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LAWRENCE RADIATION LABORATORY
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DISCLAIMER

INTERFERENCE OF NUCLEAR RESONANCE WITH ELECTRONIC ABSORPTION, AND MAGNETIC SPLITTING OF 6.25 keV γ RAYS OF ^{181}Ta*

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Abstract:

The interference of nuclear resonance absorption, followed by internal conversion, with photoelectric absorption has been observed for the 6.25 keV E1 γ transition of ^{181}Ta in single line and magnetically-split absorption spectra. The amplitude of the interference term was found in quantitative agreement with theory. From the magnetic splitting in longitudinal and transverse magnetic fields the g-factor ratio $g(9/2)/g(7/2) = 1.75 \pm 0.03$ was obtained.

A large dispersion term has recently been observed by Sauer et al.[1] in the Mössbauer absorption spectrum of the 6.25 keV E1 γ transition of ^{181}Ta. Subsequently this was explained by Trammel et al.[2] as being caused by an interference between nuclear resonance absorption, followed by internal conversion, and photoelectric absorption. In the meantime a few theoretical[3,4] and experimental[5,6] papers have been published on this subject, predicting and reporting small dispersion terms for other E1 γ transitions of ^{161}Dy, ^{155}Gd and ^{153}Eu. All the experimental work up to now has been done with single-line Mössbauer spectra. We report here the observation of large asymmetries in the Mössbauer absorption spectra of the 6.25 keV γ rays of ^{181}Ta, split by an

external magnetic field, and analyzed with a single-line absorber of Ta metal. According to our analysis this asymmetry is caused only by the interference effect and may not be interpreted as an electric quadrupole interaction as was previously done by Sauer et al.[1]

Velocity spectra were measured using a sinusoidal electro-mechanical drive as described by Kaindl et al.[7] Source and absorber were situated in a common vacuum chamber to eliminate acoustical disturbances, and an argon filled proportional counter was used to detect the 6.25 keV γ rays. The ^{181}W activity was obtained by irradiating 0.5 mg of highly-enriched ^{180}W metal (93%) in a total neutron flux of 2×10^{21} n/cm^2. The procedure used for the preparation of source and absorber was very similar to the one described by refs. 1, 8 and 9. A solution of the activity in concentrated HF-HNO_3 was dropped on a foil of tungsten metal (purity: 99.97%; thickness: 11 mg/cm^2), dried, and subsequently diffused for 1 hour at 2150°C in high vacuum (10^{-7} Torr). The Ta absorber foil (purity: 99.996%) was rolled to a thickness of 4.1 mg/cm^2 and annealed for 10 hours at 2000°C in high vacuum (10^{-8} Torr). The same source and absorber combination was used for all spectra reported here.

The velocity spectra measured in this work are shown in Fig. 1. The single line spectrum of Fig. 1a shows a distinct asymmetry, which is due to the interference effect. The experimental amplitude 2ξ of the dispersion term was obtained from a least-squares fit of the data with the following theoretical curve[2,3]

$$N(v) = N(\infty)\left[1 - \frac{A\,(W/2)^2}{(v-S)^2 + (W/2)^2}\left(1 + 2\xi\ \frac{(v-S)}{W/2}\right)\right]$$

(N = number of counts, W = experimental linewidth (FWHM), A = maximum resonance effect, v = Doppler velocity, S = isomer shift). The small deviation of the fitted curve from the measured one in Fig. 7a can be explained by the difference between the exact lineform given by the transmission integral for such a thick absorber and a Lorentzian lineshape.[10] For the magnetically split velocity spectrum the source foil was glued onto the flat surface of a cylindrically-shaped permanent magnet (9/8" long, 7/8" diameter), producing a longitudinal magnetic field of 1700 ± 50 Oe at the source, and the whole assembly was moved. The inhomogeneity of the field across the source was less than 30 Oe and the stray field at the position of the absorber was less than 12 Oe. The measured velocity spectrum, shown in Fig. 1(b), was fitted with a superposition of dispersion-modified Lorentzian lines given by the above expression. We assumed a pure magnetic splitting, with relative line intensities given by the theory of multipole radiation for a $9/2 \rightarrow 7/2$ transition and longitudinal magnetic field. Due to the finite solid angle the $\Delta m = 0$ transitions give small contributions to the total absorption spectrum. Therefore a careful solid-angle correction was carried out and the resulting mean value of $\sin^2\theta$, where θ is the angle between the direction of γ emission and the magnetic field, was kept constant during the fitting procedure. The magnetic field, $g(9/2)/g(7/2)$, W/2, S, A, 2ξ and $N(\infty)$ were used as free parameters in the fit. The results for both the single line and the magnetically-split velocity spectrum are given in Table I.

