into account, both measurements gave the same value of $\mu = 2.4 \pm 0.3$ nm. The Schmidt limit for $d_{5/2}$ is 4.8 nm. The deviation of the magnetic moment from the Schmidt value may indicate that the 114-keV state has admixtures due to coupling of phonons and particle states. The value of the magnetic moment of the 114-keV level agrees with the calculated value of Kisslinger and Sorensen.[23] It is also in agreement with the calculated value of Joshi[25] using a model in which the $g_{7/2}$ and $d_{5/2}$ single-particle states are coupled to one or two phonons.

The 272- and 158-keV transitions are found to be $E1$ from internal-conversion measurements[13,26,27] using a double-focusing beta-ray spectrometer. This showed that the 272-keV level has odd parity. The $E1$ transitions from the 272-keV level to the ground state and the 114-keV state are found to be retarded by factors of 3.0×10^5 and 1.7×10^5, respectively. This has not been explained at present.

Further theoretical investigations on this nucleus would be very helpful.

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ACKNOWLEDGMENTS

The author is grateful to Professor B. V. Thosar for his interest and encouragement in the work. Thanks are due to Professor R. M. Steffen, Dr. M. C. Joshi, Dr. H. G. Devare, Dr. Girish Chandra, and Dr. C. V. K. Baba for useful discussions. The author is also grateful to K. G. Prasad for his help in the course of the work, P. N. Tandon for use of the time-to-pulse-height converter, and to G. T. Redkar for his help in computation using the CDC 3600-160A computer.

PHYSICAL REVIEW VOLUME 141, NUMBER 3 JANUARY 1966

Reinvestigation of the Decays of Eu^{146} and Pm^{146} and the Existence of Two Close-Lying States at $\approx$1381 keV in Sm^{146}†

D. J. Buss, E. G. Funk, and J. W. Mihelich
University of Notre Dame, Notre Dame, Indiana
(Received 20 August 1965)

The decays of Pm^{146} and Eu^{146} have been reinvestigated with the primary purpose of establishing the character of the second excited state previously reported at 1384 keV in Sm^{146}. Gamma-gamma directional correlation data obtained from studies of both the beta decay of Pm^{146} and the electron capture and positron decay of Eu^{146}, along with the K-shell internal-conversion-coefficient data, establish the existence of two close-lying states in Sm^{146} at 1380.7 and 1382.0 keV with spins and parities 3− and 4+, respectively. The gamma-ray spectra were studied with a lithium-drifted germanium detector. In the beta decay of Pm^{146} the feeding to the 3− state is at least 9.7 times that to the 4+ state, while in the decay of Eu^{146} the total feeding to the 3− state is $\approx$1.2 times that to the 4+ state. In addition, gamma-ray energies and intensities are presented for the transitions observed in the decay of Pm^{144} to Nd^{144} and Pm^{146} to Nd^{146} and Sm^{146}, and for some of the more intense transitions observed in the decay of Eu^{146}. Energy systematics of 3− and 4+ states for even-even nuclei in the transition region $A = 142$ to 152 are presented.

I. INTRODUCTION

ALTHOUGH the decays of Pm^{146} and Eu^{146} to Sm^{146} have been studied rather extensively, the character of the second excited state of Sm^{146} at $\approx$1384 keV has not been firmly established. Previous work in our laboratory has determined that Pm^{146} (1500 day) decays via beta decay to states in Sm^{146} at 749 keV (2+) and $\approx$1384 keV, and via electron capture to states in Nd^{146} at 453 and $\approx$1198 keV.[1,2] Eu^{146} (4.7 day) decays via electron capture and positron decay to excited states in Sm^{146} as high as 3700 keV.[2]

The most prominent transitions in the Eu^{146} decay are those of 749 and 635 keV which depopulate the 749-keV 2+ state and the 1384-keV second excited state in Sm^{146}, respectively. The internal conversion coefficient (I.C.C.) for the 635-keV transition and the directional correlation data for the 635–749-keV cascade following the Eu^{146} decay have not been satisfactorily explained. The I.C.C. is consistent only with an $E1 + \approx 8\%$ $M2$ assignment for the 635-keV transition. An $M2$ admixture of this magnitude would be unlikely since an upper limit on the half-life of the 1384-keV state has been measured to be 0.3 nsec,[3]

