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Electromagnetic properties of low lying levels in ^{75}As

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Abstract. The g-factors of the 265 and 280 keV levels have been measured to be $0{\cdot}61\pm0{\cdot}16$ and $0{\cdot}30\pm0{\cdot}05$ respectively. The PAC technique was used for the measurements. In addition, the half-life of the 280 keV level has been remeasured to be $T_{\frac{1}{2}}=0{\cdot}32\pm0{\cdot}02$ ns using γ-γ delayed coincidences. Electromagnetic properties of the various levels calculated on the core-particle coupling model agree with the experimental results. The results are compared with other existing theoretical calculations.

Keywords. Core-particle coupling model; PAC technique.

1. Introduction

The ground state magnetic and quadrupole moments of ^{75}As show considerable deviation from the single particle shell model estimates. The E2 transition probability of a number of transitions is enhanced, suggesting the nature of the levels to be collective. In spite of the large ground state quadrupole moment, $Q_g=0{\cdot}29$ barn (Fuller and Cohen 1969), one fails to observe a rotational spectrum in this nucleus (figure 1). Theoretical calculations have been done by several workers to understand its level spectrum and electromagnetic properties. Kisslinger and Sorensen (1963) in their detailed investigation of nuclear properties in terms of pairing plus quadrupole interaction, interpreted the levels in odd A nuclei as arising from quasiparticle and phonon excitations as well as their interactions. They, however, could not get a good agreement with the experimental data in the region $28\leqslant Z\leqslant50$, $28\leqslant N\leqslant50$. In case of ^{75}As their model predicts the ground state spin to be $1/2^-$ and the first and second excited states to be $5/2^-$ and $3/2^-$ respectively. Kisslinger and Kumar (1967) improved upon the calculations of Kisslinger and Sorensen (1963) by introducing anharmonicity in the even-even core. The ground state spin was obtained to be $3/2^-$. The first three excited states were predicted to be $1/2^-$, $5/2^-$, $5/2^-$ $(7/2^-)$. Though there is an improvement over the earlier calculations (Kisslinger and Sorensen 1963), the agreement with the experimental level spectrum is poor. Scholz and Malik (1968) have interpreted the absence of a clear rotational spectrum in this nucleus on the Coriolis coupling model with a residual interaction of pairing type. Due to the band mixing resulting from rotational particle coupling they get a good agreement with the experimental spectrum. The first excited 2^+ state in the neighbouring even-even nuclei was assumed by them to have a rotational character. The nuclei ^{74}Ge and ^{76}Se, however, show a vibrational spectrum. Imanishi *et al* (1969) have also been able to get a good agreement with the experimental data for the energy level spectrum and the ground state quadrupole moment by considering the motion of an unpaired quasi-particle moving in a Nilsson orbit, to be coupled to the rotational motion by a Coriolis force. The E2 transition probability obtained by them for various transitions is about a factor of 4 to 5 off from the experimental value. Recently Paradellis and Hontzeas (1971) have investigated the level structure of this nucleus on the intermediate coupling model. The agreement with the experimental level spectrum and the static moments is good; however, the transition probabilities do not agree so well.

Certain regularities have been observed (Robinson *et al* 1967) in the Coulomb excitation studies on ^{63}Cu, ^{75}As and ^{79}Br, all having ground state spin of $3/2^-$. Core-particle coupling calculations have been successful in case of ^{63}Cu (Harvey 1963; Gove 1964; Thankappan and Truew 1965). Robinson *et al* (1967) have pointed out the applicability of this model in the case of ^{75}As and ^{79}Br. We have calculated static and transition moments for ^{75}As in the framework of core-particle coupling model. The agreement with the experimental data is good. The magnetic moments of 265 keV ($3/2^-$) and 280 keV ($5/2^-$) states in ^{75}As have been measured using perturbed angular correlation technique. In addition, the half life of the 280 keV level is measured using γ-γ delayed coincidence technique.

