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Nuclear Spectroscopic Studies of Low-Lying States in ^{77}As

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The technique of directional gamma-gamma angular correlation has been used to investigate the decay of ^{77}Ge to levels in ^{77}As. The coincidence measurements were performed using a 35 cm^3 Ge(Li) detector and a 7.6 × 7.6 cm NaI(Tl) detector. The results of nine measured correlations served to verify the spin assignments of the low energy levels and in addition yielded values for the multipole mixing ratios of the involved gamma transitions. We also make a comparative analysis of ^{77}As and ^{75}As nuclei; both isotopes have a very similar low energy level structure.

A técnica da correlação angular direcional gama-gama foi usada para estudar o decaimento do ^{77}Ge para níveis no ^{77}As. As medidas de coincidências foram feitas usando um detector de Ge(Li) de 35 cm^3 e um detector de NaI(Tl) de 7,6 × 7,6 cm. Os resultados das medidas de nove correlações foram usados para associar spins aos estados de baixa energia e forneceram valores para as misturas de multipolaridades das transições gama envolvidas. Fez-se também uma análise comparativa dos núcleos ^{77}As e ^{75}As; à baixa energia, os dois isótopos têm uma estrutura de níveis nucleares muito similar.

1. Introduction

Recent experimental results show that it is difficult to explain the nuclear properties of the odd-A As isotopes in terms of the simpler nuclear models. Although these isotopes do not show rotational spectra as clearly as nuclei in a well established deformed region, the low lying levels in ^{77}As and ^{75}As exhibit nuclear properties which have been interpreted consistently[1,2] by means of the deformed-nucleus model. Theoretical studies of the level scheme of odd-A As nuclei have been done by various authors. Recent calculations[3,4], using a Coriolis-coupling model, predict very well the low energy levels in ^{75}As and ^{77}As.

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The energy levels of ^{77}As have been stucied by several investigators[5-8]. The placement of levels below 1 MeV is well established by coincidence work but spins and parities of the levels and multipolarities of the gamma transitions are not conclusively assigned. Previous angular correlation measurements[9,10] in this nucleus have been made with NaI(Tl) detectors and the limited energy resolution did not allow to resolve all the gamma transitions. In this work. we report the measurements of various y-y directional correlations between transitions depopulating the first six excited states of ^{77}As, using a hig-resoluction Ge(Li) detector. Because the low energy decay scheme of ^{77}As and ^{75}As are similar, a precise determination of nuclear properties in ^{77}As (in ^{75}As they are well known) can be of assistance in the interpretation of these nuclei through the available models.

2. Experimental Procedure

The radioactive samples of ^{77}Ge($T_{1/2}$ = 11.3h) were produced by irradiating 20 mg of natural germanium in the form of GeO_2 in the *Instituto* de *Energia Atômica* (IEA) reactor for 8 hours. The samples were allowed to decay for a period of 12h in order to reduo: the activity due to the presence of ^{75}Ge with $T_{1/2}$ = 82 min. A dilute solution was prepared by dissoluing GeO_2 in NaOH and approximately 20 μl of this solution were transferred into a cylindrical lucite container. The final size of the sample was 2.5 mm long and 1.5 mm in diameter.

The y-y spectrometer employed a combination of a 35 cm^3 true coaxial Ge(Li) detector and 7.6 cm x 7.6 cm NaI(Tl) detector. The NaI(Tl) detector was used as the movable counter. The detectors were shielded with lead cones in order to minimize the effects of scattered gamma-rays. The γ-γ coincidences were recorded by using a standard fast coincidence system having a resolving time of 70 nsec and a 4036 channel pulse height analyser In all cases three angular positions viz 90°, 135" and 180" were selected for the movable detector. Theangleswere changed randomly every 30 min. to minimize any systematic errors in the spectrometer. The gamma-rays through the Ge(Li) detector, gated by the coincidences with an energy window in the NaI(Tl) detector spectra, were stored in the multichannel analyzer allowing the investigation of several gamma-cascades simultaneously. In order to correct for the coincidence events with the Compton scattered radiation of higher energy gamma-rays included in the windoa. the spectra in coincidence with the gate window moved to the right of the photo-peak in the NaI(Tl) detector spectra were also recorded.