† Work supported in part by the U. S. Atomic Energy Commission.
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[2] E. G. Funk, Jr., J. W. Mihelich, and C. F. Schwerdtfeger, Nucl. Phys. 39, 147 (1962).
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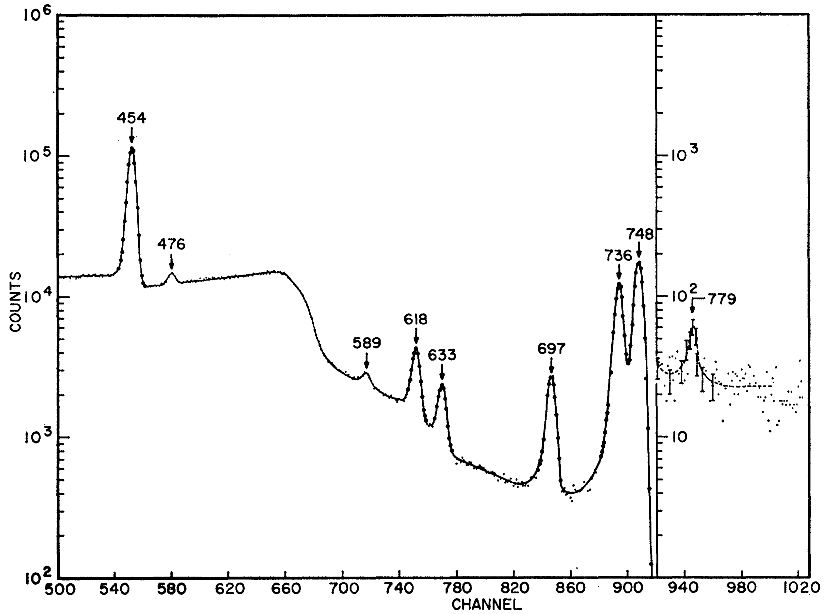

FIG. 1. Li-Ge gamma-ray spectrum obtained with the Pm^{146} source. Energies (in keV) shown are those measured in the present investigation. Insert shows evidence of a very weak transition at ≈779 keV.

while an 8% $M2$ admixture in the 635-keV transition would imply a half-life of greater than 0.8 nsec for this state.

Measured values for the directional-correlation coefficient A_2 for the 635–749-keV cascade have ranged from $A_2=0$ to $A_2=0.07$.[2,4,5] The complexity of the gamma-ray spectrum precludes an accurate measurement of this correlation.

TABLE I. Gamma-ray intensities for decay of Pm^{146} and Eu^{146}.

Nuclide	Transition energy (keV)	Gamma-ray intensity[a] (percent)
$Nd^{146}(Pm^{146}\rightarrow Nd^{146})$	453.9	65.3±5.4
	589	0.6±0.08
	736.3	23.1±1.8
	779	<0.4
$Sm^{146}(Pm^{146}\rightarrow Sm^{146})$	633.2	2.2±0.2
	634.5	<0.2
	747.5	34.7±1.8
$Sm^{146}(Eu^{146}\rightarrow Sm^{146})$	633.2	43.8±6.2[b]
	634.5	38.1∓6.2[b]
	665.8	7.1±0.8
	703.3	8.7±1.4
	747.5	100 ±4.6
$Nd^{144}(Pm^{144}\rightarrow Nd^{144})$	476	39.0±5.6
	618.1	100 ±7.6[c]
	696.7	100 ±6.4[c]

[a] Intensities are given in percent of total decay of parent nucleus.
[b] These intensities are based on the composite 634-keV gamma-ray photopeak height and the I.C.C. and directional-correlation data.
[c] These intensities were taken to be equal and were used in the relative-efficiency calibration.

[4] E. Takekoshi, Z. Matsumoto, M. Ishii, K. Sugiyama, S. Hayashibe, H. Sekiguchi, and H. Natsume, J. Phys. Soc. Japan **19**, 587 (1964).
[5] T. M. Goworek (private communication).

It had been suggested by Funk *et al.*[2] and Takekoshi *et al.*[4] that the 635-keV transition might be composite and that the 1384-keV state might actually consist of a 3−, 4+ doublet. Systematics of low-lying 3− and 4+ states in this mass region indicate that 3− and 4+ states should occur in Sm^{146} at about 1400 keV. Such a degeneracy of the 1384-keV state would explain the I.C.C. and directional correlation results since one of the composite "≈635 keV" transitions could be $E1$ and the other $E2$.

Even though the 635-keV transition following the Pm^{146} decay is weak and a Pm^{144} impurity is present in the source (the yield is too low to allow mass separation), a measurement of the 635–749-keV directional correlation would be extremely helpful in clarifying the situation. If the correlation following the Pm^{146} decay were clearly different from that following the Eu^{146} decay, this would be strong evidence for two close-lying states at ≈1384 keV.

