Published by
NIGERIAN SOCIETY OF PHYSICAL SCIENCES
Available online @ https://journal.nsps.org.ng/index.php/jnsps

J. Nig. Soc. Phys. Sci. 2 (2020) 166–169

Original Research

Journal of the Nigerian Society of Physical Sciences

Measurement of the Excited Energies Identified in ^{42}Ca using the ROSPHERE Gamma-ray Arrays

T. Daniel[a,*], A. A. McAsule[b]

[a]*Department of Physics, Benue State University, P. M. B. 102119, Makurdi, Benue State*
[b]*Department of Physics, Federal University of Agriculture, P. M. B. 2373, Makurdi, Benue State*

Abstract

Excited energy states totalling 11 in number identified to be associated with the ^{42}Ca were detected via the ROSPHERE gamma-ray array detectors of IFIN-HH Bucharest from a ^{28}Si(^{18}O, 2p2n), where a multi-particle of 2 protons and 2 neutrons were evaporated in a fusion reaction. The excited energies were identified using γ-ray coincidences. All detected gamma energies (γ) recorded were compared with various literatures from NNDC and this shows an excellent agreement with each and the results are presented together with their calculated relative intensities.

Keywords: Absolute relative error, accuracy, comparative study, stability.

Article History :
Received: 05 February 2020
Received in revised form: 20 April 2020
Accepted for publication: 03 May 2020
Published: 01 August 2020

©2020 Journal of the Nigerian Society of Physical Sciences. All rights reserved.
Communicated by: W. A. Yahya

1. Introduction

Calcium-42 is one of the isotopic-nucleus of calcium with 22 neutrons and 20 protons. The two excess neutrons present in the nucleons distinguish it from the first stable nucleus of ^{40}Ca with either protons or neutrons being magic. The heaviest of the isotopes is ^{48}Ca with 8-neutrons higher than ^{40}Ca [1]. The measured gamma energies of the nucleus have been reported in several articles with some of them showing the relative intensities of the measured gamma transitions. In this, the relative intensities of these gamma energies have been measured after they were identified to be associated with ^{42}Ca through the instrumentalities of Coincidence analysis [2].

2. Experimental Details

In the Coulomb unsafe reaction of ^{192}Os target with the ^{18}O beam at 80 *MeV* using the 9 *MV* tandem accelerator of the Horia Hulubei National Institute of Physics and Nuclear Engineering (known as IFIN-HH) in Bucharest [3], a fusion multi-particle of *2n2p* was evaporated from the fusion of ^{28}Si target with ^{18}O – beam. ^{28}Si was found to be one of the impurities in the ^{192}Os target foil material bought from the Trace company in USA. This contaminated percentage of ^{42}Ca and other chemical impurities from the target were observed to have reacted during the experiment when the ^{18}O beam delivered the laboratory energy of 80 *MeV* on the ^{192}Os target in the chamber of the accelerator. Details of the purity composition of the ^{192}Os are as shown in Table 1.

This nuclear fusion evaporation reaction produced ^{42}Ca as

*Corresponding author tel. no: +2348167598988
Email address: tdaniel@bsum.edu.ng, terver.daniel@yahoo.co.uk (T. Daniel)

the product of the reaction after evaporating $2n2p$ particles from the compound with the beam current of 20 *pnA* with a hardware trigger condition of either $LaBr_3$(Ce) – $LaBr_3$(Ce) or HPGe – HPGe [4, 5]. The predicted fusion-evaporation cross-section for the observed channels (that is, from 60 *MeV* to 100 *MeV)* have ^{42}Ca nucleus dominating the entire laboratory energy region as chosen in this work. The relative cross-section measured for the ^{42}Ca nucleus is ≤ 100 mb [4, 5].

The experiment for the ^{18}O beam on ^{192}Os target was conducted for a period of 9 consecutive days at IFIN-HH Bucharest within which an approximate count of 1,200,000.00 was recorded using the ROmanian SPectroscopy in HEavy REactions, ROSPHERE gamma-ray array of 14 High Purity Germanium, HPGe and 11 Lathanum-Bromide doped Cerium , $LaBr_3$(Ce) detectors [4, 5, 6].