2. Experimental procedure and results

The ^{75}Se activity, in dilute HCl, was obtained from Bhabha Atomic Research Centre, Trombay. The liquid source was used as such for the half life and the magnetic moment measurements of the 280 keV level. For the magnetic moment measurement of the 265 keV level, ^{75}Se ions of about 130 keV energy were implanted on a thin annealed iron foil by means of a mass separator.

The half life of the 280 keV level was measured using the 121-280 keV gamma-gamma cascade. The γ-rays were detected by lead loaded plastic scintillators mounted on RCA 8575 photomultipliers. A least squares fit of the time spectrum after correcting for chance gave $T_{\frac{1}{2}}=0{\cdot}32\pm0{\cdot}02$ nsec. This is in good agreement with the measurements of Langhoff and Schumacher (1967), Baverstam and Hojeberg (1971), Shipley *et al* (1969) and Hojeberg and Malmskog (1969).

The *g*-factor of the 280 keV level was measured in an external magnetic field of 20 kG using the 121-280 keV γ-γ cascade. A conventional two channel coincidence spectrometer with NaI (Tl) scintillators as detectors was used. The quantity $\omega\tau/H$ was obtained to be $(5{\cdot}86\pm0{\cdot}91)10^{-4}$ rad/kG. This can be compared with the values $(13{\cdot}23\pm2{\cdot}62)10^{-4}$ rad/kG, $(5{\cdot}92\pm0{\cdot}93)10^{-4}$ rad/kG and $(6{\cdot}98\pm0{\cdot}75)10^{-4}$ rad/kG reported respectively by Manning and Rogers (1960), Agarwal (1966) and Becker and Zawislak (1971). Using $\tau=(0{\cdot}415\pm0{\cdot}011)$ nsec which is the weighted average of the values given by Langhoff and Schumacher (1967), Baverstam and Hojeberg (1971), Shipley *et al* (1969) and Hojeberg and Malmskog (1969) and the present work, the *g*-factor was calculated to be $g=+(0{\cdot}295\pm0{\cdot}049)$. The sign was inferred from the sense of rotation. The spin of the level being 5/2 the magnetic moment is obtained to be $\mu=(0{\cdot}74\pm0{\cdot}12)$ n.m. The weighted average value of $\omega\tau/H$, using the values given by Agarwal (1966) and Becker and Zawislak (1971), along with ours, has been used to obtain a better value of the hyperfine field, $H_{\mathrm{hf}}=(328\pm30)$ kG, at As site in Fe (Chopra and Tandon 1972). This value is used to extract the *g*-factor of the 265 keV level from the measured rotation.

Since the lifetime of the 265 keV level is very short (17 psec) we have measured its magnetic moment making use of the large hyperfine field present at As site in iron host (Chopra and Tandon 1972). Only one implanted sample of ^{75}Se in Fe was used for the measurements. A Ge(Li)—Na(Tl) coincidence system was used. A polarising field of 1·5 kG was used for measuring the rotation. The mean precession angle was obtained to be $(16·4\pm4·0)10^{-3}$ radians. With $\tau=(17·1\pm1·0)$ psec (Langhoff and Schumacher 1967) and $H_{eff}=(329·5\pm30·3)$ kG the value of the g-factor was obtained as $g=+(0·61\pm0·16)$. The spin of thel evel being 3/2 its magnetic moment $\mu=(0·915 \pm0·240)$ n.m. is in good agreement with the recently reported value of $\mu=(1·11\pm0·33)$ n.m. by Becker and Zawislak (1971).

