Coulomb Excitation of V, Ni, Ga, and Rb†

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The Coulomb excitation of several odd-Z or odd-N medium-weight nuclei has made possible the observation of the following gamma rays: V^{50}, 226 kev; Ni^{61}, 70, 282, and 657 kev; Ga^{69}, 322 kev; Ga^{71}, 513 kev; Rb^{85}, 148 kev; Rb^{87}, 407 kev. Values of the reduced transition probability for excitation are given for each of the above gamma rays. Level schemes are proposed based on coincidence studies and excitation curves. Bombardment of the enriched odd-A isotopes of tin, Sn^{115}, Sn^{117}, and Sn^{119}, produced no observable gamma rays.

I. INTRODUCTION

There has been much theoretical interest[1,2] in using the collective approach to explain such features as the energy level spacings and large reduced transition probabilities in the even-even nuclei. Considerable evidence now supports the existence of collective effects essentially vibrational in nature in even-even nuclei of the medium-Z region. Whereas there is little evidence for the presence of rotational effects in these nuclei, Litherland *et al.*[3] have recently been able to explain many of the properties of the Al^{25} decay scheme by assuming the existence of rotational bands. Therefore, it is reasonable to expect that rotational features might be exhibited in odd-A nuclei somewhat heavier than Al^{25}, namely, the more deformed odd-A nuclei in the medium-Z region. Consequently, it was considered of interest to study the Coulomb excitation of several such nuclei. The results of this work are reported here, as are the results of a study of the odd isotopes of tin.

II. EXPERIMENTAL METHOD

The nuclei studied were bombarded with four- to five-Mev alpha particles from the Naval Research Laboratory 5-Mv Van de Graaff accelerator. The targets were made by compressing powdered materials into small depressions in planchets of stainless steel or tin. The planchets were mounted at a 45° angle to the beam direction, and gamma rays from the front face of the target were observed at 90 degrees to the beam. The gamma rays emerging from the target surface passed through approximately 0.050 inch of aluminum and 0.095 inch of magnesium oxide before reaching the detecting crystal. The isotopic enrichments used were the following: 22.83% V^{50}, 83.06% Ni^{61}, 98.08% Ga^{71}, 89.62% Rb^{87}, 14.00% Sn^{115}, 75.3% Sn^{117}, and 79.823% Sn^{119}.

The gamma-ray scintillation counter consisted of a NaI(Tl) crystal $1\frac{3}{4}$ inches in diameter by 2 inches thick and an RCA 6342 photomultiplier. Pulse-height spectra were obtained with a 20-channel pulse-height analyzer. Ba^{133}, Sb^{125}, Na^{22}, and Cs^{137} sources were used for energy calibration. Coincidence measurements were made with two NaI scintillation counters in an arrangement described in a previous article.[4]

The efficiency of the scintillation counter as a function of gamma-ray energy was determined using calculated values for the total gamma-ray absorption in NaI, experimentally checked calculated values of absorption in the material between the target and crystal, and experimentally determined photopeak-to-total intensity ratios. This efficiency curve was checked at 511 kev by two different calibrated Na^{22} sources, and it agreed with efficiencies given by them to within 2 percent. The method used for obtaining the reduced transition probabilities for excitation has been described in an earlier article.[4] Because the target-to-crystal distance was 1.77 cm, angular distribution effects were estimated to be small enough to be neglected.

The gamma-ray energies were measured to a precision of $\pm 1\%$. Absolute values of $B(E2)_{\mathrm{ex}}/e^2(\alpha_T+1)$ are considered accurate to about $\pm 20\%$.

III. RESULTS AND DISCUSSION

A summary of the results obtained in this investigation is shown in Table I. The energies of the gamma rays that were found are given along with the corresponding measured values of the reduced transition probabilities.

Table I. Values are given for the gamma-ray energies observed and reduced transition probabilities for Coulomb excitation. Since the multipole mixtures are not known in the decays, the internal conversion coefficients, α_T, have not been included in the calculation of the reduced transition probabilities.