The angular correlation coefficients *A,,* were calculated from the photo-peak coincidence counts *W(0)* after correction for the Compton contribution. accidental coincidences and for the decay of the source during the experiment. through the expression

$$W(\theta) = \sum_k A_{kk} P_k (\cos\theta),$$

where

$$A_{kk} = A_k(\gamma_1)\, A_k(\gamma_2),$$

with

$$A_k(\gamma) = [F_k(II'LL) + 2\delta F_k(II'LL') + \delta^2 F_k(II'L'L')] \times [1 + \delta^2]^{-1}.$$

The F_k coefiicients are tabulated[11] and the 6 is the multipole mixing ratio for the transition. The convention of Becker and Steffen[12] has been followed for the phase of 6. Thus, when *A,* refers to the first transition in the cascade, a phase factor $(-1)^{L'-L}$ appears in front of the interference term in the iast expression.

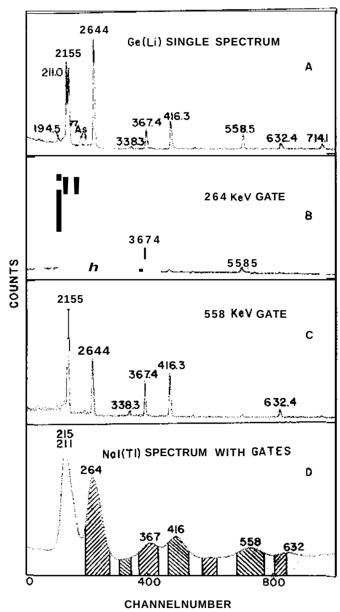

Fig. 1 - Singles spectra of low energy y-rays in ^{77}As observed with the Ge(Li) detector (A) and NaI(Tl) detector (D): figs. (B) and (C) show the Ge(Li) spectra gated by 264 keV and 558 keV γ-rays respectively in the NaI(Tl) detector.

3. Results

The low energy gamma-ray spectra in the decay of ^{77}Ge taken through the Ge(Li) detector and the NaI(Tl) detector are shown in Figs. 1-A and 1.D respectively. The sections of the NaI(Tl) spectrum used for gating windows are also shown in Fig. 1.D. Typical y-y coincidence spectra corresponding to the gates at 264 keV and 558 keV are shown in Figs. 1.B and 1.C respectively. The 367 keV and 417 keV photopeaks were not completely resolved in the NaI(Tl) detector spectrum and therefore it was not possible to measure the Compton contribution in the 367 KeV gate. An estimate of this contribution was made by using the intensities of the involved transitions.

Gamma cascade (keV)	Measured coefficients A_{22}	A_{44}	Mixed transition (keV)	Possible spin sequences	Mixing ratio (δ)
211-264	-0.209 ± 0.005	0.016 ± 0.008	264	9/2(2)5/2(1,2)3/2	-0.50 ± 0.1
367-264	-0.454 ± 0.007	-0.027 ± 0.009	264	5/2(1)5/2(1,2)3/2	-0.44 ± 0.06
417-215	-0.018 ± 0.005	-0.024 ± 0.009	215	5/2(1)3/2(1,2)3/2	-0.12 ± 0.04
558-367	-0.167 ± 0.016	0.004 ± 0.022	558	a) 5/2(1,2)5/2(1)5/2	1.1 ± 0.25
				b) 7/2(1,2)5/2(1)5/2	-0.2 ± 0.01
558-417	0.140 ± 0.013	-0.032 ± 0.017	558	a) 5/2(1,2)5/2(1)3/2	1.0 ± 0.2
				b) 7/2(1,2)5/2(1)3/2	-0.2 ± 0.01
558-632	0.105 ± 0.030	-0.007 ± 0.043	558, 632	a) 5/2(1,2)5/2(1,2)3/2	0.28 ± 0.05
				b) 7/2(1,2)5/2(1,2)3/2	0.0 ± 0.01
338-558	0.410 ± 0.060	-0.140 ± 0.100	338, 558	a) 7/2(1,2)5/2(1,2)5/2	0.88 ± 0.50
				b) 7/2(1,2)7/2(1,2)5/2	> 1
558-(367)-264	0.307 ± 0.013	-0.030 ± 0.019			
558-(417)-215	-0.075 ± 0.009	-0.015 ± 0.014			

Table I - Results of angular correlation measurements of gamma transitions in ^{77}As

