CHARGE AND ENERGY DISTRIBUTIONS OF RECOILS FROM Th^{226} ALPHA DECAY*

K. Gunter, F. Asaro, and A. C. Helmholz

Lawrence Radiation Laboratory, University of California, Berkeley, California

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The charge and energy distributions of recoils from Th^{226} alpha decay were investigated with a high-resolution alpha-particle spectrograph. Th^{226} was chosen for investigation because its decay chain contains three relatively short-lived alpha emitters which make conclusive identification of the recoils possible, because it can be prepared into an extremely thin source by electrostatic recoil collection, and because it has an appropriate complex alpha spectra.[1]

The U^{230} was milked out of a previously chemically purified Pa^{230} source which had been prepared by bombarding Th^{232} with 50-MeV deuterons. After purification, the U^{230} was vaporized in vacuo onto a platinum plate. The resulting source was invisible. The 31-min Th^{226} daughter was electrostatically collected on a platinum plate from the thin U^{230} source under a uniformly applied negative potential of 225 V/cm in an air atmosphere.

Such Th^{226} samples were used as sources in a 180° double-focusing alpha-particle spectrograph[2] with photographic emulsions for detection. The alpha particles appear in the emulsion as nearly parallel tracks of approximately the same length. The recoils appear in the emulsion as two or three alpha tracks of varying length and direction coming from a common vertex on the surface of the emulsion (2- and 3-pronged events). These 2- and 3-pronged events represent only a portion of the total number of recoils striking the plate.

As would be expected for a thin source, the +2 recoils were found to strike the emulsion quite close to the position of the Th^{226} ground-state alpha group (α_0) as shown in Fig. 1. Charges +3 through +20 were each investigated separately by altering the magnetic field so that the recoils of a given charge followed approximately the same path in the spectrograph as had the alpha particles and +2 recoils. Charges +1 through −2 were obtained with the emulsions much closer to the source than they were for the other charges, which resulted in adequate charge separation but essentially no energy resolution.

Typical results for recoils of various charges are shown in Fig. 1. Recoil peaks are identified by the notation Th^{226} R_E^{+n} where n indicates the charge of the recoils and E indicates the energy in keV of the excited state of the recoil nucleus populated by the alpha decay of Th^{226}.

The R_0^{+2} peak, shown in Fig. 1(a), is separated from the α_0 peak by 0.17 keV and was found to be much broader than the other R_0 peaks. The former effect could be the result of the recoils losing energy by collision in leaving the platinum backing plate. Such collisions

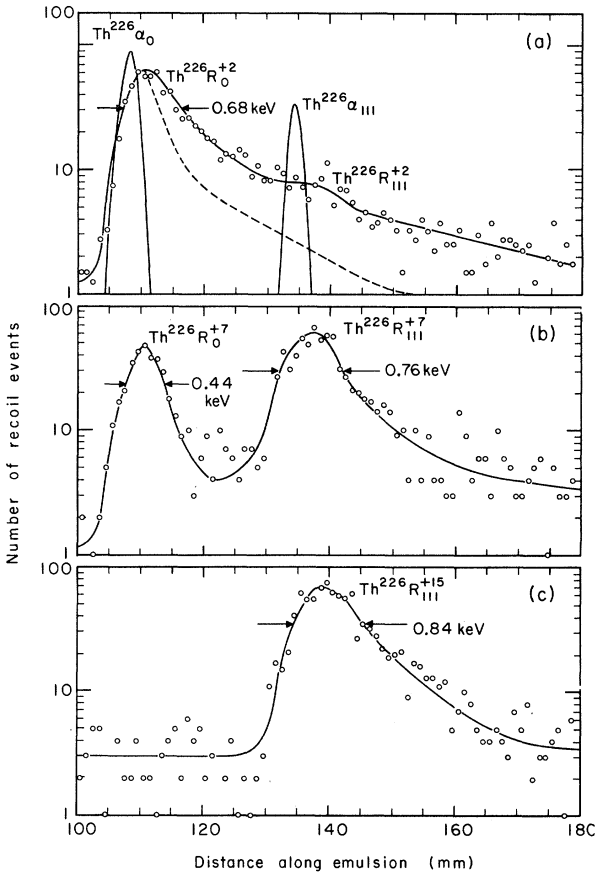

FIG. 1. Experimental alpha and recoil spectra. (a) Partial Th^{226} α spectrum (shown on an arbitrary scale) and Th^{226} R^{+2} spectrum. The dashed line is the relative shape of all the R_0^{+n} peaks with a charge greater than +2. (b) Th^{226} R^{+7} spectrum. (c) Th^{226} R^{+15} spectrum.

