Nuclear g-factor measurements of the $\frac{9}{2}^-$ and $\frac{21}{2}^-$ isomeric states in ^{173}Ta

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The nuclear g-factors of the one-quasiparticle isomeric state $\frac{9}{2}^-$ at 165.8 keV and the three-quasiparticle isomeric state $\frac{21}{2}^-$ at 1713.2 keV in ^{173}Ta nuclei have been measured using the time differential perturbed angular distribution technique. The nuclear reaction ^{165}Ho(^{12}C, $4n\gamma$)^{173}Ta was used to populate these isomeric states, and the recoiling ^{173}Ta nuclei were implanted into a thick tantalum backing in the presence of a 7.04(4) kG external magnetic field. The measured value $g(\frac{9}{2}^-) = +0.591(18)$ shows that the $\frac{9}{2}^-$ isomeric state is not a pure single-particle state but may have a collective contribution due to the octupole excitation of the core. Based on the measured value $g(\frac{21}{2}^-) = +0.620(15)$ and multi-quasiparticle calculations, the $\frac{21}{2}^-$ isomeric state is assigned a mixed configuration: $\pi^3\{\frac{9}{2}^-[514], \frac{7}{2}^+[404], \frac{5}{2}^+[402]\}$ (39%) and $\pi^1\{\frac{7}{2}^+[404]\}\otimes \nu^2\{\frac{7}{2}^-[514], \frac{7}{2}^+[633]\}$ (61%).

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I. INTRODUCTION

The odd tantalum nuclei in the region $A \sim 170$–180 are characterized by a well-deformed symmetric shape and offer good insight into the competition between intrinsic and collective excitations, configuration-dependent pairing reduction, details of the nucleon-nucleon residual interactions, and violation of the K selection rule. A large number of one- and multi-quasiparticle (qp) isomeric states with high K were predicted [1] and have been observed at low energies in Hf [2], Ta [3], W [4], and Os [5]. The decay of K isomers is hindered because of their high K value and the K selection rule. Various mechanisms, e.g., K mixing associated with Fermi-aligned configurations, tunneling through the γ degree of freedom, etc., have been proposed to explain the violation of the K selection rule, which is necessary to explain the lifetimes of many isomers; however, this complex process is still not properly understood [6]. Reliable information about the configuration changes in the decays of the states is required to expose the mechanisms involved.

High-K one- and multi-qp isomers are observed in the neutron-deficient Ta nuclei. The neutron-deficient odd-even Ta nuclei [7], away from the β stability line, have nuclear properties that are different than compared to those of the heavy odd Ta nuclei, e.g., β decay and ground state assignments. There is transition from an yrast line dominated by rotational 1-qp states in ^{173}Ta to one with a dominance of high-K multi-qp states to form the yrast line at low energies in ^{179}Ta. In the ^{177,179}Ta isotopes, the 3-qp states are observed to have admixtures of π^3 and π^1-ν^2 configurations in place of a proposed pure π^3 configuration in ^{173,175}Ta. These effects are the consequences of the nuclear structure changes due to a high density of states near the Fermi surface in the light tantalum nuclei. The K isomers in ^{173}Ta [8] were assigned pure 1- and 3-qp configurations based on excitation energies, in-band branching ratios, and the alignment of the band. The information derived from the transitional electromagnetic moments is based on various approximations, e.g., fixed deformation for all quasiproton configurations, no rotational perturbation, etc. The static electromagnetic moments are sensitive to microscopic structure and the shape of the nuclei in their equilibrium state. Wherever possible, the transitional and static electromagnetic moments provide independent information about nuclear structure.

In-beam γ-ray studies of ^{173}Ta have shown the presence of 1- and 3-qp isomeric states, $K^\pi = \frac{9}{2}^-$($E_x = 165.8$ keV, $T_{1/2} =$ 225 ns) [9] and $K^\pi = \frac{21}{2}^-$ ($E_x = 1713.2$ keV, $T_{1/2} \approx 100$ ns) [8]. The $\frac{9}{2}^-$ and $\frac{21}{2}^-$ bandheads were assigned $\pi\frac{9}{2}^-[514]$ Nilsson and 3-qp proton configurations, respectively, on the basis of the in-band analysis and the systematics in the neighboring nuclei [8,10]. The static quadrupole moment of the $\frac{9}{2}^-$ isomer in ^{171,173}Ta [11,12] and the static magnetic moment in ^{171}Ta [13] were found to be at variance with that of $\frac{9}{2}^-[514]$ Nilsson state in other nuclei [14]. The deformation in the $\frac{21}{2}^-$ isomeric state was observed to be about 1.5 times that of the $\frac{9}{2}^-$ isomeric state in ^{173}Ta [12]. The values of the intrinsic quadrupole moment Q_0 and the collective g-factor g_R used in the previous in-band analysis are therefore overestimated with respect to the subsequent experimental values. Furthermore, the configuration assignment of the state is ambiguous. With a view to resolve these issues, magnetic moment measurements have been carried out to determine the intrinsic structure of the $\frac{9}{2}^-$ and $\frac{21}{2}^-$ bandheads in ^{173}Ta.

