Physics Letters B 779 (2018) 124–129

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Re-examining the transition into the N = 20 island of inversion: Structure of ^{30}Mg

B. Fernández-Domínguez [a,b,c,*], B. Pietras [a], W.N. Catford [d], N.A. Orr [b], M. Petri [a,e,f], M. Chartier [a], S. Paschalis [a,f], N. Patterson [d], J.S. Thomas [d], M. Caamaño [c], T. Otsuka [g], A. Poves [h], N. Tsunoda [g], N.L. Achouri [b], J.-C. Angélique [b], N.I. Ashwood [i], A. Banu [j,1], B. Bastin [b], R. Borcea [l], J. Brown [f], F. Delaunay [b], S. Franchoo [m], M. Freer [i], L. Gaudefroy [n], S. Heil [e], M. Labiche [o], B. Laurent [b], R.C. Lemmon [o], A.O. Macchiavelli [k], F. Negoita [l], E.S. Paul [a], C. Rodríguez-Tajes [n], P. Roussel-Chomaz [n], M. Staniou [l], M.J. Taylor [f,2], L. Trache [j,l], G.L. Wilson [d]

[a] Department of Physics, University of Liverpool, Liverpool, L69 7ZE, UK
[b] LPC-Caen, IN2P3/CNRS, ENSICAEN, UNICAEN et Normandie Université, 14050 Caen Cedex, France
[c] Universidade de Santiago de Compostela, 15754 Santiago de Compostela, Spain
[d] Department of Physics, University of Surrey, Guildford GU2 5XH, UK
[e] Institut für Kernphysik, Technische Universität Darmstadt, 64289 Darmstadt, Germany
[f] Department of Physics, University of York, Heslington, York YO10 5DD, UK
[g] CNS, University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo, Japan
[h] Departamento de Fisica Teórica and IFT-UAM/CSIC, Universidad Autónoma de Madrid, E-28049 Madrid, Spain
[i] School of Physics and Astronomy, University of Birmingham, Birmingham, B15 2TT, UK
[j] Cyclotron Institute, Texas A&M University, College Station, TX-77843, USA
[k] Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA
[l] IFIN-HH Bucharest-Magurele, RO-077125, Romania
[m] IPN-Orsay, 91406 Orsay, France
[n] GANIL, CEA/DRF–CNRS/IN2P3, BP 55027, 14076 Caen Cedex 05, France
[o] Nuclear Structure Group, CCLRC Daresbury Laboratory, Daresbury, Warrington WA4 4AD, UK

ARTICLE INFO

Article history:
Received 14 December 2017
Received in revised form 1 February 2018
Accepted 1 February 2018
Available online 6 February 2018
Editor: D.F. Geesaman

ABSTRACT

Intermediate energy single-neutron removal from ^{31}Mg has been employed to investigate the transition into the N = 20 island of inversion. Levels up to 5 MeV excitation energy in ^{30}Mg were populated and spin-parity assignments were inferred from the corresponding longitudinal momentum distributions and γ-ray decay scheme. Comparison with eikonal-model calculations also permitted spectroscopic factors to be deduced. Surprisingly, the 0_2^+ level in ^{30}Mg was found to have a strength much weaker than expected in the conventional picture of a predominantly $2p-2h$ intruder configuration having a large overlap with the deformed ^{31}Mg ground state. In addition, negative parity levels were identified for the first time in ^{30}Mg, one of which is located at low excitation energy. The results are discussed in the light of shell-model calculations employing two newly developed approaches with markedly different descriptions of the structure of ^{30}Mg. It is concluded that the cross-shell effects in the region of the island of inversion at Z = 12 are considerably more complex than previously thought and that $np-nh$ configurations play a major role in the structure of ^{30}Mg.

The "island of inversion" (IoI) in which the neutron-rich N ≈ 20 isotopes of Ne, Na and Mg exhibit ground states dominated by cross-shell intruder configurations, has attracted much attention since the first observations [1,2]. In particular, this region has become the testing ground for our understanding of many of the concepts of shell evolution away from β-stability and has sparked the

* Corresponding author.
E-mail address: beatriz.fernandez.dominguez@usc.es (B. Fernández-Domínguez).

