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M.J. López Jiménez[1a], M.G. Saint-Laurent[1], J.C. Angélique[2], R. Anne[1], J. Äystö[3], C. Borcea[4], J.M. Daugas[1], D. Guillemaud-Mueller[5], S. Grévy[2], R. Grzywacz[6], A. Jokinen[3], M. Lewitowicz[1], F. Nowacki[7], F. de Oliveira Santos[1], A.N. Ostrowski[8], T. Siiskonen[3], and W. Trinder[1]

[1] Grand Accélérateur National d'Ions Lourds, B. P. 5027, 14076 Caen Cedex 5, France
[2] Laboratoire de Physique Corpusculaire, CNRS-IN2P3, Boulevard Maréchal juin, 14050 Caen Cedex, France
[3] Department of Physics, University of Jyväskylä, P. O. Box 35, 40351 Jyväskylä, Finland
[4] Institute of Atomic Physics, Bucharest-Magurele, P. O. Box MG6, Rumania
[5] Institute of Physique Nucléaire, CNRS-IN2P3, 91406 Orsay Cedex, France
[6] Institut of Experimental Physics, Warsaw University, Hoza 69, 00681 Warsaw, Poland
[7] Laboratoire de Physique Théorique, 3-5 rue de L'Université, 67084 Strasbourg, France
[8] Department of Physics and Astronomy, University of Edinburgh, Edinburgh EH9 3JZ, United Kingdom

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# New transitions in the $\beta$-decay of $^{36}$Ca

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[3] Department of Physics, University of Jyväskylä, P. O. Box 35, 40351 Jyväskylä, Finland
[4] Institute of Atomic Physics, Bucharest-Magurele, P. O. Box MG6, Rumania
[5] Institute of Physique Nucléaire, CNRS-IN2P3, 91406 Orsay Cedex, France
[6] Institut of Experimental Physics, Warsaw University, Hoza 69, 00681 Warsaw, Poland
[7] Laboratoire de Physique Théorique, 3-5 rue de L'Université, 67084 Strasbourg, France
[8] Department of Physics and Astronomy, University of Edinburgh, Edinburgh EH9 3JZ, United Kingdom

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**Abstract.** The $\beta$-decay of the $T_z$ = -2 nucleus $^{36}$Ca was studied at the LISE3 magnetic spectrometer at GANIL. Two new proton-emitting states have been detected by a new experimental method and the other nine $\beta$p and $\beta\gamma$ known transitions have been remeasured with improved resolution. A simulation with GEANT code has been applied to this experimental setup resulting a very useful tool for the analysis. A comparison with shell model calculations is given.

**PACS.** 27.30.+t 20< $A$ <38 – 21.10.Pc Single-particle levels and strength functions – 23.50.+z Decay by proton emission – 25.70.Mn Projectile and target fragmentation

During the past few years, improvements in experimental techniques have enabled the study of $\beta$-decay properties of very proton-rich nuclei [1]. Characterized by high energy release, these decays allow one to extract the Gamow-Teller(GT) strength for transitions to a large range of excitations energies in the daughter nucleus and thus to test the quality of model calculations.

Previous studies of high energy-release $\beta$-decays of $^{37}$Ca [2-5] ($Q_{EC}$ = 11638(22) keV [6]) and $^{36}$Ca [7,5] ($Q_{EC}$ = 10985(41) keV [6]) revealed that the good agreement between experiment and the shell-model calculations [8, 9] did not extend to high excitation energies where much more strength was observed than calculated. It was stressed, however, that the size of this effect seems to depend strongly on the interaction applied in the theory [10,5].

This letter reports on a new detailed study of the $\beta$-decay of $^{36}$Ca produced at the GANIL facility. The experiment was performed using the SISSI-$\alpha$ and LISE3 spectrometers [11-13]. A $^{36}$Ca secondary beam was produced by fragmentation reactions of a 95 AMeV $^{40}$Ca$^{20+}$ beam at an average intensity of ~400 enA impinging on a rotating 560 $\mu$m $^{nat}$Ni target. The secondary beam purity was enhanced by a 550 $\mu$m $^{9}$Be wedge shape degrader at the intermediate focal point and by using the Wien velocity filter at the exit of the LISE3 spectrometer. The 96% pure secondary $^{36}$Ca beam (12 pps) was implanted into a 500 $\mu$m thick silicon detector; the main contaminant stopped in this detector was $^{35}$K (0.5 pps). The implantation detector was positioned between two silicon counters of the same thickness for detecting $\beta$-rays ($\beta$-detectors). Two additional silicon counters, one of which being 500 $\mu$m thick and the other 150 $\mu$m thick and position sensitive, were mounted upstream. These detectors provided the energy-loss ($\Delta$E) and time-of-flight signals for identifying the isotopes transmitted to the final focus of the LISE3 spectrometer. Three large-volume (70%) germanium and two NaI detectors for registering $\gamma$-rays were mounted close to the implantation detector.

A calibration has been done by implanting the well-known $\beta$p-emitter $^{37}$Ca under similar conditions in an additional LISE3 setting. Corrections were made for different implantation depths of $^{36}$Ca and $^{37}$Ca atoms ( $\Delta \approx$ 100 $\mu$m) by imposing the condition of the well-known proton transition from the Isobaric Analogue State (IAS) [14].