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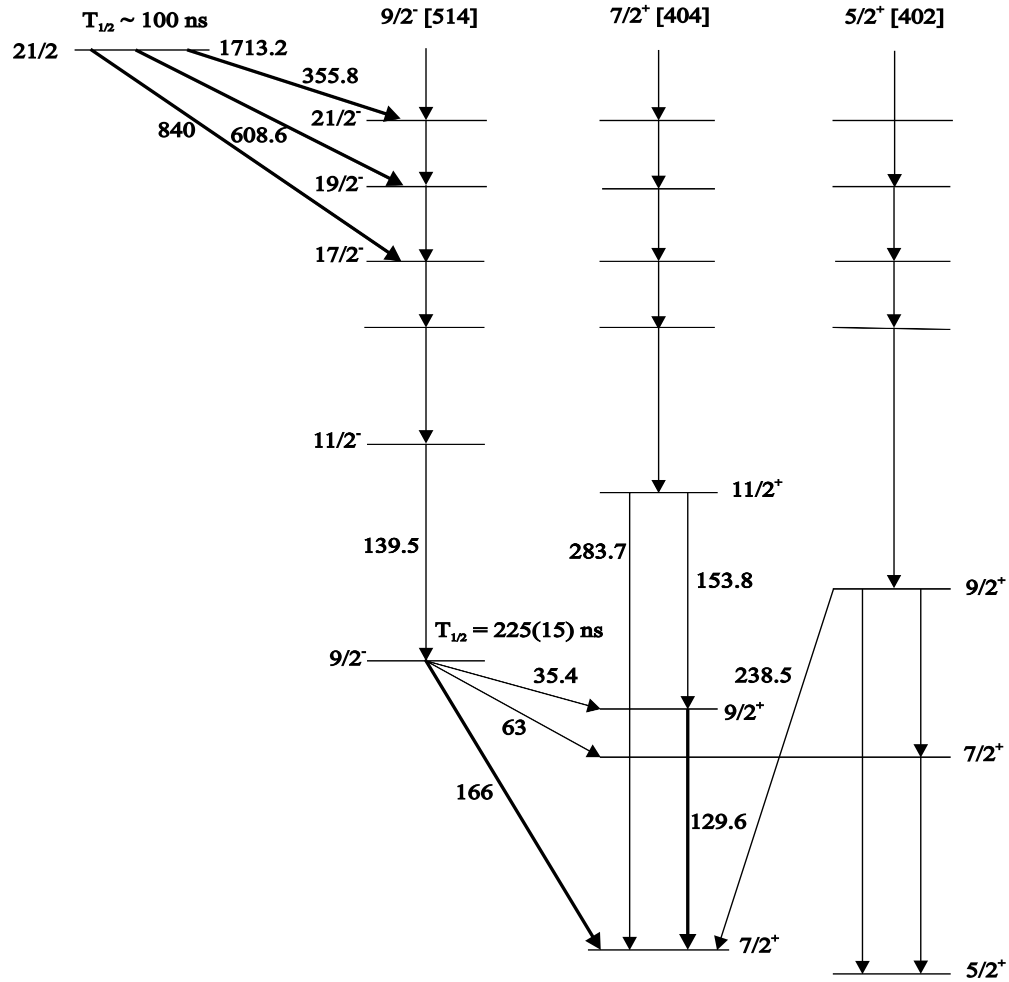

FIG. 1. Partial decay scheme of ^{173}Ta [18].

II. EXPERIMENTAL DETAILS

The lifetimes of $\frac{9}{2}^-$ and the $\frac{21}{2}^-$ bandheads in ^{173}Ta are well suited for magnetic moment measurements using the time differential perturbed angular distribution (TDPAD) technique. TDPAD measurements were carried out at the 15UD pelletron accelerator facility of the Inter-University Accelerator Centre (New Delhi). Details of the experimental setup have been described in an earlier communication [13]. Aligned isomeric states, $\frac{9}{2}^-$ and $\frac{21}{2}^-$ (Fig. 1), were populated by the heavy-ion reaction ^{165}Ho(^{12}C, $4n\gamma$)^{173}Ta using a 66 MeV ^{12}C pulsed beam of 2.5 ns pulse width and a 1 μs repetition period. The target consisted of 0.55 mg/cm^2 metallic Ho foil (100% natural abundance of ^{169}Ho isotope) on a thick Ta backing to stop the recoiling nuclei. An external magnetic field of 7.04(4) kG was applied perpendicular to the beam-detector plane. The magnetic field was measured using a Hall probe and calibrated independently under the same experimental conditions with reference to the Larmor precession frequency of the magnetic moment of the 10^+ isomeric state in ^{54}Fe [$E_x = 6.527$ MeV, $T_{1/2} = 357(4)$ ns, $g = +0.717(12)$] [15]. The 10^+ isomeric state in ^{54}Fe was excited through the reaction ^{45}Sc(^{12}C, $p2n$) in the same experiment by replacing the Ho target by a thick Sc target and decreasing the ^{12}C beam energy to 42 MeV, keeping the same beam pulse characteristics. The γ rays were recorded by two NaI(Tl) detectors positioned at angles $\pm 45^\circ$ with respect to the beam in a horizontal plane at a distance of 18 cm from the target. The data were collected in LIST mode with four parameters: the energy and time signals for each NaI(Tl) detector. The time signal was generated by a time-to-amplitude converter started by a suitably shaped anode pulse from the NaI(Tl) detector and stopped by a pulse picked up from the main oscillator of the beam pulsing system.

III. RESULTS

The acquired data, following proper gain matching for energy and time, were sorted off-line into E_γ-t matrices corresponding to the two different detectors. To investigate the delayed γ rays produced in the reaction, energy spectra gated by different time intervals with respect to the beam pulses were created. One such delayed γ-ray energy spectrum registered in between the beam bursts is illustrated in Fig. 2. The required time spectra were obtained by putting gates on the desired γ rays.

