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Level structure of ^{74}As from the $^{72}\text{Ge}(\alpha, np\gamma)$ reaction

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States of ^{74}As , excited through the $^{72}\text{Ge}(\alpha, np\gamma)$ reaction at $E_\alpha = 30$ to 55 MeV, were studied. Excitation functions, γ -ray angular distributions, γ - γ coincidences, and γ -time distributions with respect to the beam bursts, were determined. Three excited states are identified with states previously observed with the (p, n) reaction. In addition, six new levels are incorporated into the level scheme. The decay pattern of these levels is rather simple. The existence of two γ -ray cascades showing quite similar energy spacings and possible spin sequence $J=7 \rightarrow 6 \rightarrow 5 \rightarrow 4$ which mainly feed the known 3^- state at 183.0 keV is observed. A half-life $T_{1/2} = 28 \pm 2$ nsec of a level at 259.2 keV was determined. This is the state whose g factor was previously assigned to a level at 273.8 keV.

NUCLEAR REACTION $^{72}\text{Ge}(\alpha, np\gamma)^{74}\text{As}$, $E_\alpha = 30$ to 55 MeV; measured $E_\gamma, I_\gamma, \gamma(\theta)$; exc. funct., γ - γ, γ - t (nsec). ^{74}As deduced levels, $J, \pi, T_{1/2}$. Enriched Ge targets. Ge(Li) detectors.

I. INTRODUCTION

The odd-odd nucleus ^{74}As has been studied in the past by means of the $(p, n\gamma)$ (Refs. 1-4), $(^3\text{He}, d)$ (Ref. 5), and (p, d) (Ref. 6) reactions. The most recent and comprehensive investigation is that of Kimura¹ who, from the measurement of conversion electrons and cross sections determined spins, parities, and γ -ray multipolarities corresponding to levels up to about 470 keV. The earlier work on $(^3\text{He}, d)$ and (p, d) mostly contributed with spectroscopic factors and angular momentum transfer values. In addition, Christiansen *et al.*² determined the lifetime and g factor of a level proposed at 273.8 keV. The identification of this level as well as another one at 14.9 keV is at variance with other investigations.^{1,4,6}

In this paper we report the results of a study of the $^{72}\text{Ge}(\alpha, np\gamma)$ reaction at $E_\alpha = 30$ to 55 MeV leading to levels of ^{74}As . As expected, this reaction populates new levels corresponding to spin values higher than those observed up to now. The decay pattern of these levels is rather simple and exhibits interesting features like for instance the existence of two γ -ray cascades showing quite similar energy spacings and possible spin sequences $J=7 \rightarrow 6 \rightarrow 5 \rightarrow 4$ which mainly feed the known 3^- state at 183.0 keV. In turn these cascades are similar to another recently reported in the neighboring isotope ^{72}As .⁷ The present data also show that the g factor and lifetime previously assigned to a level at 273.8 keV correspond to a level at 259.2 keV.

II. EXPERIMENTAL METHODS AND DATA ANALYSIS

A 55 MeV α -particle beam, obtained from the Buenos Aires synchrocyclotron and degraded to 30 MeV in steps of 5 MeV, was used to bombard a 5 mg of enriched (82%) ^{72}Ge target bound to a thin Mylar foil.

In the present work the experimental information was obtained through the measurement of (a) γ -ray excitation functions between $E_\alpha = 30$ and 55 MeV, (b) γ - γ coincidences, (c) γ -ray time distributions with respect to the beam pulse in the nsec range, and (d) γ -ray angular distributions. Three Ge(Li) detectors were used throughout the experiments. Two of them were of about 7% efficiency and 2.4 keV resolution at the ^{60}Co lines. The third was an x-ray spectrometer of about 700 eV at 122 keV. The data were accumulated in a 4096-channel memory and the spectra were analyzed with the help of a light pen and small HP computer using a program developed in this laboratory.⁸ Energy and efficiency calibrations were obtained using standard radioactive sources of ^{152}Eu and ^{133}Ba .^{9,10} The γ -ray energies determined with the large detectors ($E_\gamma > 100$ keV) of all but the weakest lines are estimated to be accurate to within 0.2 keV, while for $E_\gamma < 100$ keV the x-ray detector was used and the energy accuracy was increased to 0.05 keV. The errors of the γ -ray intensities range from 10% for the strongest lines to 30% for the weakest and/or low energy ($E_\gamma < 80$ keV) lines. In the following we summarize the most relevant information corresponding to the different measurements.