In the first setting (48516 atoms), the $^{36}$Ca implantation profile (FWHM ~ 68$\mu$m ) was positioned at a depth of about 142 $\mu$m. In a second setting (53891 atoms), the profile was shifted to 292 $\mu$m, *i. e.*, nearer to the downstream $\beta$-counter, by removing the 150 $\mu$m $\Delta$E detector. Figure 1 shows the measured $^{36}$Ca $\beta$p energy spectra: a) proton spectrum in coincidence with $\beta$ and b) under the

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[a] *Present address:* CENBG, Le Haut-Vigneau, B.P. 120, 33175 Gradignan, France

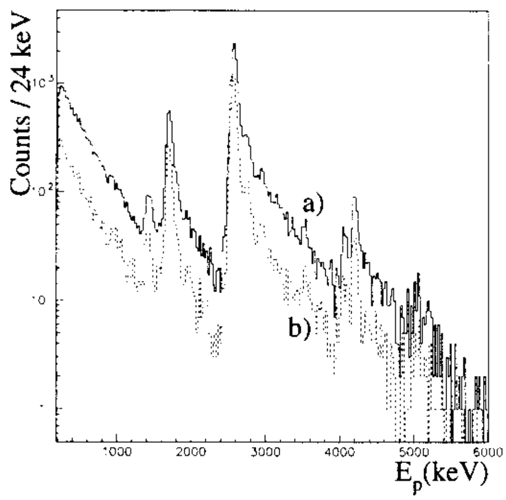

**Fig. 1.** $^{36}$Ca proton spectrum : a) $\beta$ conditioned spectrum b) spectrum conditioned with $\Delta E_\beta$ less than 300 keV.

condition of a small energy-loss of the coincident $\beta$-rays in the downstream $\beta$-detector ($\Delta E_\beta \leq 300$ keV).

Nine $\beta$p transitions were extracted from the spectra shown in Fig. 1. These lines have been assigned as single transitions that showed consistency between the two $\beta$-coincident spectra. The *difference* of the line shifts due to pulse-height defects of the recoil atoms ($^{35}$Ar,$^{36}$Ar) in $^{36}$Ca and $^{37}$Ca decay is negligible.

The relative intensities are deduced by integrating the full-energy peaks and applying a correction factor to account for protons for which the energy is only partially collected in the implantation detector. We have used GEANT [15] simulations to obtain the correction factor. The implantation depth profile deduced from the $^{36}$Ca energy-loss spectrum in the implantation detector has been taken into account. The number of identified and implanted $^{36}$Ca atoms was corrected for losses due to secondary reactions in the stopping process [16,17]. The correction factor was 1%. Absolute proton intensities are obtained by dividing the corrected number of protons by the number of $^{36}$Ca ions embedded in the implantation detector.

GEANT simulations give results which are in good agreement with experimental data. Figure 2 (left) shows the experimental IAS region of the $^{36}$Ca proton spectrum and the simulated $\beta$-p IAS decay spectrum (dotted line). The simulated spectrum has been used as a background spectrum. Figure 2 (right) shows the background-subtracted spectrum. We can observe two new weak $\beta$p transitions in the $^{36}$Ca decay (marked with a star symbol).

Two $\beta$-delayed $\gamma$ decays ($\beta\gamma$) of $^{36}$Ca were identified in the spectrum from the germanium detectors. All extracted energies and intensities of the excited states in $^{36}$K are listed in Table 1.

**Table 1.** For this study; excitation energies, intensities, logft and B(GT) strengths of the daugther levels in the $^{36}$Ca $\beta$-decay. Data from the last column correspond to reference [5].

| $E_x(keV)$ | $x_i$(%)abs | logft | B(GT) | B(GT) [5] |
|---|---|---|---|---|
| 1111.9(4) | 15.0(6) | 4.54 | 0.111(6) | 0.11(2) |
| 1617.2(4) | 29.5(1.7) | 4.05 | 0.34(2) | 0.32(4) |
| 3358(23) | 9.3(8) | 4.11 | 0.30(3) | 0.36(2) |
| 4290(23) | 37(1) | 3.2 | B(F)3.87(20) | B(F)4.05(13) |
| 4457(23) | 3.5(5) | 4.16 | 0.27(4) | 0.13(2) |
| 4644(46) | 1.0(3) | 4.6 | 0.10(3) | 0.13(2) |
| 5250(23) | 0.6(2) | 4.6 | 0.10(3) | * |
| 5761(69) | 0.9(2) | 4.2 | 0.24(7) | * |
| 5919(46) | 1.7(3) | 3.86 | 0.5(1) | 0.9(2) |
| 6791(69) | 0.3(1) | 3.53 | 1.1(4) | 0.6(2) |

The experimental $\beta$-decay transition strength for a transition to level $i$ in $^{36}$K was calculated using [18,19]

$$[B(F) + (\tfrac{g_A}{g_V})^2 B(GT)]_i = \frac{k x_i}{f(E_i)\tau_{1/2}}$$

$$k = 6127(9)s,\ \tau_{1/2} = 102(2)ms, \tfrac{g_A}{g_V} = -1.262$$

where $B(F)$ is the Fermi strength, $E_i$ is the $\beta$-endpoint energy, $f(E_i)$ the phase-space factor, $x_i$ the branching ratio of a $\beta$-transition to the $i^{th}$ daughter level.

