UCRL-16414

# University of California

# Ernest O. Lawrence Radiation Laboratory

ENERGY LEVELS OF $^{237}$Np: I. The Alpha Decay of $^{241}$Am

TWO-WEEK LOAN COPY

*This is a Library Circulating Copy which may be borrowed for two weeks. For a personal retention copy, call Tech. Info. Division, Ext. 5545*

## DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

UCRL-16414

UNIVERSITY OF CALIFORNIA

Lawrence Radiation Laboratory
Berkeley, California

AEC Contract No. W-7405-eng-48

# ENERGY LEVELS OF $^{237}$Np:
# I. The Alpha Decay of $^{241}$Am

C. M. Lederer, J. K. Poggenburg, F. Asaro, J. O. Rasmussen, and I. Perlman

September 1965

# ENERGY LEVELS OF $^{237}$Np:
# I. The Alpha Decay of $^{241}$Am*

C. M. Lederer, J. K. Poggenburg†, F. Asaro, J. O. Rasmussen, and I. Perlman

Department of Chemistry and
Lawrence Radiation Laboratory
University of California
Berkeley, California

September 1965

RADIOACTIVITY $^{241}$Am, $^{243}$Am;

measured $E_\gamma$, $I_\gamma$, $E_\alpha$, $I_\alpha$, $E_{ce}$, $I_{ce}$, $\alpha$ -, $\alpha$ce-coinc,

calc $I_\alpha$;

deduced $^{237}$Np, $^{239}$Np: levels, J, $\pi$.

*This work was performed under the auspices of the U. S. Atomic Energy Commission.

†Present address: Isotope Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Abstract

The $\gamma$-ray spectrum of $^{241}$Am from 80 to 850 keV was studied with a high resolution semiconductor $\gamma$-ray spectrometer; $\alpha$-$\gamma$- and $\alpha$-electron- coincidence spectra were studied with semiconductor and scintillator detectors. From these data and previous results, a decay scheme is constructed. Theoretical $\alpha$-intensity calculations aided in establishing the decay scheme.

Nilsson assignments 5/2+[642], 5/2-[523], and 1/2+[400] for rotational bands based on levels at 0, 59.54, and 332.36 keV are confirmed. A new 1/2-[530] band, whose lowest member is the well-known 267.54 keV 3/2- level, is positively identified, and a K = 5/2- beta-vibrational band established. The latter band decays primarily by M1 transitions, in violation of the vibrational selection rule. A new level at 770 keV with a probable $I\pi$ = 7/2+ assignment is also of probable vibrational character.

A brief study of $^{243}$Am decay reveals a similar structure for $^{239}$Np.

## 1. Introduction

Although the energy levels of $^{237}$Np have received much attention, they continue to be a fruitful medium for testing theories of nuclear structure and the interrelated theories of nuclear decay processes. The present paper reopens this subject in consequence of two major advances in technique. One of these is the use of the germanium $\gamma$-ray spectrometer which has given better definition of known transitions and shown up a large number of transitions not previously observed. For the first time we can be reasonably sure that the details of the $^{237}$Np level spectrum up to an excitation energy of about 0.4 MeV are characterized. The second major development is an advance in $\alpha$-decay theory which permits calculation of theoretical intensities of $\alpha$-groups from Nilsson wave functions of the constituent nucleons. One can now, with some confidence, use $\alpha$-intensity theory as a real aid in making state assignments. The pertinence of microscopic $\alpha$-rate theory to the present case is that detailed information on the $\alpha$-spectrum of $^{241}$Am is available.

The levels of $^{237}$Np have been identified mainly from the $\beta^-$-decay of $^{237}$U and from the $\alpha$-decay of $^{241}$Am. A $^{237}$U decay scheme proposed by Rasmussen, Canavan and Hollander[1]) has recently been refined by Yamazaki and Hollander[2]). Some information from the $\beta^-$-decay process has also come from a study of $^{237}$Pu electron-capture decay by Hoffman and Dropesky[3]). Several groups have measured the $\alpha$-spectrum of $^{241}$Am: Asaro and co-workers[4,5,6]), Gol'din and co-workers[7]), Rosenblum and co-workers[8]), Chin-Fan Leang[9]), and Baranov and co-workers[10,11]). The last reference (BKS) reports more than 20 levels in $^{237}$Np discernable through detection of $^{241}$Am $\alpha$-groups (see table 1). Low energy $\gamma$-ray and conversion-electron spectra have been studied by Day[12]),

Rosenblum and co-workers[8,13]), Baranov and Shliagin[14]), Magnusson[15]), Hollander and co-workers[16]), Jaffe and co-workers[17]), Beling and co-workers[18]), Turner[19]), Samoilov[20]), and Wolfson and co-workers[21]). The conversion electron spectrum has recently been restudied at high resolution by Wolfson and Park[22]).

The many $\alpha$-groups of $^{241}$Am bespeak a complicated level structure and complicated $\gamma$-ray de-excitation processes, but the low intensities of most of the transitions made it impossible to obtain high resolution $\gamma$-transition information. Some of the stronger transitions could be observed through their conversion electrons, but for the weaker ones, only rough measurements using NaI crystals could be made. In the present study more than thirty new $\gamma$-ray transitions have been observed. The elucidation of the level scheme was also helped by some new $\alpha$-$\gamma$- and $\alpha$-$e^-$-coincidence measurements. In the present study, coincidence measurements also were made on $^{243}$Am which decays to $^{239}$Np.

Before presenting the experiments and their results, we give a brief description of a microscopic theory of $\alpha$-decay based upon Nilsson wave functions (sect. 2). This theory permits calculation of $\alpha$-transition probabilities to the members of rotational bands assigned to specific single-particle configurations. The theoretical predictions may be compared directly with measured $\alpha$-branchings and are useful in confirming and suggesting level assignments.

## 2. Theoretical Alpha Transition Rates

The general development of microscopic $\alpha$-decay theory is given by Mang[23,24]) and we give here only a resume as it applies to present calculations. The transition rate for $\alpha$-decay from an initial state $I_iK_i$ of parity $(-)^{q_i}$ to a final state $I_fK_f$ of parity $(-)^{q_f}$ is obtained by summing the contributions of allowed $\ell$-waves given by

$$\lambda^{I_iK_iq_i}_{I_fK_fq_f\ell} = \frac{1}{\hbar} P_\ell(\epsilon_{I_f}) \frac{\hbar^2}{2MR_o^2} \left| \sum_L \left( B^{LK_i-K_f}_{\ell I_f} G_{LK_i-K_f} + (-)^{I_i-L-K_f} B^{LK_I+K_f}_{\ell I_f} G_{LK_i+K_f} \right) \right|^2 \qquad (1)$$

The two $\alpha$-probability amplitudes $G_{LK_i-K_f}$ and $G_{LK_i+K_f}$ at the nuclear surface $(R = R_o)$ arise from the two terms $(\Phi_K, \Phi_{-K})$ in the symmetrized strong-coupling wave function when $K \neq 0$. The $B^{LM}_{\ell I_f}$ are elements of the Fröman matrix accounting for the anisotropic part of the barrier which scatters L-waves near the nuclear surface into outgoing channels $\ell$ outside the barrier. The isotropic part of the barrier is contained in the penetrability factor $P_\ell$ for the transmission of an $\alpha$-particle with energy $\epsilon_{I_f}$ and angular momentum $\ell$ relative to the daughter nucleus. The problem thus resolves into two parts, the formation of the particle at the nuclear surface, and its penetration through the barrier. We consider these parts separately.

The probability amplitude is conveniently calculated by considering the contribution of protons and neutrons in specific Nilsson orbitals to the formation of an $\alpha$-particle. The amplitude $G_{LM}$ is then obtained by summing over the contributions of the various orbitals, and it contains the effect of

intrinsic nuclear structure of parent and daughter. We calculate a factor $\Gamma$, which is the projection of an $\alpha$-particle from specific Nilsson orbitals, given by

$$\Gamma_{LM}^{K_i K_f \Omega_N -\Omega_N} = R^{3/2} \int A(\psi^*_{K_i} \psi_{K_f}) \, A(\psi_{\Omega_N} \psi_{-\Omega_N}) \, \chi_\alpha(\xi) \, Y_L^M(\Omega') \, d\xi \, d\Omega' \qquad (2)$$

where $\psi_\Omega$ is the Nilsson single particle wave function, $A$ is an antisymmetrization operator, and $\chi_\alpha$ is the $\alpha$-particle wave function. The geometric factor $\Gamma$ must be multiplied by the probability amplitude that the orbitals are occupied (V) in the parent and vacant (U) in the daughter, leading to a factor $V^i_{K_f} U^f_{K_i} V^i_{\Omega_N} U^f_{\Omega_N}$, and by a factor close to unity accounting for overlap of the remaining orbitals in the parent and daughter. These occupation amplitudes are calculated by a variational method using BCS-type wave functions, and the details of this method have previously been reported[25]).

The B-matrix is calculated by the method of Fröman[26]) with the argument $B = 0.9$ which we use throughout the actinide region. The penetrability factors $P_\ell(\epsilon)$ are calculated using the WKB approximation with a Woods-Saxon nuclear potential. The details of these calculations are given in ref. 27.

Since the calculations start from Nilsson wave functions and pairing-force wave functions, both of which contain approximations, it is not surprising that calculated absolute transition rates are generally lower than experimental. We apply to all calculated rates a single factor determined by normalizing to the ground state transition of $^{238}$Pu. With this normalization the $\alpha$-transition rates to the various states frequently agree within a factor of two with experimental values.

In ref. 27, the $\alpha$-rate theoretical values are compared with experiment for several well-studied odd-mass $\alpha$-emitters. The reduced $\alpha$-

transition probabilities are extremely sensitive to the details of the wave function of the odd nucleon, and between different intrinsic states factors of $10^4$ or even $10^5$ appear. Thus, even though the theoretical calculations in some cases give transition probabilities which differ from the measured values by an order of magnitude, they are still of great value for the assignment of Nilsson states. For transitions to different members of the same band, the internal consistency of the theory is much better. As confidence developed that theoretical intensities should check the measured values semi-quantitatively, larger disagreements became grounds for questioning assignments. It was just this kind of disagreement for certain levels which led to a complete restudy of the $^{237}$Np level assignments.

## 3. Experimental Methods and Equipment

### 3.1. GAMMA-RAY SPECTROMETER

Gamma-ray spectra were measured with a lithium-drifted germanium detector[28,29]) coupled to a low-noise pre-amplifier and amplifier system[28]) and recorded on a 400 channel pulse-height analyzer. The detector was operated in vacuum at liquid-nitrogen temperature with a reverse bias of 240 volts. Resolution (FWHM) was 3.2 keV throughout the region studied. The photopeak efficiency of this detector had been carefully calibrated to an accuracy of ±10%, or to ±5% over an energy range of several hundred keV. Energy calibrations were made with the aid of $\gamma$-ray standards measured before and after each spectrum was measured.

## 3.2. COINCIDENCE SPECTROMETER

The detector housing and coincidence circuitry for the $\alpha$-$\gamma$-and $\alpha$-$e^-$-coincidence measurements have been described elsewhere in detail[30,31]). The $\alpha$-detector is a phosphorus-diffused, p-n-junction silicon semiconductor with guard ring[32]). The $\gamma$-ray detector is a commercial $7.6 \times 7.6$ cm NaI(Tl) scintillator optically coupled to a photomultiplier. Electrons are detected by a lithium-drifted silicon semiconductor operated at room temperature; an anthracene scintillator was used in one experiment. The electronics consist of a fast-slow circuit the $\alpha$-side of which can operate at rates exceeding $10^5$ $\alpha$-counts per second. The resolving time ($2\tau$) of the fast coincidence unit is $4 \times 10^{-8}$ s.