Table I shows the various studied gamma cascades and the experimental angular correlation coefficients *A*, obtained in the present study. The experimental values of *A*,, have been corrected for the effects due to finite solid angle of the detectors[13,14]. Two of the studied cascades are triple gamma angular correlations with the intermediate transition unobserved. Several cascades were measured twice using different gates; in such cases, average values of the *A*,, coefficients are quoted in Table I. The multipole mixing ratio 6 of the gamma transitions along with the spin sequences consistent with the observed directional correlation, are also presented in Table I. The value of the mixing ratio of the gamma transition in each case was determined from the χ^2 plot against 6 for themost probable spin sequence. The errors in the 6 values are based upon a 30% probability level. The level scheme of ^{77}As showing only the transitions studied in this work is presented in Fig. 2 along with the spin and parity assignments to the levels.

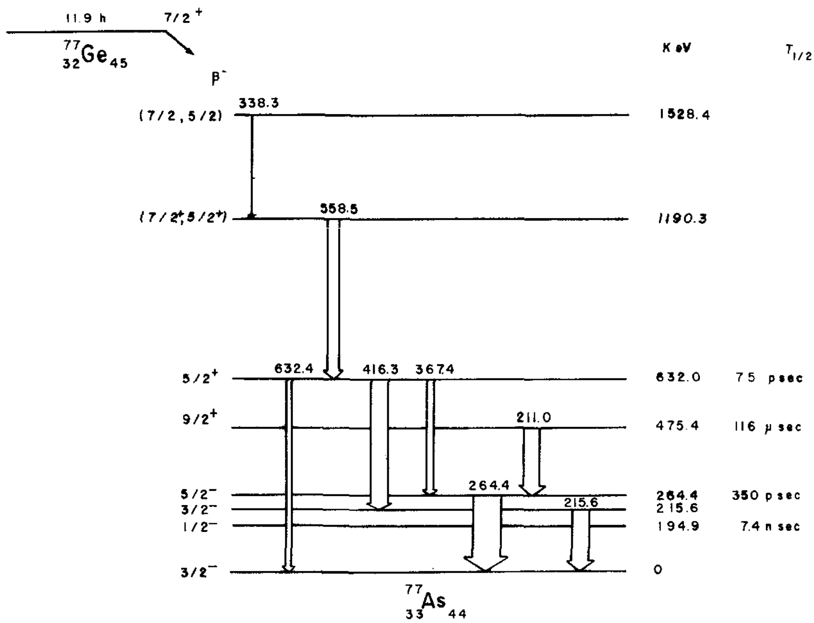

Fig. 2 - Partial decay scheme of ^{77}Ge to levels in ^{77}As.

In order to check for a possible attenuation due to internal fields. the γ-γ directional correlation of the 367-264 keV cascade was also measured using a solid GeO_2 source. Since the results were identical to the one obtained with the liquid source. it was assumed that the attenuation of the measured correlation was negligible. Because the half lives of the levels involved in the measurement are quite short (< 350 psec) (Refs. 6, 7. 15), this assumption is probablv valid for all the cascades investigated.

4. Discussion of the Results

The odd proton nuclei in the mass region $71 \leq A \leq 85$ have long eluded a very satisfactory theoretical treatment. The presence of a large number of nucleons outside the closed shells of neutrons and protons makes a rigorous shell model treatment prohibitively complicated. On the other hand. an attempt to understand the level spectra. moments and transition rates in ^{75}As in terms of rotation-particle-coupling model showed interesting results[1,2]. This Coriolis coupling model was recently refined by the incorporation of residual interaction of pairing type between protons of the even-even core. Such a model has been applied by Scholz and Malik[3] to calculate the level spectra of Ga. As. Br and Rb isotopes. Using the wave functions constructed from the Nilsson levels in 1f, 2p, 1g, 2d, and 3s subshells, the model successfully predicts many of the characteristic features of nuclei in this mass region.