In Table 1 we compare measured B(GT) strengths with the values from previous work [5]. The GT strength calculated with USD [9] and CWH [20] interactions is compared to the experimental data for $^{36}$K, in Table 2 and in Fig. 3. The shell model calculations were performed with the ANTOINE code [21]. The calculation includes quenching by the recommended value $(0.77)^2$ for the *sd* shell. For the low-lying states up to 4 MeV, the agreement of experimental data with the USD interaction is better. At higher excitation energy, the CWH hamiltonian calculations agree better with experimental data, as in the case of other nuclei such as $^{37}$Ca [5], $^{31}$Ar [22], etc.

**Table 2.** Comparison of the measured B(GT) values in the $^{36}$Ca $\beta$-decay with theoretical data [21]. For the *sd*-shell model calculations the USD interaction has been used. Level energies are also compared.

| $J^\pi$ | $E_x^{exp}$ | $B(GT)^{exp}$ | $E_x^{USD}$ | $B(GT)^{USD}$ |
|---|---|---|---|---|
| $1^+$ | 1111.9(4) | 0.111(6) | 1221 | 0.159 |
| $1^+$ | 1617.2(4) | 0.34(2) | 1603 | 0.319 |
| $1^+$ | | | 2502 | 0.0075 |
| $1^+$ | 3358(23) | 0.30(3) | 3659 | 0.45 |

A very good resolution in the proton energy spectra has been obtained. Two new weak transitions have been detected for the $^{36}$Ca decay and the other nine known $\beta$p and $\beta\gamma$ transitions have been remeasured with improved resolution. GEANT simulations accurately reproduce the experimental data. Shell model calculations have been compared with experimental data. A good agreement is found between the theoretical B(GT) values obtained with the CWH interaction and the experimental values for the new states.

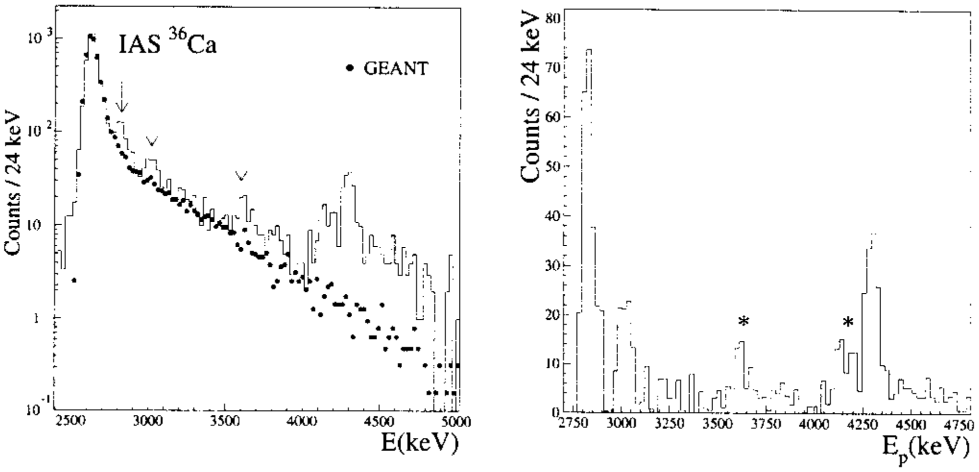

**Fig. 2.** On the left, the proton spectrum in the $^{36}$Ca IAS region and the simulated $\beta$-p IAS decay spectrum (dotted line), arrows indicate very weak transitions. On the right, the background-subtracted spectrum. Two marked peaks correspond to the new $\beta$-p transitions observed in this experiment. The other peaks were already identified in Trinder's work [5].

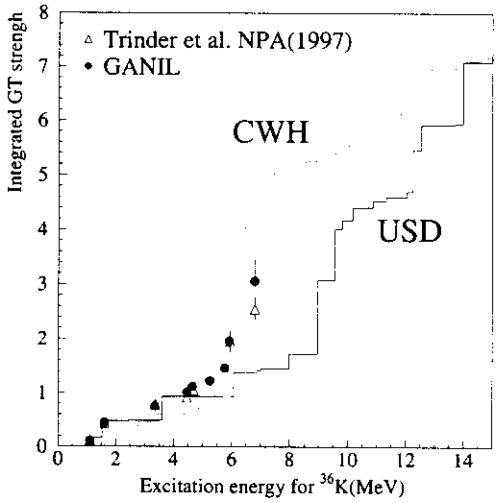

**Fig. 3.** Integrated Gamow-Teller strength for $^{36}$K nucleus. Experimental data are compared to the shell model calculations with USD interaction (solid line) and CWH interaction (dashed line). Triangle symbols correspond to data of reference [5] and points correspond to the data of this work [20].

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