could also involve a change in charge, and, in the present case, a charge of +2 would be favored because it has a closed electronic configuration. The net effect would then be a selective broadening of the R^{+2} peaks. It was found that all the $R_0{}^{+n}$ peaks except $R_0{}^{+2}$ had approximately the same shape and half-width. This peak shape is indicated by the dashed line in Fig. 1 and represents 64% of the total $R_0{}^{+2}$ peak.

The $R_{111}{}^{+n}$ peaks are composed of recoils of Th^{226} which are associated with the α group (α_{111}) which populates the 111-keV excited state (21.9%). These recoils can thus decay either by the emission of γ rays or conversion electrons. Those R_{111} recoils which decay by γ emission ($R_{111}\gamma$) should have the same charge distribution as the R_0 recoils, but they should have a slightly increased half-width due to the recoil energy associated with the γ rays. Those R_{111} recoils which decay by electron conversion ($R_{111}e$) should have a charge distribution that differs from that of the R_0 recoils because of the emission of Auger electrons associated with the conversion electrons. The half-width of the $R_{111}e$ recoil peaks should be considerably larger than that of the R_0 recoil peaks because of the recoil energy associated with the L and higher order conversion electrons. As seen in Fig. 1, the half-width of R_{111} is indeed appreciably larger than R_0. Also the spacing between the $R_0{}^{+n}$ and $R_{111}{}^{+n}$ peaks was equal to the spacing between the α_0 and α_{111} groups for all clearly resolved recoil peaks. This indicates that the increase in half-width of R_{111} must be roughly symmetrical, as would be expected from the foregoing explanation.

If one assumes that the recoils do not drift in the emulsion after their initial energy has been absorbed then one should be able to calculate the counting efficiency of the recoils in the photographic emulsion, i.e., the intensity of the 2- and 3-prong events. The absolute intensity of 3-prong events, however, was a factor of 2.5 greater than the calculated value, possibly indicating unusual behavior of the recoils in the emulsions. The recoil counting efficiency was determined by setting the total intensity of the $R_{111}{}^{+n}e$ groups equal to the known intensity of that portion of α_{111} which is followed by conversion electrons. The normalization factor so obtained was used for all the experimental recoil intensities. This procedure is valid for charges +2 through +20 because these recoils struck the photographic emulsion at essentially the same angle. However, the intensities of charges +1, 0, −1, and −2 were obtained with the photographic emulsion in a different arrangement, and hence, their

Table I. Normalized experimental results.

n	$R_0{}^{+n}/\alpha_0$ (%)	$(R_0{}^{+n}+R_{111}{}^{+n})/\alpha_0$ (%)	$R_{111}{}^{+n}/\alpha_{111}$ (%)
−2		<0.03	
−1		<0.03	
0		~20	
+1		~50	
+2		26.7 ± 1.1	
+3	7.06 ± 0.50		1.21 ± 0.86
+4	4.74 ± 0.26		1.06 ± 0.52
+5	4.55 ± 0.39		2.04 ± 0.62
+6	2.08 ± 0.11		1.91 ± 0.24
+7	0.651 ± 0.065		3.52 ± 0.30
+8	0.167 ± 0.024		6.67 ± 0.40
+9			8.07 ± 0.52
+10			10.03 ± 0.62
+11			9.64 ± 0.65
+12			9.38 ± 0.67
+13			9.26 ± 0.67
+14			5.25 ± 0.40
+15			5.10 ± 0.32
+16			3.38 ± 0.27
+17			2.67 ± 0.27
+18			1.57 ± 0.22
+19			0.80 ± 0.19
+20			0.44 ± 0.11

