Alpha-Decay Properties of Some Erbium Isotopes near the 82-Neutron Closed Shell*

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New alpha-emitting isotopes of erbium, lying near the 82-neutron closed shell, were produced by $Nd^{142}+O^{16}$ bombardments at incident energies up to 151 MeV. The nuclides studied and their alpha-decay properties are

Nuclide	Q_α(MeV)	Half-life	Alpha branching ratio
Er^{152}	4.93±0.02	10.7±0.5 sec	$0.90^{+0.05}_{-0.20}$
Er^{153}	4.80±0.02	36 ±2 sec	$0.95^{+0.05}_{-0.20}$
Er^{154}	4.26±0.02	4.5±1.0 min	···

Alpha decay from erbium isotopes with $A<152$ was not observed, indicating that the alpha-particle binding energies of these isotopes are considerably higher than those for the 84-, 85-, and 86-neutron isotopes. Alpha reduced widths, calculated from the results for Er^{152} and Er^{153}, were found to be higher than the corresponding dysprosium, holmium, and terbium isotopes. Relative excitation functions were obtained for some $Nd^{142}(O^{16},xn)$ and $Nd^{142}(O^{16},pxn)$ reactions.

I. INTRODUCTION

ALPHA radioactivity has been observed for a number of nuclides which lie near the 82-neutron closed shell in the rare-earth region. It has been found previously that for a given element the alpha-decay energy has a minimum value at $N=82$, increases very sharply with neutron number to a maximum value at $N=84$ and gradually decreases with increasing neutron number beyond $N=84$. The alpha decay properties of the 84-neutron isotopes of the elements from $Z=60$ to $Z=67$ have been reported and for some elements alpha activities from isotopes with $N=85$ to $N=88$ have been observed.[1–8]

The purpose of this paper is to report on results which were obtained for the 84-, 85-, and 86-neutron isotopes of erbium ($Z=68$). A preliminary report of these results has been given earlier.[9] Because of their proximity to the 82-neutron shell, there is strong evidence that these isotopes, as well as most of the other known alpha emitters in the rare-earth region, possess a stable spherical or near-spherical ground-state shape. It is hoped that a careful study of the alpha-decay properties of nuclides in this region will yield useful information on detailed features of alpha decay in the absence of the effects of spheroidal deformation.

II. EXPERIMENTAL DETAILS

The nuclides Er^{152}, Er^{153}, and Er^{154} were produced by $Nd^{142}(O^{16},xn)$ reactions using 75- to 151-MeV O^{16} ions from the Berkeley heavy-ion accelerator (Hilac). Samples for alpha-particle analysis were prepared using two different techniques.

In one method, which was used for the longer-lived activities, reaction recoils ejected from the target were thermalized by helium and collected on a charged plate. The plate was then placed in a Frisch-grid ionization chamber for alpha-particle analysis. The target assembly employed in these experiments was also used in a modified form to electrostatically collect recoils from the alpha decay of the erbium isotopes in order to establish parent-daughter relationships. The following is a general description of the procedure which was used. The Nd^{142} target was bombarded with O^{16} ions and recoils ejected from the target were collected on a charged plate as before. After bombardment, the helium was quickly pumped out of the target assembly and replaced by a new supply at 1-atm pressure. This was found to be necessary because it was observed that some recoils from the target were retained in the helium present during the bombardment for as long as a few minutes after bombardment. The electrode containing the target recoils was then relocated to a position in front of a second electrode in the target assembly which had been shielded during the bombardment so that no target recoils would be collected on it. A negative voltage was then applied to this electrode and recoils were collected from the alpha decay of the activity produced in the bombardment. In vacuum, it was found that beta-decay recoils could be electrostatically col-

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lected from the sample but alpha-decay recoils could not because of their longer range. At a pressure of 1 atm of helium, alpha-decay recoils were collected with good efficiency but it was no longer possible to collect beta-decay recoils. Particular attention was given to insuring that no deposition of target recoils on the electrode used to collect alpha-decay recoils took place since this would invalidate the results of the "recoil-milking" experiments. It was found that if the precautions mentioned above were taken, less than 10^{-6} of the level of activity collected during the bombardment appeared on the electrode used to collect the alpha-decay recoils. Specific details of the target assembly and arrangement of the collecting electrodes are described in earlier papers.[6,8]

