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Enhancement of Reduced Transition Probabilities for Even-Even $^{160-176}$Yb Isotopes

K. A. Gado*
Physics Department, Tabuk University, Tabuk, KSA
*Physics Department, Higher Institute of Engineering, Belbeis, Egypt

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Abstract: Reduced transition probabilities for electric quadrupole transitions B(E2) have been calculated using a collective model with half lifetimes. B(E2) have been evaluated within the context of the model by exact numerical methods for transitions within positive parity rotational bands of even-even nuclei. Comparison of experiment with theory shows quite good agreement in the even-even deformed region.

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1. Introduction:

The interaction of the electromagnetic field with the nucleus provides us with an especially useful tool for investigating certain properties of nuclear structure, and thereby also nucleon interactions. By measurements of lifetimes of nuclear states and by measurement of excitation of nuclear states with electromagnetic means we can probe without the direct involvement of nuclear forces which are present in nuclear interactions. Nevertheless, the results give information on nuclear structure and on the effects of correlations brought about by nuclear interactions within the nucleus. The subject of this paper is the enhancement of transition probabilities [1]. In order to reconcile theory and experiment for a complete description of the atomic nucleus, it is ideal to compare nuclear structure properties that can be measured in an essentially model-collective way, and at the same time, be robustly predicted by theory. Electromagnetic transition probabilities are readily calculated by most models and can be measured via intermediate-energy Coulomb excitation [2].

2. Transition Probability:

The transition probability, $T(\sigma\lambda\mu)$, for a γ-ray decay from initial spin state j_i to final spin state j_f with energy E, multipolarity λ, and component μ is [3]:

$$T(\sigma\lambda\mu) = \frac{8\pi(\lambda+1)}{\hbar\lambda\left((2\lambda+1)!!\right)^2}\left(\frac{E_\gamma}{\hbar c}\right)^{2\lambda+1} B(\sigma\lambda\mu) \ldots\ldots (1)$$

where $B(\sigma\lambda\mu)$ is the reduced transition probability, Note that while $T(\sigma\lambda\mu)$ has a transition energy dependency of $E_\gamma^{2\lambda+1}$, the reduced transition probability does not.

The lifetime of an excited state decaying by γ-ray emission is determined by the transition probability [4]:

$$t_{\frac{1}{2}} = \frac{\ln 2}{T(\sigma\lambda\mu)} \ldots\ldots (2)$$

The relation between mean lifetime τ and decay width Γ value is [5]:

$$\Gamma(\sigma\lambda\mu) = \frac{\hbar}{\tau} \ldots\ldots (3)$$

The partial width of γ – ray transition from an initial state with spin j_i to final state with spin j_f is given [6];

$$\Gamma(\sigma\lambda\mu) = \frac{8\pi(\lambda+1)}{\lambda\left((2\lambda+1)!!\right)^2}\left(\frac{E_\gamma}{\hbar c}\right)^{2\lambda+1} B(\sigma\lambda\mu) \ldots\ldots (4)$$

with the transition energy E_γ.

3. Discussion:

Calculations of electromagnetic properties give us a good test of the nuclear models predictions. The even-even nuclei with $Z = 70$ and $N = 90 - 106$ indicate excellent opportunities for studying the behavior of the total low-lying E2 strengths in the rotational region. In order to calculate the strengths $B(E2)$ the reduced transition probabilities, one can use equations (1) and (2).

Table (1): Experimental and Theoretical Reduced transition probabilities in (eb^2), and Decay width in (Mev) of the band of $^{160-176}$Yb nuclei.

^{160}Yb Nucleus					
Transition	$B(E2)_{Exper.}$	$B(E2)_{Theor.}$	$\Gamma_{By\ half\ life\ time}\ X10^{-12}$	$\Gamma_{By\ exper.B(E2)} X10^{-12}$	$\Gamma_{By\ theor.B(E2)} X10^{-12}$
$2^+\to0^+$	0.500	0.587	4.001	3.410	4.001
$4^+\to2^+$	0.690	0.718	56.31	54.08	56.31
$6^+\to4^+$	0.860	0.872	240.0	236.5	240.0
$8^+\to6^+$	0.900	0.881	506.8	517.8	506.8
$10^+\to8^+$	0.900	0.900	760.2	759.7	760.2
$14^+\to12^+$	0.700	0.692	60.01	60.63	60.02
$16^+\to14^+$	1.070	1.123	240.0	228.7	240.0
$18^+\to16^+$	0.410	0.415	217.2	214.7	217.2
$20^+\to18^+$	0.370	0.369	380.1	381.5	380.1

^{162}Yb Nucleus					
Transition	$B(E2)_{Exper.}$	$B(E2)_{Theor.}$	$\Gamma_{By\ half\ life\ time}\ X10^{-12}$	$\Gamma_{By\ exper.B(E2)} X10^{-12}$	$\Gamma_{By\ theor.B(E2)} X10^{-12}$
$2^+\to0^+$	0.730	1.124	1.140	0.741	1.140
$4^+\to2^+$	1.120	1.188	32.58	30.72	32.58
$6^+\to4^+$	1.100	1.124	142.5	139.5	142.5
$8^+\to6^+$	1.000	1.044	325.8	311.9	325.8

