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g factor and the half-life of the 250 keV state in ^{77}Se

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Abstract. The *g* factor of the 250 keV $\frac{5}{2}^-$ state in ^{77}Se has been measured by the TDPAC method in an external magnetic field of 25 kG using the 755–250 keV gamma cascade in the decay of ^{77}Br. The value of the *g* factor was found to be $+0.447 \pm 0.010$. The half-life of the 250 keV level has also been measured with improved precision; the result is $T_{1/2}(250\text{ keV}) = 9.56 \pm 0.10$ ns.

RADIOACTIVITY ^{77}Br (from ^{75}As (α, 2n)); measured $\gamma\gamma(t)$, $\gamma\gamma(\theta, t, H)$; deduced $T_{1/2}, \mu$; NaI(Tl) detectors; natural target.

1. Introduction

In recent years the level structure of ^{77}Se has been investigated using a variety of experimental techniques, such as the reactions (d, p) and (d, t) (Macefield *et al* 1963, Lin 1965), (α, nγ) (Zell *et al* 1976), (n, γ) (Rabenstein and Vonach 1971, Knerr and Vonach 1971), and Coulomb excitation (Robinson *et al* 1965, Agnihotry *et al* 1970). The decay of ^{77}Br to levels of ^{77}Se has been well studied (Monaro 1963, Ardison and Ythier 1967, Sarantites and Erdal 1969), and most recently by Braga and Sarantites (1974) using Ge(Li) detectors. All these studies have resulted in a fairly well established level scheme for ^{77}Se (Singh and Viggars 1980).

The *g* factor of the 250 keV $\frac{5}{2}^-$ state in ^{77}Se has been measured previously by Engels *et al* (1964) using the time differential perturbed angular correlation (TDPAC) of the 755–250 keV γ cascade in an external magnetic field. The main purpose of our present measurement of this *g* factor is to provide a more precise experimental value of the magnetic moment, in view of the possibility that this state may be used as a probe in further hyperfine interaction studies using the TDPAC method (Unterricker and Schneider 1983). The quoted error in the previous measurement is $\simeq$12%. In this paper we report a remeasurement of the *g* factor with a considerable improvement in the accuracy. In addition we have also remeasured the lifetime of the 250 keV level with better precision than the values reported previously (Monaro 1963, Engels *et al* 1964).

The 250 keV state in ^{77}Se is populated in the electron capture decay of ^{77}Br (half-life 57 h). The 755–250 keV gamma cascade is quite suitable for TDPAC measurements having a large anisotropy $A_{22} \simeq -0.35$ (Braga and Sarantites 1974). In spite of the use of a ^{77}Br source in the form of a dilute solution, these authors observed an attenuation of the angular correlation for the 755–250 keV cascade due to the internal field. The half-life $T_{1/2}(250\text{ keV}) \simeq 9.5$ ns of the intermediate state is, however, in the range where the time differential method, which yields the maximum information regarding the interaction, can be used.

2. Experimental procedure

The radioactive sources of ^{77}Br were obtained from the ^{75}As(α, 2n) reaction. A disc of approximately 100 mg of 99.99% pure metallic arsenic was irradiated with 28 MeV α particles at the Instituto de Engenharia Nuclear (IEN) cyclotron, Rio de Janeiro. The irradiation was for one hour at 2 μA. Measurements of the source were started 30–40 h after the end of the irradiation and no activity other than that of ^{77}Br was observed in it. Initial measurements of the metallic arsenic source showed strong attenuation of the angular correlation of the 755–250 keV cascade. The subsequent sources were prepared by chemically separating the ^{77}Br activity from the arsenic using a simple solvent-extraction procedure (Sarantites and Erdal 1969). Finally, the AgBr precipitate was dissolved in a drop of 1M solution of sodium thiosulphate ($Na_2S_2O_3.5H_2O$) and transferred to a lucite sample holder.