The magnetic splitting was additionally measured with a "magnetic drive," where the resonance absorption is observed as a function of the magnetic field at the source, with no field at the absorber, and both source and absorber at zero relative velocity. The source was situated in a transverse magnetic

field, generated by an electromagnet, with an inhomogeneity of about 1% across the area of the source. The stray field at the position of the absorber and the proportional counter was less than 10 Oe. The magnetic field was swept with a saw-tooth waveform and a sweeping time of 50 minutes. The data were stored in a multichannel analyzer operated in time-mode, the address of which was synchronously advanced with the sweep of the magnetic field. The spectrum obtained is shown in Fig. 2. The solid curve is the result of a least-squares fit, with $g(9/2)/g(7/2)$, $W/2$, 2ξ, A, $N(\infty)$ and the magnetic field as free parameters, while the isomer shift S, obtained from the velocity spectra, was kept constant during the fit. A linear dependence of the magnetic field from the channel number was assumed: this assumption was carefully checked. All individual lines were constrained to have the same linewidth in energy. In the magnetic drive spectrum the linewidths therefore increase linearly with position.

The results obtained from the analysis of the different spectra are summarized in Table I. The obtained halfwidth of $W/2 = 0.070$ mm/s, uncorrected for finite absorber thickness, corresponds to about 20 times the natural linewidth. However, a maximum resonance effect of 11%, uncorrected for background, has been observed, indicating, that a considerable amount of the broadening is due to the very thick Ta metal absorber (effective absorber thickness $t = 23$). The value obtained for the amplitude of the dispersion term may be compared with theory. According to Trammel[2] ξ is given by

$$\xi = \varepsilon\left(\frac{\alpha\, \sigma_e'}{6\pi\lambda^2}\right)^{1/2} ,$$

where σ_e' is the electronic absorption cross-section for El absorption, α is the internal conversion coefficient and λ is the wavelength of the incident

γ rays. The coefficient ε is introduced to account for the fact that α and σ_e' are proportional to the sum of the squares of amplitudes for the individual processes, whereas ξ is proportional to the sum of products of these amplitudes (see Ref. 2). Using $\alpha = 46 \pm 8$[11], $\sigma_e' = 9.8 \cdot 10^4$ b[12] we obtain $2\xi = 0.31\,\varepsilon$. Thus ε is very close to 1 in the present case.

As a final result for the g-factor ratio we give the weighted average of both measurements:

$$g(9/2)/g(7/2) = 1.75 \pm 0.03 \ .$$

With the magnetic moment of the groundstate $\mu(7/2) = +2.35 \pm 0.01$ nm[13] we obtain for the 6.25 keV state

$$\mu(9/2) = +5.29 \pm 0.11 \text{ nm} \ .$$

This value agrees within experimental accuracy with the one obtained by Sauer et al.,[1] but is of higher accuracy.

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FOOTNOTES AND REFERENCES

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Table I. Summary of experimental results

	Velocity spectra		Magnetic drive spectrum
	unsplit	magnetically split	
halfwidth W/2	0.071±0.001	0.073±0.002	0.069±0.003
dispersion amplitude 2ξ	0.30 ±0.01	0.30 ±0.01	0.35 ±0.07
isomer shift S [mm/s]	0.839±0.005	0.832±0.005	---
g-factor ratio g(9/2)/g(7/2)	---	1.74 ±0.03	1.76 ±0.04

FIGURE CAPTIONS

Fig. 1. Absorption spectra of the 6.25 keV γ rays measured with a velocity drive: (a) unsplit source, (b) source in a longitudinal magnetic field of 1700 + 50 Oe. In (b) the positions and intensities of the $\Delta m = \pm 1$ components are indicated by dashed lines. The solid curves represent the results of the least-squares fits.