Because of the short half-life of Er^{152}, a faster method for collecting and analyzing the activity was also used. This method has been useful for studying alpha activities whose half-lives are greater than 0.03 sec. Details of this procedure are reported elsewhere[10] and only the general features will be given here. Reaction recoils ejected from the target were slowed down in helium at 1-atm pressure in the target assembly. They were then swept through a small orifice into a chamber under vacuum adjacent to the target assembly where they were deposited on the surface of a collector. Alpha-particle spectra of the recoil samples were recorded at the same time the activity was collected using a gold-surface barrier detector. For the short-lived activities ($t_{1/2} \leq 2$ min), the level of activity was allowed to build up to an equilibrium value before recording alpha-particle spectra. This was convenient for the cross-section measurements since no corrections for decay were required.

Targets consisted of rare-earth oxides (~ 2 mg/cm^2) deposited on a 0.006-mm thick aluminum backing. The neodymium-oxide target that was used was enriched in Nd^{142} to 93.93%. The other neodymium isotopes were present in the following amounts: Nd^{143}, 2.46%; Nd^{144}, 2.59%; Nd^{145}, 0.29%; and Nd^{146}, 0.72%. Aluminum absorbers of varying thicknesses were used to degrade the energy of the heavy ion beam. The data of Northcliffe were used to convert range in aluminum to energy.[11] For O^{16} ions within the range of 75 to 160 MeV, the energy loss in the rare-earth-oxide target was estimated to be 5 MeV. This was obtained by extrapolating the range-energy curves for various elements given by Hubbard to the rare-earth elements and oxygen.[12]

Relative excitation functions were obtained from the intensities of the various groups in the alpha-particle spectra after normalizing to a constant integrated beam current. The counting data were also corrected for recoil collection efficiency which was found to be dependent upon bombarding energy for the electrostatic collection method but not for the gas-sweeping technique.

The gold-surface barrier alpha-particle detector that was used in the gas-sweeping experiments was made from n-type 1800 Ω-cm silicon and operated at a reverse bias of 20 V. The active surface area was 9 mm^2. Energy calibration was obtained from the alpha particles of Po^{210} (5.30 MeV),[13] Ho^{151} (4.51 MeV),[8] Dy^{150} (4.23 MeV),[14] and Tb^{149} (3.95 MeV).[1]

III. RESULTS

Alpha-particle spectra were obtained on samples collected from $Nd^{142}+O^{16}$ bombardments at incident energies ranging from 75 to 151 MeV. In addition to the known alpha emitters of dysprosium and holmium, three new alpha groups were observed—two intense groups at 4.80 and 4.68 MeV alpha-particle energy and a weak group at 4.15 MeV. None of these alpha groups was observed in $Pr^{141}+O^{16}$ bombardments which produce isotopes of the rare earth elements up to holmium.[8] Excitation functions were obtained for these activities. In each case, the variation of yield with incident bombarding energy was found to correspond very closely with results previously obtained for heavy-ion-induced compound-nucleus reactions where only neutrons are evaporated.[8,15] From these measurements it was concluded that the three new alpha groups are due to isotopes of erbium. Additional results were obtained which confirmed that these are erbium alpha emitters and information on mass assignments was also obtained. These results are discussed below.

Er^{152}

Figure 1 shows alpha-particle spectra of activity collected during $Nd^{142}+O^{16}$ bombardments at various incident O^{16} energies using the gas-sweeping technique for collecting the recoils from the target. A strong group was observed at 4.80-MeV alpha-particle energy which decays with a half-life of 10.7 ± 0.5 sec (Fig. 2). The peak of the excitation function for this activity [Fig. 3(a)] falls at an excitation energy of 85 MeV which is very close to the value of 84 MeV previously observed for the $Pr^{141}(O^{16},6n)Ho^{151}$ reaction leading to the high-spin isomer.[8] This suggests that the 10.7 sec activity is produced by the same type reaction which would yield Er^{152} as the product.