[1] Present address: Department of Physics and Astronomy, James Madison University, Harrisonburg, VA 22807, USA.

[2] Present address: Division of cancer sciences, University of Manchester, Manchester, M13 9PL, UK.

https://doi.org/10.1016/j.physletb.2018.02.002

development of sophisticated shell-model interactions. Theoretical approaches first employed mean field [3] and, later, shell-model calculations [4–9] to explain the enhanced binding energies and low 2^+ excitation energies, wherein deformation and a diminished N = 20 shell gap [15] result in fp-shell intruder configurations dominating the ground state wave functions.

In the case of the Mg isotopes, ^{30,31}Mg were first suggested to lie outside the IoI, based on their masses [10,11]. Subsequent measurements, notably the measurements of the ground state spin-parity ($J^\pi = 1/2^+$) and magnetic moment [12,13] have combined with theoretical work (e.g., Refs. [14,15]) to produce a widely accepted picture in which ^{31}Mg is the lightest magnesium isotope within the IoI. Its ground state is characterised by a strongly prolate deformed intruder structure with an almost pure neutron $2p-2h$ configuration [16,17]. In contrast, ^{30}Mg is firmly placed outside the IoI and its structure interpreted as a spherical $0p-0h$ ground state [18] coexisting with a neutron $2p-2h$ intruder-dominated deformed 0_2^+ isomeric state at 1.788 MeV [19,20] and with negative parity levels expected to appear, according to shell model calculations, at a relatively high excitation energy (>3.5 MeV [21]).

Very recently, calculations employing a new type of interaction – EEdf1 – have reproduced many of the properties of the neutron-rich isotopes of Ne, Mg and Si [22]. Significantly, the interaction was derived for the $sd + pf$ shells from fundamental principles and explicitly including three-body forces. Intriguingly, the EEdf1 calculations predict that multiple particle–hole excitations play a much bigger role than suggested by the earlier calculations. For example, in the Mg isotopic chain the admixture of neutron $2p-2h$ and $4p-4h$ configurations increases suddenly at N = 18 [22]. Indeed, the ground state structure of ^{30}Mg is predicted to be very strongly influenced by the intruder fp-shell configurations, with ~75% of the ground state wavefunction being of this nature [22].

In order to test these two very different pictures of the transition into the IoI the structural overlaps between the ^{31}Mg and ^{30}Mg states are of critical importance. To date, however, there are only indirect estimates, based on proton resonant elastic scattering on ^{30}Mg [23]. In the present work, intermediate energy single-neutron removal from ^{31}Mg is investigated. In addition to providing a measure of the overlaps between the ^{31}Mg ground state and the levels populated in ^{30}Mg, the spins and parities of previously known and newly observed states are deduced.

The experiment was performed at the GANIL facility where a high intensity ^{36}S primary beam (77.5 MeV/nucleon) was employed, in conjunction with the SISSI device [24]. A beam analysis spectrometer delivered a secondary beam of ^{31}Mg (55.1 MeV/nucleon) with a rate of ~55 pps. The secondary beam bombarded a carbon target (thickness 171 mg/cm^2) and the beam-like residues were analysed according to momentum using the SPEG spectrometer [25] and identified in mass and charge using standard ΔE-E-TOF techniques.

The γ-rays emitted by the beam-like residues were detected using an array of 8 EXOGAM Ge clover detectors [26] that were arranged symmetrically in two rings, each of 4 detectors, at polar angles of 45° and 135° with respect to the beam axis. The full-energy peak efficiency for the array, after implementing add-back, was measured to be 3.3 ± 0.1% at 1.3 MeV and the energy resolution, after Doppler correction, was 2.7%. A more complete account of the experimental details may be found in Ref. [27].

