β-γ PERTURBED ANGULAR CORRELATION IN THE DECAY OF ^{124}Sb

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Received February 3, 1971

(Communicated by Prof. B. V. Thosar, F.A.Sc.)

Abstract

The β-γ perturbed angular correlation technique is applied to the determination of g-factor of 603 keV (2^+) state ($\tau = 8 \cdot 5$ psec) of ^{124}Te populated in the decay of ^{124}Sb. The activity was diffused into a thin iron foil. A small C type electromagnet was used for polarizing the sample. Internal field acting at the Tellurium nucleus in iron was used for perturbing the β-γ angular correlation. The g-factor extracted is $g = 0 \cdot 28 \pm 0 \cdot 05$. This is in good agreement with that obtained by γ-γ perturbed angular correlation method.

Introduction

The method of perturbed angular correlations (PAC) using γ-γ cascades has been extensively applied for the determination of the magnetic moments of the excited nuclear states and hyperfine fields in ferromagnetic media. This method has also been applied to the levels populated by Coulomb excitation and nuclear reactions. The possibility of applying PAC to β-γ cascades was suggested by Nielsen and Deutch[1] and applied in the case of ^{154}Eu $\rightarrow$ ^{154}Gd. In this case radioactive Europium atoms were implanted in a thin iron foil by electromagnetic isotope separator. The uncertainties like lattice damage and interstial positions which may be present in the implanted source could give ambiguous values for the hyperfine field. It was thought that such uncertainties can be overcome if the radioactive atoms are diffused in the iron foil. In the present work we have used this method of preparing the sample and the method of β-γ PAC to determine the g-factor of the 603 KeV (2^+) first excited state of ^{124}Te populated in the decay of ^{124}Sb.

The partial decay scheme (ref. 2) of $^{124}Sb \rightarrow {}^{124}Te$ is shown in Fig. 1. The $(3^- \xrightarrow{\beta} 2^+ \xrightarrow{\gamma} 0^+)$ angular correlation in this decay has been extensively studied by many workers[2–4] and has as large anisotropy as 40%. The life-time of the 603 keV level and the hyperfine field at Te nucleus in iron are known. The g factor of the 603 keV level has been determined by various workers using the internal fields in iron by the method of γ—γ PAC[5–7] and also by IMPACT measurement[8].

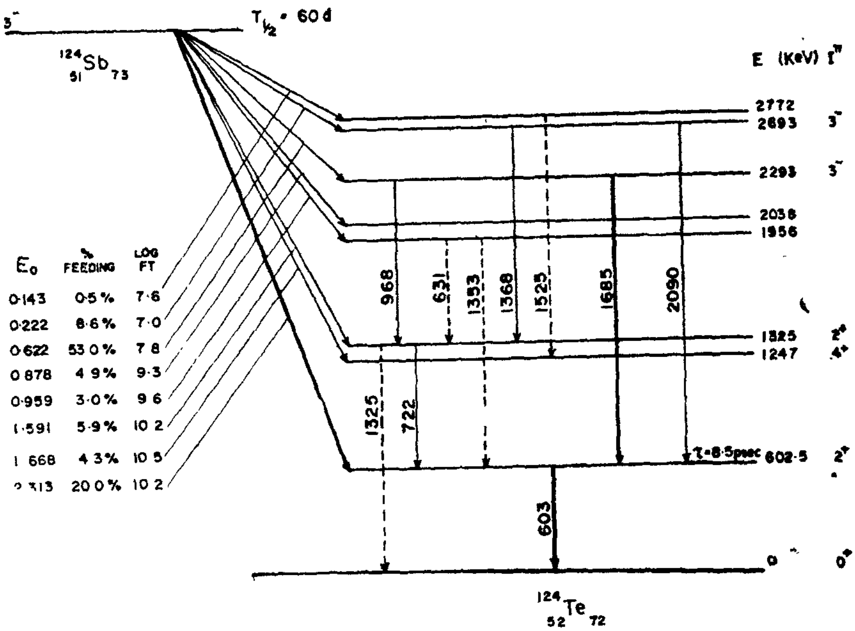

FIG. 1. Partial decay scheme of 60 *d*. $^{124}Sb \rightarrow {}^{124}Te$. (Ref. 2)

EXPERIMENTAL DETAILS

The natural Antimony metal was irradiated in CIRUS reactor, Trombay, for two months. The sample was cooled for one month for short-lived activities to decay. The Sb metal was then dissolved in concentrated HCl and electrodeposited on 16 mg/cm^2 specpure iron foil. The ^{124},Sb activity was diffused by heating the foil in argon atmosphere for 200 hrs. at 900° C. The sample was then very slowly cooled to room temperature. Finally, the surface activity was removed by etching the foil with dil. HCl. Another source with ^{124}Sb in Cu was prepared in exactly the same way using 20 mg/cm² copper foil. The gamma spectrum of the "Sb in Fe", sample taken with 5 cm × 5 cm NaI (Tl) detector is shown in Fig. 2.