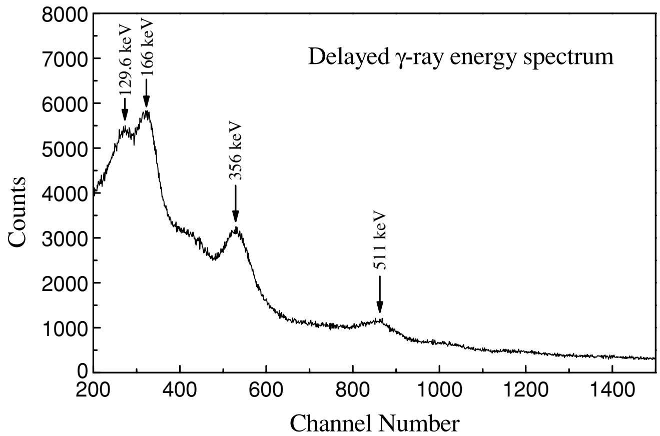

FIG. 2. Delayed γ-ray energy spectrum.

To extract the g-factors from the time spectra, a modulation ratio function $R(t)$ was formed

$$R(t) = \frac{I(t, +45^\circ) - I(t, -45^\circ)}{I(t, +45^\circ) + I(t, -45^\circ)}, \quad (1)$$

here $I(t, \pm 45^\circ)$ are the background subtracted and normalized time spectra. The experimental modulation function $R(t)$ was least-squares fitted with the following expression to obtain the value of the Larmor precession frequency ω_L for the isomeric states,

$$R(t) = A \sin(2\omega_L t + \phi) + \psi, \quad (2)$$

where A is a constant depending on the angular distribution coefficients of the deexciting γ rays, and ϕ and ψ are the phase shift and normalization correction, respectively. A, ϕ, and ψ were treated as free parameters. The experimental ratio functions $R(t)$ and corresponding fits are shown in Fig. 3. In principle, the decay of the $\frac{21}{2}^-$ isomeric state through the $\frac{9}{2}^-[514]$ band can modify the magnetic perturbation of the angular distribution pattern of the deexciting γ rays from the $\frac{9}{2}^-$ bandhead. However, the population of the $\frac{21}{2}^-$ state is so low that no rotational band has been observed on it [8].

Based on the observed γ-ray intensities [16], the feeding from the $\frac{21}{2}^-$ isomeric state to the $\frac{9}{2}^-[514]$ rotational band is expected to be less than 12%. It also appears from the undamped amplitude of $R(t)$ for the $\frac{9}{2}^-$ state that either the feeding is negligible or the g-factors of the $\frac{9}{2}^-$ and $\frac{21}{2}^-$ states are nearly the same [17]. In fact, both conditions are fulfilled in this case. The contribution of the feeding can therefore be safely neglected.

The ratio of the Larmor precession frequencies for the $\frac{9}{2}^-$ and $\frac{21}{2}^-$ isomeric states gives the ratio of corresponding g-factors, $\frac{\omega_L(\frac{21}{2}^-)}{\omega_L(\frac{9}{2}^-)} = \frac{g(\frac{21}{2}^-)}{g(\frac{9}{2}^-)} = 1.05(5)$, which is independent of the magnetic field at the target and free of systematic errors. The extracted values of g-factors from the corresponding Larmor precession frequencies $\omega_L(=\frac{gH\mu_N}{\hbar})$ are $g(\frac{9}{2}^-) = +0.591(18)$ and $g(\frac{21}{2}^-) = +0.620(15)$ and the corresponding magnetic moments are $\mu(\frac{9}{2}^-) = +2.66(8)\ \mu_N$ and $\mu(\frac{21}{2}^-) = +6.51(16)\ \mu_N$. The sign of the g-factors was established on the basis of the known positive values of the A_2 coefficients obtained in previous angular distribution measurements [8]. The diamagnetic and Knight shift corrections were not applied, as they are small (about 1%), similar in magnitude and opposite in sign.

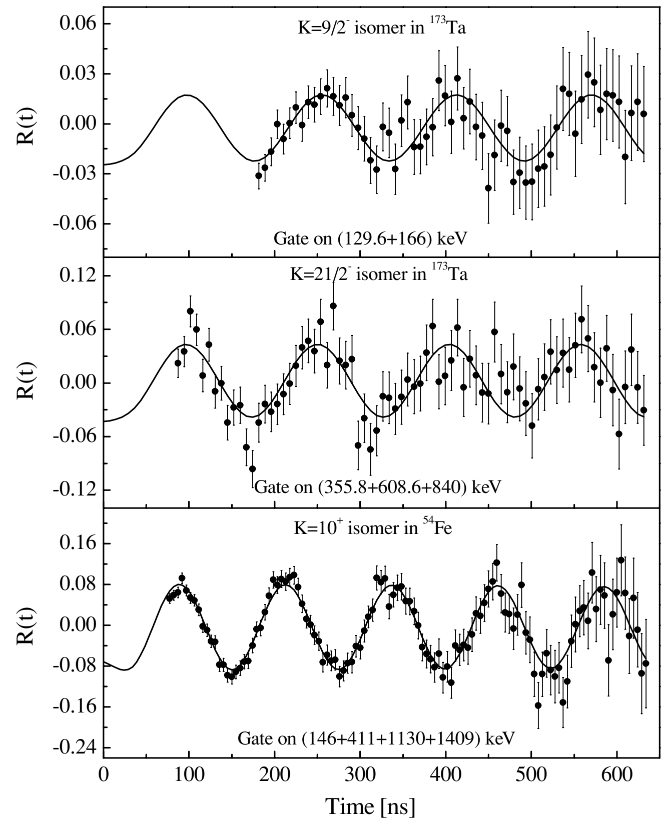

FIG. 3. Modulation spectrum of the γ-ray intensities in the presence of 7.04(4) kG external magnetic field at room temperature and least-squares fits.

