IOPscience iopscience.iop.org

Home Search Collections Journals About Contact us My IOPscience

The g-factor of the 235 keV state in ^{44}Sc

This article has been downloaded from IOPscience. Please scroll down to see the full text article.

1974 J. Phys. A: Math. Nucl. Gen. 7 2289

(http://iopscience.iop.org/0301-0015/7/18/009)

View the table of contents for this issue, or go to the journal homepage for more

Download details:
IP Address: 171.66.16.87
The article was downloaded on 02/06/2010 at 04:55

Please note that terms and conditions apply.

J. Phys. A: Math., Nucl. Gen., Vol. 7, No. 18, 1974. Printed in Great Britain. © 1974

The g factor of the 235 keV state in ^{44}Sc

G D Dracoulis, G S Foote† and M G Slocombe

Department of Nuclear Physics, Research School of Physical Sciences, Australian National University, Canberra, ACT 2600 Australia

Received 5 July 1974

Abstract. The g factor of the 235 keV, 2^- state in ^{44}Sc has been measured by observing the time-integrated perturbation of the de-exciting γ ray angular distributions under the influence of an externally applied magnetic field. The result, $g = +0{\cdot}29 \pm 0{\cdot}07$ supports the assignment of this state as a member of the $K = 0$ rotational band.

1. Introduction

Recent γ ray studies of the odd–odd nucleus ^{44}Sc have established the spins, parities and decay modes of many of the low-lying states (Dracoulis *et al* 1973a, b). Several of these states have relatively long lifetimes and when aligned, decay with anisotropic γ ray angular distributions. They are therefore amenable to g factor measurements using the method of perturbed angular correlations. This paper reports a measurement of the g factor of the 235 keV state which has a spin and parity of 2^- and a lifetime of about 18 ns.

Previous measurements have been made on the magnetic moments of the ground state ($J^\pi = 2^+$) and the isomeric 271 keV state (6^+) using the method of atomic beam magnetic resonance (Harris and McCullen 1963) and those results were consistent with expectations for shell-model states of the $(fp)^4$ configuration (Bayman *et al* 1963, McGrory 1973). The g factor of the 221 ns 68 keV state has been measured using perturbed angular correlation techniques (Bergstrom and Thieberger 1962, Ristinen and Sunyar 1967). Until recently that g factor ($+0{\cdot}34$) was not understood, but the identification of the 68 keV state as the 1^- member of a $K^\pi = 0^-$ rotational band (Dracoulis *et al* 1973a, b) has clarified the situation. The 235 keV state studied in this work is the proposed 2^- member of the same rotational band.

2. Experimental technique

2.1. *The formation and decay of the 235 keV state*

The decay of the low-lying states in ^{44}Sc is shown in figure 1(a). The 235 keV state which decays to ground and by the 167 keV transition to the 68 keV 1^- state was populated in the ^{44}Ca(p, n)^{44}Sc reaction ($Q = -4{\cdot}42$ MeV) using a 5·15 MeV proton beam. This energy is several hundred keV above threshold for the state and a high reaction yield is obtained. As was shown in the previous studies, strong alignment

† Present address: Schuster Laboratory, Manchester University, Manchester M13 9PL, UK.

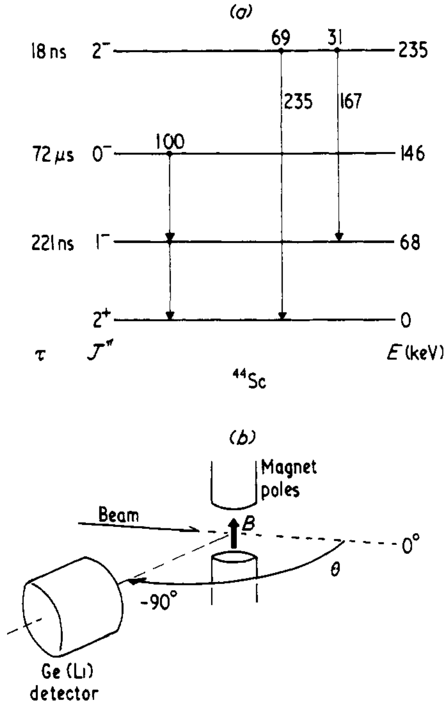

Figure 1. (*a*) The γ decay of the 235 keV state in ^{44}Sc; (*b*) schematic drawing of the field and detector geometry.

also results. The 425 and 531 keV states which have branches to the 235 keV state are only weakly populated at this energy and the observed yield of the feeding γ rays is less than 10% of the combined 235 and 167 keV yield. Further, it was observed that the angular distributions of the γ rays from the 425 and 531 keV states were not significantly perturbed by the applied magnetic field.

