



HAL
open science

Spectroscopy around ^{36}Ca

A. Bürger, F. Azaiez, M. Stanoiu, Z. Dombradi, A. Algora, A. Al-Khatib, B. Bastin, G. Benzoni, R. Borcea, C. Bourgeois, et al.

► **To cite this version:**

A. Bürger, F. Azaiez, M. Stanoiu, Z. Dombradi, A. Algora, et al.. Spectroscopy around ^{36}Ca . 41st Zakopane Conference on Nuclear Physics: Trends in Nuclear Physics, Sep 2006, Zakopane, Poland. pp.1353-1357. in2p3-00122690

HAL Id: in2p3-00122690

<https://hal.in2p3.fr/in2p3-00122690>

Submitted on 4 Jan 2007

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

1
2
3
4
5
6
7
8
9
10

Spectroscopy around $^{36}\text{Ca}^*$

A. BÜRGER¹, F. AZAIEZ², M. STANOIU³, ZS. DOMBRÁDI⁴,
A. ALGORA⁴, A. AL-KHATIB¹, B. BASTIN⁵, G. BENZONI⁶,
R. BORCEA⁷, CH. BOURGEOIS², P. BRINGEL¹, E. CLÉMENT⁸,
J.-C. DALOUZY⁹, Z. DLOUHÝ¹⁰, A. DROUART⁸, C. ENGELHARDT¹,
S. FRANCHOO², ZS. FÜLÖP⁴, A. GÖRGEN⁸, S. GRÉVY⁹, H. HÜBEL¹,
F. IBRAHIM², W. KORTEN⁸, J. MRÁZEK¹⁰, A. NAVIN⁹, F. ROTARU⁷,
P. ROUSSEL-CHOMAZ⁹, M.-G. SAINT-LAURENT⁹, G. SLETTEN¹²,
D. SOHLER⁴, O. SORLIN⁹, C. TIMIS¹¹, CH. THEISEN⁸, D. VERNEY² AND
S. WILLIAMS¹¹.

¹Helmholtz-Institut für Strahlen- und Kernphysik, Univ. Bonn, Germany
²Institut de Physique Nucléaire, IN2P3-CNRS, Orsay, France
³GSI, Darmstadt, Germany
⁴Institute of Nuclear Research, Debrecen, Hungary
⁵Laboratoire de Physique Corpusculaire, Caen, France
⁶Università degli studi e INFN sezione di Milano, Italy
⁷IFIN-HH, Bucharest-Magurele, Romania
⁸DAPNIA/SPhN, CEA Saclay, France
⁹GANIL, Caen, France
¹⁰Nuclear Physics Institute of ASCR, Řež, Czech Republic
¹¹Department of Physics, University of Surrey, UK
¹²Niels Bohr Institute, University of Copenhagen, Denmark

23 An experiment was performed to study excited states in neutron-deficient
24 nuclei around Ca. A one-neutron knockout reaction was used to produce
25 ^{36}Ca ions from a ^{37}Ca secondary beam, and in-beam γ -rays were measured.
26 The 2^+ energy in ^{36}Ca is compared to the mirror nucleus ^{36}S to deduce
27 information on the isospin dependence of the nuclear force near the proton
28 drip line. The energy of the first excited 2^+ state in ^{36}Ca and the cross
29 section for the 1-neutron knock-out reaction from ^{37}Ca at $\approx 45 \cdot A$ MeV
30 were obtained. Furthermore, for two other $T_z = -2$ nuclei, ^{28}S and ^{32}Ar ,
31 the de-excitation of the first 2^+ state has been observed.

32 PACS numbers: 21.10.-k, 23.20.Lv, 27.30+t

* Presented at the 41st Zakopane School of Physics

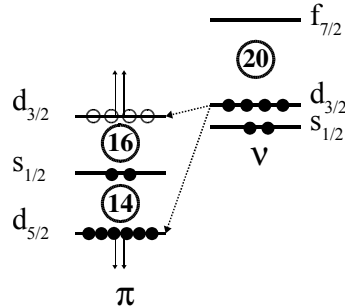


Fig. 1. Illustration of the effect of the $\nu d_{3/2}$ orbital filling in ^{36}S . Due to the tensor interaction, the $\pi d_{3/2}$ level is shifted up and the $\pi d_{5/2}$ level is shifted down in energy.