Isotope	E_γ (kev)	$\frac{B(E2)_{\mathrm{ex}}}{e^2(\alpha_T+1)}\times 10^{50}$ (cm⁴)
V^{50}	226	1.1
Ni^{61}	70	0.038
	282	0.090
	657	0.94
Ga^{69}	322	0.79
Ga^{71}	513	1.2
Rb^{85}	148	0.32
Rb^{87}	407	0.58

† The work discussed in this article has been reported by Fagg, Geer, and Wolicki in Bull. Am. Phys. Soc. Ser. II, 1, 165 (1956).
[1] G. Scharff-Goldhaber and J. Weneser, Phys. Rev. **98**, 212 (1955).
[2] L. Wilets and M. Jean, Phys. Rev. **102**, 788 (1956).
[3] A. E. Litherland *et al.*, Phys. Rev. **102**, 208 (1956).
[4] L. W. Fagg *et al.*, Phys. Rev. **100**, 1299 (1955).

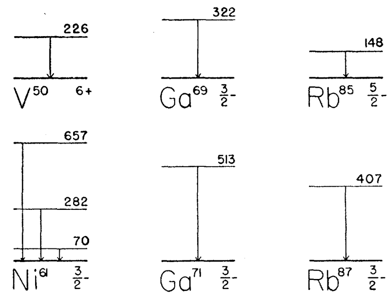

FIG. 1. Proposed energy level schemes for the nuclei studied. Energies are in kev.

The energy level scheme proposed for each of the nuclei studied is given in Fig. 1.

V^{50}

The spectrum resulting from the alpha-particle bombardment of a V_2O_5 target enriched in V^{50} is presented in Fig. 2. Prominent peaks are seen at 226 kev[5] and 337 kev. Comparison of this spectrum with that obtained from a natural V_2O_5 target (99.76% V^{51}) showed that the 226-kev peak is associated with V^{50}. The peak at 337 kev is a composite of the 320-kev gamma ray known from the Coulomb excitation of V^{51} and the 354-kev gamma ray from the $O^{18}(\alpha,n\gamma)Ne^{21}$ reaction. The experimental excitation curve for the 226-kev gamma ray, obtained by measuring the yield of this gamma ray as a function of α-particle bombarding energy, agreed well with the calculated theoretical curve for the Coulomb excitation of a level 226 kev above the ground state. Since V^{50} is an odd-odd nucleus with a ground state spin of 6^+, an accurate angular distribution measurement of the 226-kev gamma ray would be of considerable interest.

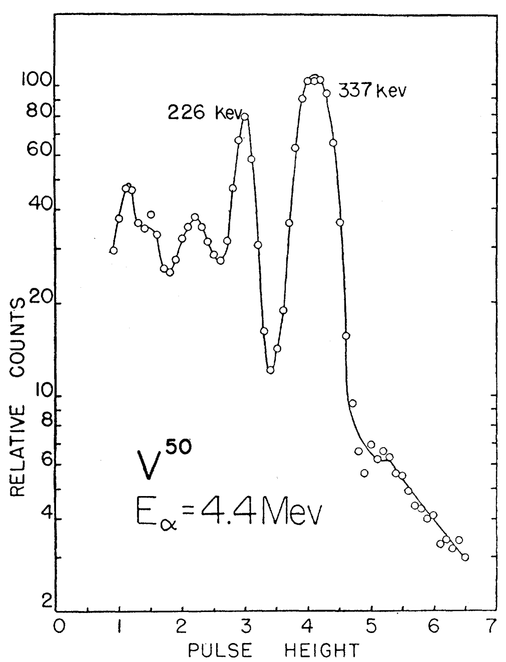

FIG. 2. Spectrum obtained from the 4.4-Mev alpha-particle bombardment $(V^{50})_2O_5$.