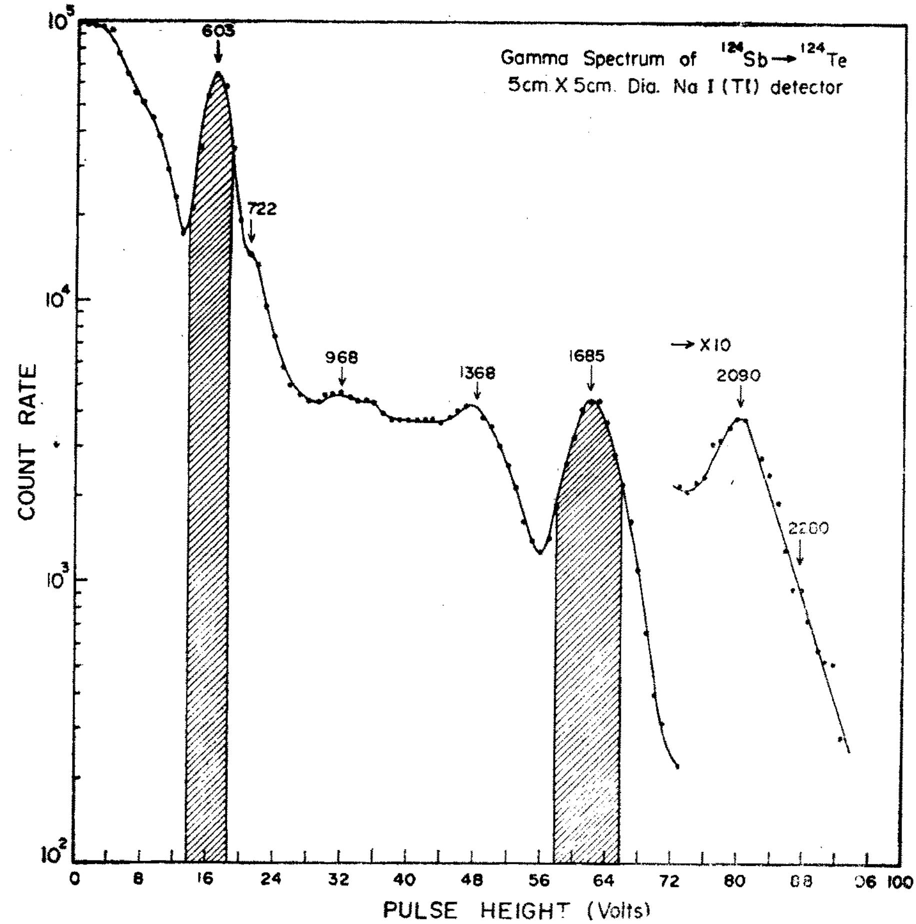

FIG. 2. Pulse height spectrum of ^{124}Sb in Fe sample with 5 cm × 5 cm dia. NaI (Tl) detector The gamma-ray energies are in keV. The single channel window settings used for γ-γ angular correlation of 603–1685 keV cascade are shown as cross-hatched areas.

The details of the experimental set-up for the measurement of β–γ angular correlation are shown in Fig. 3. The source foil was mounted in the vacuum chamber at the centre in the tips of a small C type electromagnet. The direction of the polarizing magnetic field could be reversed by reversing the direction of the current in the coil of the electromagnet. The magnetization of the iron foil used was checked by measuring the hysteresis curve and was found that it reached saturation at an external field of about

50 gauss. The β detector was $2\cdot5$ cm $\times$ 1 cm anthracene crystal mounted on a 56 AVP photomultiplier using a perspex light guide. It was necessary to use the light guide to reduce the effect of stray magnetic field on the photomultiplier. The distance of the anthracene crystal was 3 cm from the source. The typical resolution of β detector system was 16% for the 624 keV conversion electrons from ^{137}Cs source. The conversion lines in the decay of ^{137}Cs and ^{207}Bi were used for calibration. The γ detector was 5 cm $\times$ 5 cm NaI (Tl) crystal mounted directly on a 56 AVP photomultiplier. The distance of the γ detector was 7 cm from the source. Both the counters were magnetically shielded with mu-metal so that the change in the photopeak positions with and without the magnetic field was negligible. The $\gamma-\gamma$ angular correlation was measured by replacing the β counter with 5 cm $\times$ 5 cm NaI (Tl) crystal mounted on 56 AVP photomultiplier.