As the measured g-factor of the $\frac{9}{2}^-$ state is almost a factor of 2 smaller than expected for its nominal Nilsson configuration (see below), further checks were performed on the data. An analysis of the lifetimes was made to confirm the identification of the isomers and provide an in-beam check on the time calibration. For this analysis, the background subtracted and normalized time spectra at the angles $\pm 45^\circ$ were added together, which cancels out the Larmor precession. The resulting decay spectra for the $\frac{9}{2}^-$, $\frac{21}{2}^-$ isomeric states in ^{173}Ta and 10^+ in ^{54}Fe are shown in Fig. 4. Least-squares fits give the half-lives $T_{1/2}(\frac{9}{2}^-) = 163(2)$ ns and $T_{1/2}(\frac{21}{2}^-) = 132(3)$ ns in ^{173}Ta, and $T_{1/2}(10^+) = 345(4)$ ns in ^{54}Fe. Overall, these half-life results are in reasonable agreement with the previous γ-time measurements [8,9,15]. Previously the half-life of the $\frac{21}{2}^-$ level was known only to be $\gtrsim 100$ ns. The present result for the $\frac{9}{2}^-$ state falls between the previous measurements [8,9]. Note that the presence of any unresolved activity lines, which may affect the extracted lifetime, can only affect the amplitude of the ratio spectrum but not the Larmon frequency. The half-life $T_{1/2}(\frac{9}{2}^-) = 225(15)$ from the previous more reliable γ-γ coincidence measurements [9] is adopted in Fig. 1.

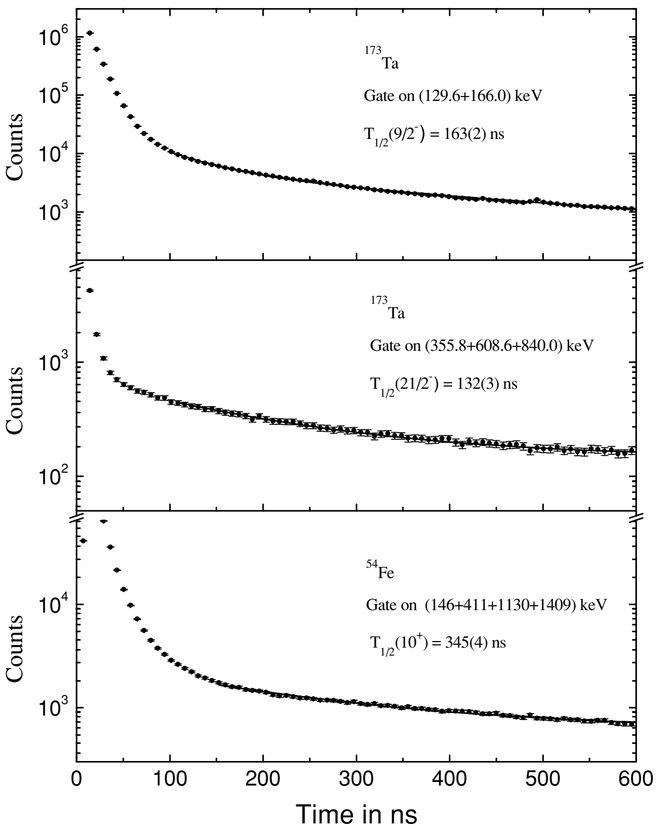

FIG. 4. Summed time spectra with gates on γ-ray transitions from the $\frac{9}{2}^-$, $\frac{21}{2}^-$ isomers in ^{173}Ta and 10^+ isomer in ^{54}Fe in the presence of 7.04(4) kG external magnetic field.

IV. DISCUSSION

A. The g-factor of $K^\pi = \frac{9}{2}^-$ isomeric state

The magnetic moment of a single-particle state strongly coupled to a deformed core is interpreted in terms of the collective g-factor g_R and the intrinsic g-factor g_K of the particle in the deformed orbit. The g_K and g_R factors of the rotational states with spin I and K are related to the mixing ratio of the intraband transition from the I state to the $I-1$ state through the well-known formula,

$$\left|\frac{g_K - g_R}{Q_0}\right| = \frac{0.93E_\gamma(I \to I-1)}{(\sqrt{I^2-1})\delta}. \quad (3)$$

The value of $|g_K - g_R|$ has been deduced to be 0.405(26) by using the measured value of the intrinsic quadrupole moment $Q_0(\frac{9}{2}^-) = 4.91(11)\ e\,$b [12] and intraband mixing ratios δ from the decay characteristics of the $\frac{9}{2}^-[514]$ band in ^{173}Ta [18]. This value, together with the measured moment and the relation

$$\mu = g_R I + \frac{K^2}{I+1}(g_K - g_R), \quad \left(K \neq \frac{1}{2}\right), \quad (4)$$

yields $g_K = 0.665(43)$ and $g_R = 0.260(24)$. In previous work [18], the assignment of the $\frac{9}{2}^-[514]$ proton configuration to the $\frac{9}{2}^-$ bandhead was based on the $(g_K - g_R)$ value extracted from the intraband mixing ratios taking the average values of $Q_0 = 7.0\ e\,$b and $g_R = 0.40$ in this mass region. Obviously, these adopted values of Q_0 and g_R are higher than the subsequent measured values. It may be noted that the experimental value of g_K is at significant variance with the theoretical value of $g_K = 1.20$ obtained from Nilsson model wave functions for the $\frac{9}{2}^-[514]$ proton configuration. The value of g_R is equal to the value of the g-factor for the 2^+ state of the core nucleus ^{172}Hf [19]. Usually g_R in the odd-proton nucleus is expected to be slightly higher than $g(2^+)$ of the core because of Coriolis interactions and pairing effects [20]. The discrepancy between the measured and the average values of g_K, g_R, and Q_0 in this mass region is in conflict with a pure one-quasiproton nature for the $\frac{9}{2}^-$ bandhead.