3. Core excitation analysis and discussion

The ground state spin of this nucleus being $3/2^-$, one expects a group of levels with spins $1/2^-$, $3/2^-$, $5/2^-$ and $7/2^-$ on the core-particle coupling model. The levels at 199 keV ($1/2^-$), 265 keV ($3/2^-$), 572 keV($5/2^-$) and 822 keV ($7/2^-$) are identified as belonging to the multiplet (figure 1). The levels at 572 keV and 822 keV have been observed to be excited in the Coulomb excitation experiment by Robinson *et al* (1967). The $5/2^-$ level at 280 keV is identified as a single particle level ($f_{5/2}$) (see below). The ' centre of gravity ' (Lawson and Uretsky 1957) of the multiplet is at 572 keV in good agreement with 596 keV for the first excited 2^+ state in ^{74}Ge and 565 keV for the same in ^{76}Se. The de-Shalit core-excitation model (1961) predicts the Ml transition probability from

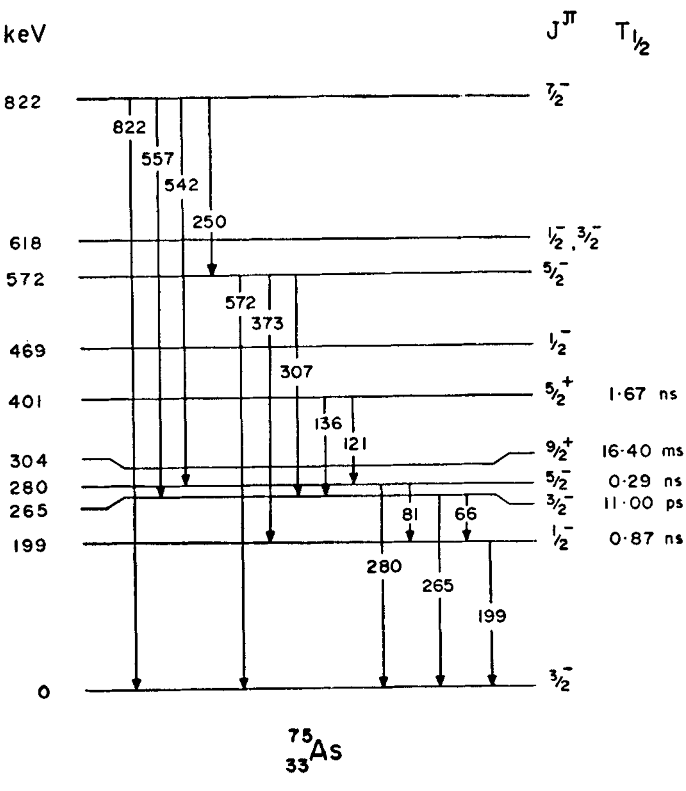

Figure 1. Partial level scheme of ^{75}As. Only transitions of interest are shown.

the excited group of levels to the ground state to be completely inhibited, however, a slight admixture among the like spin states make appreciable changes in it. The wave functions of various states can be written (Braunstein and de-Shalit 1962) as:

ground state	$\vert 3/2 \rangle_1 = A \vert 0\ 3/2; 3/2 \rangle + \sqrt{1-A^2} \vert 2\ 3/2; 3/2 \rangle$
199 keV	$\vert 1/2 \rangle = \vert 2\ 3/2; 1/2 \rangle$
265 keV	$\vert 3/2 \rangle_2 = A \vert 2\ 3/2; 3/2 \rangle - \sqrt{1-A^2} \vert 0\ 3/2; 3/2 \rangle$
280 keV	$\vert 5/2 \rangle_1 = B \vert 0\ 5/2; 5/2 \rangle - \sqrt{1-B^2} \vert 2\ 3/2; 5/2 \rangle$
572 keV	$\vert 5/2 \rangle_2 = B \vert 2\ 3/2; 5/2 \rangle + \sqrt{1-B^2} \vert 0\ 5/2; 5/2 \rangle$
822 keV	$\vert 7/2 \rangle = \vert 2\ 3/2; 7/2 \rangle$