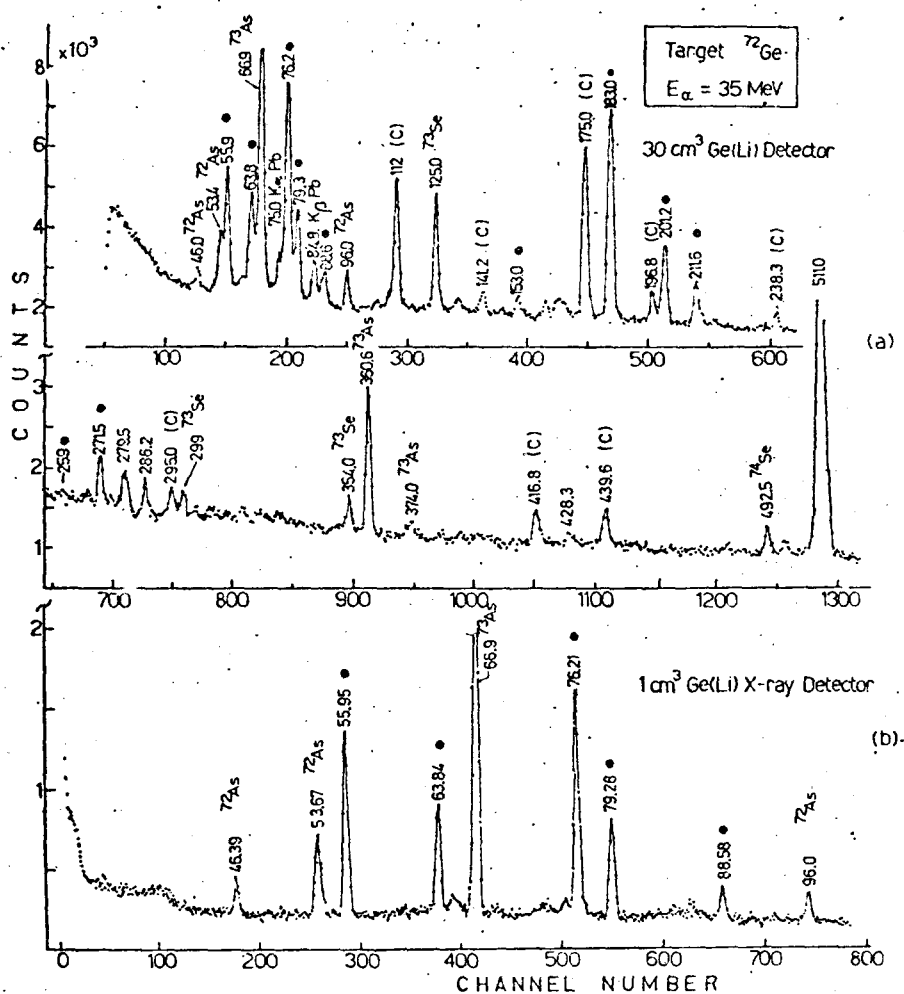


FIG. 1. Single γ -ray spectrum from the $^{72}\text{Ge} + \alpha$ reaction at $E_\alpha = 35$ MeV, obtained with a large Ge(Li) detector (upper part) and an x-ray detector (lower part). The γ rays assigned to ^{74}As are labeled with solid dots and the lines originating in the target backing with the letter C. Part of the intensity (40%) of the 183.0 keV line corresponds to the $^{16}\text{O}(\alpha, n p)^{18}\text{F}$ reaction.

