PHYSICAL REVIEW C VOLUME 37, NUMBER 6 JUNE 1988

Magnetic moments of the first excited 2^+ states of the even-even Te isotopes

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(Received 10 August 1987)

The thin, triple-foil transient field technique has been used to measure the g factors of the first excited 2^+ states of the even-even $^{122-130}$Te isotopes. The general trend of the measured g factors is similar to that seen for other even-even isotopic sequences in this mass region; however, the g factor of ^{126}Te is measured to be significantly greater than the value reported in a recent experiment.

The magnetic moments of the 2_1^+ states of the even-even Te isotopes have been measured by Shu *et al.*[1] and have been interpreted within the proton-neutron interacting boson approximation (IBA) by Sambataro and Dieperink.[2] The rather low value $g(2_1^+)=0.19\pm0.03$ for ^{126}Te reported in Ref. 1 is interpreted in the IBA model as evidence of a shell effect on an otherwise monotonic dependence of $g(2_1^+)$ on the neutron boson number N_ν. Additional support for a reduction of $g(2_1^+)$ in the region of ^{126}Te is given by the quasiparticle BCS calculations of Lombard.[3]

We have measured the g factors of the 2_1^+ states of the even-even $^{122-130}$Te isotopes using the thin, triple-foil transient field technique.[4,5] This transient field technique has been reviewed extensively in the literature.[6,7] The apparatus used in the present work has been described in detail elsewhere.[8]

The iron layers of all triple-foil targets used in the present experiment came from the central region of the same sheet of annealed, rolled iron. This ensured that target fabrication introduced only minor uncertainties in the measurement of relative angular precessions. The iron layer thicknesses of Table I indicate density nonuniformities of only ±3% over the entire iron sheet from which the targets were made. No direct measurement of the iron layer magnetization was attempted. Triple-foil targets were made by vacuum evaporating enriched Te isotopes onto 1 cm^2 iron foils that were backed by 3–5 mg/cm^2 copper layers to ensure a perturbation-free environment for stopped, excited Te nuclei.

The 2_1^+ states of the Te isotopes were Coulomb excited by a 70 MeV ^{35}Cl beam obtained from the Stanford tandem Van de Graaff accelerator. Beam currents on target were limited to less than 15 nA to prevent damage to the thin Te isotope layers of the targets. Even with this beam current limitation, the Te layers were observed to blacken and crack slightly after many hours of irradiation by the accelerator beam. Although this change in target appearance was not observed to affect the measured precessions, all targets were changed after 24 h of continuous beam irradiation. Targets were magnetized by a field of 0.050 T that was reversed periodically so as to reduce systematic error. A soft-iron cylindrical shield surrounded the accelerator beam upstream from the target region to reduce bending of the beam by the magnetizing field.

The deexcitation $2_1^+\rightarrow0^+$ gamma rays were detected by four 7.6×7.6 cm NaI(Tl) detectors placed a distance of 10 cm from the target at angles $\theta=\pm67.5^\circ$ and $\pm112.5^\circ$. The gamma rays were detected in coincidence with beam particles backscattered to an annular detector giving an angular correlation such as that shown for ^{126}Te in Fig. 1. The angular correlation $W(\theta)$ for 70 MeV ^{35}Cl on ^{126}Te was found to be

$$W(\theta)=1+0.595P_2(\cos\theta)-1.482P_4(\cos\theta) ,$$

yielding a logarithmic slope $S=-(1/W)(dW/d\theta)=3.38$ at $\theta=\pm67.5^\circ$. Since the particle–gamma-ray angular correlation produced in Coulomb excitation does not change appreciably within a given isotopic sequence, the value $S=3.38$ was used for all Te isotopes.

Recoiling Te ions passing through the magnetized iron layer experience a transient magnetic field $B(v,Z)$ that precesses the particle–gamma-ray angular correlation an amount $\Delta\theta$ given by

TABLE I. Summary of target layer thicknesses and corrected angular precessions $\Delta\theta$. Also given are $(v/v_0)_{\text{in}}$ and $(v/v_0)_{\text{out}}$, the velocities of the Te recoil ions as they enter and exit the iron layer, respectively, and T, the transit time of the Te recoil in the iron layer.

Isotope	Isotope layer thickness (mg/cm^2)	Iron layer thickness (mg/cm^2)	$(v/v_0)_{\text{in}}$	$(v/v_0)_{\text{out}}$	ΔT (ps)	$\Delta\theta$ (mrad)
^{122}Te	0.750	1.68	3.65	2.18	0.338	-11.7 ± 0.7
^{124}Te	0.850	1.68	3.57	2.12	0.347	-11.0 ± 1.2
^{126}Te	0.830	1.71	3.51	2.05	0.361	-10.8 ± 1.2
^{128}Te	0.810	1.76	3.48	1.98	0.379	-8.9 ± 1.1
^{130}Te	0.790	1.68	3.44	2.02	0.361	-10.4 ± 1.6

