. B **514**, 233 (2001).
[4] A. Watt, R. P. Singhal, M. H. Storm, and R. R. Whitehead, J. Phys. G **7**, L145 (1981).
[5] A. Poves and J. Retamosa, Phys. Lett. B **184**, 311 (1987).
[6] N. Fukunishi, T. Otsuka, and T. Sebe, Phys. Lett. B **296**, 279 (1992).
[7] A. Poves and J. Retamosa, Nucl. Phys. A **571**, 221 (1994).
[8] T. Otsuka and N. Fukunishi, Phys. Rep. **264**, 297 (1996).
[9] J. Terasaki, H. Flocard, P.-H. Heenen, and P. Bonche, Nucl. Phys. A **621**, 706 (1997).
[10] E. Caurier, F. Nowacki, A. Poves, and J. Retamosa, Phys. Rev. C **58**, 2033 (1998).
[11] Y. Utsuno, T. Otsuka, T. Mizusaki, and M. Honma, Phys. Rev. C **60**, 054315 (1999).
[12] E. Caurier, F. Nowacki, and A. Poves, Nucl. Phys. A **693**, 374 (2001).
[13] K. Wimmer *et al.*, Phys. Rev. Lett. **105**, 252501 (2010).
[14] R. W. Ibbotson *et al.*, Phys. Rev. Lett. **80**, 2081 (1998).
[15] X. Liang *et al.*, Phys. Rev. C **66**, 014302 (2002).
[16] B. Bastin *et al.*, Phys. Rev. Lett. **99**, 022503 (2007).
[17] S. Grevy *et al.*, Eur. Phys. J. A **25**, 111 (2005).
[18] Zs. Dombrádi *et al.*, Nucl. Phys. A **727**, 195 (2003).
[19] H. Scheit *et al.*, Phys. Rev. Lett. **77**, 3967 (1996).
[20] T. Glasmacher *et al.*, Phys. Lett. B **395**, 163 (1997).
[21] T. Otsuka, R. Fujimoto, Y. Utsuno, B. A. Brown, M. Honma, and T. Mizusaki, Phys. Rev. Lett. **87**, 082502 (2001).
[22] T. Otsuka, T. Suzuki, M. Honma, Y. Utsuno, N. Tsunoda, K. Tsukiyama, and M. Hjorth-Jensen, Phys. Rev. Lett. **104**, 012501 (2010).
[23] J. Retamosa, E. Caurier, F. Nowacki, and A. Poves, Phys. Rev. C **55**, 1266 (1997).
[24] P. G. Reinhard and E. W. Otten, Nucl. Phys. A **420**, 173 (1984).
[25] W. Nazarewicz, Nucl. Phys. A **574**, 27c (1994).
[26] Z. M. Wang *et al.*, Phys. Rev. C **81**, 064301 (2010).
[27] X. Liang *et al.*, Phys. Rev. C **74**, 014311 (2006).
[28] A. Hodsdon *et al.*, Phys. Rev. C **75**, 034313 (2007).
[29] Z. M. Wang *et al.*, Phys. Rev. C **81**, 054305 (2010).
[30] D. O'Donnell *et al.*, Phys. Rev. C **81**, 024318 (2010).
[31] J. A. Winger, H. H. Yousif, W. C. Ma, V. Ravikumar, Y.-W. Lui, S. K. Phillips, R. B. Piercey, P. F. Mantica, B. Pritchenko, R. M. Ronningen, and M. Steiner, in *Proceedings of the Conference on Exotic Nuclei and Atomic Masses, Bellaire, Michigan*, edited by B. M. Sherril, D. J. Morrissey, and C. N. Davids, AIP Conf. Proc. No. 455 (AIP, Woodbury, NY, 1998), p. 606.
[32] M. Lewitowicz *et al.*, Nucl. Phys. A **496**, 477 (1989).
[33] *Evaluated nuclear structure data file (ensdf)* [http://www.nndc.bnl.gov/ensdf].
[34] R. W. Ibbotson, T. Glasmacher, P. F. Mantica, and H. Scheit, Phys. Rev. C **59**, 642 (1999).
[35] M. W. Guidry *et al.*, Phys. Lett. B **163**, 79 (1985).
[36] H. Takai *et al.*, Phys. Rev. C **38**, 1247 (1988).
[37] R. Broda, M. A. Quader, P. J. Daly, R. V. F. Janssens, T. L. Khoo, W. C. Ma, and M. W. Drigert, Phys. Lett. B **251**, 245 (1990).
[38] J. F. C. Cocks *et al.*, Nucl. Phys. A **645**, 61 (1999).
[39] X. Liang, R. Chapman, K.-M. Spohr, M. Smith, P. Bednarczyk, S. Naguleswaran, F. Haas, G. de Angelis, S. Campbell, and P. Dagnall, Eur. Phys. J. A **10**, 41 (2001).
[40] A. M. Stefanini *et al.*, Nucl. Phys. A **701**, 217c (2002).
[41] A. Gadea (EUROBALL Collaboration, and PRISMA-2 Collaboration), Eur. Phys. J. A **20**, 193 (2004).
[42] F. Nowacki and A. Poves, Phys. Rev. C **79**, 014310 (2009).
[43] B. Fornal *et al.*, Phys. Rev. C **49**, 2413 (1994).
[44] E. Caurier and F. Nowacki, Acta Phys. Pol. B **30**, 705 (1999).
[45] E. Caurier, G. Martinez-Pinedo, F. Nowacki, A. Poves, and A. P. Zuker, Rev. Mod. Phys. **77**, 427 (2005).
[46] K. Blaum, W. Geithner, J. Lassen, P. Lievens, K. Marinova, and R. Neugart, Nucl. Phys. A **799**, 30 (2008).
[47] C. Force *et al.*, Phys. Rev. Lett. **105**, 102501 (2010).
[48] L. A. Riley *et al.*, Phys. Rev. C **80**, 037305 (2009).
[49] D. Mengoni *et al.*, Phys. Rev. C **82**, 024308 (2010).
[50] M. Zielinska *et al.*, Phys. Rev. C **80**, 014317 (2009).
[51] M. De Rydt *et al.*, Phys. Rev. C **81**, 034308 (2010).