A. Excitation functions

In Fig. 1 the low energy γ -ray spectrum obtained with the x-ray detector and the spectrum obtained with a large Ge(Li) diode corresponding to $E_\alpha = 35$ MeV are shown. The peaks assigned to ^{74}As are indicated with solid dots. The most prominent peaks corresponding to ^{73}Se , ^{73}As , ^{72}As , and background lines from the target (denoted C) are also labeled. The peak at 183 keV is composite but could be well resolved with the small x-ray detector. About 60% of the intensity belongs to ^{74}As while the rest corresponds to the $^{16}\text{O}(\alpha, n p)^{18}\text{F}$ reaction. Table I lists the γ -ray energies and intensities at $E_\alpha = 35$ MeV. The variation of the γ -ray intensities with bombarding energy is shown in Fig. 2. The intensities from the different runs were normalized using the photopeak area of the 835 keV line from the inelastic scattering reaction

TABLE I. Energies, intensities, and angular correlation coefficients of γ rays from the $^{72}\text{Ge}(\alpha, n p \gamma)^{74}\text{As}$ reaction at $E_\alpha = 35$ MeV.

E_γ (keV)	I_γ	A_2^a
55.95	70	-0.15 ± 0.21
63.84	46	0.13 ± 0.13
76.21	85	0.25 ± 0.10
79.28	37	0.02 ± 0.09
88.58	12	
153.0	9	
183.0	100	
201.2	54	-0.08 ± 0.14
211.76	33	-0.26 ± 0.17
259	3	
271.5	28	0.67 ± 0.11

^a The computation with both A_2 and A_1 as free parameters yielded very large errors, with A_1 consistent with zero. Hence we quote the results of fitting the data with A_1 fixed and equal to zero.

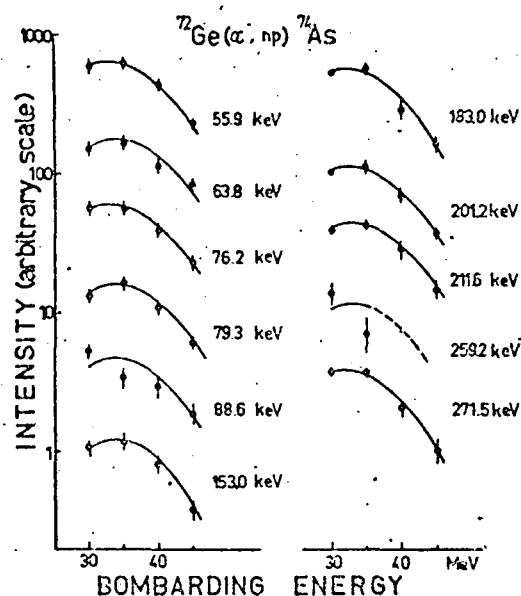


FIG. 2. Excitation functions of γ rays assigned to ^{74}As . The γ intensities were normalized to the intensity of the $2^+ \rightarrow 0^+$ transition in the target nucleus arising from inelastic scattering.

on the target as standard. A comparison with the excitation functions corresponding to other reactions produced simultaneously, shows that the (α, np) process is easily distinguishable from the others. The curves for the hitherto known^{2,4} γ rays of energies of 76.2 and 271.5 keV were used as a preliminary tool to identify the other γ rays, later confirmed by coincidences.

