Comments and Addenda

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Decay of ^{143}Ce to Levels in ^{143}Pr

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(Received 19 February 1971)

γ radiation following the decay of ^{143}Ce to levels in ^{143}Pr has been studied with curved-crystal and Ge(Li) spectrometers. Coincidence spectra were taken with a Ge(Li)-Ge(Li) combination and with a Ge(Li)-NaI(Tl) combination. 28 transitions were observed, including a transition at 891 keV which was previously unreported. The 891-keV transition has been placed in the decay scheme on the basis of coincidence data. The 557-keV γ ray known to be associated with the decay of ^{143}Ce has been observed in coincidence spectra for the first time.

1. INTRODUCTION AND EXPERIMENTAL ARRANGEMENTS

The decay of ^{143}Ce to levels in ^{143}Pr with a half-life of 33.7 h has been studied by many investigators.[1-14] Although the results of these investigations have led to a fairly well-established decay scheme, it was felt that a reinvestigation might possibly reveal some new features in the decay.

The University of Michigan 2-m curved-crystal spectrometers and the experimental techniques associated with their use have been described by Reidy and Wiedenbeck.[15-17] These spectrometers were calibrated using the 411.794 ± 0.008-keV γ ray of ^{198}Au and the 59.31918 ± 0.00035-keV $K\alpha_1$ x ray of tungsten.

Coaxial Ge(Li) detectors with depleted volumes of 32 and 38 cm^3 were used in acquiring the singles spectra. A description of the efficiency calibration and the method of the spectrometer nonlinearity determination is presented elsewhere.[18]

The detectors used in the γ-γ coincidence system were the 32-cm^3 coaxial detector in one channel and an 8-cm^2 $\times$ 0.5-cm planar detector in the other channel. In many of the experiments it was necessary to replace the planar detector with a 7.6-cm $\times$ 7.6-cm NaI(Tl) detector in order to obtain satisfactory coincidence counting rates.

2. RESULTS

A singles spectrum taken with the 32-cm^3 Ge(Li) detector is shown in Fig. 1. Series of spectra were recorded as a function of time in order to identify the impurity lines. These lines are indicated in parentheses on the figure. The principal impurities in the sources were identified as ^{141}Ce, ^{140}La, and ^{152}Eu. Lines designated with the symbol B are due to background radiation.

The results of the energy and γ-ray intensity measurements are given in Table I. The energy values and the uncertainties given for 57-, 232-, 293-, and 351-keV transitions were obtained with the curved-crystal spectrometers. The remaining energy values and their uncertainties were obtained with the Ge(Li) spectrometers. The energy calibration for the Ge(Li) spectrometers was obtained using a least-squares fit to the energies and uncertainties of the four transitions, which were measured with the curved-crystal spectrometers along with the persistent background line from ^{40}K ($E_\gamma = 1460.75 \pm 0.06$ keV).[19]

The γ-ray intensities given in column 2 were deduced from data obtained with the Ge(Li) spectrometers and represent the number of events per 100 decays. The relative γ-ray intensities were normalized to electron intensities using the experimentally determined α_K and K/L values when

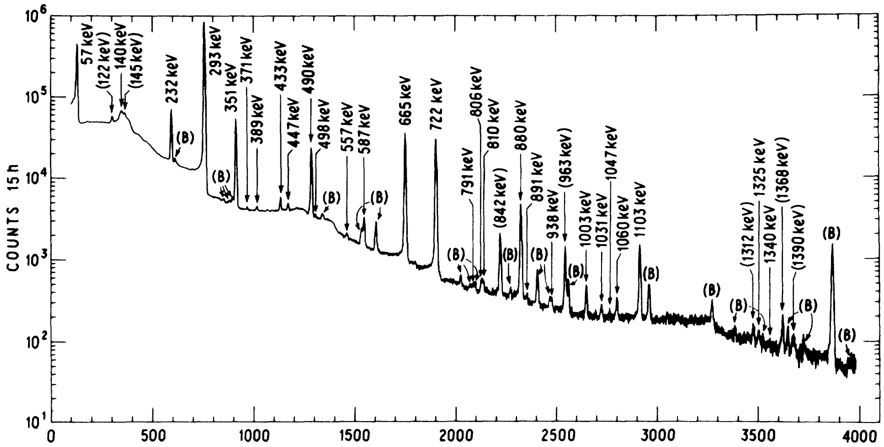

FIG. 1. A singles spectrum taken with the 32-cm^3 Ge(Li) detector. Lines indicated in parentheses are due to impurities. Lines designated with the symbol (B) are due to background radiation.

TABLE I. Energies and intensities of γ rays occuring in the decay of ^{143}Ce to levels in ^{143}Pr.