This paper presents the results of an extensive reinvestigation of the decay of Pm^{146} and Eu^{146}. The gamma-ray spectra were studied with a high-resolution lithium-drifted germanium (Li-Ge) detector and the important directional correlations were measured using electronically stabilized NaI(Tl) detectors and a stable coincidence circuit.

The results of our measurements prove conclusively that there are two close-lying states at about 1381 keV in Sm^{146}. The data are consistent with 3− and 4+ assignments for these states and energies of 1380.7 and 1382.0 keV, respectively. In addition, two weaker transitions were found in the Pm^{146} decay, and revised energies and intensities and a decay scheme for Pm^{146} are presented. Systematics of 3− and 4+ levels in this mass region are discussed.

II. PROCEDURE

The source of Pm^{146} was produced by irradiating enriched Nd^{146} with 11-MeV deuterons in the Argonne National Laboratory 60 in. cyclotron. The experiments reported in this paper were not begun until one year after irradiation. At this time the only impurities remaining in the source were Pm^{144}, Pm^{145}, Pm^{147} and probably Pm^{143}. The source of Eu^{146} was produced by irradiating enriched Sm^{147} with 18-MeV deuterons. The only appreciable impurity was Eu^{147}.

High-resolution gamma-ray spectra were obtained with a lithium-drifted germanium (Li-Ge) detector, RCA type SJGG-1, having a depletion depth of 2 mm and an effective area of 0.8 cm^2. The associated electronic circuitry consisted of a Tennelec type 100C preamplifier and the internal amplifier of the Nuclear Data 1024-channel analyzer. The resolution of the detector at 662 keV was 5.4 keV.

The Li-Ge gamma-ray spectra from $\approx$400 to 800 keV were decomposed into constituent gamma rays using contours of Cs^{137} (662 keV) and Na^{22} (511 keV).

A relative efficiency curve was obtained for the energy region using the three equal intensity transitions of 432, 613, and 723 keV in the decay of Ag^{108m} and the two equal intensity transitions of 617 and 696 keV in the decay of Pm^{144}.[1] The Pm^{144} was present as an impurity in the Pm^{146} source.

The gamma-gamma directional-correlation experiments were carried out with a coincidence circuit having a resolving time of $\approx$0.13 μsec. The sources of Pm^{146} and Eu^{146} were in the liquid form (chlorides dissolved in HCl) and were contained in cylindrical Lucite holders $\frac{1}{8}$ in. in diameter and $\frac{3}{8}$ in. in length. The detectors were integrally mounted 3-in.$\times$3-in. and 2-in. $\times$2-in. NaI(Tl) crystals (resolution $\approx$7.5% at 662 keV), and the detector systems were electronically stabilized. The crystals were shielded laterally by a thick copper-lead-copper sandwich and frontally by a 3-mm Lucite outer layer and a $\approx$1 g/cm^2 copper inner layer. Pulses were fed to a 1024 channel analyzer operated in the 32 by 32 two-parameter mode. The pulse-height spectrum for each detector covered the range from $\approx$400 to $\approx$800 keV. The data were analyzed by the method of Rose.[6] The finite-solid-angle corrections of Yates[7] were used.

III. RESULTS

A. Pm^{146}

A Li-Ge spectrum obtained with the Pm^{146} source is shown in Fig. 1. The source distance was 1.5 cm, and a frontal shield of 1.0 g/cm^2 of copper was used. It is seen that the previously unresolved pairs of transitions

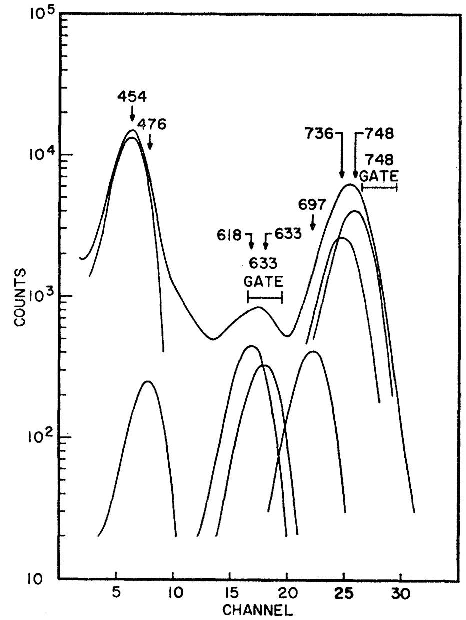

FIG. 2. Gamma-ray singles spectrum of Pm^{146} obtained with one of the 3-in.$\times$3-in. NaI(Tl) detectors. Prominent gamma-rays are shown, along with the gates chosen for the 633–748-keV directional correlation.

