Evidence of M1 and E2 Strength in the Giant Resonance Region of Ce

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Inelastic electron scattering from Ce (50 and 65 MeV, 93°, 129° and 165°) had shown evidence for an M1 and an E2 resonance at 8.7 and 12.0 MeV, respectively. These assignments have been confirmed by DWBA calculations. Reduced transition probabilities are derived for the resonances mentioned, and for the giant E1 resonance.

In an earlier paper [1] we reported on the excitation of three resonances in the giant resonance region of Ce, Pr and La by inelastic electron scattering. To check the tentative multipole assignment given in that paper and to determine reduced matrix elements we have further analysed the spectra of Ce. The spectra were fitted [2] by Breit-Wigner shape curves for the resonances and by the radiative tail [3] of the elastic peak calculated in Born approximation plus a polynomial in the energy of the final electron for the background. The best fit yielded resonances at 8.7, 12.0 and 15.1 MeV which correspond to the ones reported in Ref. [1], and one at 10 MeV, which was much weaker. To fix the background the total width of the resonance at 15.1 MeV, which is the well known giant E1 resonance, was taken as 4.35 MeV from (γ, abs.)-measurements [4]. The parameters varied were the total widths of the resonances at 8.7 and 12.0 MeV, the excitation energies, strengths, and the coefficients of the background polynominal. From the areas of the best fit curves of the resonances and the area of the elastic peak the ratio of the inelastic and elastic cross sections was obtained. The elastic scattering cross section was computed with a phase shift code [5] using a Fermi type charge distribution with $c = 5.78$ fm and $t = 2.31$ fm [6].

The cross section of the resonance at 15.1 MeV was compared with DWBA calculations using the hydrodynamical model [7]. A reduced transition probability of 40 ± 8 fm^2 was obtained from the 93° data; this agrees well with 40 fm^2 deduced from the (γ, abs.) measurements [4]. However, the measured cross sections are larger than those calculated with 40 fm^2 at backward angles indicating a transverse contribution which cannot be explained by the transition current in the hydrodynamical model. An electric spin flip contribution as it is known for the giant dipole resonance of light nuclei [8, 9] could be the reason.

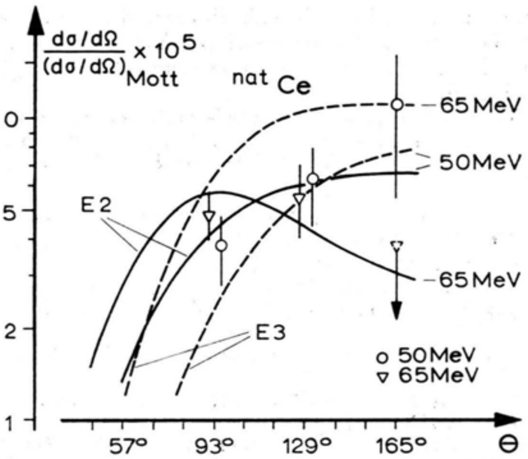

Fig. 1. The ratio of the inelastic cross section of the resonance at 12.0 MeV to the Mott cross section is plotted for primary energies of 50 and 65 MeV as a function of scattering angle. The curves show the result of DWBA calculations assuming an E2 assignment with $B(\mathrm{E2}, 0) = 2.5 \times 10^3$ fm^4 (solid lines) and an E3 assignment with $B(\mathrm{E3}, 0) = 4.3 \times 10^5$ fm^6 (dashed lines). Measured points for 93° and 129° are not drawn exactly at these angles in order to show the error bars more clearly.

The figure shows the measured ratio of the inelastic cross section of the 12.0 MeV resonance to the Mott cross section together with the corresponding DWBA curves for an E2 and an E3 transition. The DWBA curves were again calculated using the hydrodynamical model [7]. The figure shows that E2 is clearly favored. A comparison with calculated angular distributions (not shown) excludes the multipolarities $\lambda = 1$ and $\lambda \geqq 4$ in accordance with the qualitative arguments given in Reference [1]. An E0 assignment cannot be ruled out from the measurements, but seems to be unlikely since the corresponding strength would have to be explained by a collective breathing mode whose excitation energy is expected to be higher due to the low nuclear compressibility [10]. The results including the total width are given in the Table 1. The 12.0 MeV resonance can be identified with the isoscalar E2 resonance predicted by Bohr and Mottelson [11] at 11.2 MeV. The B-value exhausts 70% of their sum rule. A weak resonance barely observed at 24 MeV might be the corresponding isovector resonance in this model.