2.2. *Experimental details*

The proton beam from the ANU EN tandem accelerator was used to bombard 2 mg cm^{-2} 98·5% enriched ^{44}Ca targets, evaporated on to 0·25 mm gold backings. The targets were mounted at 45° to the beam direction in the centre of a thin-walled stainless steel chamber which was placed between the 3·8 cm diameter soft iron poles of an electromagnet. The pole gap was 1·5 cm. The field strength and uniformity was measured *in situ* with a calibrated Hall probe.

Gamma rays from the target were studied with a 33 cm^3 Ge(Li) detector placed at 26 cm from the target. Measurements were made at a number of angles between 0° and −90° to the beam direction. The geometry is sketched in figure 1(*b*). The beam movement across the target due to the applied field of about 5·9 kG was less than 1 mm in total and gave a negligible contribution to the errors in observation angle.

The yield of the observed ^{44}Sc γ rays was normalized to that of the isotropic 728 keV γ ray from the 0^+ state in ^{44}Ca, populated in the ^{44}Ca(p, p′) reaction. The chamber isotropy and alignment were checked using the 1157 keV γ ray from the decay of the ^{44}Sc activity formed during the beam irradiations. Also, a small ^{152}Eu source (with

γ rays in the energy range 122 to 1408 keV) was mounted at the beam spot position, as defined by target discolouration, to further check for anisotropies and to provide efficiency calibrations and corrections for absorption of the low energy γ rays in the target backing. Measurements were made with the field in both directions and without an applied field.

3. Results

The results for the 167 and 235 keV γ rays are shown in figure 2(*a*) for the cases with the applied field 'up' and 'down'. The measured unperturbed distributions are in good agreement with those obtained in the previous work (Dracoulis *et al* 1973a, b) and are given by $W_{235} = 1+(0{\cdot}27\pm0{\cdot}02)P_2(\cos\theta)$ and $W_{167} = 1-(0{\cdot}30\pm0{\cdot}03)P_2(\cos\theta)$. Both of the transitions are essentially dipole, with a negligible A_4 term in the distributions which would therefore be linear on the $\cos^2\theta$ plot of figure 2. The effect of the applied field is to cause a small attenuation and a net rotation of the distributions. Since the 167 and 235 keV distributions are opposite in phase the effect of the rotation is to

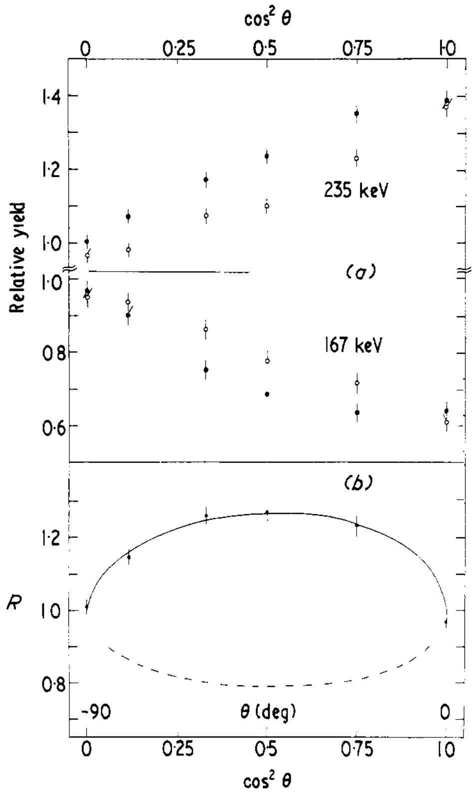

Figure 2. (*a*) The yields of the 235 and 167 keV γ rays as a function of $\cos^2\theta$. The full circles represent measurements with the field 'up', and the open circles are taken with the field 'down'. The field was 5·85 kG. (*b*) The measured ratio R (defined in equation (3) of the text) as a function of $\cos^2\theta$. The full curve is the theoretical ratio for $|\omega\tau| = 0{\cdot}147$ and a positive g factor. The broken curve is the theoretical ratio for a negative g factor of the same magnitude.

increase the yield of one γ ray and to decrease the other. This is clearly illustrated in figure 2(*a*) and the results confirm that the effect is not spurious in origin. The error bars shown on the data of figure 2(*a*) include the errors in the normalization, but not the errors in the correction for absorption in the target backing. As will be illustrated in the next section, these and other errors can be avoided by using a simple ratio technique in the analysis.