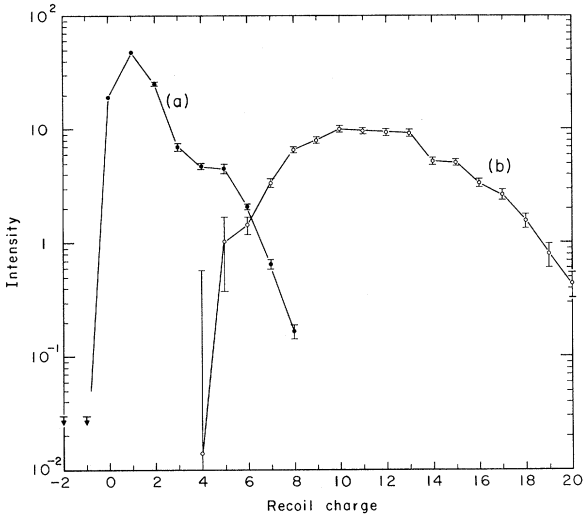

FIG. 2. Charge distributions of recoils following Th^{226} alpha decay; (a) charge distribution of R_0 recoils; (b) charge distribution of $R_{111}e$ recoils (R_{111} recoils which decay by conversion electrons).

corrected intensities can only be regarded as approximate.

The experimental intensities normalized in the above manner are presented in Table I. The errors in the table reflect 90% confidence limits, assuming no systematic errors are present.

For charge +3 the intensity of R_{111} is just the value one would expect from only $R_{111}{}^{+3}\gamma$, i.e., essentially all recoils followed by conversion electrons have higher charges. We assumed then that the 0, +1, and +2 recoils were composed of only R_0 and $R_{111}\gamma$, which was deduced from the known 111 keV γ ray intensity (4.8%). The resulting charge distributions of the R_0 recoils and the $R_{111}e$ recoils are plotted in Fig. 2.

Szucs and Delfosse[3] studied Po^{216} recoils from Rn^{220} alpha decay and found the maximum in the charge distribution occurring at zero, in contrast to our results with Th^{226} R_0 where the maximum intensity occurs at a charge of +1. The charge distribution of the Th^{226} $R_{111}e$ recoils is roughly similar to that found by Snell and Pleasonton[4] for Xe^{131}.

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NUCLEAR GIANT QUADRUPOLE RESONANCE

R. Ligensa and W. Greiner

Institut für Theoretische Physik, Universität Frankfurt, Frankfurt am Main, Germany

and

M. Danos

National Bureau of Standards, Washington, D. C.

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We have extended the description of the giant quadrupole resonance of the deformed nuclei[1,2] to include the coupling between the different collective modes in a quantum mechanical treatment, i.e., we have developed the quantum hydrodynamics of the nucleus including all modes, viz. the rotations, the surface vibrations, and the giant resonance oscillations, up to quadrupole multipolarity. The interactions with the odd particle are also taken into account. The total Hamiltonian can be written

$$H = E_R[I^2 - I_3{}^2 - j_3{}^2 - d_3{}^2 - q_3{}^2] + (\hbar^2/16B\eta^2)[(I_3 - j_3)^2 + q_3{}^2 + d_3{}^2 - 1] + (\hbar^2/8B\eta^2)(I_3 - j_3)(d_3 + q_3)$$

$$-(\hbar^2/2B)(\partial^2/\partial\xi^2 + \tfrac{1}{2}\partial^2/\partial\eta^2) + \tfrac{1}{2}C_0\xi^2 + C_2\eta^2 + H_{\text{part}} + \sum_{\mu=-1}^{+1} \hbar\omega_\mu{}^{(1)}[1 + G_\mu{}^{(1)}(\xi + 6^{1/2}\mu\eta)]b_\mu{}^{(1)+}b_\mu{}^{(1)}$$

$$+ \sum_{\nu=-2}^{+2} \hbar\omega_\nu{}^{(2)}\{1 + G_\nu{}^{(2)}[\xi - \nu(4-\nu^2)(\tfrac{2}{3})^{1/2}\eta]\}b_\nu{}^{(2)+}b_\nu{}^{(2)}. \qquad (1)$$

For H_{part} the Nilsson-Hamiltonian has been used. I, j, d, and q are the angular momentum operators of the nucleus, the odd particle, the giant dipole resonance phonons, and the giant quadrupole resonance phonons, respectively. ξ and η describe the β and γ vibrations of the surface. $b^{(1)}$ and $b^{(2)}$ are the annihilation operators for the dipole and quadrupole oscillation phonons, respectively. The diverse energies and the coupling constants $G_\nu{}^{(L)}$ are given by

$$\hbar\omega_\mu{}^{(1)} = \hbar\omega_1[1 + 0.08(-2)^{-|\mu|}\beta][1 + (-2)^{-|\mu|}\beta]^{-1},$$