Ni^{61}

Figure 3 presents the spectrum obtained from the alpha-particle bombardment of metallic Ni^{61}. Gamma rays were observed at 70, 282, and 657 kev. Comparison of this spectrum with that obtained from a natural metallic nickel target showed that all of the above gamma rays arise from Ni^{61}. The peak at 350 kev is due to a small oxygen impurity. The origin of a gamma ray at 890 kev, not shown in Fig. 3, has not been determined. Experimental excitation curves for the 70-, 282-, and 657-kev gamma rays are in good agreement with the corresponding calculated theoretical curves. Coincidence studies showed no coincidences between any of the gamma rays in this spectrum. This fact, in conjunction with the results obtained from the excitation curve determinations, permits the proposal of the energy level scheme shown in Fig. 1 for Ni^{61}. The results agree very well with those of other investigators[6] who have studied the beta decays of Co^{61} and Cu^{61}.

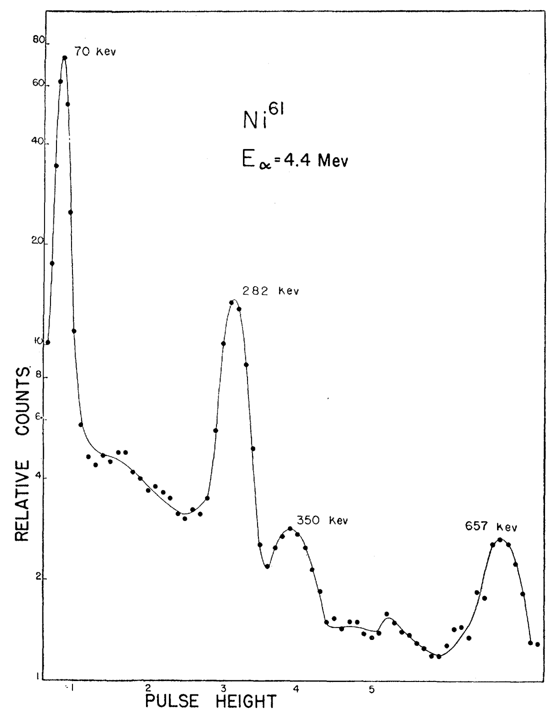

FIG. 3. Spectrum obtained from the 4.4-Mev alpha-particle bombardment of Ni^{61}.

[5] The Coulomb excitation of this gamma ray has also been observed at the Department of Terrestrial Magnetism, Carnegie Institution of Washington: N. P. Heydenberg and G. M. Temmer, Bull. Am. Phys. Soc. Ser. II, **1**, 164 (1956).

[6] R. H. Nussbaum *et al.*, Phys. Rev. **101**, 905 (1956).

Ga^{69} and Ga^{71}

The spectrum shown in Fig. 4 results from the alpha-particle bombardment of a natural metallic target of gallium. Since gallium melts at 29.8°C the target was cooled by heat conduction to dry ice through a copper rod. Prominent gamma rays were observed at 322 and 513 kev. Coincidence studies revealed no coincidences between these two gamma rays or any other gamma ray which might be masked by their Compton distributions. The intensity of the natural gallium spectrum in the region below about 180 kev is roughly twice that expected from the sum of the Compton distributions of the 322- and 513-kev gamma rays. Although the target used was considered quite pure, the origin of the excess radiation in this region has not been determined.