In our previous work on the holmium alpha emitters, mass assignments were made by identifying beta or alpha-decay daughters which were collected electrostatically as recoils from a thin sample of the parent.[8] However, because of the short half-life of the 4.80 MeV erbium alpha activity, it was not possible to use this technique. Also, the alpha decay daughter of Er^{152} is Dy^{148} which, on the basis of alpha-decay energy system-

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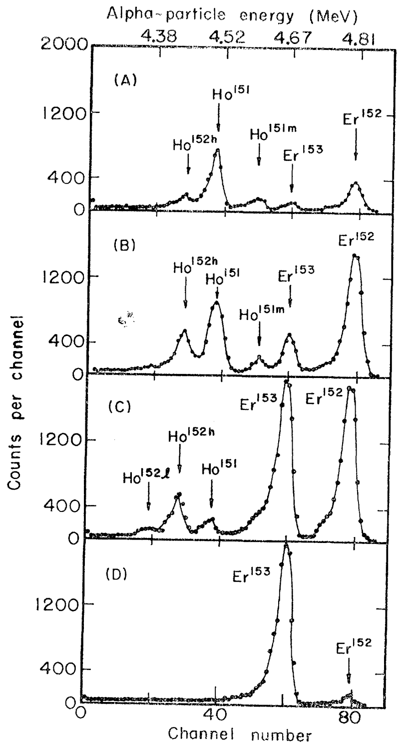

FIG. 1. Alpha-particle spectra of holmium and erbium isotopes produced by $Nd^{142}+O^{16}$ at (a) 151-MeV incident O^{16} energy, (b) 136 MeV, (c) 119 MeV, and (d) 103 MeV. These spectra were recorded under conditions of continuous bombardment, collection, and counting and correspond essentially to the equilibrium level of activity.

atics, is not expected to exhibit a measurable alpha-decay branch.

Efforts were made to establish a parent-daughter relationship through a possible Er^{152} beta-decay branch. The beta-decay daughter, Ho^{152}, has previously been studied and it has been shown that it exists as an isomer pair.[8] Alpha decay from both the ground and isomeric states has been observed. The high-spin Ho^{152} isomer ($E_\alpha=4.45$ MeV) was detected as a product in the $Nd^{142}+O^{16}$ bombardments as shown in Fig. 1 but measurements of the decay rate of the 4.45-MeV Ho^{152} group in the presence of the 10.7-sec erbium activity showed that most if not all of this activity is produced directly by an $(O^{16},p5n)$ reaction. The low-spin isomer of Ho^{152} was also detected (Fig. 1) and an excitation function for this activity was obtained. These results were reported in an earlier paper.[8] The yield curve was found to peak at an excitation energy of approximately 82 MeV and it fairly closely parallels the shape of the excitation function of the 10.7-sec erbium activity. This suggests that the low-spin Ho^{152} isomer is formed for the most part by the beta-decay branch of the 10.7-sec erbium activity which must, therefore, be due to Er^{152}. The direct formation of the low-spin Ho^{152} isomer by an $(O^{16},p5n)$ reaction is expected to have a very low cross section with a maximum value at an excitation energy of approximately 70 MeV. This is 15 MeV lower than the peak cross section for the high-spin Ho^{152} isomer. These predictions are based on previous results obtained for the production of isomer pairs by heavy-ion–compound-nucleus reactions in this region.[6,8]

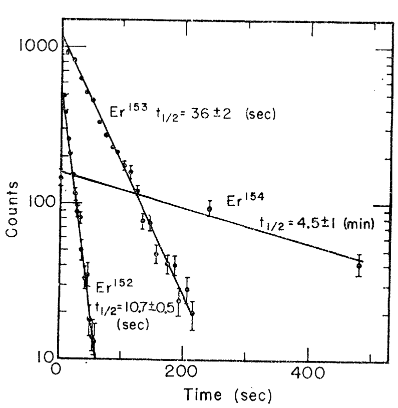

FIG. 2. Alpha-decay curves for Er^{152}, Er^{153}, and Er^{154}.

Since Er^{152} is an even-even nuclide with ground-state spin and parity of 0^+, it is reasonable to expect that the beta-decay branch would preferably populate the low-spin isomeric state of Ho^{152}. If it is assumed that the beta-decay branch of Er^{152} populates only the low-spin Ho^{152} isomer and the peak cross section for the low-spin Ho^{152} is due solely to the beta decay of Er^{152}, it is possible to calculate the alpha-branching ratio of Er^{152} from the relative intensities of the Er^{152} and Ho^{152} (low-spin) alpha groups. A value of $0.90^{+0.05}_{-0.20}$ was obtained.