Table 1. The ^{192}Os Target with the Observed Chemical Impurities [5]

Element	Symbol	Impurity Measurement (ppm)
Aluminium	Al	500
Calcium	Ca	100
Copper	Cu	70
Iron	Fe	500
Magnesium	Mg	50
Manganese	Mn	50
Nickel	Ni	100
Lead	Pb	50
Platinum	Pt	50
Silicon	Si	500
Tungsten	W	100

3. Data Analysis

Coincidence analysis was performed on the detected gamma energies from the ROPSHERE gamma-ray array detectors of the IFIN-HH Bucharest and these were identified to be associated with ^{42}Ca. Doing this, a gating condition was used where a particular gamma transition was selected as a reference energy and all other energies that were seen to be in coincidence, that is, appearing with the selected gate at the same time were recorded. This was to further confirm that the measured gamma transitions were indeed associated with ^{42}Ca [1, 7, 8]. Table 2 shows all the measured gamma transitions in the current work. The partial energy level scheme of ^{42}Ca was obtained as shown in Figure 1 using RADware.

Table 2. Details of the Observed Transitions in the Current Work as Detected from the ^{28}Si(^{18}O,2n2p)^{42}Ca

$E_\gamma(keV)$	Energy Level (keV) $E_i \rightarrow E_f$	Relative Intensity I_γ	Transition
146	6555 → 6409	23	$9^- \rightarrow 8^-$
264	6409 → 6146	7	$8^- \rightarrow 7^-$
437	3190 → 2752	50	$6^+ \rightarrow 4^+$
810	6555 → 5747	28	$9^- \rightarrow 7^-$
815	7369 → 6555	20	$10^- \rightarrow 9^-$
910	4099 → 3190	36	$5^- \rightarrow 6^+$
917	6409 → 5492	18	$8^- \rightarrow 6^-$
1227	2752 → 1525	78	$4^+ \rightarrow 2^+$
1347	4099 → 2752	7	$5^- \rightarrow 4^+$
1525	1525 → 0	100	$2^+ \rightarrow 0^+$
1645	5745 → 4099	28	$7^- \rightarrow 5^-$

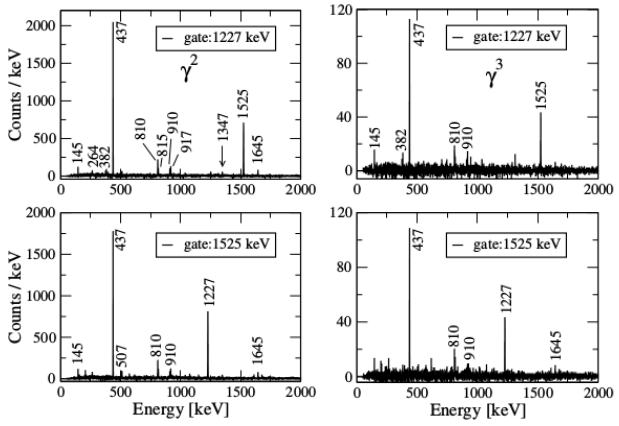

Figure 1. Symmetrical HPGe $\gamma - \gamma$ matrix showing gates on 1227 keVand 1525 keV (left panel). The right panel of the figure shows the same gates on 1227 keV and 1525 keV gamma energies but with a different folding coincidence condition of $\gamma - \gamma$ - γ (triple) trigger in HPGe detectors using RADware and GASPware softwares.

4. The Measured Energy Levels Associated with ^{42}Ca in the Current Work

The 1525-keV Level. The 1525 keV level is fed with a 1227 keV transition from the yrast $I^\pi = 4^+$ state to the $I^\pi = 2^+$. This energy level is assigned a spin of 2 with a positive parity. It decays to the ground state 0+ with the gamma energy of 1525 keV. The relative intensities of the gamma transitions have been determined in this current work as shown in Table 2.

The 2752-keV Level. This energy level is populated by 437 keV gamma transition which is a decay from the 3190 keV level to a spin and positive parity of 4^+. The relative intensity is calculated to be 50 (even though the directional correlations from

oriented states DCO's calculation is not shown here). The multipolarity is dominantly an E2, but can possibly be an M3 transition using the expression in equation (1):

$$\left|I_i - I_f\right| \leq \Delta L \leq \left|I_i + I_f\right|, \quad (1)$$

where the largest possible value of ΔL is $I_i + I_f$ and the lowest possible value $I_i - I_f$. The parity change in the transition is given by the selection rules [9].