B. γ - γ coincidences

Different runs were carried out to determine coincidence spectra using either the x-ray or one large Ge(Li) detectors to observe the γ rays selected as gates. A conventional coincidence system with a time resolution of 100 nsec was used. The data were routed into four separate 1024-channel sections of the analyzer memory corresponding to equal windows set on peaks and adequate background intervals. The net coinci-

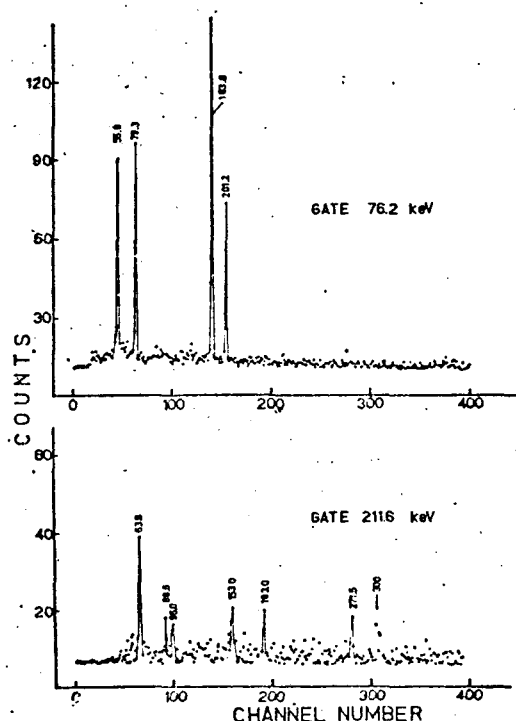


FIG. 3. γ - γ coincidences spectra obtained by gating on the 76.2 and 211.6 keV lines. The 96.0 keV peak comes from the 96.0 \rightarrow 213.8 keV cascade in ^{72}As and the 300 keV line is due to the backscattering radiation from the annihilation peak.

dence spectra for gates on the 76.2 and 211.6 keV peaks are shown in Fig. 3, and the results of these measurements are summarized in Table II.

C. Angular distributions

γ -ray spectra were taken at angles of 75°, 90°, 100°, 110°, 120°, and 133° with respect to the beam direction. The target was rolled into a cylindrical shape of 3 mm in diameter. The Ge(Li) diode was placed at 15 cm from the target. The normalization of the spectra at different angles was obtained by feeding the output of a pulser, triggered by signals from a monitor detector, into the preamplifier of the moving detector. Owing to the large errors of the experimental values plus

TABLE II. γ - γ coincidence intensities from the present experiment (intensities corrected with the detector efficiency are given in arbitrary units).

Gate \ E_γ	55.9	63.8	76.2	79.3	88.6	153.0	183.0	201.2	211.6	271.5
55.9	...		30	30			32	30		
63.8		...			8	4	8		17	14
76.2	50		...	30			62	31		
79.3	20		14	...			13	20		
183.0	110	13	140	60	20	4	...	85	15	
201.2	57		32	52			52	...		
211.6		30			8	8	10		...	27

a half-life of 28 ± 2 nsec for the 76.2 keV line and a $T_{1/2} < 5$ nsec for the preceding 56 keV transition (Fig. 4). These facts indicate that: (a) The 76 keV γ ray, observed by Christiansen *et al.*,² Kimura,⁴ and us are the same; (b) the half-life of ~ 27 nsec corresponds to the level deexcited by such γ ray. Furthermore, the Q -value analysis of Kimura shows fairly conclusively that the 183 keV transition goes to the ground state and not to the 14.9 keV state as claimed by Christiansen *et al.*, so that the level under discussion must lie at 259.2 keV. The most likely spin assignment for this state is $J=4$. This is based on the following: (a) The 76.2 keV γ ray must have dipole character because of the level's half-life and the intensity balance in and out of the 183.0 keV state. [Otherwise the correction for internal conversion would imply $I_T(76.2) > I(183.0)$]. This is consistent with our angular distribution data and is also in agreement with Kimura's internal conversion results. (b) The branching ratio $I(259.2)/I(76.2)$ and the lack of crossover transitions from upper states make the possibility $J=2$ or 3 very unlikely. In addition any of these assignments would imply quite different (of the order of 10^3) hindrance factors for the transitions depopulating the 259.2 keV state. It is to be noted that the argument utilized by Christiansen *et al.*² to propose $J=3$ instead of $J=4$ (i.e., neutron feeding intensity into this level) reverses itself if the level lies at ~ 260 and not at ~ 274 keV. Furthermore the assumption of positive parity implies an $M2$ 259.2 keV transition with a measured half-life which agrees well with the single-particle estimate and systematics, and an $E1$ 76.2 keV line hindered 10^4 times which again is in agreement with hindrance values encountered throughout the Periodic Table for $E1$ transitions. Thus we propose $J^\pi = 4^{(+)}$ for the 259.2 keV state.

