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TITLE: EXTENSION OF NUCLEAR STRUCTURE DATA BASE SEARCHES FOR GAMMA-RAY LASER CANDIDATES

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Extension of nuclear structure data base searches for gamma-ray laser candidates

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ABSTRACT

Results from a data base search of computized nuclear structure librarles have been ended and augmented so as to expand the information available for nuclei suitable as mma-ray laser candidates. The spectrum of clear levels occurring in deformed rotaonal nuclei have been calculated and have en used in conjunction with isomeric state a for odd-A systems. The results of this jmentation effort are presented with particar emphasis on results obtained for ^{177}Lu, Hf, and ^{179}Hf. For these cases some possiy interesting cases were identified that met ergy spacing criteria. However, significant ndrance factors exist for them which negate eir interest for gamma-ray laser applicaons.

1. INTRODUCTION

In a previous computerized search[1] of exrimentally based nuclear structure librars,[2,3] we identified eight pairs of nuclear vels that could be appropriate for gamma-ray ser applications. Specifically, such pairs st consist of a long-lived nuclear isomer hich acts as a laser storage state) lying ose (within several hundred electron volts) a short-lived state. If two such states ist, and the angular momentum difference tween them is not overly great, then an exrnal radiation source could be used to efct a transition between them, thus producing depopulation that could eventually lead to sing.

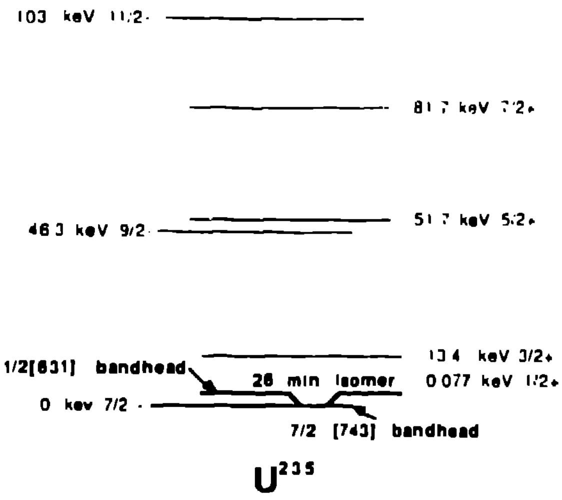
In addition to identification of these vel pairs, the search of Ref 1 produced a bulation of long-lived isomeric states for d-A and odd-odd nuclei. For such identified ses, some possibility exists that shortved levels could exist nearby that heretore had not been measured experimentally. us, if one were to augment this present exrimental level data with results from theotical calculations, then the expanded set mprised of experimentally and theoretically sed levels may provide new cases in which teresting gamma-ray laser candidates could found.

We report in this paper the beginning of e process of level data augmentation using eoretical nuclear structure model results. have concentrated on permanently deformed clei (rare earth and actinide) where simple dels applicable to odd-A systems are appropiate. In the following sections the model ll be described, nuclei appearing in the isomeric state list of Ref.1 for which this model is appropriate will be identified, and results will be presented for closely spaced level pairs determined in this study.

2. APPROACH

The methods employed utilize the particle-rotor model of Bohr and Mottleson,[4] which is applicable to deformed nuclei and which exploits symmetry properties arising from the deformations. The nuclear shape degrees of freedom of such nuclei lead to rotational bands of nuclear levels which are built upon the intrinisic states of the system. Thus, if one can specify the parameters of each rotational band, then one can construct the energy spacings, spins, and parities of the individual levels occurring in the band. We accomplish this using the particle-rotor model. The procedure (to be described in more detail later) allows one to calculate, given a relatively small amount of data, additional nuclear levels which may be missing in existing experimental nuclear structure data bases. Such information can then be combined with existing level data to identify cases that are possibly interesting for gamma-ray laser applications.