The 3190-keV Level. As shown in Figure 2 of the current work, more than two gamma transitions populated this energy level but with different experimental branching ratios, B(M1)/B(M2) (not determined here). Apart from 910 keV transition energy populating this state, both 2956 keV and 2302 keV gamma transitions are not observed in this current work. This also forms the basis for which the gamma transitions are shown as broken lines and under brackets. The observed multipolarity is M1 which is the likely dominant one. This is so because there is a strong dependence of the transition rate on multipolarity where the lowest multipolarities are most likely to occur [9]. The relative intensity of the 910 keV gamma transition is calculated as 18 and this is shown in Table 2.

5. Discussion and Conclusion

The coincidence spectra on selected gamma transition energies in the left panel of Figure 1 is a double fold: that is, $\gamma - \gamma$ matrix sorting condition in the master trigger of ROSPHERE. In this sorting, the gamma energy generally has more counts as recorded for same gates in triple fold gating condition. On the 1227 keV gate, gamma transitions of 145-, 264-, 382-, 437-, 810-, 815-, 910-, 917-, 1347-, 1525-, and 1645-keV were observed to be in coincidence with one another with 437-keV having the highest counts of approximately 2000 counts/keV. Looking at both Figures 1.0 and 2.0, 1227 keV and 1525 keV are coincident with each other. This implies that, a gate on either one should produce the other one in coincidence. On 1525 keV gate, gamma transitions found to be in coincidence are the 145-, 437-, 507-, 810-, 910-, 1227-, and 1645-keV [7, 8, 5, 10]. The coincidence analysis performed in Figure 1 further affirms the assigned nucleus of ^{42}Ca in the current work where the gamma transitions have already been reported by other researchers [1].

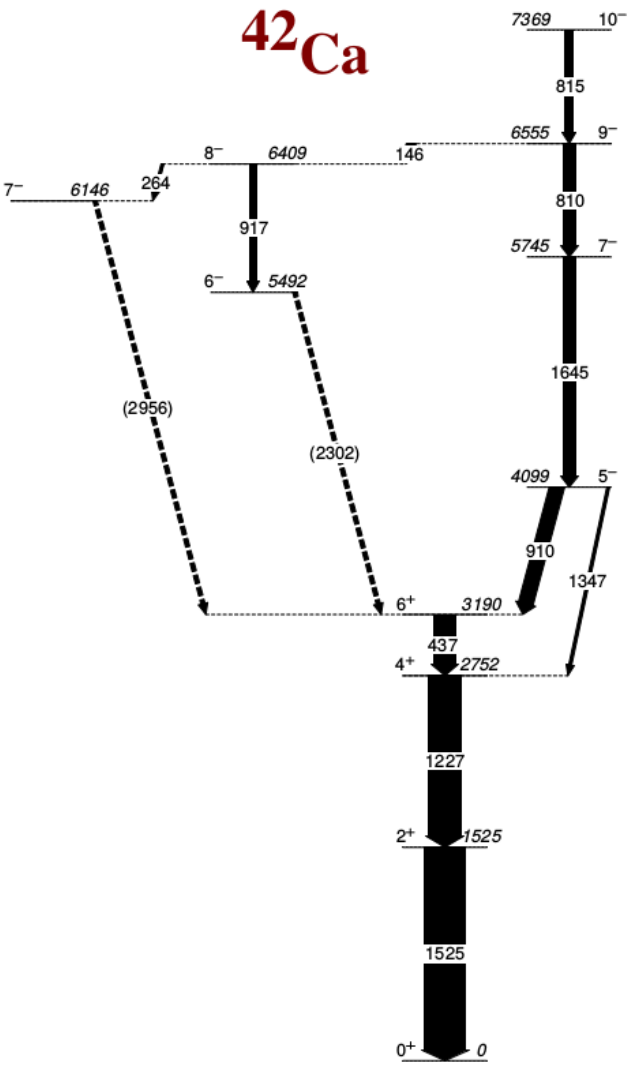

Figure 2. Partial Energy Level Scheme of ^{42}Ca Showing the Measured Gamma Transitions up to Higher Spin and Parity of $I^{\pi} = 10^{-}$ in the Current Work.