Specific regions of the $\gamma$-ray or conversion spectrum can be used to gate the coincident $\alpha$-spectrum, which is then recorded on a 100-channel pulse-height analyzer. Alternatively, one can gate on any portion of the $\alpha$-spectrum and record the coincident $\gamma$-ray or conversion spectrum. The geometries of the $\gamma$- and $e^-$-detectors are fixed. These geometries and the detector efficiencies are calibrated so that the intensity of a transition relative to the total $\alpha$-intensity can be calculated from the observed singles and coincidence counting rates. The energy and intensity calibrations are described in refs. 30 and 31.

## 3.3. SOURCES

A thin source for the coincidence experiments was prepared by vacuum flashing $^{241}$Am from a tungsten filament. The source backing was 0.013 cm thick polystyrene sheet. Total source strength was $6 \times 10^6$ $\alpha$-d/m. The $\alpha$- and $\gamma$- singles spectra of this source showed the presence of no impurity activities.

The source for the γ-ray spectrum was a single crystal of $AmCl_3$. The americium had been chemically separated from purified plutonium containing $^{241}Pu$ and carefully purified to remove all active and inactive contaminants. The γ-spectrum displayed no γ-rays which could be assigned to impurities, although above 130 keV a γ-ray more intense than 2 parts in $10^7$ $^{241}Am$ α-decays would be detectable. In particular, there were no known γ-rays of Pu or Cm isotopes, or of common long-lived fission products. The $^{243}Am$ content, as judged by the absence of $^{239}Np$ daughter radiations, was less than 1 part in $10^6$ by activity.

A thin $^{243}Am$ source ($1 \times 10^6$ α-d/m) was prepared in the same way as the thin $^{241}Am$ source. Alpha- and γ- singles spectra showed that this source had the following composition by activity: $^{243}Am$ 71%, $^{244}Cm$ 17%, $^{238}Pu$ + $^{241}Am$ 12% (mostly $^{238}Pu$). Coincidence experiments identical to the present ones have been performed[30,31]) with $^{244}Cm$ and $^{238}Pu$; coincidences due to $^{243}Am$ were found to occur at different energies, and were in all cases at least an order of magnitude more intense than those expected from the other activities present in the source.

## 4. Experimental Results

### 4.1. GAMMA SPECTRUM

The γ-ray spectrum (fig. 1) is complex, as expected; we identify over thirty new transitions. The spectra illustrated were taken through a 0.16 cm Cd absorber. The Cd greatly reduces the intensity of the 59.54 keV γ-ray, which would otherwise overload the amplifiers and analyzer. For the spectrum above 550 keV a 0.32 cm Pb absorber was also used. Corrections for absorber transmission were determined experimentally and applied to the measured intensities.

Table 2 lists the energies and intensities of the γ-rays. The intensities of the 98.7, 102.7, and 125.1 keV γ-rays are derived from a spectrum taken without the Cd absorber (not shown) and are normalized to Magnusson's intensity[15,33]) for the 59.54 keV γ-ray, (35.9±0.7)%. All other intensities measured in this experiment are normalized to the sum of the intensities of the 597.4, 618.9, 641.5, 652.7, 662.3, 680.0, 688.7, 695.4, 709.8, 722.1, 737.0, 756.8, and 770.7 keV γ-rays, $(1.07 \pm 0.25) \times 10^{-3}$%, as determined in the coincidence experiment. The reliability of the intensities stated in table 2 does not include the ±23% uncertainty introduced by this normalization.

Weak $K_{\alpha_{II}}$ and $K_{\alpha_{I}}$ x-ray lines are masked by the 98.7 and 102.7 keV γ-ray peaks. Their intensities were calculated[34]) from the measured intensity of the $K_{\beta}$ line, and small corrections applied to the intensities of the 98.7 and 102.7 keV lines.

Figure 1 shows weak peaks at 75 and 85 keV; these peaks were not observed in the spectrum taken without the Cd absorber and are probably spurious. The peak at 118 keV is caused by backscattering.

Table 2 also lists some data from other measurements. Accurate energies of numerous transitions are taken from the data of YH[2]) on $^{237}$U decay and of Wolfson and Park[22]) on $^{241}$Am decay; we adopt these energies and quote them in the following discussion. Multipolarity assignments are also taken primarily from these two papers. The intensities of low-energy photons are from refs. 12 and 15.

The intensities of transitions above 110 keV, listed in column 5 of table 2, are calculated from the photon intensities of column 3 and experimental[2]) or theoretical[35]) conversion coefficients. To obtain the intensities of prominent low-energy transitions we have normalized the electron intensities by use of the measured conversion coefficients of the 59.54 keV transition[2]).

## 4.2. COINCIDENCE MEASUREMENTS

The spectrum of α-particles in coincidence with γ-rays of energy >500 keV is shown in fig. 2(a). A 0.16-cm Cd absorber was placed between the source and the γ-ray detector to absorb the intense 59.54 keV γ-rays. The absorber reduced both true and chance coincidence rates, and prevented stack-up of the 59.54-keV γ-ray with other γ-rays in the scintillation detector. The α-peak in fig. 2(a) at 4.838±0.010 MeV, intensity $(1.0\pm0.3) \times 10^{-3}\%$ of the $^{241}$Am α-decays, defines a state in $^{237}$Np at 719±10 keV. A small shoulder on the low-energy side of this peak indicates the presence of additional unresolved α-groups to higher-lying levels. The same α-group occurs in coincidence with electrons of energy >380 keV (fig. 2(b)) with an intensity $(1.1\pm0.3) \times 10^{-4}\%$. The following discussion shows that these data argue strongly for the presence of an E0 transition from the ≈720 keV state (transition B' 5/2- → B 5/2-).

The spectra of γ-rays and conversion electrons coincident with the 4.84-MeV α-peak are shown in figs. 2(c) and 2(d). The complex γ-ray peak which appears at 662 keV in the coincidence spectrum with an intensity $(1.07\pm0.25) \times 10^{-3}\%$ (fig. 2(c)) can be seen from the singles spectrum (fig. 1) to consist of transitions at 662.3 and 722.1 keV plus numerous weaker transitions from 597 to 770 keV. These transitions define a level at 721.9 keV and two additional, weakly populated levels at 755.8 keV and 770 keV.

The electron spectrum coincident with the 4.84-MeV α-peak (fig. 2(d)) displays K and L+M+... lines of a 659±10-keV transition. This transition is identified with the 662.3-keV B' 5/2- → B 5/2- transition. A small contribution from the 652.7-keV B' 7/2- → B 7/2- transition, which is 10 times weaker and should have a similar conversion coefficient, can be ignored in the following paragraphs.

From the measured coincidence intensities, the apparent conversion coefficients of the 662.3-keV transition are $e_K/\gamma = 0.18 \pm 0.04$, $K/L+M+\ldots = 4 \pm 1$. The K-conversion coefficient is too high for a pure E1, M1, E2, or E3 transition. Observation of the 662.3 keV transition in prompt coincidence with $\alpha$-particles limits the lifetime of the transition to $\lesssim 2 \times 10^{-8}$ s, which rigorously excludes measurable admixtures of M3 and higher multipolarities. A pure M2 assignment would be consistent with the measured value of $e_K/\gamma$, but in this case the 721.9 keV level would certainly de-excite primarily by faster transitions to other levels. The only alternative explanation is that the transition contains an E0 component.

Besides the E0 component, the 662.3-keV transition must contain either an E2 or M1 (or both) component. As discussed in sect. 5.5, there is strong evidence that the predominant multipolarity is M1. If we assume that the <u>$\gamma$-ray</u> is a pure M1, the K-conversion coefficient shows that 8±4% of the total <u>transitions</u> are E0; the E0 proportion is slightly higher if the transition contains an E2 component also.

The coincidence experiments thus establish a state at ≈720 keV with spin and parity 5/2-. Similar coincidence measurements with the $^{243}$Am source establish a level in $^{239}$Np at ≈670 keV populated with an $\alpha$-intensity $(1.6 \pm 0.5) \times 10^{-3}$% in coincidence with $\gamma$-rays, and $(7 \pm 3) \times 10^{-5}$% in coincidence with electrons. The same level has been observed at 666 keV in the $\alpha$-spectrum of BKS. We determine from the coincidence measurements that it decays primarily by transitions to the ground state and the 31.14 keV first excited state of $^{239}$Np, with possible weak transitions to levels at 74.67 and 117 keV. The data are shown on the level scheme (fig. 3(b)).

A recent paper by Michaelis[36]) reports the results of extensive coincidence experiments on $^{241}$Am, employing a semiconductor $\alpha$-detector and a scintillation detector for $\gamma$-rays. These results are consistent with our $\gamma$-ray and coincidence spectra. The marked difference between our decay scheme (fig. 3(a)) and the one which Michaelis derived can be ascribed to higher resolution in our $\gamma$-spectra, and to deductions which we arrived at by taking theoretical $\alpha$-transition rates into consideration (see sects. 5.3 and 5.4).

## 5. Discussion of the Results

From previous data and assignments and the present results we have constructed the $^{241}$Am decay scheme shown in fig. 3(a). In this section the level assignments are discussed in detail.

### 5.1. LEVELS AT 0, 33.20, 75.9, AND 130 keV: THE 5/2+[642] BAND LABELLED A

The measured ground state spin of $^{237}$Np is 5/2 (refs. 37, 38, 39). Coulomb excitation experiments[40]) establish the next two members of the ground state band at 33.2±0.2 keV (spin 7/2) and 75.8±0.4 keV (spin 9/2). BKS assign an $\alpha$-group to the spin 11/2 member at 129 keV. More accurate energies for these levels (fig. 3(a)) are derived from transition energies and energy differences measured by YH and by us. These energies agree with the simple rotational formula

$$E_I = E_o + A\ I(I+1)\ ; \qquad (3)$$

the rotational constant A is 4.74 keV. The band has been assigned a 5/2+[642] Nilsson configuration[16,1,41,42,6]. The 11/2+ state would be expected to de-excite by intraband transitions and the conversion lines for these would be too weak to have been seen by Wolfson and Park[22]. Other low energy transitions involving this band have been well characterized as described in table 2.

Alpha decay to this band is highly hindered. In table 3 the calculated α-intensities are compared with intensities measured directly in the α-spectrum by BKS. The agreement is remarkable, especially if one considers that nuclear structure effects retard these transitions by factors of $10^3$-$10^4$ as compared with unhindered transitions.

As discussed in sect. 11 of the following paper, the band A probably has a considerable Coriolis admixture of the 3/2+[651] band. This should not greatly affect the α-transition rates, since the calculated transition probabilities are lower for the 3/2+[651] band than for the 5/2+[642] band.

## 5.2. LEVELS AT 59.54, 102.96, 158.52, 226.0, 304.8, AND 395.2 keV: THE 5/2-[523] BAND LABELLED B

The ground state spin of $^{241}$Am is 5/2[43,44,45]. According to the concept of favored α-decay the 59.54-keV level of $^{237}$Np, to which $^{241}$Am decays by a virtually unhindered α-transition, has the same structure as the $^{241}$Am ground state[46,47]. The 5/2-[523] configuration has been assigned to these states (refs. 16, 1, 41, 42, 6). Alpha spectra[4,5,7,8,10,11] reveal higher members of this band at approximately 103 keV (7/2-), 158 keV (9/2-), 226 keV (11/2-), 306 keV (13/2-), and 395 keV (15/2-). More accurate energies for these levels used on the decay scheme (fig. 3(a)) are derived from γ-transition energies.