The half-life of the 250 keV state was measured by the delayed γ–γ coincidence method utilising the combined 755–250, 575–250 and 568–250 keV gamma cascades. Two 2×2 in^2 NaI(Tl) detectors coupled to RCA 8850 and RCA 8575 photomultiplier tubes were used to detect the $(755 + 575 + 568)$ keV and 250 keV γ rays respectively (using gates B and A, respectively, in figure 1). A broad gate B was used in this experiment to include the 575 and 568 keV transitions in addition to the 755 keV transition feeding the 250 keV level, in order to improve the coincidence counting rate without appreciably increasing the random coincidences. A conventional fast–slow coincidence system with differential discriminators, in connection with a time-to-pulse-height converter and a multichannel analyser, was used to record the time spectrum. The detectors were placed at 180° to each other and as close as possible to the source. A rather weak source was used in this experiment to keep the random coincidence rate low.

A partial level scheme of ^{77}Se taken from the *Nuclear Data Sheets* (Singh and Viggars 1980) is presented in figure 2, showing the principal gamma transitions de-exciting through the 250 keV and 239 keV levels. In spite of the complexity of the decay scheme, with several gamma transitions in the vicinity of 570 keV, it can be seen that the 755–250 keV gamma cascade is relatively free of interference in a gamma–gamma coincidence experiment except for a very weak 766–239 keV cascade.

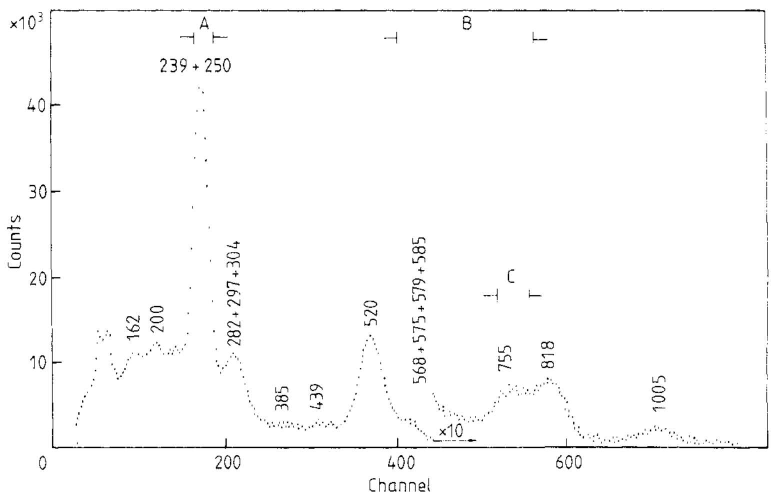

Figure 1. γ-ray spectrum of the ^{77}Br source observed with a NaI(Tl) detector.