315.1 and 335.4 keV levels. These two levels have similar decay modes, feeding the $4^{(+)}$ 259.2 and 4^- 271.5 keV states, respectively. The intensity balance (due to the internal conversion correction), and the determined half-life limit of $T_{1/2} < 5$ nsec for both indicate that the 55.9 and 63.8 keV γ rays are dipole transitions. The angular distribution of these two γ rays are essentially isotropic and hence consistent with the deduced dipole character. The nonobservation of any crossover transition into lower states suggest that their spin is $J=5$, while consideration of usual hindrance factors for $M1$ and $E1$ transitions, together with the measured half-life limit appear to favor no change of parity in either case. Hence, the spin-parities $J^\pi = (5^+)$ and (5^-) for the 315.1 and 335.4 keV levels are tentatively proposed. It should be noted that Fournier *et al.*⁶

have observed a $J^\pi = 5^-$ or 6^- level at 337 keV which could be identified with our 335.4 keV level.

Levels above 500 keV. Each of these levels decays by a single transition. Because of the transition energies and the upper $T_{1/2} < 5$ nsec limit for these states (inferred from the measured half-life of the 55.9 and 63.8 keV lines) they should deexcite through dipole radiation. This is also borne out by the angular distribution data and in the case of the 79.3 keV line, the additional argument can be used that a quadrupole transition would imply a conversion coefficient not consistent with the intensity balance. Since crossover transitions are not observed, the most likely spin assignments for the 516.3 and 547.0 levels is $J=6$ and for the 595.6 and 700.0 keV levels is $J=7$.

IV. DISCUSSION

The (α, np) reaction studied in the present work shows much more selectivity in populating states in ^{74}As than those reactions previously used to investigate this nucleus. The decay scheme obtained here is rather simple and only a fraction of the observed levels were seen in earlier works, most of which made use of the (p, n) reaction at low energy. In addition to selectivity, the (α, np) reaction should favor high spins because of the large angular momentum carried in by the projectile. However, the highest spin proposed in this work ($J=7$) is small compared to those usually obtained with (α, xn) reactions in heavier even-even nuclei. Both results, the degree of selectivity and the amount of maximum angular momentum proposed here are in agreement with what has already been reported before in studies of nuclei in this region of the Periodic Table.⁷ It is to be noted, however, that the possibility of observing higher energy levels was hampered in the present work by the lack of statistics in the high energy part of our coincidence spectra. Longer runs using a megachannel system would be desirable to determine with higher accuracy to what degree is there a significant difference with heavier even-even nuclei in this regard.

A particularly interesting feature of the level scheme obtained in this work is the appearance of two groups of levels of very similar spacing and possibly equal spin sequence which decay into the ground and 3^- 183.0 keV states. The lowest members of these two groups are the $4^{(+)}$ state at 259.2 keV and 4^- at 271.5 keV as discussed in the preceding section. The next states up have possibly spin $J^\pi = (5^+)$ and (5^-) . The fact that the two sequences of levels with proposed spins $J=4, 5$, and 6 lie at such a similar excitation energy, is remarkable and suggests that they cor-

respond to opposite parities. It is also worthwhile pointing out that a very similar "band" has been observed in ^{72}As . In this nucleus a 4^- state lies at 309.8 keV, which is mainly fed by a (6^-) -5-4 cascade with energy spacings of 200.1 and 53.0

keV, respectively, showing an interesting parallelism with ^{74}As . No simple description of these bands can be proposed here. Nonetheless, the regularity exhibited by these groups of levels is intriguing and stimulates further study.

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