Here $\vert J_c j; J \rangle$ denotes a state in which the core state J_c has been coupled to the odd particle having spin j to give a total angular momentum J. Using the general matrix element given by de-Shalit (1961) the electromagnetic properties of all the six levels have been calculated. The E2 and M1 transition probabilities, magnetic moments of $(3/2)_1$, $(3/2)_2$ and $(5/2)_1$ states and the ground state quadrupole moment can be described in terms of the following five parameters (de-Shalit 1965):

g_p=g-factor of the odd $p_{3/2}$ proton

g_c=g-factor of the first excited 2^+ state of the even-even core

$\Omega_p = \langle 3/2 \Vert \Omega_p^{(2)} \Vert 3/2 \rangle$, the reduced quadrupole matrix element for the odd proton

$\Omega_{22} = \langle 2 \Vert \Omega_c^{(2)} \Vert 2 \rangle$, the reduced quadrupole matrix element for the 2^+ state of the core

$\Omega_{20} = \langle 0 \Vert \Omega_c^{(2)} \Vert 2 \rangle$, the reduced quadrupole transition matrix element of the core.

These five parameters together with A and B defined above have been used to calculate nine E2, eight M1 transition probabilities, the magnetic moment of the $(3/2)_1$, $(3/2)_2$ and $(5/2)_1$ states and the ground state quadrupole moment.

The matrix element $\langle 3/2 \Vert \Omega_p^{(2)} \Vert 5/2 \rangle$ was calculated from the reduced single particle E2 transition probability, given by $(e^2/4\pi) \vert \frac{3}{5} R_0^2 \vert^2$ where $R_0 = 1{\cdot}2A^{1/3}$ fm. The matrix element $\langle 3/2 \Vert \Omega_p^{(1)} \Vert 5/2 \rangle$ was put equal to zero as the M1 transition between the single particle states $f_{5/2}$ and $p_{3/2}$ is l-forbidden. The value of g_c was taken to be Z/A which is consistent with the measured g-factors of 2^+ states in ^{74}Ge and ^{76}Se, $(0{\cdot}46 \pm 0{\cdot}23)$ and $(0{\cdot}40 \pm 0{\cdot}11)$ respectively (Heestand *et al* 1969). The $5/2^-$ level at 280 keV has been identified to be predominantly of single particle nature from the B(M1) ratios of (i) the 572 keV and 280 keV transitions; and of (ii) the 250 keV and 542 keV transitions (figure 1). The ratio of B(M1) in both these cases is $B^2/(1-B^2)$. Since B^2 is expected to be close to unity in core-excitation model, this relation predicts a large difference in the B (M1) of 572 keV and 250 keV transitions with respect to the 280 keV and 542 keV transitions respectively. This prediction is well borne out by the experimental data (table 2).

In the analysis A^2 was taken as an external parameter. With the experimental B(E2) values for the 822 keV, 265 keV, 199 keV transitions (Robinson *et al* 1969), the B(M1) value for the 280 keV transition and the magnetic moment of the ground state, values for all the parameters were obtained for each value of A^2. These parameters were then used to obtain the static and transition moments of various levels. A good fit was obtained for $A^2 = 0{\cdot}77$. The corresponding values for the other parameters are

Table 1. Comparison between the experimental and theoretical results. Reduced E2 transition probabilities.

Level Energy (keV)	Initial state spin	Final state spin	Transition energy (keV)	B(E2) (e^2 fm^4) Imanishi *et al* (1969)	Paradellis and Hontzeas (1971) [c]	Present work	Experimental value (Robinson *et al* 1967)
199	$1/2^-$	$3/2^-$	199	60	686	322 ± 28†	322 ± 28
265	$3/2^-$	$3/2^-$	265	50	503	47 ± 5†	47 ± 5
		$1/2^-$	66	—	9	100 ± 49	2903 ± 2232[a]
280	$5/2^-$	$3/2^-$	280	620	19	258 ± 22	299 ± 30
		$1/2^-$	81	—	281	15 ± 5	199 ± 40[a]
							$< 13{\cdot}3$[b]
572	$5/2^-$	$3/2^-$	572	90	662	680 ± 81	487 ± 50
		$1/2^-$	373	—	—	71 ± 26	160 ± 70
822	$7/2^-$	$3/2^-$	822	80	656	535 ± 50†	535 ± 50
		$3/2^-$	557	—	—	22 ± 11	26 ± 9

† Used to adjust the model parameters
[a] Calculated from the known lifetime of the level and other relevant parameters as given by Paradellis and Hontzeas (1970)
[b] Using gamma intensity given by Robinson *et al* (1967)
[c] Calculated from their tabulated values of transition probabilities

Table 2. Comparison between the experimental and theoretical results. Reduced M1 transition probabilities.