1. *Particle-rotor calculations*

Particle-rotor model calculations for ^{173}Ta were performed based on the Woods-Saxon potential [21]. The core was assumed to have a rigid axial deformation. The potential and pairing parameters employed have been summarized by Nazarewicz, Riley, and Garrett [22]. The deformation parameters for the average mean field, $\beta_2 = 0.271$ and $\beta_4 = -0.010$, were fixed at the theoretical values given in Table I of Ref. [22] for the even-even hafnium core nucleus. The moment-of-inertia parameter was set to correspond to a core with $E(2^+) = 100$ keV, which gives a reasonable description of the energy spacing in the $\frac{9}{2}^-$ band. Sometimes the Coriolis interaction matrix elements must be attenuated to improve the agreement between particle-rotor model calculations and the experimental level scheme. This ad hoc adjustment is best avoided and was not necessary here. Magnetic dipole moments and $M1$ transition rates were calculated with $g_R = 0.26$; the spin contributions to the single-particle g-factors were quenched by a multiplicative factor of 0.70. The calculated $B(M1)/B(E2)$ values for the $\frac{9}{2}^-[514]$ band are compared with experiment in Fig. 5. The magnetic moments and the quadrupole moments for the ground state ($I = \frac{5}{2}^-$) and $\frac{9}{2}^-$ bandhead are tabulated in Table I.

These calculations give a reasonable description of the deformation of the ground state, which is the $\frac{5}{2}^-$ member

TABLE I. Particle-rotor calculations of μ and Q in ^{173}Ta.

I^π	γ°	$\mu(\mu_N)$		$Q(e\,$b$)$	
		Theory	Exp.	Theory	Exp.
$\frac{5}{2}^-$	0	1.36	1.70(3)[a]	−2.023	−1.90(2)[b]
	10	1.37		−1.997	
	20	1.66		−2.03	
$\frac{9}{2}^-$	0	5.34	2.66(8)[c]	3.86	2.66(4)[d]
	10	5.34		3.78	
	20	5.32		3.55	

[a]Reference [24].
[b]Reference [23].
[c]Present work.
[d]Reference [12].

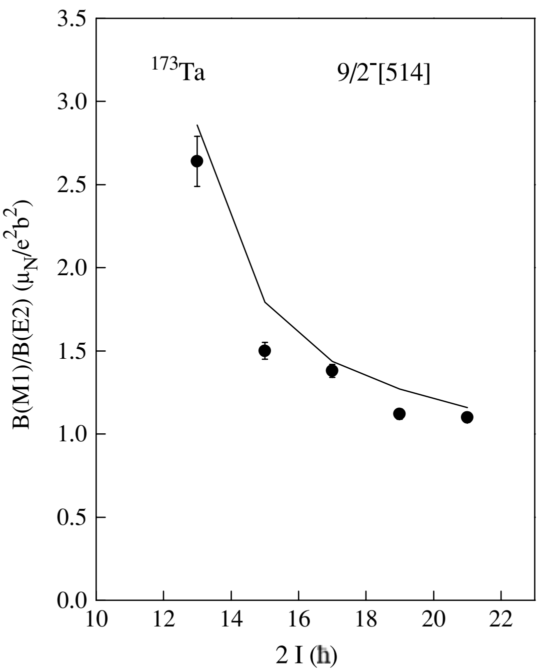

FIG. 5. $B(M1)/B(E2)$ values in the $\frac{9}{2}^-[514]$ band. Solid line corresponds to the particle-rotor calculation. Data are from Carlsson *et al.* [18].

of the $\frac{1}{2}[541]$ band, giving $Q(\frac{5}{2}^-) = -2.02\ e\text{b}$ compared with the experimental value of $Q(\frac{5}{2}^-) = -1.9(2)\ e\text{b}$ [23]. The ground-state magnetic moment is underestimated a little, $\mu_{\text{th}}(\frac{5}{2}^-) = 1.36$, compared with $\mu_{\text{exp}}(\frac{5}{2}^-) = 1.70(3)$ [24]. Turning to the $\frac{9}{2}^-$ band, the $B(M1)/B(E2)$ ratios are well reproduced in Fig. 5, possibly in better agreement with experiment than the similar calculations of Carlsson *et al.* [18]. However, the quadrupole moment of the $\frac{9}{2}^-$ bandhead is overestimated, $Q_{\text{th}}(\frac{9}{2}^-) = 3.86$, $Q_{\text{exp}}(\frac{9}{2}^-) = 2.66(4)$ [12], and the magnetic moment is significantly over estimated, $\mu_{\text{th}}(\frac{9}{2}^-) = 5.34$, $\mu_{\text{exp}}(\frac{9}{2}^-) = 2.66(8)$. The corresponding theoretical value of $g_K = 1.20$ for the $\pi\frac{9}{2}^-[514]$ orbital agrees with calculations based on the modified oscillator potential [25].

Thus the experimental g-factor is 50% lower than these calculations and the experimental value for the corresponding state in the heavier ^{181}Ta isotope [26], but it has approximately the same value as that measured for the $\frac{9}{2}^-$ isomer in ^{171}Ta [13]. The intrinsic quadrupole moment Q_0 has also been observed to be reduced by 25% for ^{171,173}Ta nuclei [11,12] as compared to the value in ^{181}Ta [27].