For odd-A isotopes of As this model predicts a $3/2^-$ ground state, a low lying, doublet of positive parity states ($9/2^+$, $5/2^+$) and a low lying triplet of negative parity states ($1/2^-$, $3/2^-$, $5/2^-$). Both positive parity states have been identified in ^{75}As and ^{77}As. The $9/2^+$ states in ^{73,75,77}As have been identified by their relatively long life times (6 μsec, 17 msec and 116 μsec, respectively). The three lowest excited levels in ^{75}As, at energies of 199, 265 and 280 keV, are known to be $1/2^-$, $3/2^-$ and $5/2^-$, respectively. With a recent measurement[7,8] of a level at 195 keV in ^{77}As this nucleus also displays the low lying triplet at 195, 215 and 264 keV with proposed spins and parities of $1/2^-$, $3/2^-$ and $5/2^-$, respectively.

In the analysis of the present directional correlation data, it has been assumed in analogy with ^{75}As that the 367 keV and 417 keV transitions populating the 264 keV and 215 keV levels respectively in ^{77}As, are pure E1 ($\delta = 0$ for both transitions). The conversion coefficient measurements are not presently available to further justify the assumption: however, it is interesting to note that the analysis results in the multipole mixing ratio $\delta(E2/M1)$ for the 264 keV and 215 keV transitions as $\delta(264) =$ $= -0.47 \pm 0.07$ and $\delta(215) = -0.12 \pm 0.04$, which are of the same order of magnitude and have the same sign as the corresponding transitions of 280 keV($\delta = -0.39 \pm 0.01$) and 265 keV($\delta = -0.06 \pm 0.02$) in ^{75}As[12].

The directional correlation results of the 211-264 keV cascade are consistent with the assignment of spin and parity of $9/2^+$ to the 475 keV level with the result that the 211 keV transition between this $9/2^+$ state and the 264 keV $5/2^-$ state is a pure M2. Using the determined values of the multipole mixing ratios for 558 keV, 264 keV and 215 keV transitions, the A_{22} coefficients of the triple correlations, 558-(367)-264 keV and 558-(417)-215 keV, were calculated to be $+0.27$ and -0.065 respectively, in reasonable agreement with the experimental values for these cascades (Table I).

Previous decay studies of ^{77}Ge have suggested the spin of 1190 keV level in ^{77}As to be either 7/2 or 5/2. The present directional correlation measurements of the 558-417 keV and 558-367 keV cascades are also consistent with spins of either 5/2 or 7/2 for this level. The multipole mixing ratio for the 5/2 spin assignement is calculated to be 1.1 ± 0.2 while for 7/2 spin it is – 0.2 ± 0.01. Using these δ values and the experimentally determined values of *A*,, for the 558-632 keV cascade, the multipole admixture of the 632 keV transition is calculated to be (92.7 ± 2.4)% E1 with a possible M2 admixture assuming 5/2 spin for the 1190 keV level while for 7i2 spin the 632 keV transition is a pure E1. From the above results, the 7/2 spin assignment for 1190 keV level is somewhat favoured although 5/2 spin can not be ruled out. Positive parity for this level is being suggested from the consideration of the model calculations of Scholz and Malik[3] which predict several positive parity states above 1 MeV in this nucleus.

The *A*,, values for the 338-558 keV cascade are consistent with 9/2, 7/2 and 5/2 spin assignments for the 1528 keV level. The 9/2 spin may, however, be ruled out from the observed gamma-transitions from this level to the $3/2^-$ states at 0 and 215 keV. No previous measurements suggest any spin assignment to this level.

There are many similitarities between the level structure of ^{75}As and ^{77}As. These include the energy, spin and parity, multipole admixtures in several corresponding transitions and the life time of some levels. The remarkable similarity between these nuclei was further confirmed by recent measurements[15,16] of the lifetime of the $5/2^-$ level at 264 keV in ^{77}As giving 500 psec. The lifetime of the $5/2^-$ state at 280 keV in ^{75}As is 400 psec (Ref. 17). The experimentally determined structure of levels in ^{73}As, however, has significant differences from ^{75,77}As. The first excited state is $5/2^-$ instead of $1/2^-$. The $5/2^+$ level is missing. A possible explanation for these deviations has been suggested to consider the deformation of ^{73}As to be negative rather than positive as in ^{75,77}As. This assumption then correctly predicts the $5/2^-$ first excited state and the single $9/2^+$ state in ^{73}As.

The general conclusion that can be drawn at present from the available experimental results is that the low energy structure of ^{73,75,77}As is reasonably well understood in terms of the Coriolis coupling model which includes the residual pairing interactions. Energy levels at higher excitations in ^{77}As are, however, less well understood and probably involve more complex interactions.

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