1 In recent years, an intensive research activity was devoted to the study
 2 of nuclear structure of extremely neutron- or proton-rich nuclei, both the-
 3 oretically and experimentally. In this context, we aimed in the present
 4 experiment to measure the excitation energy of the first 2^+ state in ^{36}Ca
 5 and compare it to its mirror nucleus ^{36}S . In the ground state of ^{36}S , the
 6 $\pi d_{5/2}$ and $s_{1/2}$ as well as the $\nu d_{3/2}$ orbitals are completely filled. In ^{36}Ca ,
 7 the same orbitals are occupied with neutron and proton shells exchanged.
 8 Due to the tensor interaction between the proton spin-orbit partners $d_{5/2}$
 9 and $d_{3/2}$ and the neutron $d_{3/2}$ orbital, the proton $d_{5/2}$ orbital becomes more
 10 bound whereas the $\pi d_{3/2}$ orbital becomes less bound than for nuclei where
 11 the $\nu d_{3/2}$ shell is not completely filled (1). Assuming that the effect of the
 12 filling of the $\nu d_{3/2}$ on the $\pi s_{1/2}$ is weak, this enlarges the gaps between the
 13 $\pi s_{1/2}$ and $\pi d_{3/2}$ levels and between the $\pi s_{1/2}$ and $\pi d_{5/2}$ levels, as illustrated
 14 in fig. 1. These shifts lead to high excitation energies for the first 2^+ states in
 15 both ^{36}S and ^{34}Si , which from this point of view reflects a spherical rigidity
 16 comparable to the doubly magic nucleus ^{40}Ca . For ^{36}Ca , the mirror nucleus
 17 of ^{36}S , the same picture should apply with protons and neutrons exchanged,
 18 so that also in this case a high excitation energy can be expected for the 2^+
 19 state.

20 The experiment was performed at the GANIL in Caen, France. The
 21 two-step fragmentation technique was used (2) to populate excited states in
 22 ^{36}Ca . A primary beam of ^{40}Ca with an energy of 95.4 MeV was fragmented
 23 on a carbon foil in the SISSI target device (3). The Alpha spectrometer,
 24 optimised for ^{37}Ca or, in a different setting, ^{36}Ca , was used to purify the
 25 resulting beam cocktail with the help of a degrader. Event-by-event iden-
 26 tification of the beam particles was achieved using a time measurement
 27 between the high frequency of the accelerator and the time signal from a
 28 CATS detector (4), that was placed just in front of the secondary target. In

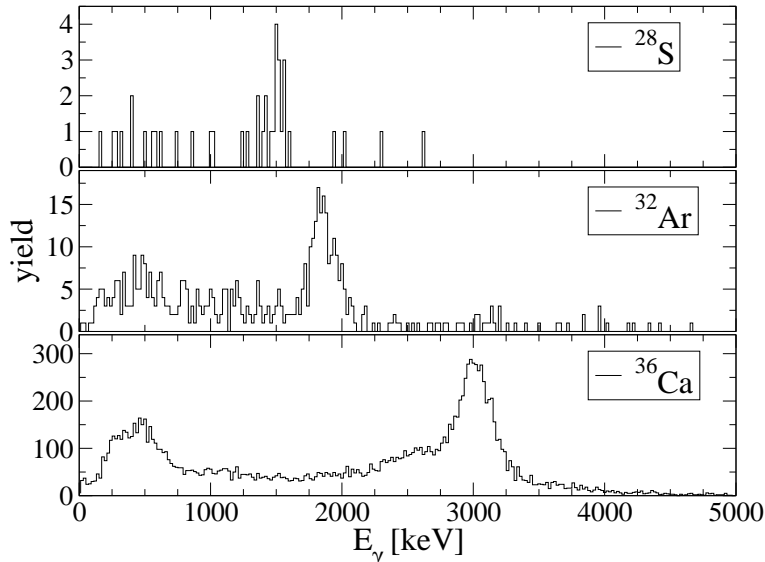


Fig. 2. Gamma-ray spectra for the nuclei ^{36}Ca , ^{32}Ar and ^{28}S . The energies of the 2^+ states have been determined to be 3036(11) keV, 1873(20) keV and 1525(30) keV, respectively.

1 the secondary target, a ^9Be foil of 200 mg/cm² thickness, further nucleons
 2 were removed at energies between $60 \cdot A$ MeV before and $35 \cdot A$ MeV after the
 3 target. Behind the secondary target, the produced fragments were identi-
 4 fied through time-of-flight, $B\rho$ and energy-loss measurements in the SPEG
 5 spectrometer (5). For some settings, suppression of the secondary beam in
 6 the focal plane necessitated the placement of an additional slit in SPEG.

7 Gamma-ray energies were measured with the *Château de Cristal*, an
 8 array of 74 BaF₂ detectors (6), that was placed around the Be target. The
 9 γ -ray detectors were calibrated using a ^{22}Na source and well separated and
 10 sufficiently intense known transitions in the nuclei ^{28}Si , ^{32}S , ^{34}Ar , ^{29}Si and
 11 ^{33}Cl , which were also produced in the secondary target from different beam
 12 components. The Doppler-correction for γ -ray energies from in-flight decays
 13 used the momentum measured in SPEG, assuming that the decays took
 14 place in the middle of the target. An add-back procedure was applied to
 15 reconstruct Compton-scattered γ -ray energies. Gamma-ray spectra for the
 16 three nuclei ^{36}Ca , ^{32}Ar and ^{28}S are shown in fig. 2. The energy of the
 17 2^+ state in ^{36}Ca has been determined to be $E(2^+) = 3036(11)$ keV, in
 18 agreement with the value measured at GSI in a similar experiment (7). The
 19 estimated $E(2^+)$ for ^{28}S is $\approx 1525(30)$ keV, and $\approx 1873(20)$ keV for ^{32}Ar ,
 20 which is 50 keV above the value reported by Cottle *et al.* (8).