4. Analysis

The time-integrated angular distribution perturbed by a field B applied at right angles to the plane of observation is given by (Grodzins 1968)

$$W(\theta, B) = \sum_{k=0}^{k_{\max}} \frac{b_k}{[1+(k\omega_B\tau)^2]^{1/2}} \cos[k(\theta \pm \Delta_k\theta)] \tag{1}$$

where the b_k depend on the A_k, the coefficients of the even-order Legendre polynomials in the unperturbed distribution, and the sign of the angular shift depends on the field direction. If only A_2 terms are present equation (1) reduces to

$$W(\theta, B) = 1+\frac{A_2}{4}+\frac{3}{4}\frac{A_2}{[1+(2\omega_B\tau)^2]^{1/2}} \cos[2(\theta \pm \Delta\theta)] \tag{2}$$

where $\Delta\theta = \frac{1}{2}\tan^{-1} 2\omega_B\tau \simeq \omega_B\tau$ for small $\Delta\theta$, ω_B is the precession frequency and τ is the mean lifetime of the perturbed state.

Rather than using expression (2) to extract ω_B from the data of figure 2(*a*) a more reliable method is suggested. This is to take, at each angle measured, the ratio of the relative yield of the 235 and 167 keV γ rays as observed with the field 'up', to the relative yield with the field 'down'. An obvious advantage here is that the errors due to normalizations to the monitor γ ray intensity are eliminated, consequently statistical errors are minimized and effects due to movement of the beam and non-uniformity of the target are avoided. Further, the corrections for absorption in the target backing are eliminated and one is left only with the contribution of the statistical and background subtraction errors in each spectrum. Finally, there are no corrections for dead-time effects since one is observing the relative yield of γ rays in the same spectrum. It is noted however that the uncertainties in normalization and efficiency do contribute to the error in the unperturbed angular distribution.

The required ratio is

$$R(\theta) = \frac{W_{235}(\theta, \uparrow)/W_{167}(\theta, \uparrow)}{W_{235}(\theta, \downarrow)/W_{167}(\theta, \downarrow)}. \tag{3}$$

The experimental ratio is plotted against $\cos^2\theta$ in figure 2(*b*) and the results are listed in table 1.

Since the unperturbed distributions are symmetric about 0° and 90°, the ratio R for equal field in both directions should be unity at 0° and 90°. This is borne out by the results of figure 2(*b*). A least-squares fit of expression (3) to the experimental data was made by varying the magnitude (and sign) of the angular shift $\Delta\theta$, and the product $\omega_B\tau$ was extracted. The fit for a positive g factor and $|\omega_B\tau| = (0{\cdot}147 \pm 0{\cdot}015)$ rad is shown as the full curve in figure 2(*b*). The broken curve represents the expected results for a negative g factor.

Table 1. The experimental ratios of the relative yields of the 235 and 167 keV γ rays, with field up and down (see text, equation (3)), and the theoretical values for $|\omega\tau| = 0{\cdot}147$ and a positive g factor.

Observation angle (deg)	Experimental ratio	Theoretical ratio $\lvert\omega\tau\rvert = 0{\cdot}147$
0	$0{\cdot}963 \pm 0{\cdot}028$	1·0
−30	$1{\cdot}232 \pm 0{\cdot}029$	1·235
−45	$1{\cdot}269 \pm 0{\cdot}028$	1·265
−55	$1{\cdot}253 \pm 0{\cdot}024$	1·244
−70	$1{\cdot}145 \pm 0{\cdot}023$	1·160
−90	$1{\cdot}009 \pm 0{\cdot}021$	1·0

From these results together with the measured field of $5{\cdot}85 \pm 0{\cdot}05$ kG and the previously measured lifetime of $18{\cdot}3 \pm 3{\cdot}3$ ns, the g factor for the 235 keV state is found to be $+0{\cdot}29 \pm 0{\cdot}07$. The main contribution to the error is from the uncertainty in the lifetime.