The elctromagnetic spectrum (table 2) establishes cascade, crossover, and interband E1 transitions which de-excite the 5/2-, 7/2-, 9/2-, and 11/2- members of the band. The intensity balance between the feeding and de-exciting radiation for these four lowest members is given in table 4. For the states labelled B 13/2- and B 15/2- we have only the α-intensity data and a single weak γ-ray de-exciting each level: B 13/2- → B 9/2- (146.3 keV) and B 15/2- → B 11/2- (169.2 keV). Each of these, as drawn in, is an intraband crossover transition. It is possible to estimate the intensities of the unobserved cascade transitions from the B 13/2- and B 15/2- states if one assumes relative intraband transition rates given by rotational model formulae[48]). Based on these formulae, theoretical conversion coefficients[35]), the measured intensities of the 164.3 and 169.2 keV γ-rays, and the measured M1-E2 mixing ratio for the 43.42 keV B 7/2- → B 5/2- transition[2,22]), we calculate total de-excitation intensities for the B 13/2- and B 15/2- states which agree within a factor of 2 with the α-group intensities of BKS. Placement of the 146.3 and 169.2 keV γ-rays as the intraband crossover transitions is thus consistent with their intensities.

Energy spacings in the band can be described by the usual rotational formula with a second order term

$$E_I = E_o + A\, I(I+1) + B\, I^2(I+1)^2 \quad , \tag{4}$$

with A = 6.249 keV, and B = $-1.86 \times 10^{-3}$ keV, as determined from the energies of the 5/2-, 7/2-, and 9/2- members. The calculated energies of the 11/2-, 13/2-, and 15/2- levels are then 226.0, 305.2, and 395.8 keV, compared to experimental values 226.0±0.1, 304.8±1.0, and 395.2±1.0 keV.

Comparison of the theoretical and experimental α-intensities for this band (table 3) shows satisfactory agreement. Note that the total intensity for this band (99.6%) normalizes the theoretical intensity calculations for the other α-groups. This normalization could have been avoided, had we chosen to compare the transition rates or partial half-lives instead of α-branchings. The calculated partial half-life of the favored transition to the 59.54 keV state differs by only 20% from the experimental value; we have therefore chosen to compare the more convenient α-branchings and ignore the 20% difference thereby introduced into the intensities calculated for weaker α-groups.

YH find evidence for some K = 3/2 admixture in band B, although the amount need not be large.

## 5.3. LEVELS AT 332.36, 368.59, 370.94, 452.7, AND 459.8 keV: THE 1/2+[400] BAND LABELLED D

From the study of $^{237}$U $\beta^-$-decay RCH assigned $^{237}$Np levels at 332 keV (1/2+), 369 keV (5/2+), and 371 keV (3/2+) to a 1/2+[400] band. (Preference over a 1/2+[660] assignment is based on the magnitude of the decoupling parameter.) Re-examination of this decay scheme by YH confirms the spin assignments. BKS assigned $^{241}$Am α-groups to these three states, and to additional members of the band at 456 keV (9/2+) and 463 keV (7/2+).

Our γ-spectrum is consistent with the $\beta^-$-decay results concerning the 1/2+, 5/2+, and 3/2+ levels. In addition, we see transitions of 322.6, 376.8, 383.5, 419.6, and 426.7 keV which de-excite levels at 452.7±1.0 and 459.8±1.0 keV. We equate these levels to those at 456 and 463 keV observed in the α-spectrum by BKS.

Table 5 shows the intensity balance for the band; note particularly that the agreement for the spin 1/2 member is unsatisfactory. We consider that the α-groups which populate the D 5/2+ and D 3/2+ states are too close to be meaningfully resolved in the spectra of BKS, as are those which populate the D 9/2+ and D 7/2+ states, and have accordingly quoted only the total intensity of each doublet. It is assumed in table 5 that the intraband transitions which could de-excite the D 9/2+ and D 7/2+ states are weak compared to the observed interband transitions. This assumption is consistent with the agreement between the total intensity of the observed transitions and the intensity of the D 9/2+ – D 7/2+ α-doublet. For reasons discussed by YH in sect. 6 of the following paper, it is also assumed that these states do not decay substantially by E1 transitions to band C.

The disagreement between α-feeding and de-excitation intensity for the 1/2+ level cannot be due to the existence of unobserved transitions or a known doublet. A clue to this problem is the measured energy of the α-group, which places the level at 327±2 keV[11]), whereas the energy of the 1/2+ level is 332.36±0.04 keV[2]). This discrepancy and the intensity disagreement indicate that there is an additional level near 327 keV, distinct from the known 1/2+ level at 332.36 keV. Tentatively, we assign an α-feeding intensity of $5 \times 10^{-4}$%, the total intensity of the de-exciting transitions, to the 332.36 keV level. The remaining intensity of the "$\alpha_{327}$" group, $8 \times 10^{-4}$%, we assign a new level at about 327 keV. In sect. 5.4 this level is assigned as the 7/2- member of a K = 1/2- band. The apparent absence of γ-rays depopulating this state is taken as evidence that it de-excites by means of a low-energy intraband transition to the state at 267.54 keV.

The energy spacing of a K = 1/2 band can be described by the expression

$$E_I = E_o + A\ [I(I+1) + a(-1)^{I+1/2}\ (I+1/2)] \qquad (5)$$

Using the measured energies of the 1/2+, 5/2+, and 3/2+ states, the rotational constant A is 6.195 keV, and the decoupling parameter a is +1.076. The predicted energies of the 9/2+ and 7/2+ members of the band are 454.4 and 458.6 keV, only in fair agreement with the observed level energies, 452.7±1.0 and 459.8±1.0 keV. The inclusion of a second order $[I^2(I+1)^2]$ term alone does not improve the fit. If we assume, however, that the decoupling parameter has a spin-dependent term as indicated by Nathan and Nilsson[49]), we obtain satisfactory agreement.

The α-intensities predicted for band D are compared in table 3 with experimental values based on the de-excitation intensities; they are uniformly about an order of magnitude low. The relative intensities predicted for different band members are in remarkable agreement with the unusual intensity pattern observed; note particularly that the alternating intensities are reproduced.

In line with modern concepts, according to which states in odd-A nuclei may generally have admixtures of one- and three-quasiparticle character, we may speculate on other possible components in the band designated 1/2+[400]. An obvious component to consider is the 5/2+[642] proton coupled to a γ-vibrational ($Y_{22}$) phonon. The dominance of M1 over E2 in de-exciting transitions to the ground state band argues against such a γ-vibrational component being large. One might wonder if the 1/2+ band contains an appreciable component of 5/2-[523]

coupled to a K = 2 octupole phonon. If the α-decay went mainly via such a component, with the odd proton state of parent $^{241}$Am remaining unchanged, we would expect mainly L = 3 α-waves with projection M = 2 on the nuclear symmetry axis. This would lead to an intensity signature with the decay to the 7/2+ state exceeding that to the 9/2+ state, in striking disagreement with the experimental intensities. The marked alternation in α-intensities to 1/2, 3/2, 5/2, 7/2, 9/2 levels is a result of interference of M = 2 and M = 3 alpha waves, as given naturally by the one-quasiparticle component 1/2+[400]. Possibly the discrepancy between theoretical and experimental absolute intensities arises from an underestimation of nucleon radial wave functions by the harmonic-oscillator approximation.

## 5.4. LEVELS AT 267.54, 281.35, 327, 357, 438, AND 485 keV: THE 1/2-[530] BAND LABELLED C

The grouping of these levels as a rotational band is based upon substantial evidence, but missing are the many γ-ray transitions which aided identification of the other bands. The lowest-lying member of this band (at 267.54 keV) has been well characterized as a 3/2- state[1]) with a half-life of 5.4 nsec[50]). The decay pattern of this state is interesting in that competing modes involving E1, E2, M1, and M2 transitions are all observed[1,2]). It is sufficient for present purposes to say that the E1 and M1 transitions, in particular, are very slow and that this accounts qualitatively for the failure to observe corresponding transitions from the higher levels of the band. These apparently de-excite to the 267.54 keV state by fast low-energy intraband transitions which are highly converted, hence not seen in the γ-ray spectrum.

Of the levels grouped here, only the one at 281.35 keV has not been observed in the α-spectrum of BKS. According to our assignment this is the 1/2 member of the 1/2-[530] band and the calculated α-intensity to this state is too low to be observed. Two of the levels (438 and 485 keV) plus a third (549 keV) were assigned by BKS to a 3/2-[521] band. The corresponding rotational constant, 9.4 keV, is improbably high, and the calculated intensities of α-groups to a band with this description are two orders of magnitude lower than the measured values. These assignments seem to be untenable.

The level at 357 keV has been assigned[11]) to a 3/2+[651] configuration. This also is likely to be wrong, for although the calculated α-intensity to this state agrees with the observation, the calculations also show that higher members of the band should be observed in comparable intensity.

As discussed in sect. 5.3, the level at 327 keV which we assign to band C is seen in the α-spectrum[11]); the "α-group" $\alpha_{327}$ is actually a doublet which feeds this level and the 332.36 keV D 1/2+ level with intensities $8 \times 10^{-4}$% and $5 \times 10^{-4}$% respectively.

The 3/2- level at 267.54 keV has been variously assigned to a 3/2-[521] band[1,41]) or to a 1/2-[530] band[42]) which is the assignment made for the ground state band in certain protactinium isotopes. The calculated α-intensity for either assignment is in satisfactory agreement. One of the pieces of evidence[8]) favoring a K = 1/2 assignment is that the 267.54 keV transition (C 3/2- → A 5/2+) has an M2 component competing with E1 [1,2]) and this can best be explained by making the E1 transition K-forbidden. The positions of all of the levels grouped here can also be well explained as a K = 1/2 band. The α-intensity pattern provides another essential clue to the identification of this band.

If we take the 267.54 keV state as the 3/2- member, one can obtain a self-consistent set of level spacings with the adjustable parameters A = 6.72 keV, a = -1.64 (see eq. (5)). For these the 3/2- state is taken to be at 267.54 keV and the others are 280 keV (1/2-), 326 keV (7/2-), 356 keV (5/2-) 438 keV (11/2-), 486 keV (9/2-). Comparison with the levels shown in fig. 3(a) indicates excellent agreement. The agreement is not likely to be fortuitous because five energy differences are taken into good account with just two parameters.

Prior to the work of YH, it was thought that 96% of the $^{237}U$ $\beta^-$-decays populate the 267.54 keV C 3/2- state directly[1]. As discussed above, we assign this state as the lowest member of a K = 1/2 band, in consequence of which the spin 1/2 member, predicted near 280 keV but not seen in the $\alpha$-spectrum, should actually receive a sizable fraction of the total $^{237}U$ $\beta^-$-intensity. YH have obtained striking confirmation of this level at 281.35 keV. It receives 53% of the direct $\beta^-$-decays, and it decays, as expected, by a strong 13.81 keV intra-band transition to the 267.54 keV C 3/2- state and by a very weak E2 transition to the 59.54 keV B 5/2- state. It is also fed weakly by an E1 transition from the 332.36 keV D 1/2+ state. The 13.81 keV transition had previously escaped detection because of its low energy, the other two because of their low intensity. The 281.35 keV level should receive some indirect feeding from the C 5/2- state in $^{241}Am$ decay, but the transitions by which it de-excites would be extremely difficult to detect.