at 736 and 748 keV, and 618 and 633 keV are well resolved with this detector. The 476, 618, and 697 keV photopeaks are due to the decay of Pm^{144}(450 day), an impurity. The small peak at 589 keV is probably due to a gamma-ray transition between a 4+ level at $\approx$1040 keV and the 2+ level at 454 keV in Nd^{146}. This transition has previously been observed in the decay of Pr^{146}.[8] There is also evidence, as shown in the insert of Fig. 1, of a very weak transition of $\approx$779 keV, which has tentatively been placed as depopulating a level at 1233 keV in Nd^{146}. This could correspond to the $\approx$790-keV transition observed in the Pr^{146} decay.[8] When the spectrum is carefully analyzed, there is evidence for a weak transition of $\approx$742 keV, which can be attributed to an impurity of Pm^{143} in the source.

To determine the transition energies more precisely, a Li-Ge spectrum was taken with a composite source of Pm^{146}, Mn^{54}, Cs^{137}, and Ir^{192}. This allowed an accurate determination of the energies of the relatively intense 453- and 749-keV transitions of Pm^{146}. The energy standards used were the following: 295.9, 316.5, and 468.0 keV from[9] Ir^{192}; 661.6 keV from Cs^{137}, and 835.0 keV from Mn^{54}.[10] The Pm^{146} energies obtained from a least-squares fitting procedure were 453.9$\pm$0.3 and 747.5$\pm$0.3 keV. The quality of fit was excellent as indi-

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[8] D. C. Hoffman (private communication).

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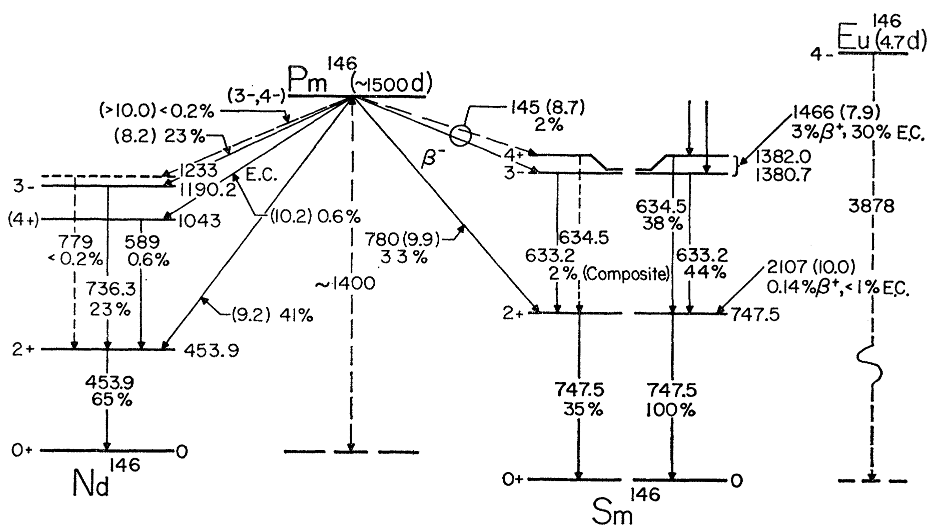

FIG. 3. Revised decay scheme of Pm^{146} and partial decay scheme of Eu^{146}. Intensities are given in percent of total decay of parent nucleus. Energies are in keV.

cated by the fact that the values of the standard energies obtained from the fit differed by less than 0.1 keV from the input values quoted above.

Energies and intensities for all the transitions occurring in the Pm^{146} spectrum were obtained after careful decomposition of the spectrum shown in Fig. 1. The energy calibration was based on the 453.9- and 747.5-keV transition energies. The following values resulted: 736.3±0.5 keV in Nd^{146}, 633.2±0.5 keV in Sm^{146}, and 618.1±0.5 and 697.0±0.5 keV in Nd^{144}. Because of the small number of counts in the 697-keV photopeak, a spectrum was taken using a composite source of Mn^{54}, Cs^{137}, Ir^{192} and Ce^{144} ($Ce^{144} \rightarrow Pr^{144} \rightarrow Nd^{144}$) in which the 697-keV transition is very intense. Using the same energy standards described above, a value of 696.7±0.7 keV was obtained for this transition. The energy and intensity data are presented in Table I.