Fig. 2. Absorption spectrum of the 6.25 keV γ rays measured with a magnetic drive. The positions and intensities of the components are indicated by dashed lines. The solid curve represents the result of the least-squares fit.

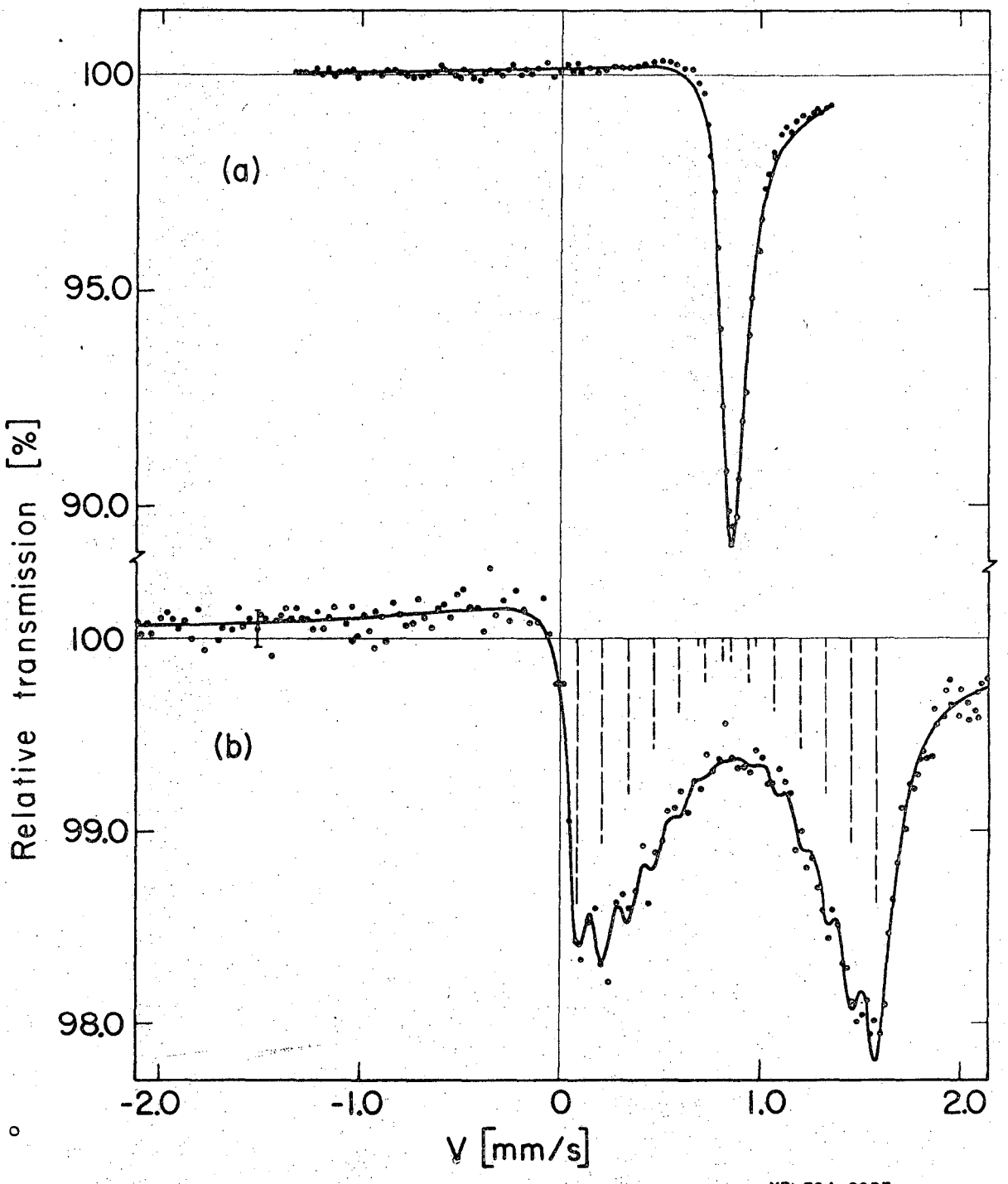
100
95.0
90.0
(a)
100
99.0
98.0
(b)
Relative transmission [%]
-2.0
-1.0
0
1.0
2.0
V [mm/s]
XBL 704-2687