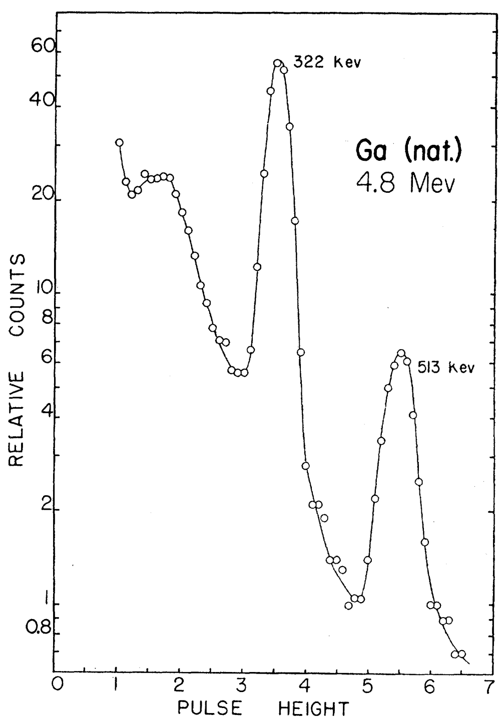

FIG. 4. Spectrum obtained from the 4.8-Mev alpha-particle bombardment of natural gallium.

A comparison was made between the spectrum obtained from natural gallium and from gallium enriched in Ga^{71}. However, since the enriched gallium came in the form of Ga_2O_3, whose reduction process is not well known, this comparison was made between the spectra obtained from the targets in oxide form. Thus, despite the dominant gamma ray at 355 kev from the oxygen impurity, subtraction from the natural curve in Fig. 5 shows that the 322-kev gamma ray comes from Ga^{69}. In Fig. 5 it is also evident that the 513-kev gamma ray comes from Ga^{71}. The latter gamma ray is probably the same as the 0.51-Mev gamma ray found in the study of the Zn^{71} beta decay.[7] The good agreement of the experimental excitation curves with those theoretically calculated shows that the 322- and 513-kev gamma rays arise from nuclear levels at the same energies above the ground states in Ga^{69} and Ga^{71}, respectively.

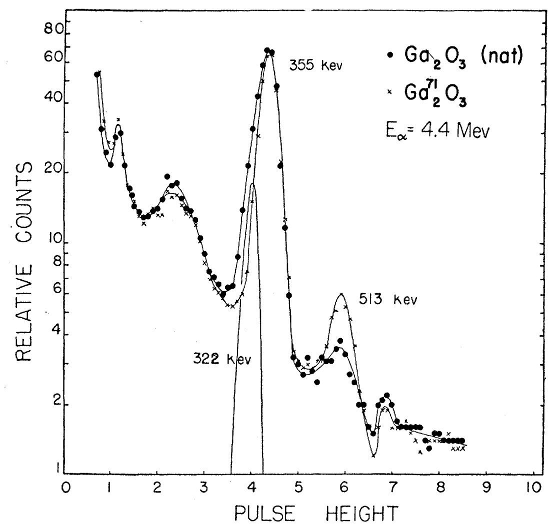

FIG. 5. Spectra obtained from the 4.4-Mev alpha-particle bombardment of natural Ga_2O_3 and $(Ga^{71})_2O_3$.

Rb^{85} and Rb^{87}

The spectrum obtained from the alpha-particle bombardment of a target of natural RbCl is presented in

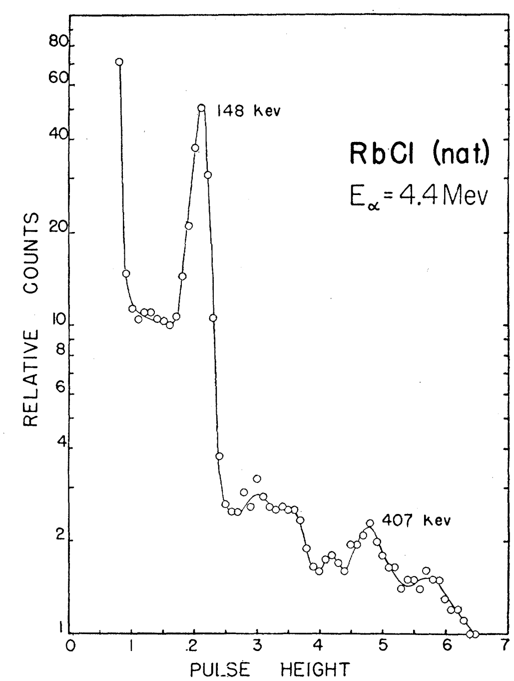

FIG. 6. Spectrum obtained from the 4.4-Mev alpha-particle bombardment of natural RbCl.