The 633.2-keV photopeak appeared to be a single peak in the Pm^{146} spectrum obtained with the Li-Ge counter. However, this transition is relatively weak and further evidence for the existence of two transitions at about this energy was sought by employing directional-correlation techniques.

For the Pm^{146} directional-correlation measurements, the source was placed 10 cm from the 3-in.×3-in. NaI(Tl) detectors. Data were taken every 45 degrees in the normal double quadrant sequence. Figure 2 shows the singles spectrum obtained with one detector. The photopeaks due to the prominent gamma rays are shown in Fig. 2, together with the regions selected for the directional correlation gates. The analysis of the NaI spectra was based on the high-resolution Li-Ge data.

For the 633–748-keV correlation, the 748-keV gate was selected so that any contribution from the 618–697-keV cascade in the Pm^{144} decay would be negligible. The resulting coefficients for the 633–748-keV directional correlation are: $A_2 = -0.074 \pm 0.018$ and $A_4 = 0.006 \pm 0.025$. These values are consistent with a $3(D,Q)2(Q)0$ sequence and a quadrupole content of less than 0.1% for the single 633-keV transition. Thus, the results obtained from the Li-Ge spectrum and the 633–748-keV directional correlation in the decay of Pm^{146} in themselves do not establish the existence of two close-lying levels at 1381 keV in Sm^{146}. However, the fact that the correlation coefficients are significantly different from those measured previously (and in the present investigation) following the Eu^{146} decay establishes the fact that there are two gamma-rays of about 633 keV and hence there must be two close-lying levels at about 1381 keV in Sm^{146}.

If it is assumed that the 1381-keV level in Sm^{146} is actually a composite of two unresolved close-lying 3− and 4+ levels and that the gamma-ray transitions between these two states and the 748 keV 2+ state are pure $E1$ and pure $E2$, respectively, then the measured A_2 value requires that the 3− to 2+ transition be at least 9.7 times as intense as the 4+ to 2+ transition. (The A_4 coefficient is also consistent with this result; the large error precludes any additional conclusions.) The fact that a possible 4+ level in Sm^{146} might be fed weakly compared to the feeding to a 3− level is, of course, consistent with the Pm^{146} electron-capture branching ratio to the 3− and 4+ states in Nd^{146}. The revised decay scheme for Pm^{146} is shown in Fig. 3.

As a check on the 633–748-keV correlation experiment, the data for the 736–454-keV cascade were also analyzed. The corrected coefficients were: $A_2 = -0.061 \pm 0.006$ and $A_4 = -0.001 \pm 0.008$. These values agree within errors with the values reported previously in our laboratory,[1] and are consistent with a $3(D,Q)2(Q)0$ sequence with a quadrupole content of 0.02%. The theoretical values for a $3(D)2(Q)0$ sequence are $A_2 = -0.070$ and $A_4 = 0$. The measured A_2 does not quite overlap the value −0.070, but a small contribution from the Pm^{144} correlations (positive asymmetry) could result in the slightly lower value of -0.061 ± 0.006.

B. Eu^{146}

The gamma-ray spectrum of 4.7-day Eu^{146} is quite complex above 800 keV. Figure 4 displays the spectrum from $\approx$400 to 800 keV obtained with the Li-Ge detector. The source distance was 6 mm and no frontal shielding was used. The energy calibration for this spectrum was carried out using the annihilation radiation peak at 511.0 keV and the 747.5-keV transition which was accurately measured in the Pm^{146} experiment. The energies of the more intense photopeaks are determined to be: 430.3 ± 0.5, 634.0 ± 0.5, 665.8 ± 0.5, and 703.3 ± 0.5 keV. After decomposition of the spectrum, the 634-keV photopeak appears to be too wide to be due to a single transition, thereby furnishing some direct evidence for the composite nature of this transition. Using the constraint of a transition of 633.2 keV (from the Pm^{146} analysis), a second peak is obtained with an energy of 634.5 keV as shown in Fig. 5. The two constituent transitions have an intensity ratio $I_{633.2}/I_{634.5}=0.85$. It must be noted that this is not a unique break-apart since a small shift in the 633.2-keV energy affects the resulting intensities quite drastically. The gamma-ray energy and intensity data for Eu^{146} are summarized in Table I.