Acknowledgments

TD thanks in a special way his PhD supervisors, Profs. Patrick Regan and Zsolt Podolyak for their mentorship during his programme at the University of Surrey, Guildford, UK. TD thanks Dr. Stanimir Kisyov of the IFIN-HH Bucharest and all other staff of the Institute for their various contributions during the ^{192}Os(^{18}O,^{16}O)^{194}Os experiment late 2015.

References

[1] Evaluated Nuclear Data File (ENSDF), http://www.nndc.bnl.gov/ensdf. Retrieved (2020).

[2] N. Marginean, D. I. Balabanski, D. Bucurescu, S. Lalkovski, L. Atanasova, I. Cata-Danil, G. Cata-Danil, J. M. Daugas, D. Deleanu, P. Detistov, G. Deyanova, D. Filipescu, G. Georgiev, D. Ghia, K. A. Gladnishki, R. Lozeva, T. Glodariu, M. Ivacu, S. Kisyov, R. Mihai, R. Marginean, A. Negret, S. Pascu, D. Radulov, T. Sava, L. Stroe, G. Suliman, & N. V. Zamfir, "In-beam Measurements of Sub-nanosecond Nuclear Lifetimes with A Mixed Array of HPGe and $LaBr_3$(Ce) Detectors", Europium Physics Journal A **46** (2010) 329.

[3] T. Daniel, S. Kisyov, P. H. Regan, N. Marginean, Zs. Podolyak, R. Marginean, K. Nomura, M. Rudigier, R. Mihai, V. Werner, R. J. Carroll, L. A. Gurgi, A. Oprea, T. Berry, A. Serban, C. R. Nita, C. Sotty, R. Suvaila, A. Turtrica, C. Costache, L. Stan, A. Olacel, M. Boromiza, & S. Toma, "γ-ray Spectroscopy of Low-lying Excited States and Shape Competition in ^{194}Os", Physical Review C **95** (2017) 024328.

[4] T. Daniel, J. S. Gemanam, and E. C. Hemba, "Gamma-ray Spectroscopy of the Low-lying Energy-state Populating the 0.64 ms $13/2^{+}$ Isomeric

State in ^{205}Po nuclei using the Coincidence Techniques", Nigerian Journal of Pure and Applied Sciences, **8** (2016) 280.

[5] T. Daniel, *Nuclear Structure Studies of Low-lying States in ^{194}Os using Fast-timing Coincidence Gamma-ray spectroscopy*, PhD Thesis University of Surrey, Guildford (2017).

[6] D. Bucurescu, I. Cata-Danil, G. Ciocan, C. Costache, D. Deleanu, R. Dima, D. Filipescu, N. Florea, D. G. Ghia, T. Glodariu, M. Ivacu, R. Lica, N. Marginean, R. Marginean, C. Mihai, A. Negret, C. R. Nita, A. Olacel, S. Pascu, T. Sava, L. Stroe, A. Serbau, R. Suvaila, S. Toma, N. V. Zamfir, G. Cata-Danil, I. Gheorghe, I. O. Mitu, G. Suliman, C. A. Ur, T. Braunroth, A. Dewald, C. Fransen, A. M. Bruce, Zs. Podolyak, P. H. Regan & O. J. Roberts, "The ROSPHERE γ-ray Spectroscopy Array", Nuclear Instruments and Methods in Physics Research A, **837** (2016) 1.

[7] E. K. Warburton, J. J. Kolata & J. W. Olness, "Decay Schemes for High-spin States in ^{42}K and ^{42}Ca", Physical Review C **11** (1975) 700.

[8] P. Herges, H. V. Klapdor & T. Oda, "High-spin states in ^{40}K and ^{42}Ca", Nuclear Physics A **372** (1981) 253.

[9] J. S. Lilley, *Nuclear Physics: Principles and Applications*, John Wiley and Sons Ltd, Chichester, West Sussex (2001).

[10] H. H. Eggenhuisen, I. O. Ekstrom, G. A. P. Engelbertink & H. J. M. Aarts, "High Spin States of ^{39}K and ^{42}Ca", Nuclear Physics A **305** (1978) 245.