Several further calculations were therefore performed to examine the dependence of the magnetic moment on deformation and triaxiality. It was found that the calculated moment varies very little with either deformation or triaxiality (Table I). This insensitivity to deformation stems from the fact that the wave function of the $\frac{9}{2}^-[514]$ orbit remains close to that of the spherical $h_{11/2}$ orbit, virtually independent of deformation. It appears that the one-quasiproton configuration of the $\frac{9}{2}^-$ bandhead, based on the Nilsson model, does not give the correct picture for the light odd-A Ta nuclei near the transitional region.

2. *Effects of particle-octupole vibration coupling*

We suggest that the measured g-factor of the $\frac{9}{2}^-$ state requires the inclusion of effects associated with the coupling of the odd particle to the surface vibrational modes of the core, i.e., collective admixtures are important. The coupling of the γ-vibrational mode to the $\pi\frac{9}{2}^-[514]$ configuration has been considered to account for the reduction of g_K by 50% for the $I^\pi = \frac{11}{2}^-$ state at 899 keV in ^{177}Ta [28]. Coupling to collective modes in ^{173}Ta is supported by the decay characteristics of the $\frac{9}{2}^-$ bandhead to the rotational states of the opposite parity pseudo-spin doublet bands, $\frac{5}{2}^+[402]$ and $\frac{7}{2}^+[404]$. Specifically, the $\frac{9}{2}^-$ bandhead has been observed to decay by $E1$ transitions mainly to the $\frac{7}{2}^+$ and $\frac{9}{2}^+$ rotational states of the $\frac{7}{2}^+[404]$ band with a very weak branch to the $\frac{7}{2}^+$ rotational state of the $\frac{5}{2}^+[402]$ band [18]. These $E1$ transitions are of relatively large transition strength (compared to the single-particle estimate) and have a strong spin dependence indicating deviation from the Alaga rule. It is well known that low energy $E1$ transitions below the first band crossing are strongly hindered [29]. Earlier theoretical and experimental studies [29,30] recognized that it is not possible to explain the enhancement of the $B(E1)$ magnitude and its angular momentum dependance without invoking the particle-octupole vibration coupling (even in the odd-A rare earth nuclei, which are not prone to octupole deformation). In several publications [31,32] the enhanced $E1$ transition strength has been estimated to be the combined effect of the octupole deformation and the quadrupole deformation. The deviation from Alaga's rule could be explained [33] by including weak Coriolis forces, which are not so effective for the allowed transitions.

Carlsson *et al.* [18] considered it necessary to include the coupling of particle degrees of freedom to both the modes $K = 0$ and ± 1 of the octupole vibrations to explain the enhancement of the $B(E1)$ values in ^{173}Ta, similar to the analysis of the data for ^{169}Lu by Hagemann *et al.* [34]. Recently, the coupling of the octupole vibration has been considered as the only K-mixing mechanism for the K-forbidden transitions between opposite parity bands [35], particularly the hindrance factors for $E1$ transitions in ^{170,172}Hf [36,37] and photoresonances in ^{180}Ta^m [38]. These observations are consistent with the present measurements in that other mechanisms do not seem applicable. For example, Coriolis mixing in the nominal $\pi\frac{9}{2}^-[514]$ state tends to increase the value of g slightly, and statistical mixing of low-K states at low energy is improbable because of the low level density and the opposite parity of most nearby states.

To estimate the effect of coupling octupole vibrations on the Nilsson orbits, we note that when expanded in a spherical basis, the wave function of the $\frac{9}{2}^-[514]$ orbit has $>99\%$ $h_{11/2}$ parentage for all reasonable prolate deformations. (See, for example, the Nilsson wave functions tabulated by

TABLE II. g-factors of octupole-coupled (spherical) configurations calculated assuming $g(3^-) = 0.42$.

Nilsson configuration	Dominant spherical configuration	g
$\frac{9}{2}^-[514]$	$\pi h_{11/2}$	1.27
$\frac{7}{2}^+[404]$	$\pi g_{7/2}$	0.68
$\frac{5}{2}^+[402]$	$\pi d_{5/2}$	1.58
$\frac{7}{2}^+[404] \otimes 3^-$	$(\pi g_{7/2} \otimes 3^-)_{11/2}$	0.56
$\frac{5}{2}^+[402] \otimes 3^-$	$(\pi d_{5/2} \otimes 3^-)_{11/2}$	0.95

Chi [39].) Thus the g_K value remains close to the g-factor of the spherical $h_{11/2}$ proton orbit, virtually independent of deformation. Similarly the $\frac{7}{2}^+[404]$ Nilsson state has >99% $g_{7/2}$ parentage, and the $\frac{5}{2}^+[402]$ orbit has >96% $d_{5/2}$ parentage for all reasonable deformations. Thus, as a first estimate of the effect of octupole coupling on the g_K values, we examine the g-factors of spherical configurations weakly coupled to an octupole vibration.

In the absence of any theoretical calculation, the collective octupole vibration is expected to have a g-factor near Z/A. The g-factors of the octupole-vibration-coupled $\pi d_{5/2}$, $\pi g_{7/2}$, and $\pi h_{11/2}$ spherical shells are listed in Table II. In each case, the value of the g_K-factor is reduced because of the octupole vibration coupling. This indicates that the value of g_K for the $\frac{9}{2}^-$ bandhead can be reduced by admixing the $\pi\frac{7}{2}^+[404] \otimes 3^-$ configuration to the $\frac{9}{2}^-[514]$ configuration. Unfortunately, the fraction of the admixture is difficult to determine, and information about it is not available from in-band γ-ray spectroscopy. The main fraction of the $E1$ decay is to the $\frac{7}{2}^+[404]$ band, which suggests that the $\pi\frac{7}{2}^+[404] \otimes 3^-$ configuration is the dominant admixture.