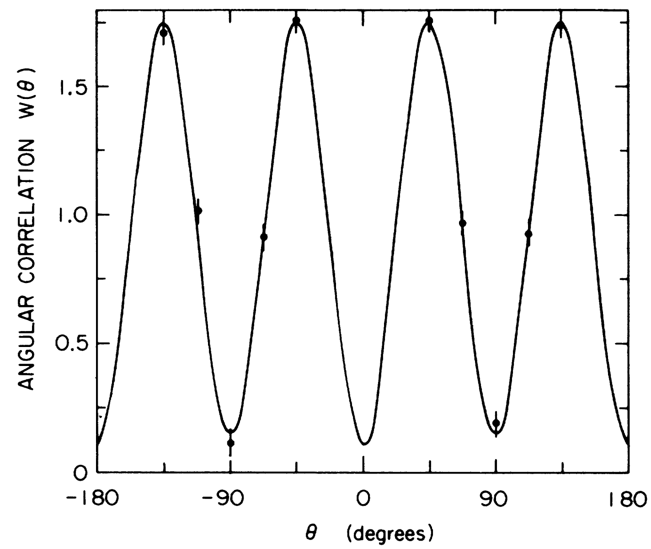

FIG. 1. Measured angular correlation between backscattered beam particles and 0.666 MeV gamma rays from the 2_1^+ state of ^{126}Te. The solid line is a Legendre polynomial fit as described in the text.

$$\Delta\theta=-\frac{g\mu_N}{\hbar}\int_0^T B(v,Z)e^{-t/\tau}dt\ , \tag{1}$$

where μ_N is the nuclear magneton, v the Te ion velocity, Z the atomic number of the ion, τ the lifetime of the excited 2^+ state, and T the time spent by the Te ion in the iron layer. The Te ion velocity may be calculated using standard stopping power compilations.[9] The velocities of Te ions as they enter and exit the iron layer are given in units of the Bohr velocity $v_0=e^2/\hbar$ in Table I along with the iron layer transit time T and measured angular precession $\Delta\theta$.

From the experimental angular precessions $\Delta\theta$, g factors can be calculated using Eq. (1) if an appropriate expression for $B(v,Z)$ is available. A global fit to transient field data for $Z=8$ to $Z=62$ has yielded a universal parametrized transient field given by[10]

$$B(v,Z)=97(v/v_0)^{0.45}Z^{1.1}\mu_B N_p\ , \tag{2}$$

where μ_B is the Bohr magneton, N_p is the number density of polarized electrons in iron, and $\mu_B N_p=0.1714$ T for iron at room temperature.[11] In Ref. 1 the parametrization of Eq. (2) was substituted directly into Eq. (1) to compute g factors.

In the present work we have retained the functional dependence $B(v,Z)\propto v^{0.45}Z^{1.1}$ suggested by Eq. (2) but have adjusted the overall magnitude of $B(v,Z)$ to fit the angular precession data for ^{122}Te and ^{124}Te for which g factors are known from integral perturbed angular correlation (IPAC) experiments.[12–18] Thus, the g factors of the present work and those of Ref. 1 should differ only by an overall normalization factor. In the IPAC experiments, the ^{122}Sb or ^{124}Sb parent is dissolved into a ferromagnet and the precession $\Delta\theta$ of the angular correlation of the gamma cascade through the Te 2_1^+ excited state is measured. The IPAC g factor is then calculated using[12]

$$g=\frac{\hbar}{\mu_N}\frac{1}{\tau}\frac{\Delta\theta}{B_{\text{eff}}}\ ,$$

where B_{eff} is the effective static hyperfine field experienced by Te nuclei in the ferromagnetic host lattice. Table II summarizes the IPAC precession measurements for ^{122}Te and ^{124}Te.[12–18] The lifetimes of the 2_1^+ states in ^{122}Te and ^{124}Te have been calculated using recent gamma ray energy[19,20] and Coulomb excitation $B(E2)$ (Ref. 21) measurements to be 10.85±0.07 and 9.02±0.08 ps for ^{122}Te and ^{124}Te, respectively.[22] The g factors given in Table II have been computed with these more recent lifetime determinations. Although there is some scatter to the g factors given in Table II the degree of scatter does not exceed that expected from the one standard deviation uncertainties stated in the references. A weighted mean of the IPAC data of Table II yields $g(2_1^+)=+0.36\pm0.02$ for ^{122}Te and $g(2_1^+)=+0.28\pm0.03$ for ^{124}Te. These values were used to calibrate the overall strength of the transient field acting on fast Te ions in the present experiment.

TABLE II. Summary of IPAC measurements of the 2_1^+ g factors of ^{122}Te and ^{124}Te. The precession measurements from the original references have been combined with more recent lifetime data to calculate the g factors given here.