The inclusive cross section for single-neutron removal from ^{31}Mg was determined to be 90 ± 12 mb where the error arises principally from the uncertainty in the integrated secondary beam intensity. The γ-ray spectrum, for events observed in coincidence with ^{30}Mg residues, is shown in Fig. 1, after Doppler and add-back

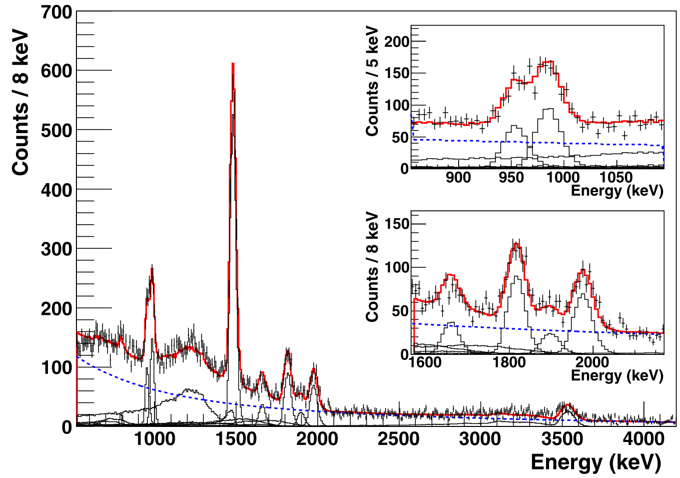

Fig. 1. (Color online.) Doppler corrected and add-back reconstructed γ-ray energy spectrum ($E_\gamma > 500$ keV) in coincidence with ^{30}Mg. The overall fit (red line) includes Geant4 generated lineshapes for each transition (black histograms) and an exponential background (blue dashed line). The insets show the details of the regions from 850 to 1100 keV and 1575 to 2175 keV.

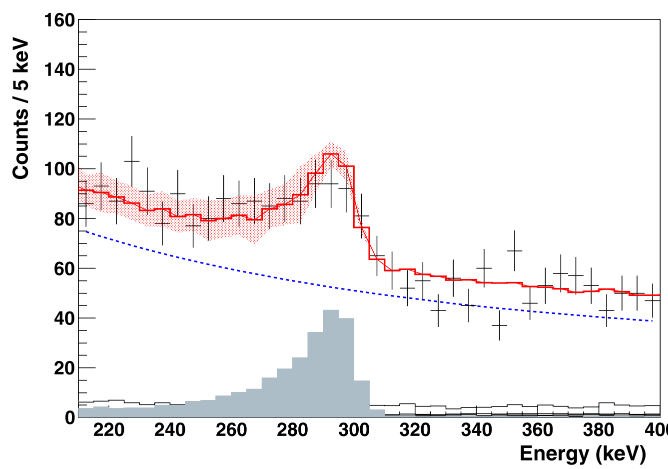

Fig. 2. (Color online.) Spectrum for the forward angle EXOGAM detectors for $E_\gamma <$ 500 keV. The grey histogram is the simulated lineshape for the $0_2^+ \to 2_1^+$ decay – $E_\gamma = 300 \pm 5$ keV. The red shading reflects the uncertainty in the half-life – 3.9 ± 0.5 ns [19].

corrections were applied. Nine known transitions [28,21,29] were observed. The energies and intensities are listed in Table 1 and the deduced decay scheme shown in Fig. 3. A further weak, previously unreported transition, which is not in coincidence (within the statistics) with any other γ-ray line, was identified at 1660(2) keV. The γ-ray energy spectrum was fitted with lineshapes generated for each transition using Geant4 [30], plus a smooth continuum background.

Below 500 keV, no γ-ray lines were observed other than an asymmetric peak at ~300 keV corresponding to the known 306 keV transition from the isomeric 0_2^+ 1789 keV level to the 2_1^+ state (half-life 3.9(5) ns [19]). The lineshape for the isomeric decay was simulated (Fig. 2) using Geant4 and taking into account the half-life and the ^{30}Mg post-target velocity ($\beta = 0.303$). The analysis employed only the data acquired with the forward four detectors as the corresponding lineshape exhibited particular sensitivity to the lifetime.

The ^{30}Mg level and γ-decay scheme in Fig. 3 is in accord with previous studies [28,21,29], with the exception of two previously reported transitions at 990 keV and 1060 keV [21] for which no