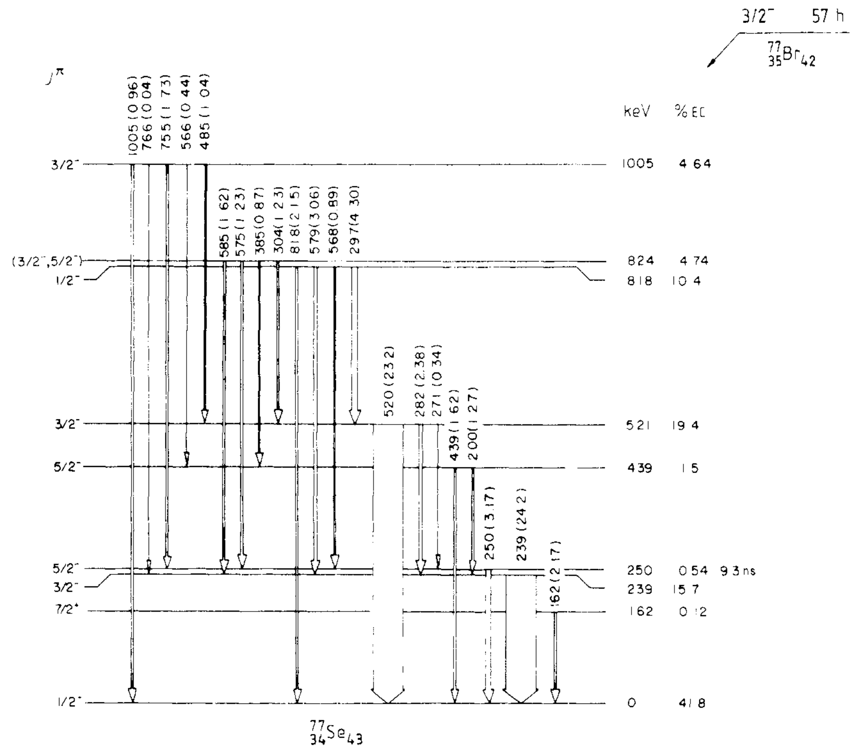

Figure 2. Partial decay scheme of ^{77}Br to the levels in ^{77}Se.

In our time differential experiment for the *g* factor measurement we utilised a similar set-up to that described above except that the detectors were coupled to the phototubes through light guides of 30 cm in length. The 755–250 keV gamma cascade was used for the measurment of delayed γ–γ coincidences (gate C and gate A, respectively, in figure 1). The detectors were placed at a distance of 5 cm from the source. An external magnetic field of 25 kG supplied by a water-cooled electromagnet was applied perpendicularly to the plane of the detectors. The coincidence spectra for alternate directions of the magnetic field were stored in two different subgroups of the multichannel-analyser memory. The field direction was changed every hour with the two detectors remaining fixed at 135° to each other. In this manner each source was measured for about one week. A total of three such sources were used for this experiment, each with a starting activity of approximately 35 μCi.

3. Results

The γ-ray spectrum in the decay of ^{77}Br taken with the NaI(Tl) detector is shown in figure 1. The gate positions are marked as A, B and C. The time distribution of the delayed coincidences for the combined 755–250, 575–250 and 568–250 keV gamma cascades is presented in figure 3. The prompt peak in this spectrum is due to the presence of 579–239 and 585–239 keV gamma cascades in the gate settings. The experimental data were least-squares fitted to the exponential function. The effects of the prompt coincidences and finite

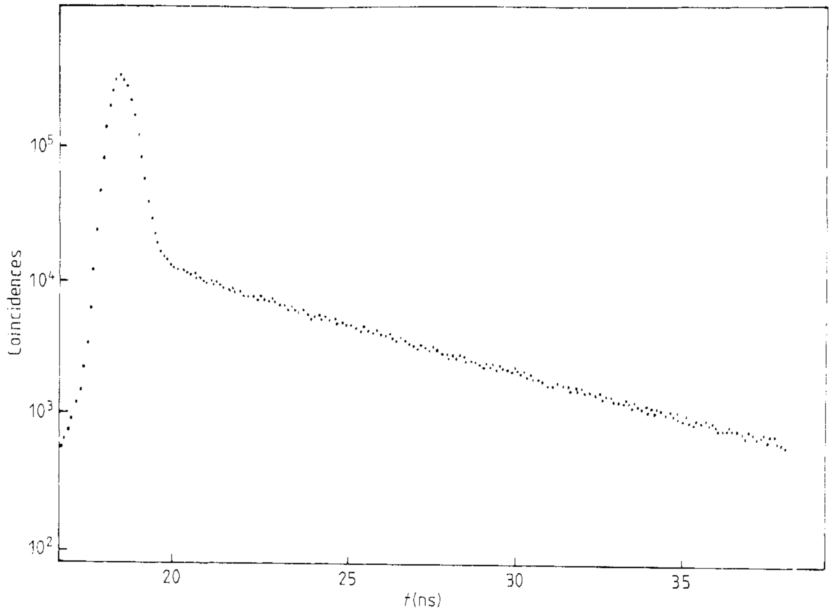

Figure 3. Delayed gamma–gamma coincidence spectrum of the combined 755–250, 575–250 and 568–250 keV γ cascades. The prompt coincidences in this spectrum are due to the presence of 579–239 and 585–239 keV cascades in the gate settings. The half-life is $T_{1/2} = 9.56 \pm 0.10$ ns.