Er^{153}

The second prominent erbium alpha activity that was observed has an alpha-particle energy of 4.67 MeV (Fig. 1) and a half-life of 36 ± 2 sec (Fig. 2). A yield curve for this activity was obtained which was found to peak at an excitation energy of 71 MeV [Fig. 3(a)]. This compares favorably with a value of 72 MeV previously observed for the $Pr^{141}(O^{16},5n)Ho^{152}$ reaction leading to the high-spin isomer.[8] From these results, it was concluded that the probable mass assignment for the 36 sec erbium alpha activity is Er^{153}.

The alpha decay daughter of Er^{153}, Dy^{149}, is not conveniently detectable because it does not possess an alpha-decay branch. However, the beta decay daughter of Dy^{149}, Tb^{149}, has an alpha branch which has been well characterized.[1] In order to determine whether the 36 sec erbium activity is due to Er^{153}, alpha-decay recoils were electrostatically collected from a thin sample of this activity and analyzed for the presence of Tb^{149}. The samples were prepared by electrostatic collection of recoils from the Nd^{142} target at two incident O^{16} bombarding energies. At 103 MeV, the level of the 36-sec erbium activity is almost a maximum value and the 10.7 sec Er^{152} is barely detectable. Alpha decay recoils collected from samples at this bombarding energy clearly showed the presence of Tb^{149} alpha activity [Fig. 4(a)] which was identified by alpha-particle energy (3.95 MeV) and half-life (4.1 h).[1,2] When samples were collected at a bombarding energy of 84 MeV where the level of the 36-sec erbium activity is reduced by a factor of 60, no Tb^{149} was detected in the alpha spectrum of the recoils from alpha decay. At the 103-MeV bombarding energy, only the 36-sec erbium alpha group has sufficient intensity to have produced the level of Tb^{149} alpha activity that was observed [Fig. 1(d)]. The 36-sec activity must, therefore, be due to Er^{153}. Ho^{153} which is produced in $Nd^{142}+O^{16}$ bombardments can also form Tb^{149} as a product of alpha decay but the intensity of this alpha group is so small that only an immeasurably small amount of Tb^{149} can be formed from the alpha decay of this nuclide.

In order to obtain an estimate of the alpha-branching ratio of Er^{153}, assumptions were made with regard to the expected peak cross section for the $Nd^{142}(O^{16},5n)$ reaction relative to the $Nd^{142}(O^{16},6n)$ reaction. It was previously observed that the ratio of the $(O^{16},5n)$ to $(O^{16},6n)$ peak cross sections for the $Ce^{140}+O^{16}$ reaction is 1.22.[8] If the same value is used for the corresponding products of the $Nd^{142}+O^{16}$ reaction, it is possible to calculate the alpha branching ratio of Er^{153}. A value of $0.95^{+0.05}_{-0.20}$ was obtained.

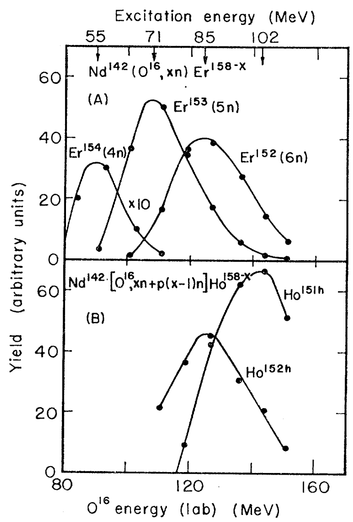

FIG. 3. $Nd^{142}+O^{16}$ excitation functions for the production of (a) Er^{152}, Er^{153}, and Er^{154} and (b) the high-spin isomers of Ho^{151} and Ho^{152}. The yields are corrected for alpha-branching ratios with the exception of Er^{154}. The cross sections are in arbitrary units but the relative values are as shown in the figure. The yield scales for (a) and (b) are the same.