^{164}Yb Nucleus					
Transition	$B(E2)_{Exper.}$	$B(E2)_{Theor.}$	$\Gamma_{By\ half\ life\ time}\ X10^{-12}$	$\Gamma_{By\ exper.B(E2)} X10^{-12}$	$\Gamma_{By\ theor.B(E2)} X10^{-12}$
$2^+\to0^+$	0.920	2.287	0.518	0.208	0.518
$4^+\to2^+$	1.360	1.501	15.20	13.77	15.20
$6^+\to4^+$	1.460	1.528	91.22	87.14	91.22
$8^+\to6^+$	1.700	1.775	304.1	291.1	304.1
$10^+\to8^+$	1.600	1.693	570.1	538.5	570.1
$12^+\to10^+$	1.600	1.476	760.5	823.6	760.5
$14^+\to12^+$	1.300	1.345	651.6	629.3	651.6
$16^+\to14^+$	1.100	1.114	253.4	250.1	253.4
$18^+\to16^+$	1.600	1.714	651.6	607.9	651.6

^{166}Yb Nucleus					
Transition	$B(E2)_{Exper.}$	$B(E2)_{Theor.}$	$\Gamma_{By\ half\ life\ time}\ X10^{-12}$	$\Gamma_{By\ exper.B(E2)} X10^{-12}$	$\Gamma_{By\ theor.B(E2)} X10^{-12}$
$2^+\to0^+$	1.050	4.139	0.368	0.093	0.368
$4^+\to2^+$	1.470	1.735	8.605	7.289	8.605
$6^+\to4^+$	1.560	1.626	57.73	55.39	57.73
$8^+\to6^+$	1.700	1.835	217.2	201.1	217.2
$10^+\to8^+$	1.600	1.675	456.1	435.6	456.1
$12^+\to10^+$	1.400	1.569	760.2	678.0	760.2
$14^+\to12^+$	1.400	1.421	912.2	898.3	912.2
$16^+\to14^+$	1.600	1.733	414.6	382.7	414.6

^{168}Yb Nucleus					
Transition	$B(E2)_{Exper.}$	$B(E2)_{Theor.}$	$\Gamma_{By\ half\ life\ time}\ X10^{-12}$	$\Gamma_{By\ exper.B(E2)} X10^{-12}$	$\Gamma_{By\ theor.B(E2)} X10^{-12}$
$2^+\rightarrow0^+$	1.260	6.928	0.294	0.054	0.294

^{170}Yb Nucleus					
Transition	$B(E2)_{Exper.}$	$B(E2)_{Theor.}$	$\Gamma_{By\ half\ life\ time}\ X10^{-12}$	$\Gamma_{By\ exper.B(E2)} X10^{-12}$	$\Gamma_{By\ theor.B(E2)} X10^{-12}$
$2^+\rightarrow0^+$	1.120	8.469	0.285	0.038	0.285
$8^+\rightarrow6^+$	2.000	2.093	152.0	145.2	152.0
$10^+\rightarrow8^+$	2.000	2.041	393.2	385.1	393.2
$12^+\rightarrow10^+$	1.510	1.516	592.3	589.7	592.3

^{172}Yb Nucleus					
Transition	$B(E2)_{Exper.}$	$B(E2)_{Theor.}$	$\Gamma_{By\ half\ life\ time}\ X10^{-12}$	$\Gamma_{By\ exper.B(E2)} X10^{-12}$	$\Gamma_{By\ theor.B(E2)} X10^{-12}$
$2^+\rightarrow0^+$	1.160	10.962	0.271	0.028	0.271
$4^+\rightarrow2^+$	1.800	2.536	3.966	2.814	3.966
$6^+\rightarrow4^+$	1.760	1.925	26.67	24.38	26.67
$8^+\rightarrow6^+$	2.180	2.272	130.3	125.0	130.3
$10^+\rightarrow8^+$	2.080	2.130	345.5	337.4	345.5
$12^+\rightarrow10^+$	2.600	2.706	877.1	842.6	877.1

^{174}Yb Nucleus					
Transition	$B(E2)_{Exper.}$	$B(E2)_{Theor.}$	$\Gamma_{By\ half\ life\ time}\ X10^{-12}$	$\Gamma_{By\ exper.B(E2)} X10^{-12}$	$\Gamma_{By\ theor.B(E2)} X10^{-12}$
$2^+\rightarrow0^+$	1.180	12.845	0.262	0.024	0.262
$4^+\rightarrow2^+$	1.680	2.416	3.378	2.349	3.378
$6^+\rightarrow4^+$	2.400	2.669	32.58	29.29	32.58
$8^+\rightarrow6^+$	2.300	2.497	126.7	116.7	126.7
$10^+\rightarrow8^+$	2.100	2.065	300.1	305.0	300.1
$12^+\rightarrow10^+$	2.200	2.152	691.0	706.2	691.0
$14^+\rightarrow12^+$	1.800	1.794	1086	1089	1086