Because of the weakness of the interband transition from the spin 1/2 member, we assume that higher members of band C de-excite almost entirely by rotational transitions which eventually funnel through the 267.54 keV 3/2- state.

As a quantitative check on this assumption, the total intensity of transitions depopulating the 267.54 keV level is $(2.4\pm0.4) \times 10^{-3}\%$, of which $0.5 \times 10^{-3}\%$ is accounted for by direct $\alpha$-feeding and $0.3 \times 10^{-3}\%$ by feeding from the 332.36 keV level. The remainder, $(1.6\pm0.4) \times 10^{-3}\%$, is in agreement with the total $\alpha$-population of higher-lying members of the band, $1.8 \times 10^{-3}\%$.

The strongest interband transitions from this band (except from the 3/2- lowest member) should de-excite the states C 7/2- and C 11/2-, because these states receive substantial $\alpha$-decay, and because the inverted level order permits only a single E2 intraband transition from each of them. No such interband transitions from the C 11/2- state are observed. It is possible that the weak 221.5 keV $\gamma$-ray is the transition C 7/2- $\rightarrow$ B 7/2-; it is also possible that a portion of the 267 keV $\gamma$-ray de-excites the C 7/2- state to the 59.54 keV B 5/2- state. From the intensity ratio $W_\gamma(267.54)/W_\gamma(208.00)$ observed in $^{237}U$ decay[2], one expects an intensity $(1.8\pm0.3) \times 10^{-5}\%$ for the 267.54 keV $\gamma$-ray (C 3/2- $\rightarrow$ A 5/2+), whereas the measured intensity is $(2.7\pm0.7) \times 10^{-5}\%$. The intensity of a possible 267 keV $\gamma$-ray (C 7/2- $\rightarrow$ B 5/2-) is $<2 \times 10^{-5}\%$.

Comparison of the measured and calculated intensities of $\alpha$-groups (table 3) shows quite good agreement. In particular, note the alternation in intensities and the very low intensity calculated for the 1/2- state which, as pointed out, has not been seen in the $\alpha$-spectrum.

The 1/2-[530] band occurs as the ground states of $^{231}Pa$ and $^{233}Pa$ (refs. 42, 6). The rotational constants and decoupling parameters are A = 6.34 keV, a = -1.40 in $^{231}Pa$; A = 6.0 keV, a = -1.3 in $^{233}Pa$; similar to the constants obtained for the band in $^{237}Np$ — A = 6.72 keV, a = -1.64.

## 5.5. LEVELS AT 721.9 AND 755.8, THE 5/2-[523] β-VIBRATIONAL BAND LABELLED B'

As already discussed in sect. 4.2, the γ-ray spectrum and α-γ and α-$e^-$-coincidence measurements establish a 5/2- state at 721.9±0.3 keV. There was also strong evidence that this state decays in part by an E0 transition to the 59.54 keV state (B 5/2-). This latter finding taken along with the low reduced α-hindrance factor* (4.8) makes it tempting to characterize this level as a β-vibrational state based upon the 59.54 keV state (B 5/2-) which receives the favored α-decay. Such a state would be analogous to the excited 0+ states in neighboring even nuclei[30,31]). Although this is given as the assignment, further analysis shows that it is not a complete description of the state.

Aside from the expected E0 component, a β-vibrational state should decay to the lower band by E2 transitions, whereas M1 transitions are forbidden by the vibrational selection rules. This presumption can be tested by examining the branching ratios for the transitions B' 5/2- → B 5/2-, B 7/2-, and B 9/2-. These depend strongly on whether the transitions are M1 or E2[52]), the presence or absence of the B' 5/2- → B 9/2- having special significance, since this transition must in any case be a pure E2.

The comparisons are given in table 6, from which it may be seen that the agreement is much better with an M1 assignment. It is well known that

---

*Defined[31]) as the hindrance factor divided by the hindrance factor for the favored transition, where the hindrance factors have been calculated according to the method of Preston[51]).

mixing of a vibrational band with the base band can cause deviations from the theoretical branching ratios. Such effects have been studied for the case of E2 transitions from γ-vibrational bands[53-55]). We have performed a simple mixing calculation and it does not change the branching ratios in such a way as to permit E2 assignments.

Another characteristic of the level at 721.9 keV is the de-excitation to the ground band (A 5/2+ and A 7/2+) by a pair of E1 transitions. Such transitions in which the particle state and vibrational quantum number both change should be forbidden. The existence of the E1 transitions implies impurities in the wave functions of one or both of the bands, as does the earlier cited evidence.

BKS assigned a level at 758 keV as the 7/2- member of the β-vibrational band. We observe 5 transitions which define this level at 755.8 keV. Since these transitions feed states of spin and parity 5/2-, 7/2-, 9/2-, 5/2+, and 9/2+ (a possible transition to the 33.20 keV 7/2+ state is masked), the spin of the level is almost certainly 7/2, although we do not determine the parity. Assuming the K I $\pi$ = 5/2 7/2- assignment we have calculated the branching ratios in table 6. The observed ratios clearly disagree with the predictions for E2 transitions, while the agreement for M1 transitions is better. Taking mixing into account does not improve the agreement for E2 transitions. Thus both the 721.9 keV 5/2- and 755.8 keV 7/2- states decay predominantly by M1 transitions.

The low reduced α-hindrance factor for the 755.8 keV state (25) strongly favors assignment to the same band as the 721.9 keV state, although the energy spacing, 33.9 keV, is surprisingly low compared to 43.42 keV for corresponding members of the lower-lying 5/2- band.

Whatever may be the accurate description of these states, it is likely from the low α-decay hindrance factors and from the E0 component of one of the transitions that they have some collective character and some intrinsic likeness to the 5/2-[523] band. It is also likely that these two levels have been compressed toward each other by interaction with other states not yet observed. Great difficulty exists in learning more about them by studying radioactive decay, because they can only be populated by the α-decay of $^{241}$Am, and the transitions here are extremely weak.

## 5.6. THE STATE AT 770 keV LABELLED E

Four weak transitions define an additional level at 770±2 keV. If these transitions, which feed 5/2+, 7/2+, 5/2-, and 11/2+ states, are all correctly placed in the decay scheme, the only reasonable spin and parity assignment is 7/2+. Possible transitions to the 75.9 keV 9/2+ and 102.96 keV 7/2- states are masked.

If the level is indeed a 7/2+ state, the only available Nilsson band to which it could be assigned is 7/2+[631]. The calculated α-intensity is 3 orders of magnitude too low, which rules out this assignment. The low value of the reduced hindrance factor for this state (55) suggests that it may be an octupole-vibrational excitation. The hindrance factor and excitation energy are quite similar to those of K = 0 octupole states in neighboring even nuclei[30,31]. Much less is known about octupole states with K π = 1- or 2-. A recent study of $^{240}$Pu decay[31]) has disclosed a band around 700 keV in $^{236}$U, appearing to have a K = 2 octupole character, for which the α-decay hindrance factor (for the spin 3 member (?)) is also about 60.

On the other hand, an octupole vibration might be expected to decay by E1 transitions to the K = 5/2- band near ground, whereas the 770 keV state decays predominantly (assuming the 7/2+ assignment) by E2 (+M1) transitions to members of the ground state band. This preference for E2 de-excitation suggests that the 770 keV state may also have an admixture of a β- or γ-vibration built on the ground state.

The possibility that the 7/2+ assignment for the 770 keV level may be incorrect raises one further point of interest: if it were instead a 7/2- state, it could provide a convenient explanation for the compression of the nearby β-vibrational (B') band.

## 5.7. THE 549 keV LEVEL

BKS observe a doubtful α-group which defines a possible level at 549 keV. Our measurements shed no light on the existence or the character of this level.

## 5.8. THE DECAY SCHEME FOR $^{243}$Am

The decay scheme for $^{243}$Am is shown in fig. 3(b). The intensities of transitions to and from the 666 keV level of $^{239}$Np are deduced from our coincidence experiments. Because of the low reduced hindrance factor (5.8) for this state, we assign it to the same β-vibrational configuration as the 721.9 keV level of $^{237}$Np. The remaining information shown on the decay scheme is derived from the α-spectrum (BKS) and from $^{239}$U decay[56].

The ground band and the band based on the 74.67 keV level[56] have been assigned 5/2+[642] and 5/2-[523] respectively[16,41,42]. Alpha decay to the latter band is favored, as in $^{241}$Am decay. The levels at 267, 327, 359, and

438 keV have similar α-branchings and energies almost identical to members of the 1/2-[530] band in $^{237}$Np, so we have tentatively assigned these levels to that configuration. Levels at 348 and 427 remain unassigned.

States analogous to the 485, 755.8, and 770 keV states of $^{237}$Np have not been seen in $^{239}$Np, consistent with the expectation that α-branching to them should be very weak. The only other difference in the band structure of $^{239}$Np is the absence of the 1/2+[400] band. From the failure to identify this band, we conclude that it lies at somewhat higher energy than in $^{237}$Np. Some of its members may be fed by $^{243}$Am α-groups which are unassigned.

## 6. Conclusions

Much of the level structure of $^{237}$Np is firmly established; of 24 known levels, 23 have been given definite spin and parity assignments. These levels belong to five rotational bands based on four single-quasiparticle states and one "vibrational" excitation. The 770-keV level, which is probably a 7/2+ state, is probably also of vibrational-excited character. Alpha-decay branchings are consistent with the given Nilsson assignments for the single quasiparticle states, although the presence of some admixtures in at least the two lowest-lying bands has important effects on the de-excitation processes[2]). This structure accounts for all $^{241}$Am α-transitions of intensity greater than $10^{-4}$%, and very probably includes all rotational bands below about 400 keV excitation in $^{237}$Np. $^{239}$Np has a very similar structure, although our knowledge of it is more sketchy.

A challenging problem for future work is to elucidate details of the admixture of vibrational-excited components (i.e., 3-quasiparticle components)

and one-quasiparticle components in the bands of odd-mass deformed nuclei. A partial study of β-vibrations in heavy nuclei[30,31]) has revealed irregularities from one nucleus to the next which are incompatible with a simple macroscopic vibrational interpretation. In $^{237}$Np, the first odd-mass nucleus for which transitions from a β-vibrational band have been studied in detail, the predominant M1 character of these transitions is strongly at odds with the vibrational model. The calculations of Soloviev[57]) using a microscopic model seem a promising approach toward explaining such failures of simple "vibrational" models.

The α-decay calculations described in sect. 2 provided clues which revealed the existence of the 1/2-[530] band. For this band and the three other Nilsson bands known in $^{237}$Np, the predicted α-intensities are correct within an order of magnitude or less, and the intensity patterns within the rotational bands are also correctly predicted.

The complexities of the level systems detectably populated in odd-mass α-decay are great enough that no single approach is sufficient. The combination of α-decay and β-decay studies exploiting the high-resolution γ-spectroscopic capabilities of germanium, coupled with theoretical estimates of relative α- and γ-transition rates, can significantly extend our knowledge of many heavy nuclei. Inelastic scattering studies on $^{237}$Np would be a welcome addition to probe vibrational-excited components based on the ground state.

Acknowledgments

The source for the γ-ray spectrum was lent to us by Prof. B. B. Cunningham and co-workers. The efficiency of the γ-ray spectrometer was calibrated by Dr. Toshimitsu Yamazaki, Dr. Stanley Prussin, and Judd Haverfield. Design and construction of the coincidence spectrometer was performed by Dr. Sven Bjørnholm, Fred S. Goulding, and Donald Landis. Principal credit for the microscopic α-decay theory, so useful to our study, goes to Dr. Hans-Jörg Mang, now of the Technische Hochschule, Munich. We are also grateful to Dr. J. M. Hollander, Dr. T. Yamazaki, Dr. Frank S. Stephens, Jr., and Dr. Richard M. Diamond for helpful discussions of the results.