In our application of this technique, the first step was the identification of nuclei associated with the 51 odd-A isomeric states, listed in Ref 1, for which this model would be applicable. Of the 51 nuclei presented there, eleven can be described using a simple version of the particle-rotor model. These are the rare earth nuclei, ^{153}Ho, ^{165}Dy, [illegible], [illegible], ^{177}Lu, ^{177}Hf, ^{179}Hf, ^{179}W, ^{183}Os, ^{185}W, and the actinide nucleus, ^{235}U. After identification of a nucleus as appropriate for the particle rotor model, a second criterion must be met, namely the isomeric state of interest must lie at a high enough excitation energy that a real possibility exists for new unmeasured levels to be identified. In our application these must lie close to the isomer. An extreme example, ^{235}U, appears in Ref 1 and illustrates this point. Here the [illegible] isomeric state of interest (which is the first member of the excited 1/2[631] band [illegible] 80) electron volts above the ground state band. The spacing of the higher lying levels in this band (the $9/2^-$, $11/2^-$, [illegible] states, is on the order of tens of kilovolts, and any higher-lying band members identified with theoretical calculations would [illegible] higher excitation energies. Thus, [illegible] levels (other than the ground [illegible] within an energy spacing that would [illegible] interest for a gamma-ray laser applic[illegible]



gure 1. The band and level structure of ^{235}U. iergies of the 7/2[743] ground-state band mbors appear on the left; energies of the 2[631] band, which includes the isomer, ap-ar on the right.

After consideration of this second crite-on only 3 of the 11 nuclei have their known omeric levels occurring at high enough citation energy for there to be a possiblity at missing levels can be identified. These e ^{177}Lu (E_x = 970.2 keV, J^π = 23/2$^-$, half-fe = 160.5 days), ^{177}Hf (E_x= 2740 KeV, J^π = /2$^-$, halflife = 51.4 min) and ^{179}Hf (E_x = 05.7 keV, J^π = 25/2$^-$, halflife = 25.1 days). r these nuclei, rotational bands were entified from existing experimental data and re constructed using the following particle-tor expression to complete the spectrum of clear levels for each band:

$$E(J,K) = \varepsilon_K + (\hbar^2/2I)\,[J(J+1)-K^2 + \delta_{K,1/2}(-1)^{J+1/2}\,a(J+1/2)], \qquad (1)$$

ere ε_K is the single particle (quasi-parti-el energy, I is the moment of inertia, J is e total angular momentum, K its projection the body-fixed symmetry axis, and a is the coupling parameter. The last term in Eq. , in which a appears, arises from Coriolis eractions. It has been assumed that the so-lled recoil term can be absorbed into the asi-particle energy. Finally, band mixing fects have been ignored.

The solution of Eq. (1) then requires owledge of three states to determine the ree unknowns (ε_K, I, a) for K=1/2 and knowl-ge of two states to determine the two un-owns (ε_K,I) for K ≠ 1/2. If insufficient perimental information exists (the usual le), one can use Nilsson[7] or Nilsson-like culations to complete,as much as possible, low-lying spectrum. Note that the first members of a given low-lying band are the most accurately known experimentally. In such cases the best possible values are obtained for ε_K, I, and a (if K=1/2) provided that one does not attempt to calculate band members too high in spin values where I=I(ω). Another rea-son to confine the calculation of the discrete level spectrum to lower excitation energies is that more complex states than those treated here arise as the excitation energy increases. The code NUKLEV was developed to carry out solutions of Eq.(1) as just described.

Table 1 lists for the three cases consid-ered here the rotational band information (bandhead energies, spin, and K quantum num-ber) used to produced the results described in the next section. This information was taken from data appearing in Ref 6-7.