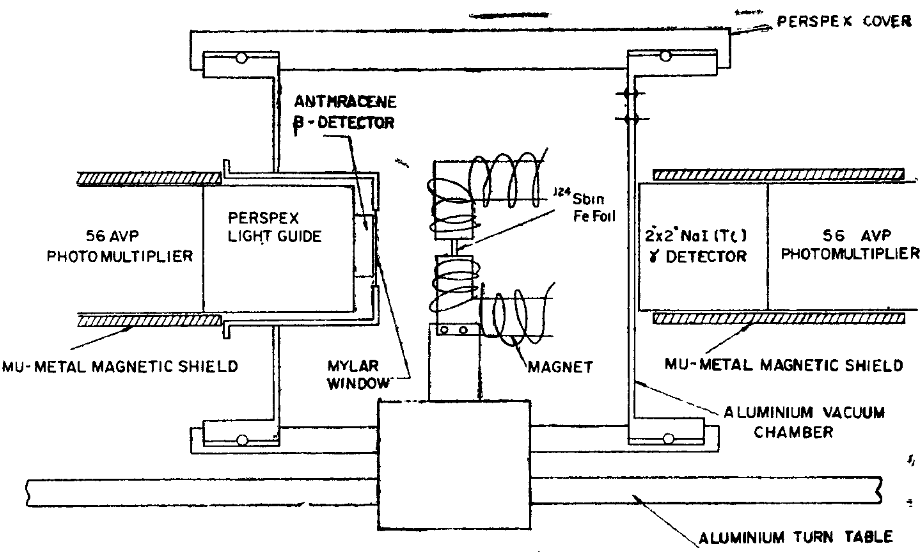

FIG. 3. Vacuum chamber assembly used for the β-γ angular correlation studies showing the C type electromagnet used for the field measurements.

The electronics used was the conventional slow-fast coincidence circuit with resolving time of 50 nanoseconds.

MEASUREMENTS AND RESULTS

The integral unperturbed β-γ angular correlation was measured for $3^- \xrightarrow{\beta} 2^+ \xrightarrow{\gamma} 0^+$ cascade. The β gate was fixed above 1,600 keV and γ gate set to accept 603 keV γ-raypeak. The angular correlation was measured at seven angles between $\theta = 90°$ and $\theta = 180°$. At each angle over 10^4 coincidence counts were collected. The normalised counts were least squares fitted to the standard expression

$$W(\theta, W) = 1 + A_2P_2(\cos\theta) + A_4P_4(\cos\theta)$$

where W is the total β energy in units of electron rest energy. The Figures 4 (A) and 4 (B) show the angular correlation curves for "^{124}Sb in Fe" and "^{124}Sb in Cu" respectively.

The A_2 and A_4 coefficients after correcting for the solid angle are found to be

^{124}Sb in Fe

$$A_2 = -0{\cdot}25 \pm 0{\cdot}01$$

$$A_4 = +0{\cdot}05 \pm 0{\cdot}02.$$

^{124}Sb in Cu

$$A_2 = -0{\cdot}24 \pm 0{\cdot}01$$

$$A_4 = +0{\cdot}002 \pm 0{\cdot}02.$$

The results are in agreement with the measurement of earlier workers indicating that there is no loss of β–γ angular correlation in the samples used in the present work.

Since A_4 coefficient is small as compared to A_2. The movable γ counter was fixed at $\theta = 135°$ w.r.t. the β counter for the field measurements. The ratio R defined as

$$R = 2\left(\frac{C_+ - C_-}{C_+ + C_-}\right)$$

was measured at 20, 40, 120 and 320 ampere turns. The C_+ and C_- are the coincidence count rates for field up and down respectively.