References

1) J. O. Rasmussen, F. L. Canavan, and J. M. Hollander, Phys. Rev. 107 (1957) 141; this paper is referred to hereafter as RCH.

2) T. Yamazaki and J. M. Hollander, Nucl. Phys. (1966) (following paper); this paper is referred to hereafter as YH.

3) D. C. Hoffman and B. J. Dropesky, Phys. Rev. 109 (1958) 1282

4) F. Asaro, F. L. Reynolds, and I. Perlman, Phys. Rev. 87 (1952) 277; see correction in F. Asaro and I. Perlman, Phys. Rev. 93 (1954) 1423

5) F. Asaro and I. Perlman, unpublished results (1961) quoted in ref. 6

6) Earl K. Hyde, Isadore Perlman, and Glenn T. Seaborg, Nuclear Properties of the Heavy Elements, Prentice-Hall, Inc., Englewood Cliffs, New Jersey (1964)

7) L. L. Gol'din, E. F. Tret'yakov, and G. I. Novikova, Conf. Acad. Sci. USSR on Peaceful Uses of Atomic Energy, Phys. Math. Sci. (July 1955) p. 226 [Consultants Bureau Translation AEC-tr-2435, part 1, p. 167; UCRL translation UCRL-242 tr.]

8) S. Rosenblum, M. Valadares, and J. Milsted, J. Phys. (Paris) 18 (1957) 609

9) Chin-Fan Leang, Compt. rend. 255 (1962) 3155

10) S. A. Baranov, V. M. Kulakov, A. G. Zelenkov, and V. M. Shatinsky, JETP 43 (1962) 795; [Translation: Soviet Phys. JETP 16 (1963) 562]; Nucl. Phys. 43 (1963) 547

11) S. A. Baranov, V. M. Kulakov, and V. M. Shatinsky, Nucl. Phys. 56 (1964) 252; referred to hereafter as BKS.

12) P. P. Day, Phys. Rev. 97 (1955) 689

13) J. Milsted, S. Rosenblum, and M. Valadares, Compt. rend. 239 (1954) 259, 700

14) S. A. Baranov and K. N. Shliagin, Conf. Acad. Sci. USSR on Peaceful Uses of Atomic Energy, Phys. Math. Sci. (July 1955) p. 251; [Consultants Bureau Translation AEC-tr-2435, part 1, p. 183.]

15) L. B. Magnusson, Phys. Rev. 107 (1957) 161

16) J. M. Hollander, W. G. Smith, and J. O. Rasmussen, Phys. Rev. 102 (1956) 1372

17) H. Jaffe, T. O. Passell, C. I. Browne, and I. Perlman, Phys. Rev. 97 (1955) 142

18) J. K. Beling, J. O. Newton, and B. Rose, Phys. Rev. 87 (1952) 670; Phys. Rev. 86 (1952) 797

19) J. F. Turner, Phil. Mag. 46 (1955) 687

20) P. S. Samoilov, Bull. Acad. Sci. USSR, 23 (1959) 1416 [Consultants Bureau Translation 23 (1959) 1401]

21) J. L. Wolfson, W. J. King, and J. J. H. Park, Can. J. Phys. 41 (1963) 1489

22) J. L. Wolfson and J. J. H. Park, Can. J. Phys. 42 (1964) 1387

23) H. J. Mang, Annual Review of Nuclear Science, Vol. 14, Annual Reviews, Inc., Palo Alto, California (1964) p. 1

24) H. J. Mang and J. O. Rasmussen, Kgl. Danske Videnskab. Selskab, Mat. Fys. Skrifter, 2 (1962) No. 3

25) H. J. Mang, J. K. Poggenburg, and J. O. Rasmussen, Nucl. Phys. 64 (1965) 353

26) P. O. Fröman, Kgl. Danske Videnskab. Selskab, Mat. Fys. Skrifter 1 (1957) No. 3

27) J. K. Poggenburg, University of California Lawrence Radiation Laboratory Report UCRL-16187, (Ph.D. Thesis) 1965

28) W. L. Hansen and B. V. Jared, Nucl. Instr. Methods 31 (1964) 301

29) G. T. Ewan and A. J. Tavendale, Nucl. Instr. Methods 26 (1964) 183; Can. J. Phys. 42 (1964) 2286

30) S. Bjørnholm, M. Lederer, F. Asaro, and I. Perlman, Phys. Rev. 130 (1963) 2000

31) Charles Michael Lederer, University of California Lawrence Radiation Laboratory Report UCRL-11028 (Ph.D. Thesis) 1963

32) Fred S. Goulding and William L. Hansen, Nucl. Instr. Methods 12 (1961) 249

33) F. Asaro, F. S. Stephens, J. M. Hollander, and I. Perlman, Phys. Rev. 117 (1960) 492

34) A. H. Wapstra, G. J. Nijgh, and R. Van Lieshout, Nuclear Spectroscopy Tables, North-Holland Publishing Co., Amsterdam (1959)

35) L. A. Sliv and I. M. Band, Coefficients of Internal Conversion of Gamma Radiation, Academy of Sciences of the USSR, Moscow-Leningrad, Part 1 (1956), Part II (1958)

36) W. Michaelis, Z. Physik 186 (1965) 42

37) F. S. Tomkins, Phys. Rev. 73 (1948) 1214

38) J. E. Mack, Rev. Mod. Phys. 22 (1950) 64

39) B. Bleany, P. M. Llewellyn, M. H. L. Pryce, and G. R. Hall, Phil. Mag. 45 (1954) 992

40) J. O. Newton, Physica 22 (1956) 1129; Nucl. Phys. 5 (1958) 218

41) B. R. Mottelson and S. G. Nilsson, Kgl. Danske Videnskab. Selskab, Mat. Fys. Skrifter 1 (1959) No. 8

42) F. S. Stephens, Frank Asaro, and I. Perlman, Phys. Rev. 113 (1959) 212

43) M. Fred and F. S. Tomkins, Phys. Rev. 89 (1953) 318

44) R. Thorne, Nature 178 (1956) 484

45) Richard Marrus, William A. Nierenberg, and Joseph Winocur, Phys. Rev. 120 (1960) 1429

46) J. O. Rasmussen, Arkiv Fysik 7 (1953) 185

47) A. Bohr, P. O. Fröman, and B. R. Mottelson, Kgl. Danske Videnskab. Selskab, Mat.-Fys. Medd 29 (1955) No. 10

48) Aage Bohr and Ben R. Mottelson, Kgl. Danske Videnskab. Selskab, Mat.-Fys. Medd. 27 (1953) No. 16

49) O. Nathan and S. G. Nilsson, in Alpha-, Beta-, and Gamma-ray Spectroscopy, Ed. by Kai Siegbahn, North-Holland Publishing Co., Amsterdam (1965) Chap. X

50) M. E. Bunker, J. P. Mize, and J. W. Starner, Bull. Am. Phys. Soc. 2 (1957) 104

51) Melvin A. Preston, Phys. Rev. 71 (1947) 865; Helen V. Michel, University of California Lawrence Radiation Laboratory Report UCRL-9229 (unpublished) 1960

52) G. Alaga, K. Alder, A. Bohr, and B. R. Mottelson, Kgl. Danske Videnskab. Selskab, Mat.-Fys. Medd 29 (1955) No. 9

53) P. Gregers-Hansen, O. B. Nielsen, and R. K. Sheline, Nucl. Phys. 12 (1959) 389

54) O. B. Nielsen, Proceedings of the Rutherford Jubilee International Conference, Heywood, London (1961) p. 317

55) J. Borggreen, O. B. Nielsen, and H. Nordby, Nucl. Phys. 29 (1962) 515

56) K. J. Blinowska, P. G. Hansen, H. L. Nielsen, O. Schult, and K. Wien, Nucl. Phys. 55 (1964) 331

57) V. G. Soloviev, Nucl. Phys. 69 (1965) 1

Table 1
$\alpha$-groups of $^{241}Am$

Baranov, Kulakov, and Shatinsky (ref. 11)

| Excited state energy, keV | $\alpha$-intensity, % | Excited state energy, keV | $\alpha$-Intensity, % |
|---|---|---|---|
| 0 | 0.25 | | |
| 32.0 | 0.12 | 357 | $6 \times 10^{-4}$ |
| 59.6 | 86.0 | 369 | $9 \times 10^{-4}$ |
| 76.5 | <0.04 | 373 | $3 \times 10^{-4}$ |
| 103 | 12.7 | 395 | $7 \times 10^{-4}$ |
| 129 | ≈0.01 | 438 | $4 \times 10^{-4}$ |
| 158 | 1.33 | 456 | $\approx 4 \times 10^{-4}$ |
| 226 | 0.015 | 463 | $\approx 4 \times 10^{-4}$ |
| 270 | $5 \times 10^{-4}$ | 485 | $1.4 \times 10^{-4}$ |
| 306 | $2.4 \times 10^{-3}$ | 549 | $10^{-4}$ |
| 327 | $1.3 \times 10^{-3}$ | 723 | $7 \times 10^{-4}$ |
| | | 758 | $8.6 \times 10^{-5}$ |