Table 1. Band Parameters

	Band Energy (keV)	K	Bandhead State Spin,Parity
^{177}Lu	0	7/2	7/2$^+$
	150.39	9/2	9/2$^+$
	457.9	5/2	5/2$^+$
	569.62	1/2	1/2$^+$
	761.65	1/2	1/2$^-$
	970.15	23/2	23/2$^-$
	1230.7	11/2	11/2$^+$
	1356.9	15/2	15/2$^+$
	1502.6	13/2	13/2$^-$
^{177}Hf	0.	7/2	[illegible]
	321.3	9/2	9/2$^+$
	508.1	5/2	[illegible]
	559.4	1/2	[illegible]
	608.	1/2	[illegible]
	745.9	7/2	[illegible]
	805.7	1/2	[illegible]
	1057.8	[illegible]	[illegible]
	1315.4	23/2	[illegible]
	1434.	3/2	[illegible]
	1634.	1/2	[illegible]
	1882.	1/2	[illegible]
^{179}Hf	0.	9/2	[illegible]
	214.	7/2	[illegible]
	374.8	[illegible]	[illegible]
	518.4	5/2	[illegible]
	614.	[illegible]	[illegible]
	720.	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]
	1105.7	25/2	[illegible]

The next step in this process will involve milar procedure applied to a subset of the someric states identified for odd-odd nu- in Ref 1. Here the chances of successful itification of potentially interesting il pairs may be increased significantly due he complexity of low-lying band structures uch nuclei. In these instances, bandhead itification may occur through the examina- of systematic trends obtained by studying coupling of single-particle orbits in ad- nt odd-A nuclei or through use of Nilsson gle particle orbits. In isolated cases lied so far, theoretical evidence has been ented for the existance of levels that are e to low-lying isomers, as was done in the of ^{158}Ho by Sood et al.[8] These inves- itions will also require information ob- ed from more microscopic nuclear structure l development currently underway[9] that al- more realistic specification of contribu- s due to residual n-p interactions.

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3. RESULTS

In this section results obtained for ^{177}Lu, ^{177}Hf, and ^{179}Hf are presented. For ^{177}Lu, nine rotational bands were used that resulted in a total of 51 calculated levels extending to an excitation energy of 1752 keV. Of these, the closest level to the 160-day isomer at $E_x = 970.15$ keV was the $5/2^-$ level lying at 962 keV, which has been identified previously experimentally. No new additional theoretical levels were identified at energies below that of the isomeric state.

For our investigation of ^{177}Hf, data for twelve bands were used in the calculation, a condition necessitated in part by the high excitation energy (2740 keV) of the isomer. This calculation produced 127 levels up to an excitation energy of 2787 keV as compared with approximately fifty levels that are known experimentally. The closest calculated levels to the $J^{\pi} = 37/2^-$ isomer are a $25/2^-$ level at 2709 keV and a second $25/2^-$ level at 2743 keV. Thus, the closest level is predicted to lie several kilovolts from the isomer. Even more important are the large changes in spin and K quantum number required to induce a transition between the isomer and the closest short-lived level. In this case, $\Delta J = 6$ (an E6 transition) and $\Delta K = 18$ exist, which produce overwhelming hindrance factors for transitions between these levels.

Finally, for ^{179}Hf, eight rotational bands were used to produce 47 levels up to an energy of 1366 keV vs the 26 that are known experimentally. The closest levels to the $25/2^-$ isomer at 1105.7 keV are the $17/2^-$ state calculated to occur at $E_x = 1105.3$ keV and the $11/2^-$ state at 1131 keV. Although the energy difference between the isomer and the state calculated to exist at 1105.3 keV is 400 electron volts (which is attractive from the point of view of the gamma-ray laser criteria discussed earlier), once again large spin and K differences will effectively eliminate transitions between these two level pairs. In this case, an E4 transition and a change in nine units of K would be required to effect a transition.

4. CONCLUSIONS

A simple particle-rotor model has been applied to augment experimental level data used in searches for nuclear level pairs appropriate to gamma-ray laser concepts. Two significant problems hampered this effort. The first occurred because the experimentally determined odd-A isomeric levels of interest lay, for the most part, at low excitation energies below the energy region where additional levels would be predicted. A more fundamental problem exists in that, even when the level spacing criteria of less than a kilovolt separation was satisfied, unacceptably large differences in spin and K quantum number existed between the members of the pair. These in turn produce large hindrance factors for transitions between the two levels.