The rotation of the angular correlation $\Delta\theta = \omega\tau$ can be deduced from R using the following expression:

$$R(\theta = 135°) = \frac{4b_2\omega\tau}{(1 + (2\omega\tau)^2)} \quad \text{if } A_2 \gg A_4$$

where

$$b_2 = \frac{3A_2}{4 + A_2},$$

ω is the Larmour frequency and τ the mean lifetime of the nuclear level involved. For each value of magnetizing current the ratio "R" was also measured for "Sb in Cu" source to check and correct for the stray field effects. More than a million coincidence counts were collected for each field measurement. Figure 5 shows the plot of the corrected $\omega\tau$ values as a function of magnetizing current in the magnet. The last point, *i.e.*, 320 ampere turns is not taken into consideration because the correction due to stray field effect found in Cu is as large as 70%. The curve drawn through the first three points shows that almost full value of saturation is

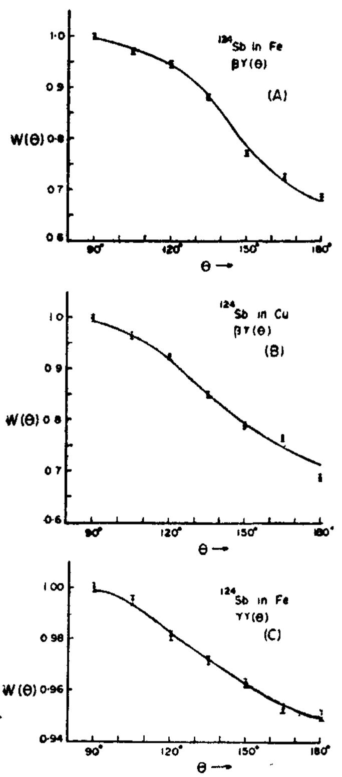

FIG. 4. (A) β-γ angular correlation for^{124} Sb in Fe for $3^- \xrightarrow{\beta}$; $2^+ \xrightarrow{\gamma} 0^+$ cascade. (B) β-γ angular correlation for^{124} Sb in Cu sample. (C) γ-γ angular correlations for ^{124}Sb in Fe sample, using 1685–603 keV $3^- \xrightarrow{\gamma} 2^+ \xrightarrow{\gamma} 0^+$ cascade.

reached at magnetizing current of even 50 ampere turns. The average $\omega\tau$ value taken for the calculation of g factor is

$$\omega\tau = -(0{\cdot}71 \pm 0{\cdot}20) \times 10^{-2}.$$

The g factor is given by

$$\omega\tau = g\mu_N \frac{H_{eff}}{\hbar} \tau$$

where μ_N is the nuclear magneton, H_{eff} is the effective magnetic field at the Te nucleus, τ the mean life time of the intermediate state. We have used the values

$$H_{eff} = 620 \pm 20 \text{ KG (Frenkel[9])}$$
$$\tau = 8{\cdot}5 \text{ psec (Stelson[10])}$$

and obtained

$$g = 0{\cdot}28 \pm 0{\cdot}05.$$

We have also measured the g factor of 603 keV level using γ-γ PAC method. In this case 1685–603 keV $(3^- \xrightarrow{\gamma} 2^+ \xrightarrow{\gamma} 0^+)$ cascade was used. Figure 4 (C) shows the unperturbed γ-γ angular correlation. The corrected A_2 and A_4 coefficients obtained are

$$A_2 = -0{\cdot}038 \pm 0{\cdot}002$$
$$A_4 = -0{\cdot}007 \pm 0{\cdot}002$$

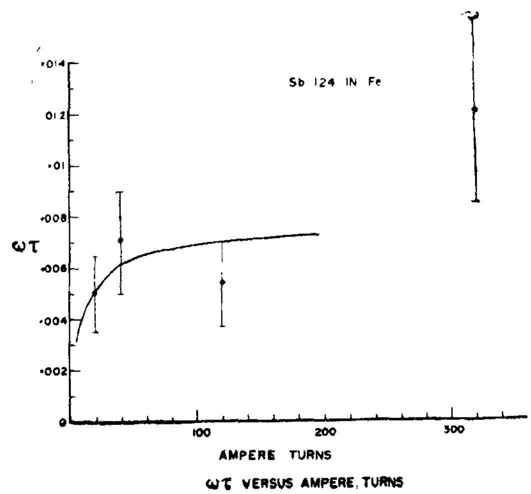

FIG. 5: Plot of $\omega\tau$ (corrected for stray field) against magnetizing ampere turns. The point for 320 ampere turns is not taken into consideration as the stray field correction here is as large as (70%).

and are in fair agreement with the earlier measurements. The field measurement was performed at 320 ampere turns. The $\omega\tau$ in this case is

$$\omega\tau = -(0{\cdot}80 \pm 0{\cdot}28) \times 10^{-2}$$

yielding $g = (0{\cdot}31 \pm 0{\cdot}06)$

which agrees well with the measurement by β-γ PAC.