γ-ray energy (keV)	γ-ray intensity (% per decay)
57.365 ± 0.001 [a]	11.6 ± 1.2
139.67 ± 0.20	0.097 ± 0.030
231.559 ± 0.033 [a]	1.98 ± 0.21
293.262 ± 0.021 [a]	41.3
350.587 ± 0.050 [a]	3.30 ± 0.33
371.13 ± 0.35	0.021 ± 0.006
389.49 ± 0.18	0.029 ± 0.008
433.02 ± 0.07	0.13 ± 0.03
447.21 ± 0.14	0.066 ± 0.012
490.36 ± 0.07	1.94 ± 0.21
497.91 ± 0.19	0.033 ± 0.008
556.86 ± 0.21	0.025 ± 0.008
587.28 ± 0.15	0.24 ± 0.04
664.55 ± 0.10	5.16 ± 0.54
721.96 ± 0.11	5.04 ± 0.50
791.09 ± 0.33	0.017 ± 0.004
806.46 ± 0.23	0.025 ± 0.008
809.93 ± 0.23	0.025 ± 0.008
880.39 ± 0.13	0.91 ± 0.08
891.10 ± 0.40	0.012 ± 0.004
937.81 ± 0.31	0.031 ± 0.006
1002.97 ± 0.21	0.066 ± 0.012
1031.47 ± 0.32	0.017 ± 0.004
1047.04 ± 0.30	0.009 ± 0.002
1060.52 ± 0.30	0.034 ± 0.007
1102.98 ± 0.18	0.36 ± 0.05
1324.63 ± 0.36	0.012 ± 0.004
1339.92 ± 0.80	0.0037 ± 0.0012

[a] Curved-crystal spectrometer measurement.

available[20] or the theoretical values[21] and the prescription $\alpha_T = \alpha_K + 1.33\alpha_L$. The normalization was accomplished by assuming no β feeding to the ground state[20] and that the sum of the total transition intensity to the ground state was 100. The result of this normalization is a calculated total β feeding of 100.3% and a value for the γ-ray intensity of the 293-keV transition of 41.3% in agreement with the result of the β-γ coincidence measurement of Macklin, Lazar, and Lyon[22] of 42.6%.

In general the γ-ray energy and relative intensity values obtained in the present study were found to be in good agreement with the results of previous investigations. However, the value for the intensity of the weak 498-keV transition obtained in the present study was found to be a factor of 2 smaller than that reported by Gregory *et al.*,[14] but is in agreement with the value reported by Arutyunyan *et al.*[11]

A previously unreported transition was observed in this study with an energy 891.10 ± 0.40 keV. No evidence was found for the weak 709-keV transition which was reported by Gregory *et al.*[14] However, the upper limit which we place on the intensity of this transition is comparable with the γ-ray intensity which was reported by Gregory *et al.*[14]

The decay scheme for ^{143}Ce deduced from the present study is shown in Fig. 2. This scheme incorporates all but two of the transitions which were observed in this study. It is essentially the same one proposed by Gregory *et al.*[14] with the deletion of a level at 1157 keV and the addition of the 891-keV transition. Transitions which are

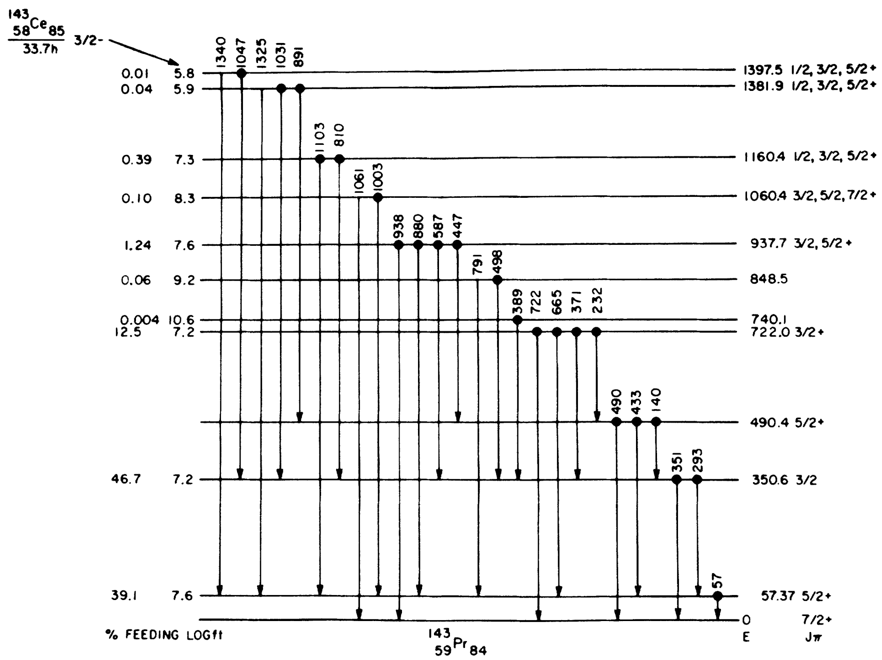

FIG. 2. The decay scheme of ^{143}Ce deduced from the present study. Spins and parities are from Ref. 14.