Table 2
$^{241}$Am γ-ray spectrum

| 1<br>Transition initial state → final state | 2<br>Transition energy, keV | 3<br>Photons per 100 $^{241}$Am α-decays | 4<br>Multipolarity (mixing ratios refer to photon intensities) | 5<br>Transitions per 100 $^{241}$Am α-decays |
|---|---|---|---|---|
| C 1/2- → C 3/2- [a] | 13.81 [2] | | M1 + 0.15% E2 | |
| B 5/2- → C 7/2+ | 26.35 [2] | 2.5 ± 0.2 [15] | E1 [2,22] | |
| A 7/2+ → A 5/2+ | 33.20 [2] | 0.014 [15,12] | M1 + 1.4% E2 [2] | 21 ± 4 [b] |
| D 3/2+ → D 1/2+ [a] | 38.54 [2] | | E2/M1 > 0.3 [2] | <1.2 × $10^{-4}$ [b] |
| A 9/2+ → A 7/2+ [c,d] | 42.6 [35] | | [M1 + E2] [e] | |
| B 7/2- → B 5/2- | 43.42 [2] | 0.07 [15] | M1 + 14% E2 [2,22] | 15 ± 3 [f] |
| D 1/2+ → C 1/2- [a] | 51.01 [2] | | E1 [2] | (7±2) × $10^{-5}$ [b] |
| B 9/2- → B 7/2- | 55.56 [22] | | M1 + 17% E2 [22] | 1.4 ± 0.3 [f] |
| B 5/2- → A 5/2+ | 59.54 [2] | 35.9 ± 0.7 [15,33] | E1 [33,2] | 76 ± 7 [b] |
| D 1/2+ → C 3/2- [a] | 64.83 [2] | | E1 [2] | (2.5±0.8) × $10^{-4}$ [b] |
| B 11/2- → B 9/2- | 67.5 [22] | | M1 + 10% E2 [g] | (9±4) × $10^{-4}$ [f] |
| A 9/2+ → A 5/2+ [d] | 76 [39] | | [E2] [e] | |
| B 9/2- → B 5/2- | 98.7 ± 1.0<br>99.00 [22] | 0.024±0.003 [h]<br>0.023 [15] | E2 [22] | 0.35 ± 0.07 [f] |
| B 7/2- → A 5/2+ | 102.7 ± 1.0 | 0.019 ± 0.003 [i]<br>0.019 [15] | [E1] [e] | 0.021 ± 0.003 |
| not assigned | 106.3 ± 2.0 ? | <0.001 | | |
| Np $K_\beta$ x-rays | 113.8 ± 1.5 | (7±4) × $10^{-4}$ | | |
| B 11/2- → B 7/2- | 122.1 ± 2.0 ? | ≤0.002 | [E2] [e] | ≤0.013 |
| B 9/2- → A 7/2+ | 125.1 ± 2.0 | (5±2) × $10^{-3}$ | [E1] [e] | (6±2) × $10^{-3}$ |
| B 13/2- → B 9/2- | 146.3 ± 1.0 | (1.6±0.6) × $10^{-4}$ | [E2] [e] | (5.9±2.3) × $10^{-4}$ |
| B 11/2- → A 9/2+ | 150 ± 2 ? | ≤2.4 × $10^{-5}$ | [E1] [e] | ≤2.9 × $10^{-5}$ |
| C 3/2- → B 7/2- | 164.4 ± 1.0<br>164.61 [2] | (4.1±2.1) × $10^{-5}$ | E2 [2] | (1.1±0.6) × $10^{-4}$ |
| B 15/2- → B 11/2- | 169.2 ± 1.0 | (1.0±0.4) × $10^{-4}$ | [E2] [e] | (2.5±1.0) × $10^{-4}$ |
| C 3/2- → B 5/2- | 208.2 ± 0.5<br>208.00 [2] | (5.6±1.0) × $10^{-4}$ | M1 + 2.1% E2 | (2.2±0.4) × $10^{-3}$ |
| not assigned [j] | 221.5 ± 1.0 | (3.5±0.8) × $10^{-5}$ | | |
| C 1/2- → B 5/2- [a] | 221.80 [2] | | E2 [2] | |
| C 3/2- → A 7/2+ [a] | 234.40 [2] | | M2 [2] | (5±1) × $10^{-6}$ [b] |
| C 3/2- → A 5/2+ | 267.2 ± 1.0<br>267.54 [2] | (2.7±0.7) × $10^{-5}$ | E1 + M2 [2] | (5±2) × $10^{-5}$ [b] |
| D 5/2+ → A 9/2+ | 292.0 ± 1.5<br>292.7 [2] | (2.1±0.7) × $10^{-5}$ | [E2] [e] | (2.5±0.8) × $10^{-5}$ |
| not assigned | 311.9 ± 1.0 | (2.7±0.8) × $10^{-5}$ | | |
| D 9/2+ → A 11/2+ | 322.6 ± 0.5 | (1.6±0.3) × $10^{-4}$ | [M1] | (3.0±0.6) × $10^{-4}$ |
| D 1/2+ → A 5/2+ | 332.4 ± 0.7<br>332.56 [2] | (1.8±0.4) × $10^{-4}$ | E2 [2] | (2.1±0.5) × $10^{-4}$ |
| D 5/2+ → A 7/2+ | 335.3 ± 0.5<br>335.38 [2] | (5.7±1.0) × $10^{-4}$ | M1, <15% E2 [2] | (1.0±0.2) × $10^{-3}$ |
| D 3/2+ → A 7/2+ [a] | 337.7 ± 0.5 [2] | | [E2] [e] | <4 × $10^{-6}$ |
| D 5/2+ → A 5/2+ | 368.5 ± 1.0<br>368.59 [2] | (2.8±0.6) × $10^{-4}$ [k] | M1, <15% E2 [2] | (4.5±1.0) × $10^{-4}$ |
| D 3/2+ → A 5/2+ | 370.94 [2] | <5 × $10^{-5}$ [k] | M1, <15% E2 [2] | <8 × $10^{-5}$ |
| D 9/2+ → A 9/2+ | 376.8 ± 0.5 | (1.6±0.3) × $10^{-4}$ | [M1] | (2.5±0.5) × $10^{-4}$ |

Table 2. Continued

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Transition initial state → final state | Transition energy, keV | Photons per 100 $^{241}$Am α-decays | Multipolarity (mixing ratios refer to photon intensities) | Transitions per 100 $^{241}$Am α-decays |
| D 7/2+ → A 9/2+ | 383.9 ± 1.0 | $(2.9\pm0.8) \times 10^{-5}$ | [M1] | $(4.4\pm1.2) \times 10^{-5}$ |
| D 9/2+ → A 7/2+ | 419.6 ± 1.0 | $(3.6\pm1.0) \times 10^{-5}$ | [M1] | $(5.2\pm1.4) \times 10^{-5}$ |
| D 7/2+ → A 7/2+ | 426.7 ± 1.0 | $(3.3\pm0.9) \times 10^{-5}$ | [M1] | $(4.7\pm1.3) \times 10^{-5}$ |
| D 9/2+ → A 5/2+ | 454 ± 2 ?? | $<1.7 \times 10^{-5}$ | [E2] [e] | $<1.9 \times 10^{-5}$ |
| D 7/2+ → A 5/2+ | (460) not observed | $<1.0 \times 10^{-5}$ | [M1] | $<1.3 \times 10^{-5}$ |
| B' 7/2- → B 11/2- | (530) not observed | $<7 \times 10^{-6}$ | [E2] [e] | $<7 \times 10^{-6}$ |
| B' 5/2- → B 9/2- | (563) not observed | $<5 \times 10^{-6}$ | [E2] [e] | $<5 \times 10^{-6}$ |
| not assigned | 570.2 ± 2.0 | $(1.0\pm0.5) \times 10^{-5}$ | | |
| B' 7/2- → B 9/2- | 597.4 ± 1.5 | $(1.0\pm0.5) \times 10^{-5}$ | M1 [l] | $(1.2\pm0.6) \times 10^{-5}$ |
| B' 5/2- → B 7/2- | 618.9 ± 0.5 | $(8.5\pm0.5) \times 10^{-5}$ | M1 [l] | $(9.9\pm0.6) \times 10^{-5}$ |
| E(7/2+) → A 11/2+ | 641.5 ± 1.5 | $(1.0\pm0.3) \times 10^{-5}$ | — | $(1.0\pm0.3) \times 10^{-5}$ |
| B' 7/2- → B 7/2- | 652.7 ± 0.5 | $(5.5\pm0.3) \times 10^{-5}$ | M1 [+E0] [l] | $(7\pm1) \times 10^{-5}$ |
| B' 5/2- → B 5/2- | 662.3 ± 0.3 | $(5.3\pm0.3) \times 10^{-4}$ | M1 + 8% E0 [m] | $(6.4\pm0.5) \times 10^{-4}$ |
| not assigned | 676 ± 2 ?? | $\leq 2.2 \times 10^{-6}$ | | |
| B' 7/2- → A 9/2+ | 680.0 ± 1.5 | $(5.3\pm1.7) \times 10^{-6}$ | [E1] [e] | $(5.3\pm1.7) \times 10^{-6}$ |
| B' 5/2- → A 7/2+ | 688.7 ± 0.5 | $(4.3\pm0.5) \times 10^{-5}$ | [E1] [e] | $(4.3\pm0.5) \times 10^{-5}$ |
| B' 7/2- → B 5/2- | 695.4 ± 1.0 | $(1.0\pm0.2) \times 10^{-5}$ | M1 [l] | $(1.2\pm0.2) \times 10^{-5}$ |
| E(7/2+) → B 5/2- | 709.8 ± 1.0 | $(9\pm2) \times 10^{-6}$ | | $(9\pm2) \times 10^{-6}$ |
| B' 5/2- → A 5/2+ | 722.1 ± 0.5 | $(2.8\pm0.2) \times 10^{-4}$ | E1 [e,n] | $(2.8\pm0.2) \times 10^{-4}$ |
| E(7/2+) → A 7/2+ | 737.0 ± 1.0 | $(1.2\pm0.2) \times 10^{-5}$ | | $(1.3\pm0.2) \times 10^{-5}$ |
| B' 7/2- → A 5/2+ | 756.8 ± 1.0 | $(1.3\pm0.2) \times 10^{-5}$ | [E1] [e] | $(1.3\pm0.2) \times 10^{-5}$ |
| not assigned | 767.0 ± 2.0 | $(8\pm3) \times 10^{-6}$ | | |
| E(7/2+) → A 5/2+ | 770.7 ± 2.0 | $(1.0\pm0.3) \times 10^{-5}$ | | $(1.1\pm0.3) \times 10^{-5}$ |

[a] Observed only in $^{237}$U $\beta^-$-decay

[b] Calculated with the use of $^{237}$U intensity data[2])

[c] Observed in $^{237}$Pu EC decay

[d] Observed in Coulomb excitation of $^{237}$Np

[e] Required by the decay scheme

[f] Calculated with the use of relative electron intensities[22]) normalized as described in sect. 4.1

[g] Recalculated from the $L_I/L_{II}$ ratio[22]) with use of theoretical conversion coefficients of Sliv and Band[35])

[h] A small contribution from Np $K_{\alpha_{II}}$ x-rays has been subtracted

[i] A small contribution from Np $K_{\alpha_I}$ x-rays has been subtracted

[j] This γ-ray is 2 orders of magnitude too intense to be the C 1/2- → B 5/2- transition

[k] The intensities of the unresolved 368.59 and 370.94 keV γ-rays are apportioned by use of the intensity ratio $W_\gamma(368.59)/W_\gamma(335.38)$ known from $^{237}$U decay[2]).

[l] See sect. 5.5

[m] From the measured K-conversion coefficient (see sect. 4.2). The E0 component is expressed as the fraction of total transitions.

[n] The measured limit on the K-conversion coefficient (<0.02) is consistent only with an E1 or E2 assignment

Table 3
Comparison of calculated and experimental α-intensities

| Level energy | Spin | α-intensity, % | |
|---|---|---|---|
| | | Calculated | Experimental |
| | K = 5/2+[642] band (A) | | |
| 0 | 5/2 | 0.23 | 0.25[a] |
| 33.20 | 7/2 | 0.10 | 0.12[a] |
| 75.9 | 9/2 | 0.028 | <0.04[a] |
| 130 | 11/2 | 0.006 | ≈0.01[a] |
| (191) | 13/2 | $3.5 \times 10^{-5}$ | --- |
| (262) | 15/2 | $2.6 \times 10^{-4}$ | --- |
| | K = 5/2-[523] band (B) | | |
| 59.54 | 5/2 | 87.1 | 86.0[a] |
| 102.96 | 7/2 | 10.8 | 12.7[a] |
| 158.52 | 9/2 | 1.8 | 1.3[a] |
| 226.0 | 11/2 | 0.020 | 0.015[a] |
| 304.8 | 13/2 | 0.0035 | 0.0024[a] |
| 395.2 | 15/2 | 0.0004 | 0.0007[a] |
| | K = 1/2-[530] band (C) | | |
| 267.54 | 3/2 | 0.0015 | 0.0005[a] |
| 281.35 | 1/2 | 0.000035 | --- |
| 327 | 7/2 | 0.0016 | 0.0008[b] |
| 357 | 5/2 | 0.0005 | 0.0006[a] |
| 438 | 11/2 | 0.00028 | 0.0004[a] |
| 485 | 9/2 | 0.00005 | 0.00014[a] |
| (606) | 15/2 | 0.00006 | --- |
| (671) | 13/2 | $7 \times 10^{-7}$ | --- |

Table 3. Continued

| Level energy | Spin | α-intensity, % | |
|---|---|---|---|
| | | Calculated | Experimental |
| | K = 1/2+[400] band (D) | | |
| 332.36 | 1/2 | 0.00007 | 0.0005[c] |
| 368.59 | 5/2 | 0.00012 | 0.0015[c] |
| 370.94 | 3/2 | 0.000026 | <0.00020[c] |
| 452.7 | 9/2 | 0.00006 | 0.0006[c] |
| 459.8 | 7/2 | 0.000034 | 0.00009[c] |
| (589) | 13/2 | $1.5 \times 10^{-6}$ | --- |
| (595) | 11/2 | $2.2 \times 10^{-6}$ | --- |

[a]Measured directly from the α-spectrum by BKS.