DISCUSSION

In Table I we have compared results of the present measurements with those of others. The first three measurements are with radioactive sources utilizing internal fields in iron. The fourth is from the PAC following Coulomb excitation. Our value compares well with that of Bhattacherjee and Heestand.

TABLE I

Cascade (keV)	$-\omega\tau$	g	Ref.
$1685\gamma - 603\gamma$	$(0{\cdot}66 \pm 0{\cdot}24) \times 10^{-2}$	$0{\cdot}22 \pm 0{\cdot}05$	Bhattacherjee[5]
$722\gamma - 603\gamma$	$(0{\cdot}54 \pm 0{\cdot}13) \times 10^{-2}$		
$722\gamma - 603\gamma$	$(0{\cdot}97 \pm 0{\cdot}13) \times 10^{-2}$	$0{\cdot}39 \pm 0{\cdot}09$	Murray[6]
$1685\gamma - 6$[illegible]γ	$(0{\cdot}75 \pm 0{\cdot}13) \times 10^{-2}$	$0{\cdot}40 \pm 0{\cdot}23$	Bozek[7]
IMPACT (Coulomb Exci.)	$(1{\cdot}29 \pm 0{\cdot}09) \pm 10^{-2}$	$0{\cdot}21 \pm 0{\cdot}05$	Heestand[8]
$3500\beta - 603\gamma$	$(0{\cdot}71 \pm 0{\cdot}20) \times 10^{-2}$	$0{\cdot}28 \pm 0{\cdot}05$	Present work
$1685\gamma - 603\gamma$	$(0{\cdot}80 \pm 0{\cdot}28) \times 10^{-2}$	$0{\cdot}31 \pm 0{\cdot}06$	

The present measurement shows that the method of β-γ PAC can be applied successfully in favourable cases for the measurement of nuclear g factors. This method may be useful where a suitable γ—γ cascade is not available. It is also observed that the foil saturation is reached even at small magnetizing currents, indicating that in some ferromagnetic media like permalloy of high retentivity even the retained field after the removal of the external magnetic field may be enough to give saturation value of $\omega\tau$. This will minimize the correction due to stray fields.

In such measurements one should also take into consideration, the possible deflection of β particles caused by the saturated fields within the foil. Such effects could be investigated by the same technique applied to a case where intermediate state has very short life time ($< 10^{-12}$ sec.). In that event the nuclear perturbations will be negligible and the observed rotation will be entirely due to saturation fields. In the present measurement it is not very evident that such saturation field effect is appreciable.

Acknowledgement

The authors wish to thank Professor B. V. Thosar for his interest in this work.

References

1. Nielsen, K. B. and Deutch, B. K. *Phys. Lett.*, 1967, **25 B**, 208.
2. Cippola, S. J. and Steffen, R. M. *Nucl. Phys.*, 1970, **143**, 404.
3. Steffen, R. M. .. *Phys. Rev. Lett.*, 1960, **4**, 290.
4. Mitra, S. K. .. *Nucl. Phys.*, 1963, **47**, 293.
5. Bhattacherjee, S. K., Bowman, J. D. and Kaufmann, E. N. *Phys. Lett.*, 1967, **24 B**, 651.
6. Murray, J., McMath, T. A., Brooker, W. H. and Cameron, J. A. *Can. J. Phys.*, 1967, **45**, 1600.
7. Bozek, E., Broda, R., Golczewski, J., Hrynkiewicz, A. Z., Kulessa, R., Ogaza, S., Rybicka, M. and Walus, W. *Hyperfine Structure and Nuclear Radiation.* Asilomar Conf., 1967, p. 158.
8. Heestand, G. M., Borchers, R. R., Herskind, B., Grodzins, L., Kalish, R. and Murnick, D. E. *Nucl. Phys.*, 1969, **A 133**, 310.
9. Frenkel, R. B., Huntzicker, J., Mathias, E., Rosenblum, S. S., Shirley, D. A. and Stone, N. J. *Phys. Lett.*, 1965, **15**, 163.
10. Stelson, P. H. and Grodzins, L. *Nuclear Data*, 1965, **1**, 31.