Er^{154}

When the Nd^{142} target was bombarded with O^{16} ions at incident energies between 80 and 110 MeV, a weak alpha group was observed at 4.15-MeV alpha-particle energy which decays with a half life of 4.5 ± 1.0 min. Figure 5 shows alpha-particle spectra of target recoils collected by the electrostatic method at incident energies of 103 and 92 MeV, where the 4.15-MeV group is clearly indicated. A yield curve was obtained for this alpha group which was found to peak at an excitation energy of 55 MeV (Fig. 3). Previous results with the $Ce^{140}+O^{16}$ and $Pr^{141}+O^{16}$ reactions showed that the $(O^{16},4n)$ excitation function in this region peaks in the vicinity of 50- to 55-MeV excitation energy[8] so that on the basis of its excitation function the 4.15-MeV erbium alpha activity is most likely due to Er^{154}.

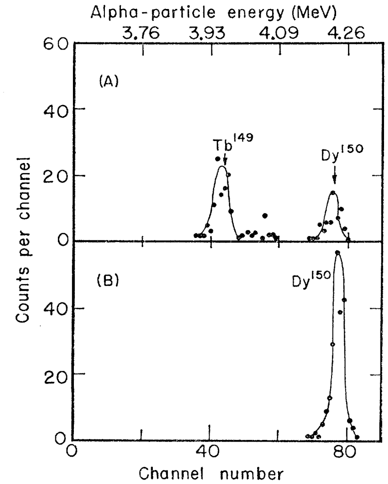

FIG. 4. Alpha-particle spectra of alpha recoils collected from samples containing Er^{153} and Er^{154} produced from $Nd^{142}+O^{16}$. For spectrum (a) the bombarding energy was 103 MeV and for spectrum (b) 84 MeV.

Proof that this activity is due to Er^{154} was obtained from the experiments where alpha decay recoils were collected from samples containing the erbium alpha emitters. Figure 4(a) shows the alpha-particle spectrum of recoils collected from the alpha activity of samples produced by $Nd^{142}+O^{16}$ bombardments at an incident energy of 103 MeV and Fig. 4(b) at an energy of 84 MeV. In both spectra an alpha group with the characteristic decay properties of Dy^{150} ($E_\alpha=4.23$ MeV, $t_{1/2}=7.4$ min)[2,14] was observed. The 4.15-MeV alpha group is the only alpha activity produced at both of these energies with sufficient intensity to have yielded the amount of Dy^{150} activity observed. This activity must, therefore, be associated with Er^{154}. The sample

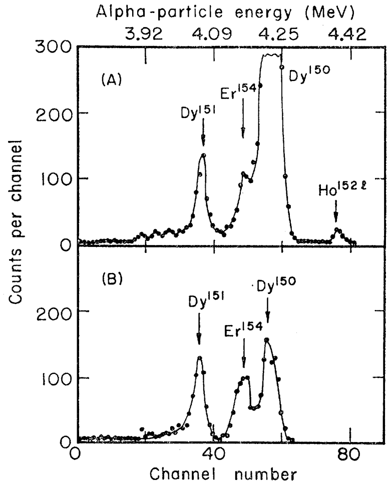

FIG. 5. Alpha-particle spectra of nuclides produced by $Nd^{142}+O^{16}$ at (a) 103-MeV O^{16} energy and (b) 92-MeV O^{16} energy. Samples were prepared by electrostatic collection of target recoils. Bombardment time was 2 min and samples were counted for a 2-min period 5 min after bombardment.

corresponding to the higher bombarding energy also showed the presence of Tb^{149} which, as discussed above, is a grand-daughter of Er^{153} alpha decay. The specific activity of Dy^{150} is approximately a factor of 60 higher than Tb^{149}. This is the reason why the intensity of the Dy^{150} alpha group is greater than the Tb^{149} group even though the alpha-decay rate of Er^{153} is much higher than for Er^{154}. The level of the Dy^{150} activity observed as alpha decay recoils is higher at the 84-MeV bombarding energy than at 103 MeV. This is consistent with the excitation function data and assignment of Er^{154} for the 4.15-MeV alpha group.