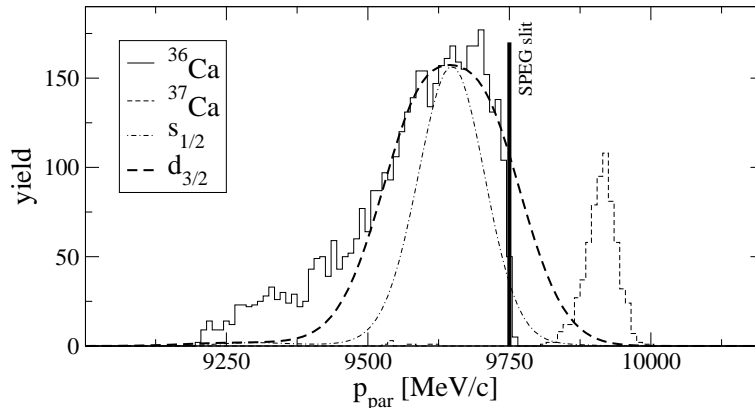


Fig. 3. Inclusive momentum distributions of ^{36}Ca and ^{37}Ca as measured in SPEG. The distribution for ^{36}Ca is cut by a slit that was installed in SPEG to suppress the secondary beam; in the dedicated run for ^{37}Ca this slit was not installed. Included are calculated momentum distributions for one-neutron removal from $d_{3/2}$ or $s_{1/2}$ states, folded with the distribution of the secondary beam.

1 The measured value for the energy of the first 2^+ state in ^{36}Ca is 266 keV
 2 lower than that in the mirror nucleus, ^{36}S . This is, besides ^{14}C - ^{14}O where
 3 the difference is 422(11) keV, one of the largest mirror energy differences
 4 observed so far for a first excited 2^+ state. Qualitatively, this might be
 5 explained as the combined effect of: (i) an almost pure ν nature of the 2^+
 6 state in ^{36}Ca due to the $Z = 20$ gap, (ii) an almost pure π nature of the 2^+
 7 state in ^{36}S due to the $N = 20$ gap, (iii) the almost pure 1-particle 1-hole
 8 configurations of the 2^+ states in ^{36}Ca and ^{36}S due to the large $Z, N = 16$
 9 gaps, and (iv) the Coulomb energy difference between typical s and d states.

10 Figure 3 shows the momentum distribution for ^{36}Ca and a comparison
 11 with calculated momentum distributions (9; 10; 11) as expected for neutron
 12 knock-out from the valence orbits $d_{3/2}$ and $s_{1/2}$. The width of the inclu-
 13 sive experimental momentum distribution fits well to the neutron knock-out
 14 from a $d_{3/2}$ state. From the integral of the extrapolated distribution, the
 15 number of ^{36}Ca ions was determined. Using the number of incident ^{37}Ca
 16 ions and the target thickness, a preliminary experimental cross section for
 17 the one-neutron removal $^{37}\text{Ca} \rightarrow ^{36}\text{Ca}$ of 5.3 (20) mb was obtained, while the
 18 calculated cross section is 18.6 mb assuming a knock-out from $\nu d_{3/2}$. This
 19 represents a quenching of $\approx 30\%$ similar to what has been found in the case
 20 of one-neutron knockout from ^{32}Ar , a nucleus which has a similarly large
 21 neutron separation energy (12).

22 We wish to thank the accelerator crew of GANIL for their smooth run-
 23 ning of the secondary beam production and the SPEG technical staff for

1 their support during the experiment.

2 **REFERENCES**

- 3 [1] T. Otsuka *et al.*, Phys. Rev. Lett. **95**, 232502 (2005).
4 [2] M. Stanoiu *et al.*, Eur. Phys. J. A **20**, 95 (2003).
5 [3] E. Baron, J. Gillet, and M. Ozille, Nucl. Instr. Meth. A **362**, 90 (1995).
6 [4] S. Ottini-Hustache *et al.*, Nucl. Instr. Meth. A **431**, 476 (1999).
7 [5] L. Bianchi *et al.*, Nucl. Instr. Meth. A **276**, 509 (1989).
8 [6] F. A. Beck, in *Nuclear Science Research Conference Series* (Harwood,
9 New York, 1984), Vol. 7, p. 129.
10 [7] P. Doornenbal *et al.*, Phys. Rev. C (2006), submitted.
11 [8] P. D. Cottle *et al.*, Phys. Rev. C **88**, 172502 (2002).
12 [9] C. A. Bertulani and P. G. Hansen, Phys. Rev. C **70**, 034609 (2004).
13 [10] C. A. Bertulani and A. Gade, Comp. Phys. Comm. **175**, 372 (2006).
14 [11] P. G. Hansen and J. A. Tostevin, Ann. Rev. Nucl. Part. Sci. **53**, 219
15 (2003).
16 [12] A. Gade *et al.*, Phys. Rev. Lett. **93**, 042501 (2004).