If one combines the internal-conversion-electron data of Funk *et al.*[2] with our gamma-ray intensities obtained from the Li-Ge spectrum, a value of $(4.1\pm0.4)\times10^{-3}$ is obtained for the internal-conversion coefficient of the 634-keV composite transition. The photon and electron intensities were normalized for the 748-keV ($E2$) transition. The value of the I.C.C. of $(4.1\pm0.4)\times10^{-3}$ is consistent with either a single transition of multipolarity $E1+(7.3\pm1.6\%)M2$, or composite pure $E1$ and pure $E2$ transitions having an intensity ratio of 0.95 ± 0.26. The intensity ratio obtained by direct decomposition of the 634-keV photopeak is in good agreement with the ratio obtained from the I.C.C.

The directional correlation of the 634–748-keV cascade was remeasured in the hope of obtaining more

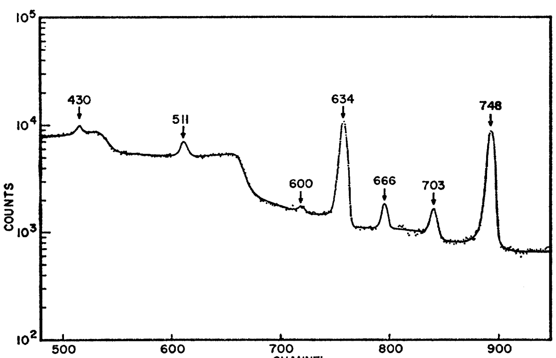

FIG. 4. Li-Ge gamma-ray spectrum from $\approx$400 to 800 keV obtained with the Eu^{146} source.

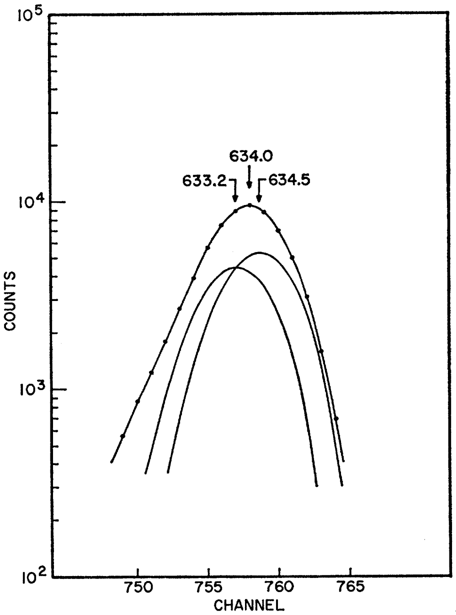

FIG. 5. Expanded 634-keV photopeak from Eu^{146} spectrum of Fig. 4 after subtraction of Compton contributions from higher energy transitions. Also shown are the constituent photopeaks obtained by placing one of the transitions at 633.2 keV (from the Pm^{146} analysis).

accurate data than previously reported by our laboratory.[2] The source was placed 15 cm and 10 cm from the 3-in.×3-in. and 2-in.×2-in. NaI detectors, respectively. The singles spectrum from the 3-in.×3-in. detector is shown in Fig. 6. Data were taken for 40 minutes each at five angles per quadrant, and were analyzed in two different ways.

In the first method of analysis, no attempt was made to correct for interfering cascades which contribute about 10% to the 634–748-keV correlation. The complexity of the spectrum makes it unfeasible to make a reasonably good estimate of interferences by the usual procedure of decomposing the composite spectrum into its individual gamma-ray contributions. Furthermore, the correlations for even the more intense interfering cascades are not well known.

The gates were chosen on the low-energy side of the 635-keV and the high-energy side of the 748-keV photopeaks, respectively, as shown in Fig. 6. The data corrected for finite solid angle led to the following values: $A_2=0.012\pm0.006$, and $A_4=0.002\pm0.009$. These results are consistent with a $3(D,Q)2(Q)0$ sequence with a quadrupole admixture of 1.2%. The assumption of close-lying $3-$ and $4+$ levels at 1381 keV, and pure transitions gives 1.0 ± 0.1 for the ratio of the $3-\rightarrow2+$ and $4+\rightarrow2+$ transition intensities. (A_4 is consistent with lower and upper limits of zero and infinity.)