The cross section of the resonance at 8.7 MeV exhibits the transverse angular dependence of a magnetic transition. We tried to analyse the data with two models. The code of Tuan et al. [12], which uses a transition current contribution only, cannot reproduce the angular dependence for any spin assignment. The code of Drechsel [13] using a pure spin flip model gives roughly the correct dependence assuming an M1 transition, although the agreement is still not satisfactory. The B-value given in the Table 1 was calculated using model "E" of this code. However, other spin flip models of this code reproduce the angular distribution

Table 1. The results for the three resonances. See text for model dependence of the reduced transition probabilities. The single particle units WU are defined as in Ref. [14] and Γ_t for the E1 resonance was taken from Reference [4].

E_x/MeV	λ_π^0	$B(\mathrm{X}\lambda\downarrow, 0)$/fm$^{2\lambda}$	Γ_γ^0/eV	Γ_γ^0/WU	Γ_t/MeV
8.7 ± 0.3	1^+	0.4 ± 0.2	0.9×10^2	6 ± 3	2.2 ± 0.4
12.0 ± 0.2	2^+	$(2.5 \pm 0.8) \times 10^3$	1.0×10^2	12 ± 4	2.8 ± 0.3
15.1 ± 0.2	1^-	40 ± 8	5.0×10^4	8.0 ± 1.6	(4.35)

nearly as well although with different *B*-values. A model dependence of a factor of two has therefore to be considered in addition to the experimental error given in the Table 1.

We wish to express our gratitude to Professor P. Brix for encouraging discussions. We thank Professor F. R. Buskirk, Dr. H. Theissen and Dr. O. Titze for their advice and suggestions. We are indebted to Professor D. Drechsel for helpful discussions and to Professor A. Bohr and B. Mottelson for making parts of their book available to us prior to publication and for contributing important comments. This work was sponsored by the Bundesministerium für Bildung und Wissenschaft. The computer calculations were performed at the Deutsches Rechenzentrum, Darmstadt.

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The Mössbauer Effect of the 60.0 keV Transition in ^{155}Gd and the 54.5 keV Transition in ^{157}Gd

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Using the Mössbauer technique the lifetimes of the 60.0 keV level in ^{155}Gd and the 54.5 keV level in ^{157}Gd have been measured.

^{155}Gd and ^{157}Gd are strongly deformed nuclei with a similar structure differing in only two neutrons. Therefore a comparison is very interesting. While on ^{155}Gd many experiments have been done [1], only a few papers on ^{157}Gd have been published [2–4]. Here we give our first results of lifetime measurements of the first excited rotational states in these nuclei.

Whereas Mössbauer measurements have been performed in ^{157}Gd using the 64.0 keV transition [3, 4], the ME of the first excited state has been observed for the first time. This was only possible by using a γ-detector with a high energy resolution.

The ^{157}Gd activity ($T_{1/2} = 15$ h) was produced at the Darmstadt Electron Linear Accelerator by means of the reaction ^{158}Gd$(\gamma,p)^{157}$Eu. The ^{157}Eu was separated and imbedded in a Gd_2O_3 matrix. For the absorber we used enriched $^{157}Gd_2O_3$ (69.6%). The thickness was 47 mg ^{157}Gd/cm^2.

The temperature of source and absorber was 4.2 °K. Using a Ge(Li)-detector with an energy resolution of better than 1.7 keV any background of the 64.0 keV transition and the X-rays could be avoided. The experimental details have been described elsewhere [4].

The observed spectrum is shown in Figure 1. As known from other measurements [4] the hyperfine interaction is very small in comparison with the linewidth. Therefore a single Lorentzian was fitted to the data. The experimental linewidth was found to be

$$\Gamma(54.5) = (73.5 \pm 1.5) \text{ mm/sec.}$$

For the correction of the line broadening due to the absorber thickness we used the theoretical conversion coefficients of Hager and Seltzer [5] and the mixing ratio $\delta(E2/M1)$ from the Tables of Lederer et al. [6]. The interpolated value turned out to be $\alpha_{\text{th}}(54.5) = 12.60$. With a Debye temperature of $\Theta = 220$ °K [7] and an assumed error of 10% we got the Debye-Waller factor $f(54.5) = 0.43 \pm 0.03$. Therewith the linewidth was corrected [8] by the factor 1.91, and the lifetime $\tau(54.5) = (187 \pm 12)$ psec * was found. As a test for this correction we estimated the maximum absorption (center of the resonance) as $(33.5 \pm 2.3)\%$, which is in very good agreement with the experimental value of $(32 \pm 4)\%$.

The lifetime of the 60.0 keV level in ^{155}Gd has been estimated from Coulomb excitation data [9] to be $\tau(60.0) = 140$ psec, while Krusche et al. [10] reported (350 ± 90) psec. From a Mössbauer experiment [11] a larger value of (2.7 ± 0.7) nsec was obtained. Because of this discrepancy the lifetime was re-measured and analysed in the way described before.

