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TITLE: NUCLEAR STRUCTURE PROPERTIES FOR GAMMA-RAY LASERS

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NUCLEAR STRUCTURE PROPERTIES FOR GAMMA-RAY LASERS

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ABSTRACT

We summarize some initial results in our investigation of the nuclear physics issues of gamma-ray lasers. We describe what is known thus far from existing experimental data and illustrate how theoretical models may be employed for systematic searches of candidate nuclei.

SURVEY OF EXPERIMENTAL DATA

We have earlier reported on simple nuclear physics considerations that indicate which mass regions may be most fruitful to search¹ for gamma-ray lasers and have cursorily examined the appropriate experimental data and theoretical tools.² Since then we have searched two computerized nuclear structure data libraries. The first, CDRL82,³ is based on the particle-reaction and nuclear decay data contained in the 1978 Table of Isotopes⁴ compilation. The second library used, ENSDF,⁵ is from Nuclear Data Sheets⁶ and is current to the 1980s for some mass chains.

The criterion used to perform the search was initial identification of isomeric states having a lifetime greater than 5 seconds. After identification of such a state, the spacings of nearby levels were examined to determine which ones (if any) fell within a specified excitation energy window, ΔE , of width 1 keV or 5 keV. If one relaxes the constraint that one member of the closely-spaced level pair be an isomeric level, then a substantially larger number of closely-spaced level pairs can be identified. Figure 1 illustrates, as a function of atomic mass, the number of level pairs having spacings ≤ 1 keV lying below an excitation energy of 1.5 MeV, and which exclude ground-states as one member of the pair. A total of 242 such pairs were identified. However, imposition of the requirement that one of the levels be an isomer with a lifetime greater than five seconds results in the six candidate nuclei shown in Fig. 2. Of these, ¹⁷⁹Hf is of particular interest because it exhibits the closest level spacing (~ 200 eV) of any nucleus identified.

We have also searched both nuclear structure files for all known isomeric states. We have performed scans on each file, for isomeric state half-lives, $T_{1/2}$, that are greater than 1 s, 1 min, 10 min, and 1 h. For each of these ranges we have calculated the average number of isomeric states as a function of the nuclear mass number A . Figure 3 illustrates the results for the range $T_{1/2} > 10$ min for the ENSDF file. Strong dependencies on mass number are evident. As we expected,^{1,2} regions of shell closure in neutron number N and proton number Z , as well as deformed rare earth and actinide nuclei, contain the largest numbers of isomeric states.

Fig. 1. Pairs of levels lying below $E = 1.5$ MeV with separations ≤ 1 keV as identified through the experimental data search.

Fig. 2. Possible nuclear candidates fulfilling the level spacing and lifetime requirements discussed in the text.

In particular, the regions $N = (28, 50, 82)$, $Z = (2, 8, 20, 28, 50, 82)$, the rare earths ($150 \leq A \leq 190$), and the actinides and transactinides ($A > 220$), exhibit well-defined peaks. However, the largest peak (for each of the four half-life ranges studied) occurs for $A = 195-197$, which corresponds to isotopes of ^{76}Os , ^{77}Ir , ^{78}Pt , ^{79}Au , and ^{80}Hg . These nuclei are representative of the transition region between the heavy deformed rare earths and the spherical nuclei near doubly magic ^{208}Pb . Clearly, this region could be further investigated for possible gamma-ray laser considerations.

Fig. 3. Average number of isomeric levels with half-lives greater than 10 min as a function of nuclear mass number. The ENSDF evaluated nuclear structure file⁵ was used.

THEORETICAL CONSIDERATIONS

It is apparent that none of the six above candidates meet the present requirements of a gamma-ray laser. Consequently, experimental work will be required to search for a more suitable nuclear candidate. Because of the amount of time required, this effort must be guided by theoretical considerations. The accuracy of theoretical models in the regions of interest is, at best, a few keV. This inaccuracy stems from an incomplete knowledge of the nucleon-nucleon interaction and mesonic corrections, and from the inherent inaccuracy of the nuclear models employed. The nucleus is a true many-body system with the interaction between any two nucleons depending upon all the other nucleons in the nucleus.

A very brief review of the mechanisms that may produce isomers was given in Ref. 2. Also discussed there were models that may be used to calculate the properties of levels in nuclei of interest. It was noted that odd-odd nuclei in the rare-earth region would be a likely place to begin a search for appropriate gamma-ray laser candidates.

We briefly illustrate the usefulness of nuclear models by discussing the structure of such a nucleus which has been proposed as a likely candidate. ^{186}Re has an isomer at an excitation of approximately 150 keV which has been tentatively identified as an 8^+ . The lifetime of this level is 2×10^5 yr. In order for Re to meet the requirements of a laser, there must be a 7^- level within a keV of the 8^+ isomer. No such level is known, although it is easily conceivable that such a state would have been missed in the earlier experiments.

The structure of ^{186}Re is modeled by assuming the odd neutron and odd proton move in deformed orbits and interact via a phenomenological neutron-proton interaction. The energies of the odd nucleon may be checked by comparing with ^{185}Re and ^{185}W . The two lowest bands of ^{186}Re are a $K = 1^-$ (composed of a $K_n = 3/2^-$ neutron and a $K_p = 5/2^+$ proton) and a $K = 3^-$ ($K_n = 1/2^-$, $K_p = 5/2^+$). Neither band has a 7^- state below 500 keV. The lowest 7^- arises from a $K = 6^-$ band ($K_n = 7/2^-$, $K_p = 5/2^+$) and lies at approximately 400 keV. Although the error in the predicted energies may be as much as 30 keV in this initial calculation, nevertheless, the accuracy is sufficient to eliminate ^{186}Re as a viable candidate. As the calculations are refined, they will have an order of magnitude better accuracy, although the models are already very useful.

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