[7] LeBlanc, Cork, and Burson, Phys. Rev. **97**, 750 (1955).

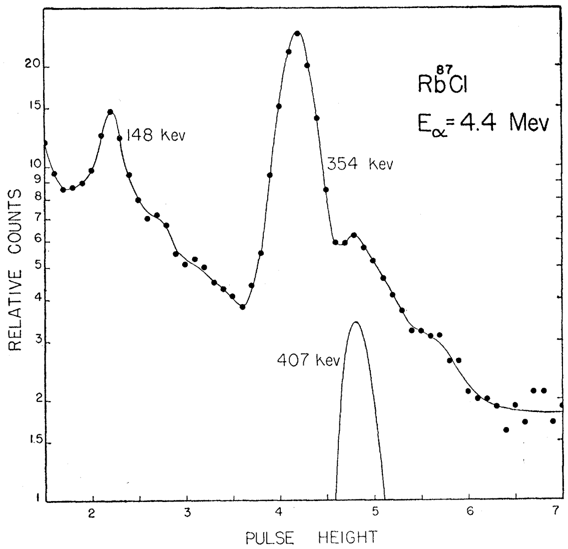

FIG. 7. Spectrum obtained from the 4.4-Mev alpha-particle bombardment of $Rb^{87}Cl$.

Fig. 6. Gamma rays are seen at 148 kev[8] and 407 kev. This spectrum was compared with that resulting from a RbCl target enriched in Rb^{87} as shown in Fig. 7. The comparison shows that the 407-kev gamma ray is associated with Rb^{87} despite the masking effect of the 354-kev gamma ray from an unfortunate oxygen impurity. Futhermore, it is obvious from this comparison that the 148-kev gamma ray comes from Rb^{85}. These gamma rays are probably the same as the 150- and 403-kev gamma rays arising from the beta-decay of Kr^{85} or Sr^{85} and Kr^{87}, respectively.[9,10] The experimental excitation curve of the 148-kev gamma ray is in good agreement with the corresponding calculated theoretical curve. Therefore, this gamma ray results from the decay of a level 148 kev above the Rb^{85} ground state. Because of its low intensity, a satisfactory excitation curve of the 407-kev gamma ray could not be obtained. A rough measurement of the angular distribution of the 148-kev gamma ray showed it to be isotropic within 5%. This result allows only the elimination of 9/2 as a possible value for the spin of the 148-kev state in Rb^{85} whose ground state spin is 5/2. Since the remaining possibilities for the excited-state spin range from 1/2 to 7/2, a more sensitive measurement is required in order to obtain a unique determination of this spin.

Sn^{115}, Sn^{117}, and Sn^{119}

Although it is well known that Coulomb excitation is not observed in natural tin, the conclusions drawn from such results may not apply to the odd-A isotopes of tin because of their low natural abundance. It was felt that the last odd neutron might cause enough deformation of the nuclear charge to make Coulomb excitation possible under alpha-particle bombardment of separated isotopes. However, with bombarding energies up to 4 Mev, there are no observable gamma rays which could be associated with the Coulomb excitation of these isotopes.

This paper has presented data on the low-lying levels of the nuclei studied. However, investigation of the higher levels in these and other deformed nuclei in the medium-Z region is necessary before any conclusions can be drawn concerning the possible existence of rotational characteristics.

IV. ACKNOWLEDGMENTS

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[8] This gamma ray has also been observed by N. P. Heydenberg and G. M. Temmer (private communication).

[9] I. Bergström, Arkiv Fysik **5**, 191 (1952); A. W. Sunyar *et al.*, Phys. Rev. **86**, 1023 (1952); and M. Ter-Pogassion and F. T. Porter, Phys. Rev. **81**, 1057 (1951).

[10] S. Thulin, Arkiv Fysik **9**, 137 (1955).