[b]See discussion of this level, sects. 5.3 and 5.4

[c]Based on our γ-spectrum and the decay scheme

Table 4
Intensity balance for the K = 5/2-[523] (B) band

| Level | α-group intensity, % (BKS) | Total feeding of level, % | De-exciting ratiation | |
|---|---|---|---|---|
| | | | Transition | Intensity, % |
| 59.54 B 5/2- | | | 26.35 → A 7/2+ | [21±4][a] |
| | | | 59.54 → A 5/2+ | 76±7 |
| | 86.0 | 99.6 | total | 97±8 |
| 102.96 B 7/2- | | | 43.42 → B 5/2- | 15±3 |
| | | | 102.96 → A 5/2+ | 0.021 |
| | 12.7 | 14.1 | total | 15±3 |
| 158.52 B 9/2- | | | 55.56 → B 7/2- | 1.4±0.3 |
| | | | 99.00 → B 5/2- | 0.35±0.07 |
| | | | 125.1 → A 7/2+ | $(5\pm2) \times 10^{-3}$ |
| | 1.33 | 1.3 | total | 1.75±0.4 |
| 226.0 B 11/2- | | | 67.5 → B 9/2- | $(9\pm4) \times 10^{-3}$ |
| | | | 122.1 → B 7/2- | ≤0.013 |
| | | | 150 → A 9/2+ | $\leq 3 \times 10^{-5}$ |
| | 0.015 | 0.017 | total | >0.009, <0.022 |

[a]The intensity of this transition is assumed equal to the intensity of the 33.20 keV transition

Table 5
Intensity balance for the K = 1/2+[400] (D) band

| Level | α-group intensity, % (BKS) | De-exciting radiations | |
|---|---|---|---|
| | | Transition | Intensity, % |
| 332.36 D 1/2+ | $1.3 \times 10^{-3}$ | 55.01 → C 1/2- | $0.7 \pm 0.2 \times 10^{-4}$ |
| | | 64.83 → C 3/2- | $(2.5 \pm 0.8) \times 10^{-4}$ |
| | | 332.36 → A 5/2+ | $(2.1 \pm 0.5) \times 10^{-4}$ |
| | | total | $(5.3 \pm 1.0) \times 10^{-4}$ |
| 368.59 D 5/2+ | $1.2 \times 10^{-3}$ | 292.7 → A 9/2+ | $(2.5 \pm 0.8) \times 10^{-5}$ |
| | | 335.38 → A 7/2+ | $(1.0 \pm 0.2) \times 10^{-3}$ |
| | | 368.59 → A 5/2+ | $(4.5 \pm 1.0) \times 10^{-4}$ |
| | | total | $(1.5 \pm 0.4) \times 10^{-3}$ |
| 370.94 D 3/2+ | | 38.54 → C 3/2- | $<1.2 \times 10^{-4}$ |
| | | 337.7 → A 7/2+ | $<4 \times 10^{-6}$ |
| | | 370.94 → A 5/2+ | $<8 \times 10^{-5}$ |
| | | total | $<2.0 \times 10^{-4}$ |
| 452.7 D 9/2+ | $8 \times 10^{-4}$ | intraband transitions | [0] |
| | | 322.6 → A 11/2+ | $(3.0 \pm 0.6) \times 10^{-4}$ |
| | | 376.8 → A 9/2+ | $(2.5 \pm 0.5) \times 10^{-4}$ |
| | | 419.6 → A 7/2+ | $(5.2 \pm 1.4) \times 10^{-5}$ |
| | | total | $(6.0 \pm 0.8) \times 10^{-4}$ |
| 459.8 D 7/2+ | | intraband transitions | [0] |
| | | 383.9 → A 9/2+ | $(4.4 \pm 1.2) \times 10^{-5}$ |
| | | 426.7 → A 7/2+ | $(4.7 \pm 1.3) \times 10^{-5}$ |
| | | 460 → A 5/2+ | $<1.3 \times 10^{-5}$ |
| | | total | $(9.1 \pm 2.0) \times 10^{-5}$ |

Table 6
Branching ratios for transitions between band B' and band B

| Initial state | Final state | Branching ratios | | |
|---|---|---|---|---|
| | | Experimental | M1 | E2 |
| 721.9 B' 5/2- | 59.54 B 5/2- | (100) | (100) | (100) |
| | 102.96 B 7/2- | 16 ± 2 | 33 | 95 |
| | 158.52 B 9/2- | <1 | --- | 21 |
| 755.8 B' 7/2- | 59.54 B 5/2- | (100) | (100) | (100) |
| | 102.96 B 7/2- | 530 ± 120 | 153 | 3 |
| | 158.52 B 9/2- | 100 ± 50 | 115 | 50 |
| | 226.0 B 11/2- | <70 | --- | 18 |

## Figure Captions

Fig. 1. $^{241}$Am $\gamma$-rays measured with the lithium-drifted germanium detector. The spectrum shown is a composite of three measurements covering different energy intervals.

Fig. 2. $^{241}$Am coincidence spectra

(a) $\alpha$-particles coincident with all $\gamma$-rays of energy >500 keV.

(b) $\alpha$-particles coincident with all conversion electrons of energy >380 keV.

(c) $\gamma$-rays coincident with the 4.84 MeV $\alpha$-peak. The width of the $\alpha$-window used in (c) and (d) was great enough to include the entire complex $\alpha$-peak.

(d) Conversion electrons coincident with the 4.84 MeV $\alpha$-peak.

Fig. 3. (a) Decay scheme for $^{241}$Am. Energies (in keV) and spins are given in boldface type. Absolute photon intensities are given on the $\gamma$-rays, and relative photon intensities (normalized to 100 for each level) above the $\gamma$-rays, all intensities being in lighter type. Slant numbers to the right of the $\alpha$-intensities are hindrance factors.

(b) Decay Scheme for $^{243}$Am. See caption for fig. 3(a).

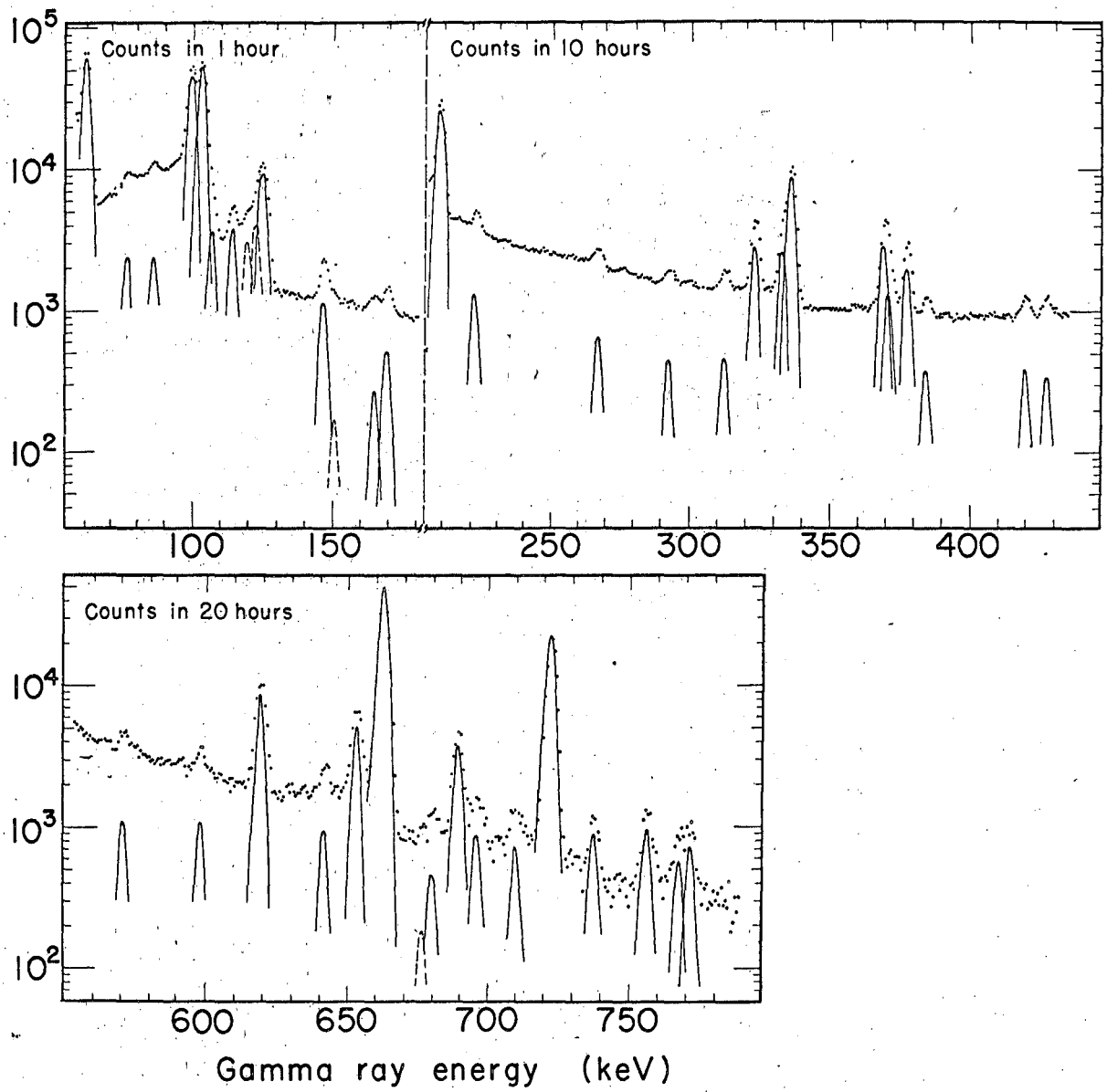

Counts in 1 hour
Counts in 10 hours
Counts in 20 hours
$10^5$
$10^4$
$10^3$
$10^2$
100
150
250
300
350
400
600
650
700
750
Gamma ray energy (keV)
MUB-7120