Fig. 1

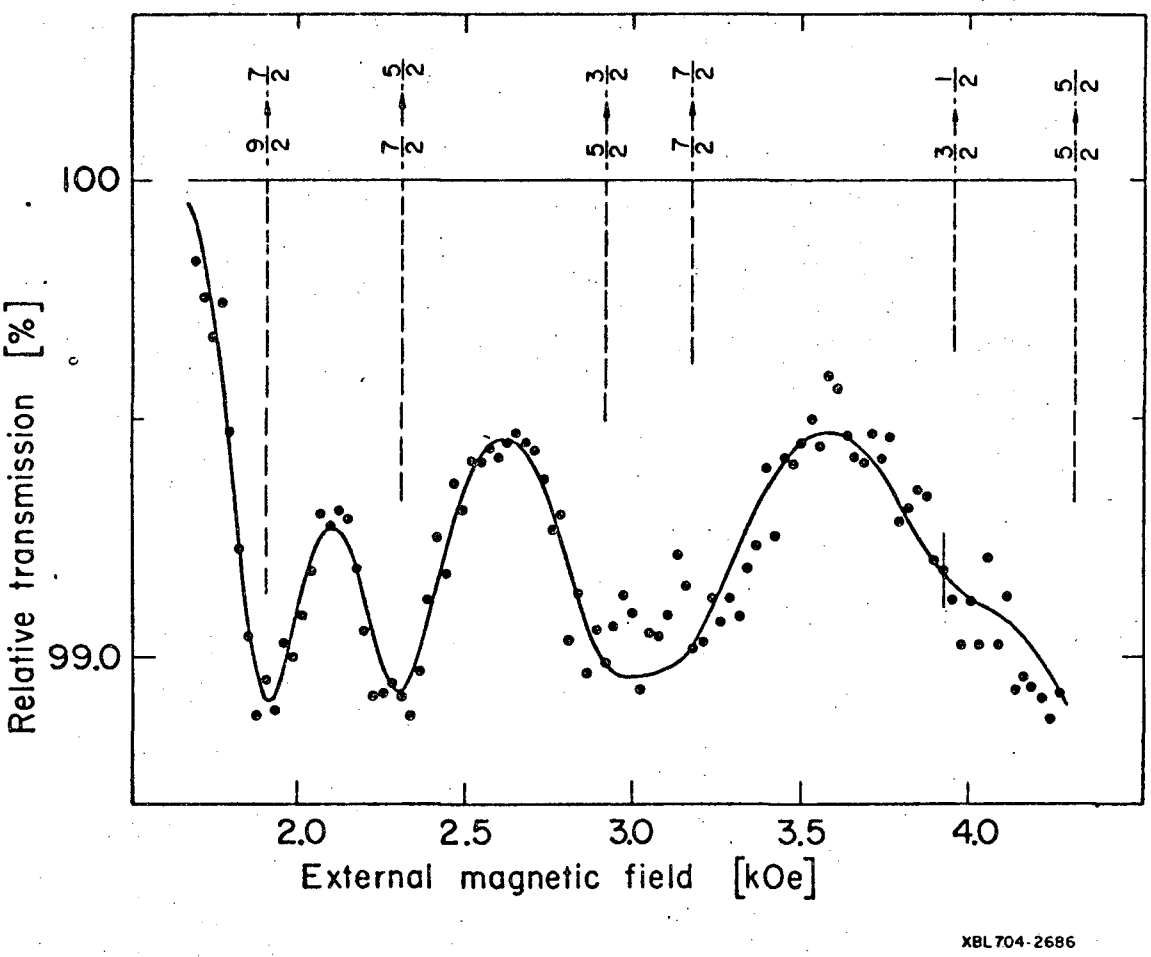
7/2
9/2
5/2
7/2
3/2
5/2
7/2
7/2
1/2
3/2
5/2
5/2
100
99.0
Relative transmission [%]
2.0
2.5
3.0
3.5
4.0
External magnetic field [kOe]
XBL704-2686

Fig. 2

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