The ^{155}Eu activity produced by means of the reaction ^{154}Sm$(n,\gamma)^{155}$Sm$(\beta^-)^{155}$Eu ($T_{1/2} = 1.7$ y) was separated and imbedded in a CeO_2 matrix. 13 mg ^{155}Gd/cm^2 of enriched $^{155}Gd_2O_3$ (94.4%) were used as an absorber. The experimental linewidth was found to be

$$\Gamma(60.0) = (36.2 \pm 4.6) \text{ mm/sec.}$$

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* The error includes also an assumed error for α_{th} of 10%.

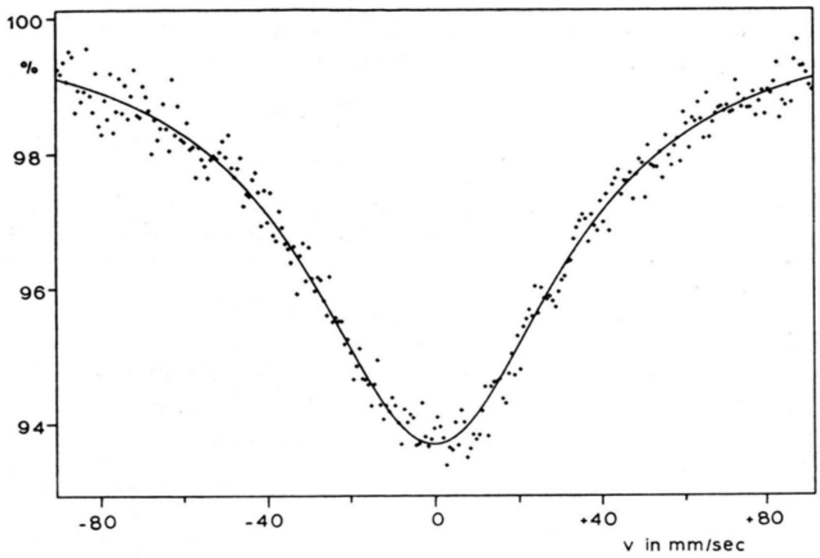

Fig. 1. Mössbauer spectrum of the 54.5 MeV transition in ^{157}Gd at 4.2 °K with a least squares fitted Lorentzian. Source: ^{157}Eu in Gd_2O_3, absorber: $^{157}Gd_2O_3$.

With $\alpha_{\text{th}}(60.0) = 9.55$ and $f(60.0) = 0.36 \pm 0.03$ we got a correction factor 1.24 and a lifetime

$$\tau(60.0) = (224 \pm 29) \text{ psec.}$$

The rather large value determined by BALABANOV et al.[11] using a Na(Tl)-detector is due to the very high background of the 86.5 keV transition; this second excited state has a lifetime of $\tau(86.5) = (9.16 \pm 0.13)$ nsec[10] and a comparable large Mössbauer cross section.

The errors of the available values are still too large for a detailed discussion of the relevant theoretical parameters, but further experiments will be done to improve the accuracy.

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Über den Schwellenwert der Pumpenergie von Flüssigkeitslasern im quasistationären Betrieb

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Threshold Pump Intensity of Flash Lamp Pumped Liquid Lasers

Laser parameters of flash lamp pumped dye lasers are interpreted on the base of a simplified term scheme. The obtained formular contain the fluorescence characteristics of the liquid solutions.

Über die Deutung der Wirkungsweise von Flüssigkeitslasern im quasistationären Betrieb sind mehrere Mitteilungen erschienen[1]. In gegenwärtiger Arbeit wird der Verstärkungskoeffizient und die Schwellenenergie des Pumpens auf die Lumineszenzcharakteristiken zurückgeführt. Auf Grund des in Abb. 1 dargestellten vereinfachten Termschemas läßt sich die Besetzungsdichte n_i der Elektronenenergieniveaus bei langsamer Änderung der Pumpintensität wie folgt ausdrücken:

$$\begin{gathered} n_1 + n_2 + n_3 = n\,, \\ \mathrm{d}n_1/\mathrm{d}t = -n_1\,U_{\mathrm{p}}(\nu) + n_3\,A_{31} + n_3\,U_{\mathrm{l}}(\nu) + n_2\,P_{21} = 0, \quad (1) \\ \mathrm{d}n_2/\mathrm{d}t = n_3\,P_{32} - n_2\,P_{21} = 0\,. \end{gathered}$$