5. Interpretation

As was mentioned in the introduction, the levels of ^{44}Sc have been discussed in terms of the coexistence between spherical states of the $(fp)^4$ configuration and deformed states. The 235 keV state is the proposed 2^- member of a $K^\pi = 0^-$ rotational band based on the $d_{3/2}$ proton hole state (Dracoulis *et al* 1973a, b). An expression for the magnetic moment of a deformed odd–odd nucleus has been given by Varshalovich and Peker (1961) following Nilsson (1955) and Bohr and Mottelson (1953) as,

$$\mu = (g_K - g_R)\frac{K^2}{I+1} + g_R I$$

with

$$g_K = \frac{1}{K}(\Omega_p g_{\Omega p} + \Omega_n g_{\Omega n})$$

where $g_{\Omega p}$ and $g_{\Omega n}$ are the intrinsic g factors of the odd proton and neutron and g_R is the rotational g factor. Ω and K are the usual projections on the nuclear axis of the intrinsic and total spins. If $K = 0$ the g factor is just the rotational g factor, g_R which is approximately given by $0{\cdot}7Z/A$. Further, the g factor of the 235 keV state should be equal to that of the 68 keV 1^- state (a proposed member of the same band) which has been measured as $+0{\cdot}342 \pm 0{\cdot}006$ (Ristinen and Sunyar 1967). The observed value of $g = +0{\cdot}29 \pm 0{\cdot}07$ is in agreement in both sign and magnitude with the expected result for a $K = 0$ band member.

It is also of interest to estimate the g factor for a state based on an alternative configuration, for example the *spherical* $[\pi d_{3/2}^{-1} \nu f_{7/2}]_{2^-}$ state. The magnetic moment of such a state is approximately given by (Elliott and Lane 1957),

$$\mu = \frac{I(I+1)(g_{jp}+g_{jn}) + (g_{jp}-g_{jn})[j_p(j_p+1) - j_n(j_n+1)]}{2(I+1)}$$

where the j_p and j_n refer to the orbitals of the odd proton and neutron. This expression assumes *j–j* coupling and neglects higher-order configurations. Using empirical values of +0·26 and −0·45 (from ^{39}K and ^{41}Ca; Shirley 1968) for g_{jp} and g_{jn} rather than the Schmidt values, one obtains $g = -0{\cdot}83$, in disagreement with the observed value.

One could postulate other configurations to explain the *g* factor of the 235 keV state but it is doubtful whether they would explain the low energy of this state and its peculiar decay properties as has been done by the simple rotational model.

6. Conclusion

The *g* factor of the 235 keV 2^- state has been measured as $+0{\cdot}29 \pm 0{\cdot}07$ supporting the assignment of this state as a member of the $K^\pi = 0^-$ rotational band. The main contribution to the error is from the uncertainty in the lifetime.

References

Bayman B F, McCullen J D and Zamick L 1963 *Phys. Rev. Lett.* **11** 215–6
McGrory J B 1973 *Phys. Rev.* C **8** 693–710
Bergstrom I and Thieberger P 1962 *Ark. Fys.* **22** 307–15
Bohr A and Mottelson B R 1953 *K. Danske Vidensk. Selsk., Mat.-Fys. Meddr* **27** No 16
Dracoulis G D, Durell J L and Gelletly W 1973a *J. Phys.* A: *Math., Nucl. Gen.* **6** 1030–6
—— 1973b *J. Phys.* A: *Math., Nucl. Gen.* **6** 1772–99
Elliott J P and Lane A M 1957 *Handb. Phys.* vol 39, ed S Flugge (Berlin: Springer-Verlag)
Grodzins L 1968 *Ann. Rev. Nucl. Sci.* **18** 291–342
Harris D L and McCullen J D 1963 *Phys. Rev.* **132** 310–5
Nilsson S G 1955 *K. Danske Vidensk. Selsk., Mat.-Fys. Meddr* **29** No 16
Ristinen R A and Sunyar A W 1967 *Phys. Rev.* **153** 1209–13
Shirley V S 1968 *Hyperfine Structure and Nuclear Radiation* eds E Matthias and D A Shirley (Amsterdam: North-Holland) p 985
Varshalovich D A and Peker L K 1961 *Izvest. Akad. Nauk.* **25** 287 (1961 *Bull. Acad. Sci. USSR, Phys. Ser.* **25** 274–83)