time resolution were taken into consideration in the analysis. This was carried out using a computer program in which the exponential part of the decay was deconvoluted from the total spectrum using the experimental prompt shape. The error in the lifetime includes the statistical error plus the error in the time calibration. The time calibration was carried out by introducing delay lines which are known precisely into the stop channel. The time resolution of the equipment for this experiment was ~1.7 ns. The half-life of the 250 keV level was determined as $T_{1/2} = 9.56 \pm 0.10$ ns; this is in good agreement with the previous results of 9.7 ± 0.8 ns (Monaro 1963) and 9.3 ± 0.4 ns (Engels *et al* 1964). However, the present result is more precise. In the case of the g factor measurement the time resolution was ~2.2 ns, this somewhat inferior resolution being due to the use of light guides.

The asymmetry ratio $R(t, \theta = 135°) = (N\uparrow - N\downarrow)/(N\uparrow + N\downarrow)$ calculated from the time spectra measured for the alternate direction of the magnetic field is plotted in figure 4. The full curve is the least-squares fit of the experimental data to the function

$$R(t) = \left(\frac{3A_{22}}{4 + A_{22}}\right) e^{-\lambda t} \sin 2\omega_L t$$

where A_{22} is the unperturbed angular-correlation coefficient, λ is the exponential decay constant associated with the attenuation of the amplitude and ω_L is the Larmor precession frequency. The results of the least-squares fit are $A_{22} = -0.30 \pm 0.02$, $\omega_L = 53.48 \pm 1.00$ MHz and $\lambda = (24.1 \pm 3.6) \times 10^6$ s^{-1}.

The A_{22} value extracted from the present data is in fair agreement with the value of Monaro (1963) ($A_{22} = -0.320 \pm 0.023$) but somewhat smaller than the more recent value obtained by Braga and Sarantites (1974) using Ge(Li) detectors ($A_{22} = -0.354 \pm 0.021$). In spite of the use of liquid sources for the measurement, the presence of some attenuation

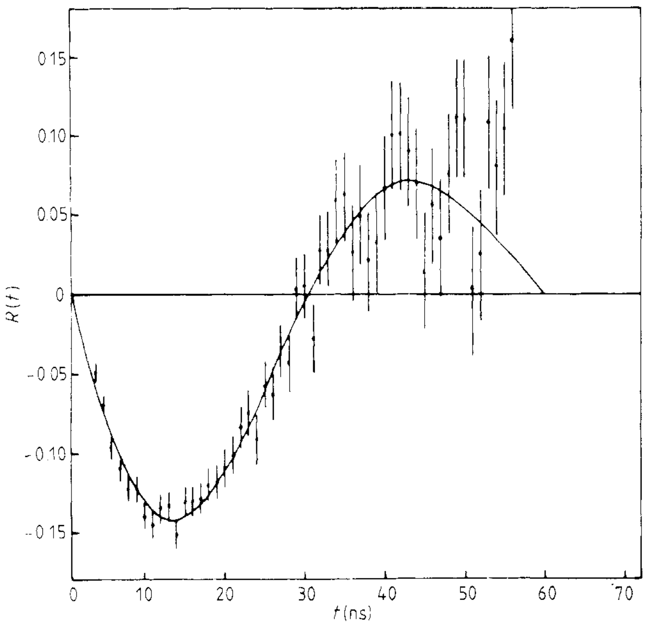

Figure 4. Spin-precession curve of the 250 keV state of ^{77}Se in an external magnetic field of 25 kG.

of the amplitude of the precession curve can be seen clearly (figure 4). However, the attenuation of this magnitude should not affect the determination of the Larmor precession frequency in the TDPAC experiment. The value calculated for the g factor is $g = +0.447 \pm 0.010$, in agreement with the value of $+0.48 \pm 0.06$ obtained by Engels *et al* (1964) but representing a considerable improvement in precision.