designated by a filled circle in the level scheme are placed on the basis of energy fits and coincidence results. The remaining transitions are placed only on the basis of energy fit. The spins and parities for the levels are taken from the work of Gregory *et al.*[14] The β feedings were deduced from total transition intensities and $\log ft$ values extracted from these β feedings by the use of the nomogram of Verrall, Hardy, and Bell.[23]

Gregory *et al.*[14] proposed the existence of a level at 1157 keV based upon the evidence of an 806–293-keV coincidence and intensity balance considerations. Although an 806–293-keV coincidence was observed in the present investigation, the 806-keV transition has not been placed in the decay scheme, because of the fact that the observation of such a coincidence does not establish that the 806-keV transition feeds the 351-keV level. The 557-keV transition, which had not been placed in the decay scheme by previous investigators, was observed in the present study to be in coincidence with the 490-keV transition. There are not enough additional data, however, to allow the 557-keV transition to be placed in the decay scheme.

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†This work was supported in part by the U. S. Atomic Energy Commission.

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PHYSICAL REVIEW C VOLUME 4, NUMBER 2 AUGUST 1971

Quadrupole Effect of Polarized Nuclei on Elastic Scattering of Charged Particles*

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The partial-wave calculation of the quadrupole effect of polarized target nuclei on the elastic scattering of charged particles at low incident energies is carried out. It is shown that the second-order quadrupole effect can easily dominate the first-order effect. The case in which muons are projectiles is exceptional.

The effect of the static quadrupole moment of polarized target nuclei on the elastic scattering of charged particles at low energies has been studied recently by various authors.[1-4] Although many competing processes may obscure the situation, we consider in the following only the static quadrupole interaction in order to estimate to what extent this effect may be significant. The motion of the system can be described by the Schrödinger equation

$$(H_0+H')\psi=E\psi\,, \tag{1}$$

where

$$H_0=-\frac{\hbar^2}{2m}\nabla_r^2+\frac{Z_1Z_2e^2}{r} \tag{2}$$

and

$$H'=\tfrac{1}{2}Z_1Q_0e^2f(r)P_2(\cos\angle(\alpha N))\,. \tag{3}$$

(Here and in the following the notation is the same as in Ref. 1.) Assuming that $H_0 \gg H'$, we employ the perturbation approximation. From Eq. (1) we obtain [Eq. (7) of Ref. 1]

$$\psi=\psi_C+\tfrac{4}{5}\pi\frac{mZ_1Q_0e^2}{\hbar^2}\int K(\vec{r},\vec{r}\,')\frac{1}{r'^3}\sum_{q=-2}^{2}(-1)^q \times Y_{2q}(\theta_N,\phi_N)Y_{2-q}(\theta_\alpha,\phi_\alpha)\psi_C(\vec{k}_1,\vec{r}\,')d\vec{r}\,'\,, \tag{4}$$

where $K(\vec{r},\vec{r}\,')$, the kernel of the integral equation, is given in Ref. 1. Now, the scattering amplitude $f(\theta)$ may be written as

$$f(\theta)=f_C(\theta)+f_q(\theta)\,, \tag{5}$$

where $f_C(\theta)$ is the Coulomb scattering amplitude and $f_q(\theta)$ is the quadrupole interaction amplitude.

We are mainly interested in the determination of the deviation δ of the scattering cross section from the Coulomb cross section, i.e.,

$$\delta=\frac{\sigma(\theta)-\sigma_C(\theta)}{\sigma_C(\theta)}=\frac{|f(\theta)|^2-|f_C(\theta)|^2}{|f_C(\theta)|^2}=\delta_1+\delta_2\,, \tag{6}$$

where

$$\delta_1=\frac{2\,\mathrm{Re}[f_C^*(\theta)f_q(\theta)]}{|f_C(\theta)|^2}\,,\qquad \delta_2=\frac{|f_q(\theta)|^2}{|f_C(\theta)|^2}\,. \tag{7}$$

In the previous work[1,2] we assumed that the quadrupole interaction was much weaker than the Coulomb interaction, and accordingly the second-order effect δ_2 was neglected in the calculation of δ. However, this assumption is not generally valid. An incorrect phase factor was also used for the amplitude $f_q(\theta)$. The phase factor should have been $i^{(l+l')}$ instead of $i^{(l-l')}$, as was used in Eq. (14) of Ref. 1.[5] We have, in this note, explicitly calculated the second-, as well as first-order effects, assuming that the target nucleus is completely polarized along the direction of relative motion before the collision. For the case of a head-on collision ($\theta=\pi$), the expressions for δ_1 and δ_2 are greatly simplified and we obtain

$$\delta_1=-\frac{2m}{\hbar^2}\,\frac{Q_0Z_1e^2k}{\eta}S(\eta)\,, \tag{8}$$

where

$$S=S_{l-2,l}+S_{l,l}+S_{l,l+2}\,,$$