Fig. 1

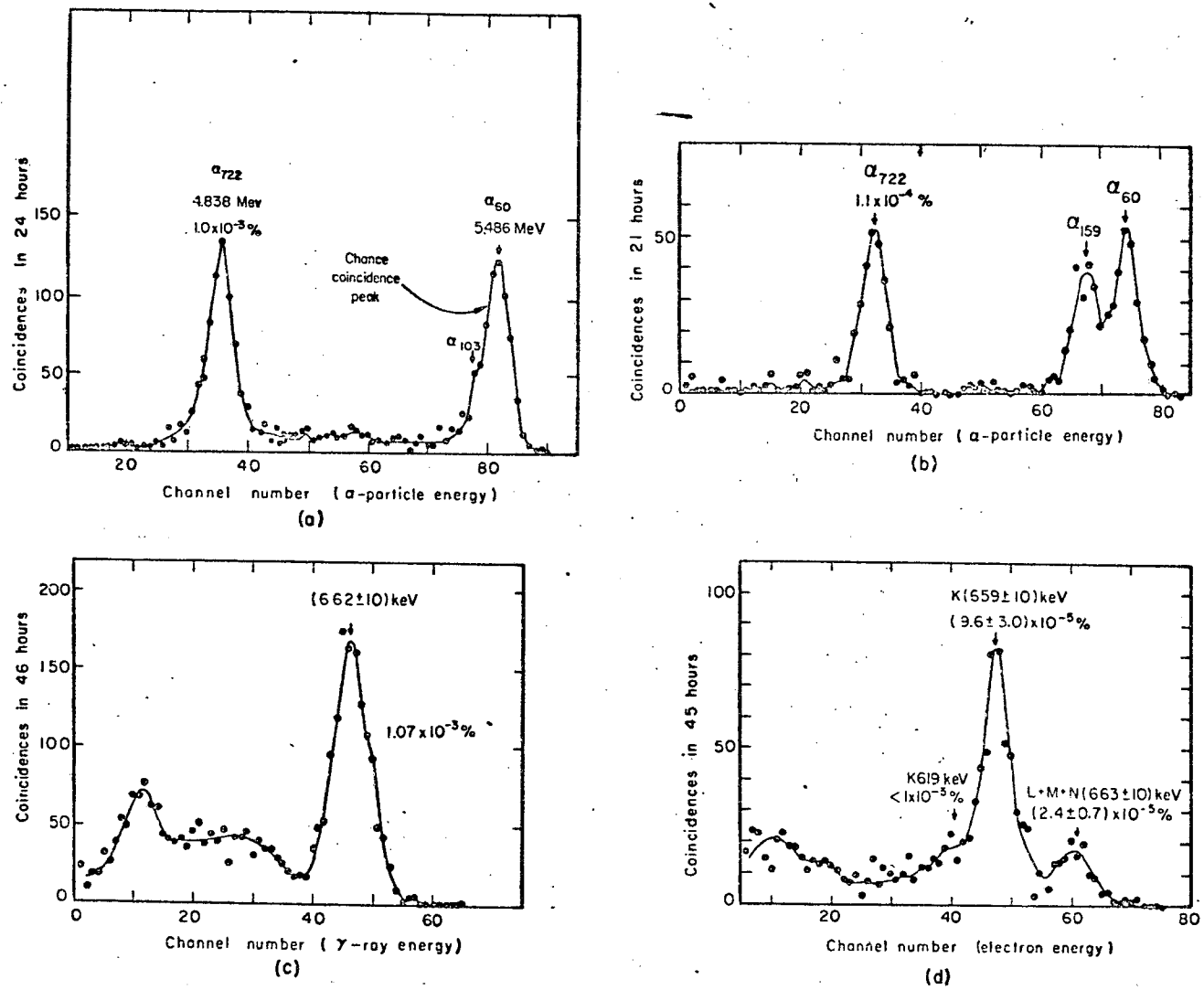

Coincidences in 24 hours
$\alpha_{722}$
4.838 Mev
$1.0 \times 10^{-3}$%
$\alpha_{60}$
5.486 MeV
Chance coincidence peak
$\alpha_{103}$
Channel number ( α-particle energy )
(a)
Coincidences in 21 hours
$\alpha_{722}$
$1.1 \times 10^{-4}$ %
$\alpha_{159}$
$\alpha_{60}$
Channel number ( α-particle energy )
(b)
Coincidences in 46 hours
(662±10) keV
$1.07 \times 10^{-3}$%
Channel number ( γ-ray energy)
(c)
Coincidences in 45 hours
K(659±10) keV
$(9.6 \pm 3.0) \times 10^{-5}$%
K619 keV
$< 1 \times 10^{-5}$%
L+M+N(663±10) keV
$(2.4 \pm 0.7) \times 10^{-5}$%
Channel number (electron energy)
(d)
MUB 6725A

Fig. 2

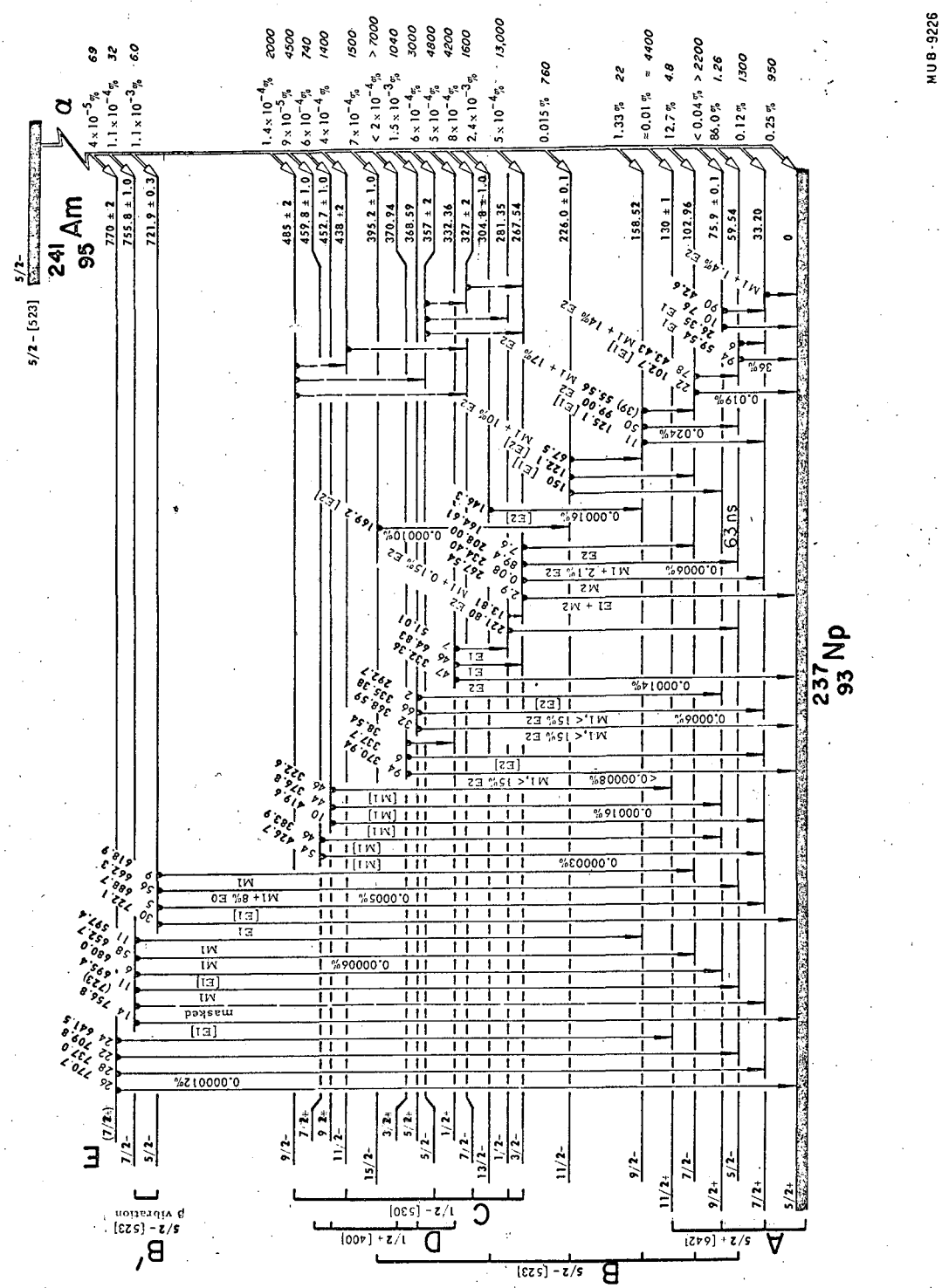
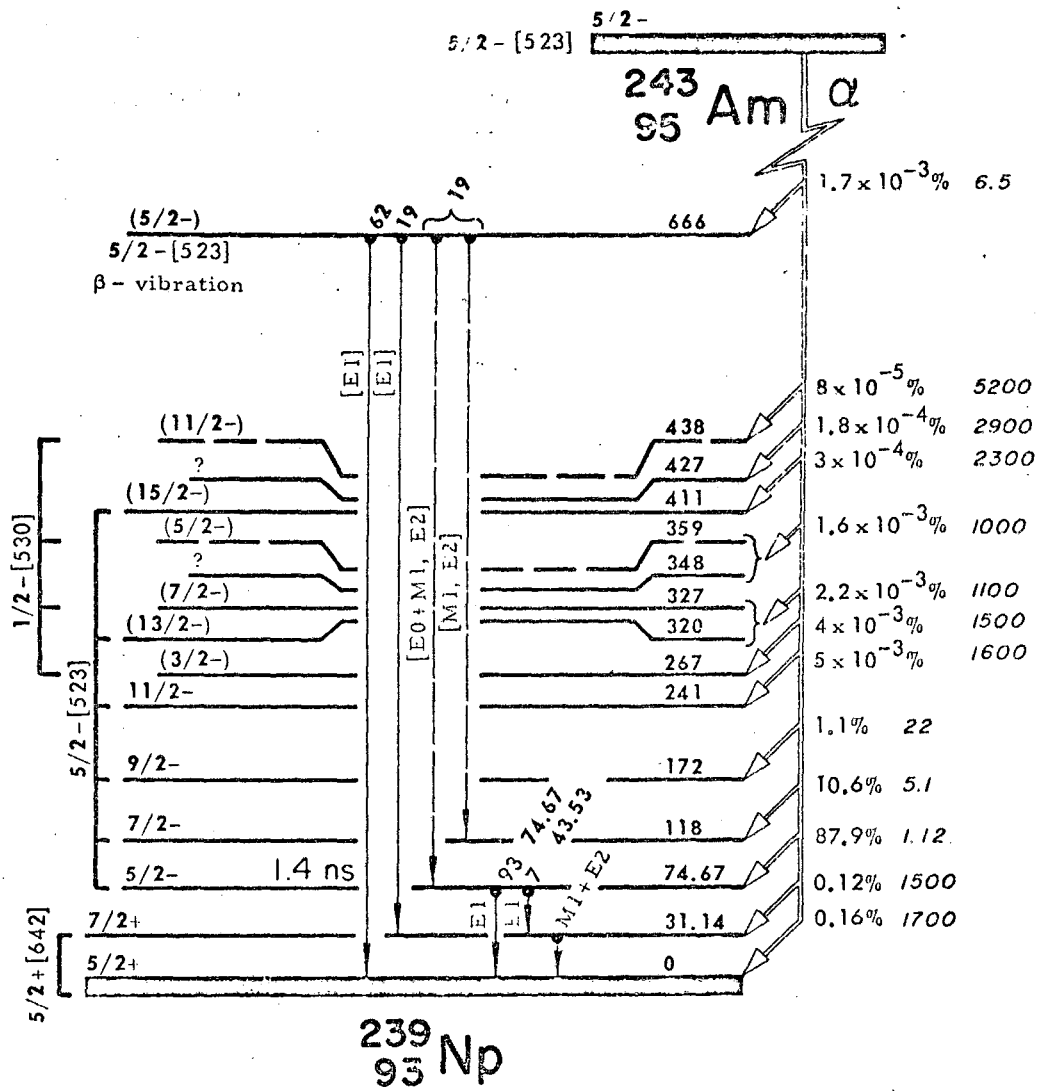

241 95 Am
237 93 Np
α
5/2- [523]
5/2-
MUB-9226
A
B
C
D
B'
5/2 + [642]
5/2 - [523]
1/2 + [400]
1/2 - [530]
5/2 - [523]
β vibration

Fig. 3(a)




MUB-9489

Fig. 3(b)

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.