4. Discussion

The spin and parity assignment of $\frac{5}{2}^-$ for the 250 keV level in ^{77}Se is fairly well established from various studies (Singh and Viggars 1980). The large spectroscopic factor observed for this state in the (d, p) reaction (Lin 1965) and the B(E2) value obtained from the lifetime measurement and Coulomb excitation studies (Robinson *et al* 1965, Agnihotry *et al* 1970) indicate that this is a rather pure $f_{5/2}$ state. The single-particle g factor for the $f_{5/2}$ neutron state, $g = +0.55$, is somewhat higher than the experimental value. The magnetic moment of the $\frac{1}{2}^-$ ground state, which is considered to be a mostly pure $p_{1/2}$ single-particle state (Lin 1965), has been measured by the NMR method (Walchli 1954). A value of $g_{eff} = 0.83 g^s_{free}$ is estimated to account for the deviation from the single-particle value in this case. A similar value of g_{eff}, if used in the case of the $\frac{5}{2}^-$ state, will give good agreement between the experimental value and the single-particle estimate.

Very recently a measurement of the quadrupole interaction of ^{77}Se in arsenic metal has been carried out by Unterricker and Schneider (1983) using the 250 keV $\frac{5}{2}^-$ state and the TDPAC method. Using the systematic dependence of the electric field gradient (EFG) on the impurity valence and the observed quadrupole interaction frequency $\nu_Q = 700 \pm 60$ MHz, these authors deduce in a somewhat approximate manner the quadrupole moment of the

$\frac{5}{2}^-$ state to be $Q = 1.1 \pm 0.5$ b indicating a high deformation for the state. Such a large quadrupole moment is far outside the limit of the single-particle shell model.

Information on the high-spin states of ^{77}Se populated in the ^{74}Ge(α, nγ) reaction has recently been obtained by Zell *et al* (1976). These authors make an interesting suggestion in which the 250 keV $\frac{5}{2}^-$ state is considered as the ground state for a rotational band. In the Nilsson model it is the $\frac{5}{2}$ (303) orbit. A good fit has been obtained for the energies of the band up to spin $\frac{15}{2}^-$. A somewhat strange observation by these authors that only the stretched transitions such as $\frac{15}{2}^- \to \frac{11}{2}^-$, $\frac{13}{2}^- \to \frac{9}{2}^-$ and $\frac{11}{2}^- \to \frac{7}{2}^-$, rather than the usual cascade transitions, are observed from the $\frac{15}{2}^-$, $\frac{13}{2}^-$ and $\frac{11}{2}^-$ states of the band has been explained as an accidental cancellation due to the g factor of the ground state of the band having a value very close to g_R. The magnetic moment of the ground state can be written in the present case as

$$\mu = gI = \frac{I}{I+1}(g_R + g_k I)$$

and using $I = \frac{5}{2}$ one obtains

$$(g_k - g_R) = \frac{7}{5}(g - g_R).$$

The right-hand side of this expression has a vanishingly small value, since $g_R = Z/A \sim 0.44$ in the hydrodynamic approximation and $g = 0.447$ (in fact, the authors used the value of Engels *et al* (1964)). Since the M1 transition probability is proportional to $(g_k - g_R)^2$ one expects a large hindrance for the M1 cascade transitions for the $\frac{5}{2}^-$ band. In this case the crossover E2 transitions will be favoured over the predominantly E2 cascade transitions. This can be shown easily since the E2 decay probability $T(\text{E2}, I_i k \to I_f k)$ is proportional to $E_\gamma^5\ (I_i k 20|I_f k)^2$, where E_γ is the transition energy and the second term is the appropriate Clebsch–Gordan coefficient. The branching ratios of the crossover E2 to the cascade E2 transitions are approximately 170, 20 and 34 for the decay of the $\frac{15}{2}^-$, $\frac{13}{2}^-$ and $\frac{11}{2}^-$ states of the band, respectively.

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