A_{31} ist der Einsteinsche Integralkoeffizient der spontanen Emission, mit P_{ik} sind die Häufigkeiten der strahlungslosen Übergänge bezeichnet (s. Abb. 1). In den Formeln der durch die Gleichungen

$$U_{\mathrm{p}}(\nu) = \int_0^\infty u_{\mathrm{p}}(\nu)\, B_{13}(\nu)\, \mathrm{d}\nu\,,$$

$$U_{\mathrm{l}}(\nu) = \int_0^\infty u_{\mathrm{l}}(\nu)\, B_{31}(\nu)\, \mathrm{d}\nu \qquad (2)$$

definierten Größen bedeuten $u_{\mathrm{p}}(\nu)$ bzw. $u_{\mathrm{l}}(\nu)$ die spektrale Energiedichte der Pumpstrahlung bzw. der Laseremission, $B_{13}(\nu)$ und $B_{31}(\nu)$ die auf die Absorption bzw. auf die erzwungene Emission bezüglichen Einsteinschen Koeffizienten. Aus (1) folgt

$$n_1 = n(1-S)\,,\quad n_3 = n\,P\,S\,,\quad n_2 = n\,S(1-P)\,, \qquad (3)$$

worin

$$S = \frac{U_{\mathrm{p}}(\nu)}{U_{\mathrm{p}}(\nu) + P\,U_{\mathrm{l}}(\nu) + P(A_{31}+P_{32})} \qquad (4)$$

$$1/P = 1 + P_{32}/P_{21}$$

ist.

Wie ersichtlich, ist im Parameter P die Wirkung des Triplettniveaus 2 berücksichtigt. Offenbar kann der Verstärkungskoeffizient $K_{\mathrm{l}}(\nu)$ in der Form

$$K_{\mathrm{l}}(\nu) = \frac{h\,\nu\,n^0}{c}\, n[P\,S\,B_{31}(\nu) - (1-S)\,B_{13}(\nu)] \qquad (5)$$

geschrieben werden; hier ist c die Lichtgeschwindigkeit und n^0 der Brechungsindex. Es ist zweckmäßig, $B_{31}(\nu)$ mittels des normierten Lumineszenzquantenspektrums $f_{\mathrm{q}}(\nu)$, der natürlichen Lebensdauer τ_0 und der relativen Lumineszenzausbeute $\eta^*(\nu)$ [2] auszudrücken:

$$K_{\mathrm{l}}(\nu) = n\,\frac{c^2}{8\,\pi\,\tau_0\,\nu^2\,n^{02}}\, f_{\mathrm{q}}(\nu)\,P\,S - (1-S)\,k(\nu)\,\eta^*(\nu)\,. \qquad (6)$$

Mit dem Ansatz für den Verlustkoeffizienten

$$K_{\mathrm{V}} = \varrho + [1-\eta^*(\nu)]\,k(\nu)$$

(der Anteil ϱ ist unabhängig von der Frequenz ν) und Benützung des Zusammenhanges $A_{31}+P_{32} \approx 1/\eta_{\max}\,\tau_0$ (bezüglich des Maximalwertes der Ausbeute $\eta_{\max}$, vgl. [3]), kann aus der Schwellengleichung $K_{\mathrm{l}}(\nu) = K_{\mathrm{V}}(\nu)$ mit Beachtung der obigen Zusammenhänge die Schwellenenergie $U_{\mathrm{p}}{}^{\mathrm{S}}(\nu)$ als Funktion der Frequenz der Laserstrahlung wie folgt erhalten werden

$$U_{\mathrm{p}}{}^{\mathrm{S}}(\nu) = \left\{ [k(\nu)+\varrho]\,\frac{1}{\eta_{\max}\,\tau_0} \right\} \Big/ \left\{ \frac{n\,c^2}{8\,\pi\,\tau_0\,n^{02}\,\nu^2}\, f_{\mathrm{q}}(\nu) - \frac{\varrho + [1-\eta^*(\nu)]\,k(\nu)}{P} \right\} \qquad (7)$$

[$k(\nu)$ ist der Absorptionskoeffizient].

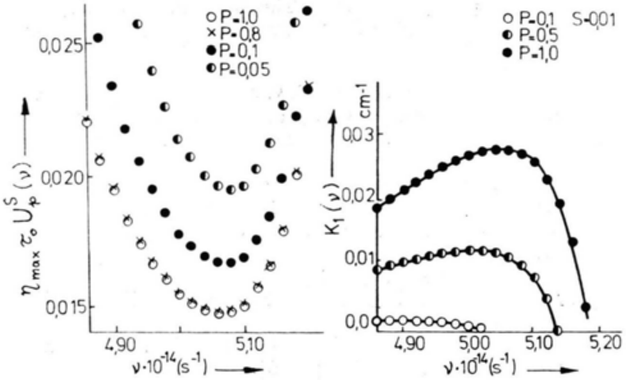

Abb. 1

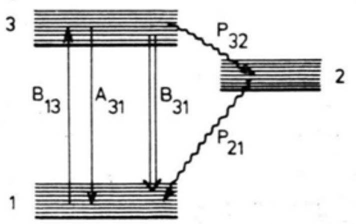

Abb. 2

Abbildung 2 zeigt den Schwellenwert der Pumpenergie als Funktion der Frequenz und die Verstärkungskurve für eine Äthylalkohollösung von Rhodamin 6 G.

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