Isotope	$\Delta\theta$ (mrad)	B_{eff} (T)	$\Delta\theta/B_{\text{eff}}$ (rad/$T\times10^{-4}$)	g factor[a]	Reference	Mean
^{122}Te	15.4±1.5	63.4±2.1	2.4±0.3	0.47±0.05	12	
	13.2±1.3	63.7±2.1	2.1±0.2	0.40±0.04	13	
	10.5±1.0	62.0±2.0	1.7±0.2	0.33±0.03	14	
	9.9±1.2	62.0±2.0	1.6±0.2	0.33±0.03	14	
	11.5±2.0	60.0±2.5	1.9±0.3	0.37±0.07	15	0.36±0.02
^{124}Te	6.6±2.4	62.0±2.0	1.1±0.4	0.25±0.09	14	
	5.4±1.3	62.0±2.0	0.9±0.2	0.20±0.05	14	
	9.7±1.3	61.0±2.5	1.6±0.2	0.37±0.05	16	
	7.5±4.4	62.0±2.0	1.2±0.7	0.28±0.17	17	
	7.1±2.0	62.0±2.0	1.1±0.3	0.27±0.08	18	
	8.0±2.8	62.0±2.0	1.3±0.5	0.30±0.11	18	0.28±0.03

[a] Calculated using the lifetimes $\tau=10.85\pm0.07$ ps for ^{122}Te and $\tau=9.02\pm0.08$ ps for ^{124}Te as discussed in the text.

TABLE III. Experimental g factors for the 2_1^+ excited states of the even-even Te isotopes.

Isotope	Radioactivity	This work	Shu *et al.*[a]
^{120}Te			0.29±0.03
^{122}Te	0.36±0.02	0.33±0.02	0.33±0.03
^{124}Te	0.28±0.03	0.31±0.04	0.26±0.03
^{126}Te		0.31±0.04	0.19±0.03
^{128}Te		0.25±0.03	0.31±0.04
^{130}Te		0.29±0.05	0.29±0.06

[a] Reference 1.

The precession angles $\Delta\theta$ of Table I were corrected for (i) accelerator beam bending, (ii) excited state lifetime τ, and (iii) the effect of the different recoil velocity distributions on the transient field experienced by different isotopes.[23] These corrections to the angular precessions were typically 1–5 %. The calibration g factors for ^{122}Te and ^{124}Te were used to determine the overall scale of the final g factors presented in Table III.

In Table III one finds good agreement between the Te 2_1^+ g factors determined using calibration g factors in the present work and those of Ref. 1 where a universal transient field parametrization establishes the scale of the g factors. The major difference between the two data sets is the g factor for ^{126}Te where Ref. 1 gives $g(2_1^+)=0.19\pm0.03$, which is significantly lower than the value $g(2_1^+)=0.31\pm0.04$ in the present work.

In Fig. 2 the g factors of Table III are compared with various theoretical predictions. The $g=Z/A$ prediction of the simple nuclear hydrodynamic model lies well above the measured g factors, and the collective model predictions of Greiner[1,24] with a deformation ratio of $\beta_0(n)/\beta_0(p)=1.2$ are also somewhat too high. The g factors of the present work do not exhibit a strong shell effect such as the strong minimum at ^{126}Te predicted by the IBA calculations of Sambataro and Dieperink[2] or the general minimum in the BCS quasiparticle calculations of Lombard.[3]

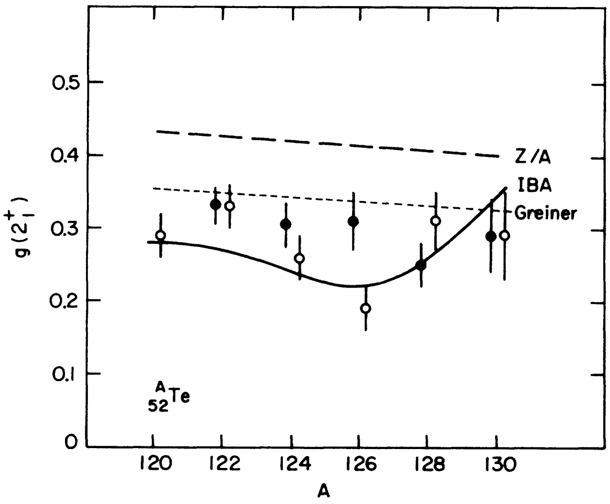

FIG. 2. Comparison between the measured g factors of this work (black circles) and Ref. 1 (open circles). The theoretical estimates of the Z/A model (dashed line), the Greiner model (Ref. 24) (dotted line), and the IBA model (Ref. 2) (solid line) are shown.

To resolve the discrepancy between transient field measurements in cases such as ^{126}Te, it may be necessary to remove sources of relative error that occur when separate isotopic targets are prepared and are then used sequentially and subjected to different irradiation histories in the accelerator beam. Recently, it was reported that the g factors of an entire isotropic sequence were measured simultaneously in the same triple-foil target using the transient field technique and high resolution Ge(Li) detectors to resolve the gamma rays.[25]

This work was supported in part by the National Science Foundation.

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