Level energy (keV)	Initial state spin	Final state spin	Transition energy (keV)	B(M1) (10^{-2} (nm)^2) Paradellis and Hontzeas (1971)[b]	Present work	Experimental value (Robinson *et al* 1967)
199	1/2⁻	3/2⁻	199	0·41	6·69	0·46 ± 0·06
265	3/2⁻	3/2⁻	265	3·69	4·12	18 ± 1
		1/2⁻	66	35·63	11·19	19 ± 5
280	5/2⁻	3/2⁻	280	0·02	0·54†	0·54 ± 0·02[a]
572	5/2⁻	3/2⁻	572	1·51	2·58	7·3 ± 1·9
		3/2⁻	307	—	8·65	< 0·3
822	7/2⁻	5/2⁻	250	—	6·88	6 ± 1
		5/2⁻	542	—	1·43	< 1·0

†Used to adjust the model parameters
[a]Calculated from the lifetime of 280 keV level and other relevant parameters as given by Paradellis and Hontzeas (1970)
[b]Calculated from their tabulated values of transition probabilities

Table 3. Comparison between the experimental and theoretical results. Static moments.

Moment	Level (keV)	Imanishi *et al* (1969)[a]	Paradellis and Hontzeas (1971)	Present work	Experimental value
Magnetic moment (nm)	Ground state	2·037[b] 1·507[c]	1·455	1·439†	1·439
	265	2·432[b] 1·832[c]	—	1·027	0·92 ± 0·24
	280	2·386[b] 2·057[c]	1·043	1·005[b] 1·665[c]	0·74 ± 0·12
Quadrupole moment (barn)	Ground state	0·28	0·22	0·52 ± 0·02	0·29

†Used to adjust the model parameters
[a]Calculated using wavefunctions given by Imanishi *et al* (1969)
[b]Calculated for $g_s^{eff} = g_s^{free}$
[c]Calcuated for $g_s^{eff} = 0{\cdot}6\, g_s^{free}$

$B^2=0{\cdot}828\pm0{\cdot}006$, $g_P=1{\cdot}076$, $\Omega_{20}=(0{\cdot}504\pm0{\cdot}026)$ eb

$\Omega_P=(0{\cdot}565\pm0{\cdot}022)$eb and $\Omega_{22}=-(0{\cdot}405\pm0{\cdot}104)$eb

The errors quoted have been derived from the experimental values used to calculate the parameters. The B(E2) and B(M1) values calculated from these parameters are listed in tables 1 and 2, and the static moments are given in table 3. Unless otherwise mentioned, the experimental values of B(E2) and B(M1) for various transitions are taken from Robinson *et al* (1967).