In the second method of analysis, an attempt was made to minimize the effects of interfering cascades in the following way. Coincidences occurring with the

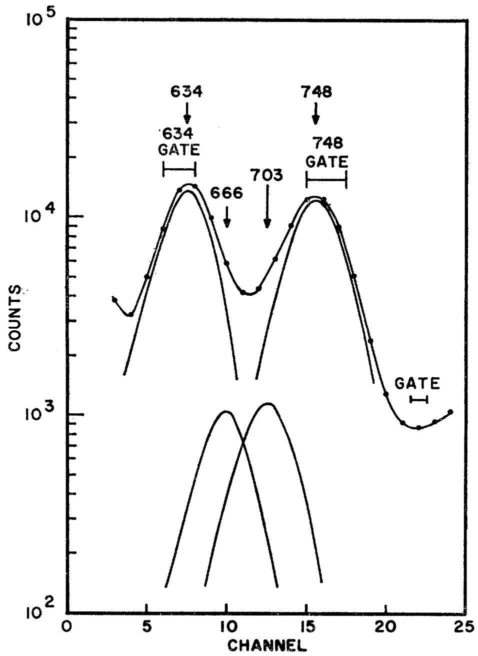

FIG. 6. Gamma-ray singles spectrum of Eu^{146} in the 600–800 keV region obtained with the 3-in.×3-in. NaI(Tl) detector. The gamma-ray photopeaks in this region are shown, along with the gates chosen for the 634–748-keV directional correlation. The narrow gate above the 748-keV photopeak was used in an attempt to correct for interfering cascades.

one-channel gate just above the 748-keV photopeak shown in Fig. 6 were assumed to be representive of the contributions from the interfering cascades. Counts in this channel were multiplied by the number of channels comprising the 748-keV gate, and subtracted from the counts in this gate. This correction removes a positive asymmetry of 2% and produces an isotropic correlation which leads to values of $A_2=0.0001\pm0.0070$, and $A_4=0.007\pm0.011$. These values are consistent with a $3(D,Q)2(Q)0$ sequence having a quadrupole content of 0.9%. Assuming degenerate 3− and 4+ levels and pure transitions, the A_2 value yields the ratio of 1.4 ± 0.1 for the intensities of the $3-\rightarrow 2+$ and $4+\rightarrow 2+$ transitions. (A_4 is consistent with lower and upper limits of zero and infinity.)

Needless to say, there are uncertainties in the latter procedure. These are principally due to statistical errors on the small number of counts in the one-channel gates, and the assumption of a uniform "background" under the 748-keV gate. However, it seems reasonable to assume that the ratio of $3-\rightarrow 2+$ and $4+\rightarrow 2+$ transition intensities as determined by the directional-correlation data lies between the limits obtained from the first and second procedures, i.e., between 0.9 and 1.5. The results of analysis of the I.C.C. and directional correlation data obtained from the Eu^{146} decay experiments have been appropriately combined to produce a most probable value of 1.15 for the ratio of intensities of the $3-\rightarrow 2+$ and $4+\rightarrow 2+$ transitions.

Thus, experimental evidence supporting the hypothesis of a 3−, 4+ doublet at 1380.7 and 1382.0 keV in Sm^{146} has been presented. For the case of Eu^{146} decay, the K-shell internal-conversion-coefficient data and gamma-gamma directional correlation data are consistent, and indicate that these levels are fed nearly equally. A Eu^{146} gamma-ray spectrum taken with the Li-Ge detector also indicates transitions of nearly equal intensity. For the case of the decay of Pm^{146}, directional correlation data indicate that the 3− level in Sm^{146} is fed by the Pm^{146} beta decay at least ten times more intensely than the 4+ level, and a spectrum taken with the Li-Ge detector indicates that the lower member of the doublet is the 3− state depopulating with a 633.2 ±0.2-keV transition to the 747.5-keV 2+ state. Using this transition energy for one of the photopeaks, the composite 634-keV peak from the Eu^{146} Li-Ge spectrum yields another peak at 634.5 keV.

IV. DISCUSSION

Logft values for the decay of Pm^{146} were obtained using the gamma-ray intensity data of Table I, a half-life of 1500 days,[11] and a Pm^{146}-Nd^{146} ground-state energy difference of 1400 keV. The logft values for the beta decay to the Sm^{146} 2+ state, and the electron-capture decay to the Nd^{146} 2+ and (4+) states are 9.9, 9.2, and 10.2, respectively. Seeger[12] predicts an energy difference of 1516 keV, while Cameron[13] lists a value of 897 keV (which is obviously too low) for these nuclei. In any case, a variation of plus or minus 100 keV from our assumed value of 1400 keV has little effect on these logft values.[1] The logft values, in conjunction with the previous assignment of 3− or 4− for the Pm^{146} ground state,[1] indicate retarded first-forbidden transitions. The logft value of 8.2 in the electron-capture decay to the 1190 keV 3− state in Nd^{146} indicates a strongly retarded allowed classification for this transition. It may be remarked that ft values for nuclei in this region are consistently greater (generally two or three orders of magnitude) than those expected for a given ΔI, $\Delta\pi$, which can readily be seen by an examination of the decay schemes for Pm^{148},[14] Eu^{148},[15] and Eu^{150},[16] for example. This could possibly be explained by some selection rule analogous to the K-forbiddenness observed in the neighboring deformed nuclei. If one assumes that the logft values for the 145-keV beta decay to the close-lying 3− and 4+ levels in Sm^{146} are the same as those measured for the electron capture