It was not possible to obtain a meaningful estimate of the alpha branching ratio of Er^{154} by comparing excitation function data from $Ce^{140}+O^{16}$ and $Pr^{141}+O^{16}$ reactions with that obtained for the $Nd^{142}+O^{16}$ reaction. The reason for this is that at the incident O^{16} energy where the $(O^{16},4n)$ excitation function peaks, the compound nucleus formation cross section is very sensitively dependent upon bombarding energy. A slight shift of the $(O^{16},4n)$ excitation function to higher energies for the $Nd^{142}+O^{16}$ reaction due to increased neutron binding energies will greatly affect the magnitude of the peak cross section of the $(O^{16},4n)$ reaction when compared with the $(O^{16},5n)$ and $(O^{16},6n)$ excitation functions.

IV. DISCUSSION

It would be more meaningful to defer a detailed discussion of the alpha-decay properties of the erbium isotopes in relation to the systematics of the other rare-earth alpha emitters until the study of alpha decay in the higher numbers of the rare-earth elements has been completed. We can, however, mention some observations which refer specially to the erbium isotopes.

A. Alpha-Decay Energies

These first comments refer to the variation of alpha-decay energy with mass number. This was found to progressively increase with decreasing mass number from $N=86$ to $N=84$. In our experiments, although sufficient excitation energy was available to have yielded some Er^{151} and possibly a small amount of Er^{150}, there was no evidence of alpha decay from these nuclides. This indicates that the alpha-decay energies of these nuclides are considerably less than for the 84-neutron isotope, Er^{152}, and is consistent with results from precise mass measurements of the lighter rare-earth nuclides which show that the alpha-decay energies of the 82- and 83-neutron isotopes are much lower than the values for the 84-neutron isotopes.[16]

Another observation concerning the alpha-decay energies of the erbium isotopes is the relatively small difference between the alpha-decay energies of Er^{152} and Er^{153} (130 keV) and the much larger difference between Er^{153} and Er^{154} (540 keV). These differences are observed to a somewhat lesser extent with the 84-, 85-, and 86-neutron isotopes of dysprosium where they differ by 170 and 400 keV, respectively. For the nuclides below $Z=64$, however, the alpha-decay energies of 84-, 85-, and 86-neutron isotopes for a given element differ by approximately the same amount ($\sim$500 keV). It appears that this change in the differences in the alpha-decay energies of neighboring isotopes begins at $\sim Z=66$ which suggests that it may be associated with the structural change which occurs between $Z=64$ and $Z=66$ where there is evidence of a minor closed proton shell.[1,2]

B. Alpha-Reduced Widths

Alpha-reduced widths (δ^2) were calculated for Er^{152} and Er^{153} from the experimental results using the method of Rasmussen.[17] The alpha-reduced width is defined in the following expression:

$$\lambda = \delta^2 P/h\,,$$

where λ is the alpha-decay constant, P is the barrier penetrability and h is Planck's constant. The nuclear potential used in the calculation of P is the sum of the Coulomb potential, the centrifugal potential and the real part of the alpha-nucleus potential given by[18]

$$V(r) = -1100 \exp\{-[r-(1.17A^{1/3}/0.574)]\}\ \text{MeV}.$$

A value of 0.091 MeV was obtained for the reduced width of Er^{152} and 0.13 MeV for Er^{153} assuming $l=0$ α waves only. These values are a factor of 1.6 to 9 times higher than the corresponding isotopes of holmium, dysprosium, and terbium which means that alpha decay is more favored for the erbium isotopes. A possible qualitative explanation for this is as follows. In the earlier work of Rasmussen and co-workers on the gadolinium, terbium, and dysprosium alpha emitters, they observed a break in the alpha-decay energy curve at $Z=64$ which they interpreted as being due to a minor closed shell at $Z=64$.[1,2] This idea received support from the proton level sequence scheme proposed by Mottelson and Nilsson which shows a substantial energy gap between the $d_{5/2}$ proton level, a level which is presumably completely filled at $Z=64$, and the next level, an $h_{11/2}$ state.[19] Additional experimental support for this particular level sequence has been obtained from the observation of long-lived isomeric states for Tb^{149}, Ho^{151}, and Ho^{152}.[6,8] The smaller values of δ^2 for dysprosium, holmium, and terbium [$\delta^2(Tb^{149}) < \delta^2(Dy^{150}) < \delta^2(Ho^{151}) < \delta^2(Er^{152})$] could be the result of significant differences in the proton part of the nuclear wave functions of the initial and final states involved in the alpha-decay process. As more protons are added to the $h_{11/2}$

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TABLE I. Summary of results.