The value $\Omega_{20}=(0{\cdot}504\pm0{\cdot}026)$ eb is in good agreement with the experimental values $(0{\cdot}56\pm0{\cdot}02)$ eb and $(0{\cdot}68\pm0{\cdot}03)$ eb for ^{74}Ge and ^{76}Se respectively (Stelson and Grodzins 1965). For vibrational nuclei the quadrupole moment of the first excited 2^+ state should be zero; however, it is found to be of the same magnitude as the transition moment (Kisslinger and Kumar 1967). The quadrupole moment of the first excited 2^+ state, $Q(2^+)$, can be calculated from Ω_{22}. Its value $-(0{\cdot}31\pm0{\cdot}08)$b as derived from Ω_{22} can be compared with the experimental values $-(0{\cdot}25\pm0{\cdot}10)$b and $-(0{\cdot}17\pm0{\cdot}10)$b for ^{74}Ge (Grissmer *et al* 1972). The quadrupole moment of the first excited 2^+ state in ^{76}Se is not known, but from the trend of $Q(2^+)$ in this mass region (Smilansky 1970) it should be negative. It is remarkable that the sign of the $Q(2^+)$ is predicted correctly in our analysis. The positive sign of the ground state quadrupole moment of ^{75}As suggests it to be a $3/2^-$ hole state $(p_{3/2})^3$, the single particle estimate for this being $Q_{s.p.}=(2/5)\langle r^2\rangle$ barn, where $\langle r^2\rangle=(3/5)R_0^2$ with $R_0=1{\cdot}2A^{1/3}$fm. The value, $Q_{s.p.}=0{\cdot}061$ b, obtained from these relations can be compared with the value $(0{\cdot}400\pm0{\cdot}015)$b derived from the parameter Ω_P. It may be pointed out that in finding out the $Q_{s.p.}$ effective charges have not been used.

The E2 transition probability of 265 keV transition is a sensitive function of A and for this reason it was used in fitting for the model parameters. Except for 66 keV and 81 keV transition the calculated B(E2) values are in good agreement with the experimental data (*see* table 1). The large error quoted in the B(E2) of 66 keV transition is due to the uncertainty in its E2 content (Paradellis and Hontzeas 1970). The 81 keV transition has not so far been seen in the singles gamma spectrum. The branching ratio for this transition has been reported by Paradellis and Hontzeas (1970) from their Ge(Li)—Ge(Li) coincidence experiments. However, if one takes the gamma intensity for this transition to be $<1\times10^{-3}$ (Robinson *et al* 1967), one gets its B(E2) value as $<13{\cdot}3\ e^2$ fm^4 in good agreement with the calculated value of $(15\pm5)e^2$ fm^4. The calculated values for B(M1) agree well with the experimental results except for the 199 keV and 307 keV transitions (table 2). The ground state magnetic moment being known very accurately (Fuller and Cohen 1969) the error in the static and transition magnetic moments depend only on the error in B^2. This error is less than one per cent and is not mentioned in the calculated values of B(M1) and magnetic moments. The magnetic moment of the 280 keV level has been calculated for $g_s^{\mathrm{eff}}=g_s^{\mathrm{free}}$ and $0{\cdot}6\ g_s^{\mathrm{free}}$. The experimental value is in good agreement with the value obtained with g_s^{free}. The magnetic moment of the 265 keV level agrees well with our experimental results.

It has been suggested by Becker and Zawislak (1971) that the states at $199(1/2^-)$, $265\ (3/2^-)$ and 280 keV $(5/2^-)$ can be considered as members of a rotational band on the intrinsic state $1/2^-$ (199 keV). With the B(M1) value of the 66 keV transition and our experimental value for the magnetic moment of the 280 keV state as input data the magnetic moment of the 265 keV state has been calculated. Its value 1·32 n.m., for $g_K=2{\cdot}38$, is in agreement with the experimental results, however, the two values of the decoupling parameter '*a*' obtained from (i) the level spacing and (ii) the g_K are not consistent with each other. Calculations have also been done for the magnetic moment of the ground state, the 265 and the 280 keV states using the wave-functions given by Imanishi *et al* (1969). The values obtained with $g_s^{eff}=g_s^{free}$ and 0·6 g_s^{free} are given in table 3. The ground state magnetic moment calculated with $g_s^{eff}=0{\cdot}6\ g_s^{free}$ agrees well with the experimental result while the magnetic moment of 265 and 280 keV states are off by a factor of two.

Quantitative explanation of the intramultiplet transition probabilities is a stringent test of the applicability of core-particle coupling model. The calculated values of the B(E2) and the B(M1) are in good agreement with the experimental results (Robinson *et al* 1967). The core-particle coupling model, thus, provides a good description of the electromagnetic properties of low lying levels in this nucleus.

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