The admixing of the low-K configuration to the $K^\pi = \frac{9}{2}^-$ state is expected to influence the purity of the K quantum number and to facilitate the K-forbidden transitions. Clearly, K mixing can influence both the magnetic moment and the quadrupole moment of the state. The 'effective' K value of the admixed wave function can be evaluated if the same quadrupole deformation is assumed for the $\pi\frac{9}{2}^-[514]$ and $\pi\frac{7}{2}^+[404]$ orbitals. This is a valid assumption considering the positive slope of the orbitals in the Nilsson energy diagram and the theoretical predictions of [22]. A value $Q_0(\frac{9}{2}^-) = 4.91(11)$ eb has been deduced from the measured spectroscopic quadrupole moment value $Q_s(\frac{9}{2}^-) = 2.66(4)$ eb [12] using the relation in the strong coupling approximation

$$Q_s = \frac{3K^2 - I(I+1)}{(I+1)(2I+3)} Q_0 \quad (5)$$

for $K = \frac{9}{2}$. The deduced value of $Q_0(\frac{9}{2}^-)$ is lower than the corresponding value $Q_0(\frac{7}{2}^+) = 7.8(8)$ eb [23] of the ground state in ^{175}Ta. The effective value of K comes out to be 3.96 by solving Eq. (5) for K and substituting the measured value of $Q_s(\frac{9}{2}^-)$ and $Q_0(\frac{9}{2}^-) = 7.8$ eb. The effective K value is significantly less than the pure K value of the $\frac{9}{2}^-$ isomer. This also points toward a low-K configuration component in the underlying structure of the $K^\pi = \frac{9}{2}^-$ isomer in ^{173}Ta. The g-factors are more sensitive to configuration admixing in the wave function. In the absence of any other mechanism available to explain the observed lowering of g_K, g_R, and Q_0 values with respect to the pure configuration values in this mass region, we suggest that the wave function of the $\frac{9}{2}^-$ isomeric state can be considered to be composed of admixtures of the $\pi\frac{9}{2}^-[514]$ and $\pi\frac{7}{2}^+[404] \otimes 3^-$ configurations.

B. The g-factor of $K^\pi = \frac{21}{2}^-$ isomeric state

The 3-qp state $K^\pi = \frac{21}{2}^-$ in ^{173}Ta is a weakly populated state, and no rotational level structure has been observed on it because of the large energy difference from the yrast line. The branching ratios in the deexcitation of the state are also not known. In the absence of any rotational band related properties, e.g., alignments and $(\frac{g_K - g_R}{Q_0})$, the configuration assignment of the state was mainly based on the systematics of the π^3 and π^1-ν^2 configurations in the neighboring nuclei. The $\frac{21}{2}^-$ isomeric state in ^{175}Ta has been assigned a pure $\pi^3\{\frac{5}{2}^+, \frac{7}{2}^+, \frac{9}{2}^-\}$ configuration, and the $\frac{21}{2}^-$ isomer in ^{173}Ta has been predicted to have the same structure, with $g_K = 1.12$ [10]. Following Ref. [10], we can adopt $g_R = 0.44(10)$ and use formula (4) to determine the experimental value of $g_K = 0.63(1)$ for the $\frac{21}{2}^-$ state in ^{173}Ta. Although this value of g_K is not sensitive to the exact value of g_R, an increase in the value of g_R is expected, compared with that adopted for the single-quasiparticle states, due to a reduction in the proton pairing. This change in g_R is supported by the value of the magnetic moment of the 6^+ core state in ^{172}Hf [40]. Thus, the experimental g-factor is not consistent with a pure proton configuration for the $\frac{21}{2}^-$ state.

1. *Configuration assignment*

The configurations of 3-qp states can be investigated further by considering the trend of the excitation energies

TABLE III. Experimental g-factors and corresponding g_Ω values in odd-A nuclei.

State	Shell	g-factor	g_Ω	Nucleus
$\pi\frac{9}{2}^-[514]$	$h_{11/2}$	+1.173(20)[a]	+1.378(26)	^{181}Ta
$\pi\frac{7}{2}^+[404]$	$g_{7/2}$	+0.649(13)[a]	+0.763(22)	^{175}Ta
$\pi\frac{5}{2}^+[402]$	$d_{5/2}$	+1.309(17)[a]	+1.733(31)	^{181}Ta
$\nu\frac{7}{2}^-[514]$	$h_{9/2}$	+0.227(1)[a]	+0.220(14)	^{177}Hf
$\nu\frac{5}{2}^-[512]$	$f_{7/2}$	−0.242(7)[a]	−0.439(22)	^{175}Hf
$\nu\frac{9}{2}^+[624]$	$i_{13/2}$	−0.142(3)[a]	−0.229(14)	^{179}Hf
$\nu\frac{7}{2}^+[633]$	$i_{13/2}$	−0.187(6)[b]	−0.312(16)	^{175}W

[a]Reference [14]; $g_R = 0.25(5)$.
[b]Reference [42].

TABLE IV. Experimental and calculated g_K-factors for 3-qp isomeric state: $\frac{21}{2}^-$ in ^{173}Ta.