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decay to the 3− and 4+ states in Nd^{146}, a ratio of ≈86 is obtained for the relative feeding of the 3− and 4+ levels. This is consistent with the lower limit of 9.7 derived from the Pm^{146} directional correlation data. This result is interesting but certainly questionable since there is little justification for the assumption stated.

It is of interest to see if any additional knowledge of systematics of energy levels may be gained. Figure 7(a) is a plot of the energies of the first 3− and 4+ states versus mass number for even-even nuclei in the region $A=142$ to 152.[17,18] This is the region between the closed neutron shell at $N=82$ and the beginning of the deformed region at $N=88$. For spherical nuclei near closed shells, relatively high phonon frequencies are expected owing to dominance of the pairing forces over the effects of the "aligned coupling scheme."[19]

As more nucleons are added beyond closed shells, the latter effect begins to overcome the former, and although the stable equilibrium shape presumably remains spherical, the collective parameters change in such a way that the phonon frequencies become smaller. This general trend applies to both quadrupole and octupole phonons. However, the decrease in energy with increasing mass number is expected to be more pronounced for quadrupole vibrations since these excitations are more purely surface-dependent than the higher multipole vibrations, and are therefore more sensitive to the nucleon dynamics in the outermost subshells. Thus the ratio of energies of the first octupole to the first quadrupole phonons should increase rather rapidly with increasing mass number. Such a trend is shown in Fig. 7(b). It is seen from these figures that the energy of the proposed 3− and 4+ states in Sm^{146} fit quite well the trend for even-even nuclei in this region.

Note added in proof. Avotina *et al.*[20] have recently reported on the conversion-electron spectrum of Eu^{146}. They observed two lines (intensity ratio of 0.43±0.07) which they assigned as the K lines of two transitions of 633.4 and 634.2 keV, respectively. The corresponding gamma-ray intensity ratio (using internal conversion coefficients for pure $E1$ and $E2$, respectively) is in excellent agreement with that obtained directly by us. In addition, they obtained a value of 747.4 keV for the energy of the first 2+ state in Sm^{146} which is in excellent agreement with our value of 747.5 keV.

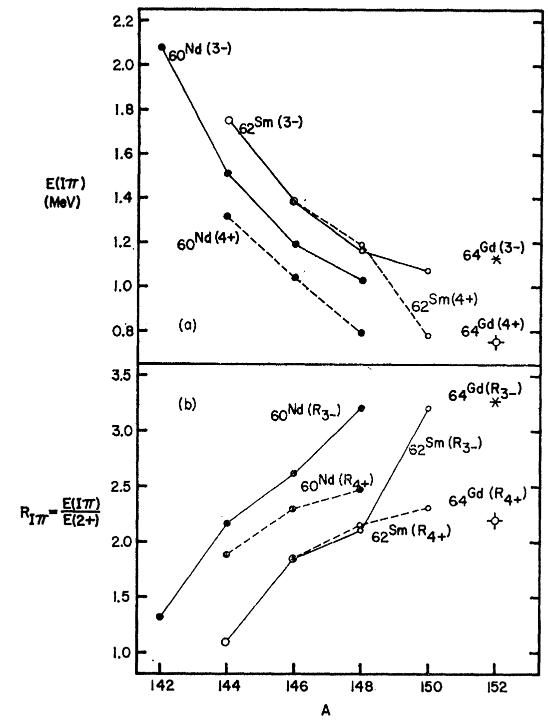

FIG. 7. Energy systematics of first 3− and 4+ states of even-even nuclei in the mass region $A=142$ to 152, including the results of this paper. Figure 7(a) shows energies of 3− and 4+ states versus A for Nd, Sm, and Gd isotopes. Figure 7(b) shows energy ratios of 3− to first 2+ and 4+ to first 2+ states.

ACKNOWLEDGMENTS

We should like to thank Milan Oselka and the operating crew of the Argonne 60-in. cyclotron for making the target irradiations for us.

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