^{176}Yb Nucleus					
Transition	$B(E2)_{Exper.}$	$B(E2)_{Theor.}$	$\Gamma_{By\ half\ life\ time}\ X10^{-12}$	$\Gamma_{By\ exper.B(E2)} X10^{-12}$	$\Gamma_{By\ theor.B(E2)} X10^{-12}$
$2^+\rightarrow0^+$	1.060	8.685	0.259	0.032	0.259
$4^+\rightarrow2^+$	1.570	2.136	4.146	3.047	4.146
$6^+\rightarrow4^+$	1.900	2.018	35.08	33.02	35.08
$8^+\rightarrow6^+$	2.000	2.052	147.1	143.4	147.1
$10^+\rightarrow8^+$	1.910	1.912	380.1	379.6	380.1
$12^+\rightarrow10^+$	1.840	1.840	773.0	772.8	773.0
$14^+\rightarrow12^+$	1.660	1.667	1200	1195	1200

Looking at the details of Tables 1, we can see the good agreement between the theoretical values and the available experimental data [7-15] for reduced transition probabilities for all the states, except the cases ($2^+\rightarrow0^+$) for $^{166-176}$Yb when we are close to the neutron core at (N = 82), this is presented in tables 1 where the first column gives the transition between states and the second column gives the available experimental data [7-15], and the third column gives the our values for each state.The behavior for B (E2; $2^+ \rightarrow 0^+$) versus neutron number (N) for $^{160-176}$Yb nuclei Fig (1) can be discussed where, the observed location of the diffraction minimum is very well reproduced at N = 82 for this curve.

The values of B(E2) do not vary on the proton number and strongly depend on the number of neutron. These results are quite useful for compiling to nuclear data table, which makes it a good reference. In view of tables 1 one can point out that the values of partial gamma widths Γ(E2) productive by experimental B(E2) are less than that estimated by half life time and by theoretical B(E2) especially when the nucleon number deviated more and more from the magic neutron number, since the cooperative effects appear between nucleons and the rotational motion must be taken in regard.

We see that an unstable quantum state has $\Gamma(\mathrm{E2})$ since nuclear states are typically separated by energies in the MeV range; the width is small compared to state separations if the lifetime is greater than $\sim 10^{-22}$ Sec. This is generally the case for states decaying through the weak or electromagnetic interactions [16].

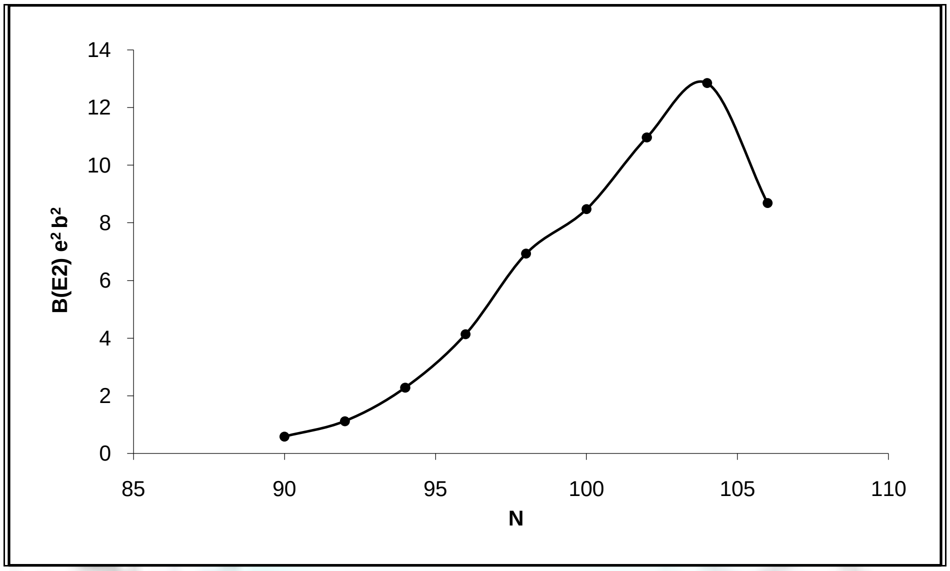

Fig. 1: Theoretical reduced transition probability B $(\mathbf{E2};\ 2^{+} \rightarrow 0^{+})$ as a function of neutron number for $^{166\text{-}176}$Yb nuclei.

4. Conclusions:

Our goal is the study of these nuclei in order to find how the structure of a nucleus changes when more and more nucleons (neutrons) are being added. The present work is provided a compilation of experimental values of $\mathrm{B(E2)}$ to $^{160\text{-}176}$Yb nuclei with $160 \leq \mathrm{A} \leq 176$ for comparison with experimental values. Also the partial widths of γ – ray transition extracted from half –lives and with the values are predicted by theoretical model.

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