Isotope	I^π	Configuration	g_K Calc.	g_K Exp.
^{173}Ta	$\frac{21}{2}^-$	$\pi^3\{\frac{9}{2}^-[514], \frac{7}{2}^+[404], \frac{5}{2}^+[402]\}$	+1.257(49)	0.63(1)
		$\pi^1\{\frac{7}{2}^+[404]\} \otimes \nu^2\{\frac{7}{2}^-[514], \frac{7}{2}^+[633]\}$	+0.224(32)	
		$\pi^1\{\frac{9}{2}^-[514]\} \otimes \nu^2\{\frac{7}{2}^-[514], \frac{5}{2}^-[512]\}$	+0.559(46)	
		$\pi^1\{\frac{5}{2}^+[402]\} \otimes \nu^2\{\frac{7}{2}^-[514], \frac{9}{2}^+[624]\}$	+0.388(55)	

and the associated intrinsic g-factors. The excitation energy calculations of multi-qp configurations have been carried out by treating pairing correlations based on the blocked Lipkin-Nogami approach and including residual nucleon-nucleon interactions in Ta nuclei [41]. The calculations were limited to the fixed nominal value of the deformation parameter and the 1-qp energies were adjusted to the energies of the corresponding states. The 3-qp configurations in ^{173}Ta are given below in ascending order of their excitation energies:

(i) $\pi^3\{\frac{9}{2}^-[514], \frac{7}{2}^+[404], \frac{5}{2}^+[402]\}$,
(ii) $\pi^1\{\frac{7}{2}^+[404]\} \otimes \nu^2\{\frac{7}{2}^-[514], \frac{7}{2}^+[633]\}$,
(iii) $\pi^1\{\frac{9}{2}^-[514]\} \otimes \nu^2\{\frac{7}{2}^-[514], \frac{5}{2}^-[512]\}$,
(iv) $\pi^1\{\frac{5}{2}^+[402]\} \otimes \nu^2\{\frac{7}{2}^-[514], \frac{9}{2}^+[624]\}$.

The (ii), (iii), and (iv) configurations were found to be approximately at 300, 800, and 1600 keV excitation energies, respectively, with reference to the (i) configuration. In ^{175}Ta, the order of the (ii) and (iii) configurations is reversed, but they are at approximately the same energy ~100 keV with respect to the (i) configuration. The value of g_K for these configurations can be estimated, based on the simple Nilsson model, from the sum of intrinsic g-factors, g_{Ω_i}, by using the expression

$$K g_K = \sum_{i=1}^{3} \Omega_i g_{\Omega_i}, \quad K = \Omega_1 + \Omega_2 + \Omega_3. \tag{6}$$

The intrinsic g_{Ω_i}-factors for each quasiparticle have been extracted from the experimental magnetic moments of low lying states in the neighboring odd-mass nuclei [42] and are listed in Table III. Note that the g_K value of the $\frac{9}{2}^-[514]$ state is taken from ^{181}Ta where the experimental value is consistent with that of a pure configuration.

The calculated values of the g_K-factor for the 3-qp configurations considered above are listed in Table IV. The measured value of $g_K = +0.63(1)$ for the $K^\pi = \frac{21}{2}^-$ bandhead is smaller than the calculated value $g_K = 1.26$ for the π^3 configuration and larger than for the other three π^1-ν^2 configurations. The measured value is also ten times larger than the corresponding measured value of $g_K = 0.062(11)$ in ^{177}Ta [43] considered to be of the π^1-ν^2 configuration. These comparisons show that the $\frac{21}{2}^-$ state is not of pure 3-quasiproton structure as predicted by the multi-qp calculations; nor it is a pure π^1-ν^2 configuration either. Clearly, its structure must include admixtures of the lowest π^3 and π^1-ν^2 configurations. Compared with the 2-quasiproton 6^+ core states of ^{172,174}Hf [40], which have been observed to have small admixtures (<8%) of the $\nu^2\{\frac{7}{2}^-[514], \frac{5}{2}^-[512]\}$ configuration, the $\frac{21}{2}^-$ state of ^{173}Ta has a larger π^1-ν^2 component. In view of these observations and the trend shown by the multi-qp calculations, we can propose the configuration of the $\frac{21}{2}^-$ state in ^{173}Ta to be approximately $\pi^3\{\frac{9}{2}^-[514], \frac{7}{2}^+[404], \frac{5}{2}^+[402]\}$ (39%) and $\pi^1\{\frac{7}{2}^+[404]\}\otimes \nu^2\{\frac{7}{2}^-[514], \frac{7}{2}^+[633]\}$ (61%).

V. SUMMARY

The nuclear g-factors of $\frac{9}{2}^-$ and $\frac{21}{2}^-$ bandheads in ^{173}Ta were measured directly using the TDPAD technique. The value of $g(\frac{9}{2}^-) = +0.591(18)$ agrees with the previous measurements on the related state in ^{171}Ta but deviates from Nilsson model predictions. It is suggested that the deviation may be due to admixing of the $\pi\frac{7}{2}^+[404] \otimes 3^-$ and $\pi\frac{9}{2}^-[514]$ configurations, in accord with the previously discussed role of octupole vibration coupling in the K mixing mechanism between the $\frac{9}{2}^-[514]$ and $\frac{7}{2}^+[404]$ bands. The g-factor of the $\frac{21}{2}^-$ state was compared with the values for the 3-qp configurations, π^3 and π^1-ν^2, predicted by the excitation energy calculations based on BCS theory for fixed normal deformation. The previously proposed pure π^3 configuration and assumption of fixed quadrupole deformation are clearly at variance with the experimental observations [12,44]. The configuration of the $\frac{21}{2}^-$ isomeric state seems to be a more complex mixture of π^3 and π^1-ν^2 configurations. We plan to extend these measurements to ^{175}Ta nuclei where the rotational band is observed on the $\frac{21}{2}^-$ bandhead.

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