Nuclide	Q_α (MeV)	Half-life	Alpha branch	δ^2 (MeV)
Er^{152}	4.93±0.02	10.7±0.5 sec	$0.90^{+0.05}_{-0.20}$	0.091
Er^{153}	4.80±0.02	36 ±2 sec	$0.95^{+0.05}_{-0.20}$	0.13
Er^{154}	4.26±0.02	4.5±1.0 min	...	...

level, however, these differences would tend to become smaller and as a result the reduced widths would be expected to become larger. Further work in progress on thulium, ytterbium, lutetium, and hafnium alpha emitters near the 82-neutron closed shell may indicate more clearly how δ^2 varies as more protons are added beyond $Z=64$.

The results obtained on the erbium alpha emitters are summarized in Table I.

ACKNOWLEDGMENTS

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Electromagnetic Properties of Li^7

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The energy level and magnetic data of Li^7 are more or less adequately explained by assuming an $(1p)^3$ configuration. However, there seems to be some discrepancy between the value for the quadrupole moment as predicted from this assumption and the measured value given by Kahalas and Nesbet. This discrepancy is explained in terms of a weak particle-surface coupling which need only affect the electric quadrupole operator.

RECENT investigations by Kahalas and Nesbet[1] have led them to assign a definite value to the quadrupole moment of Li^7. The purpose of the present paper is to consider this result together with the other well-known low-level electromagnetic properties of the Li nucleus, in order to determine whether they can be adequately accounted for in terms of the usual single-configuration assumption, so successfully employed in energy-level calculations of the $1p$ shell.[2,3] It will be shown that the introduction of configuration mixing of the kind manifesting itself as a weak coupling between individual-particle and nuclear surface motion is probably all that is needed to explain the data satisfactorily.

Assuming Li^7 to be adequately described by the single configuration $(1p)^3$, the most general wave function that one can write for the ground state is

$$\psi(J=3/2)=C_1\,{}^{22}P[3]+C_2\,{}^{22}P[21]+C_3\,{}^{24}P[21]+C_4\,{}^{22}D[21]+C_5\,{}^{24}D[21], \quad (1)$$

where the notation is ${}^{2T+1,\,2S+1}L[\lambda]$ and λ designates the spatial symmetry properties of the wave function. The magnetic moment μ and quadrupole moment Q are then given, respectively, by

$$\mu=3.12C_1^2-1.054C_1C_2-0.282C_1C_4-0.01C_2^2+3.98C_2C_3-0.56C_3^2+0.80C_3C_5+0.81C_4^2+5.328C_4C_5+0.39C_5^2 \quad (2)$$

in units of nm, and

$$Q/e\langle r^2\rangle=-0.24C_1^2+0.252C_1C_2-0.112C_1C_4-0.358C_2C_4-0.16C_3^2-0.48C_3C_5. \quad (3)$$

In energy-level calculations[2,3,4] with central and spin-orbit forces the ground state is predominantly ${}^{22}P[3]$, with the result that μ and Q are very insensitive to the variation of the parameters involved. These parameters usually are, in standard notation, $W,M,B,H,L/K,a/K$, with $W+M+B+H=1$. Thus, taking the force mixture to be that used by Inglis[2] and Kurath[3] (i.e., $M=0.8$, $B=0.2$), we obtain, after diagonalization of the 5×5 energy matrix[5] with which the ground state is associated and extraction of the eigenvector corresponding to the ground-state energy value:

[1] S. L. Kahalas and R. K. Nesbet, Phys. Rev. Letters **6**, 549 (1961). The quadrupole moment is given there by $Q/e=(-3.56\times10^{-26}\pm10\%)$ cm², but, according to a private communication from Dr. Kahalas, this value has been revised to -4.4×10^{-26} cm², with no real error estimate that can be associated with this value. Our conclusions, originally based on the first-mentioned value, were strengthened by this revision.
[2] D. R. Inglis, Rev. Mod. Phys. **25**, 390 (1953).
[3] D. Kurath, Phys. Rev. **101**, 216 (1956).
[4] J. M. Soper, Phil. Mag. **2**, 1219 (1957).
[5] See, for example, J. P. Elliott, Proc. Roy. Soc. (London) **A218**, 345 (1953).