LOW-LYING STATES OF ODD NUCLEI IN THE SOUTH–WEST ^{208}Pb REGION

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Binding energy of the ground state, energy levels and the B(E2) values of both positive and negative parities for ^{203,205}Au, ^{203,205}Hg, $^{203\text{-}207}$Tl and $^{203\text{-}207}$Pb isotopes have been calculated through shell model calculations using the shell model code OXBASH for Windows by employing the Modified Kuo-Herling interaction (khhe) for neutron and proton hole orbits in ^{208}Pb. The binding energy calculations were in good agreement with experimental data. The predicted low-lying levels (energies, spins and parities) and B(E2) values results were reasonably consistent with the available experimental data.

Key words: shell model, B(E2) values, energy levels, binding energy, OXBASH.

1. INTRODUCTION

Study of low-lying excited states of closed shell and near-closed shell provide information about specific nuclear orbital nuclei [1]. This is because only a few nuclear orbits dominate the contribution to their wave function. In case of the ^{208}Pb region, the experimental and theoretical information available on neutron-rich species is relatively limited. For example, previous studies of low-lying states for nuclei near ^{208}Pb region were scattered and uncompleted. Whereas ^{205}Hg and ^{205}Tl were studied in [2], odd-mass Tl isotopes in [3] and the nucleon-pair approximations (NPA) was applied to calculate the low-lying states of Ir, Pt, Au, Hg and Tl isotope with neutron numbers between 120 and 125 [4, 5]. Experimental studies on this region have been limited to measuring the excited states in ^{207}Tl [6] and ground state of ^{205}Au [7]. The isomeric states were observed in heavy neutron-rich nuclei populated in the fragmentation of a ^{208}Pb beam [8].

The purpose of this study is to apply the shell model and use Modified Kuo-Herling (khhe) interaction for neutron and proton hole orbits in ^{208}Pb energy levels and the B(E2) values of odd A (Au, Hg, Tl and Pb) nuclei with proton ranging

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from 79 to 82 and neutron numbers from 121 to 126, a total of ten nuclei. Concerning the valence proton holes and neutron holes with respect to ^{208}Pb, a doubly closed shell nucleus is used in this study to construct the shell model configurations of the nuclei of interest. The purpose of this paper is to concentrate on the extent to which these nuclei describe binding energies, low-lying level schemes and B(E2) values for odd A nuclei.

2. SHELL MODEL CALCULATIONS

The calculations have been carried out using the code OXBASH for windows [9] on the nuclei near of ^{208}Pb. The code uses an m-scheme Slater determinant basis. With a projection technique wave functions with good angular momentum J and isospin T are constructed. The jj56pn model space was comprised of (1g7/2, 2d5/2, 2d3/2, 3s1/2 and 1h11/2) below the Z = 82 closed shell for proton holes and (1h9/2, 2f7/2, 2f5/2, 3p3/2, 3p1/2and 1i13/2) below the closed N = 126 shell for neutron holes. Based upon the energy levels observed near the ^{208}Pb region [10] the proton single-particle energies are +11.483, +9.696, +8.364, +8.013 and +9.361 for the 1g7/2, 2d5/2, 2d3/2, 3s1/2 and 1h11/2, respectively. And the neutron single-particle energies are +10.781, +9.708, +7.938, +8.266, +7.368 and +9.001for the 1h9/2, 2f7/2, 2f5/2, 3p3/23p1/2 and 1i13/2 orbitals, respectively. The *two-body interaction matrix elements* (TBMEs) are from [10]. We are extended the modifications of the Kuo-Herling interaction to apply to all nuclei near the ^{208}Pb region, and these modifications are explained in [8]. In addition we used the harmonic oscillator potential (HO, x), x<0.

This study presented the calculated results of low-lying states of the odd A nuclei, proton ranging from 79 to 82, with neutron numbers from 121 to 126. The results include binding energies with respect to ^{208}Pb, energy levels and the B(E2) values.

2.1. BINDING ENERGY

Binding energies are important to nuclear astrophysicists when determining *Q*-values of proton capture reactions and beta decays [11]. The binding energies of nuclei near ^{208}Pb using the effective interaction khhe have been calculated by using the shell model OXBASH code. Binding energy *B* is defined by [5]

$$B = B(^{208}\mathrm{Pb}) - \langle H \rangle$$

The experimental binding energy of ^{208}Pb ($B(^{208}\mathrm{Pb})$) was taken to be 1636.430 (0.001) MeV [12-14]. The experimental and theoretical binding energies with errors, $\delta B = B(\mathrm{exp.}) - B(\mathrm{Cal.})$, are presented in Table 1. It can be seen that the experimental binding energies were reproduced satisfactorily. The root mean square deviation of the ten masses was 2.262 MeV. The shell model calculations of binding energies for these nuclei were not fitted with experimental data.

Table 1

Experimental and calculated binding energies of even A isotopes

Z	*N*	Nucleus	*B*(exp.) MeV[12-14]	σ MeV	*B*(Cal.) MeV	δ*B* MeV
82	121	^{203}Pb	1599.112	0.007	1597.0032	2.1088
	123	^{205}Pb	1614.238	0.001	1613.6182	0.6198
	125	^{207}Pb	1629.063	0.001	1629.1742	-0.1112
81	122	^{203}Tl	1600.869	0.001	1597.8567	3.0123
	124	^{205}Tl	1615.071	0.001	1613.9808	1.0902
	126	^{207}Tl	1628.427	0.005	1628.1766	0.2504
80	123	^{203}Hg	1601.159	0.002	1597.4846	3.6744
	125	^{205}Hg	1614.321	0.004	1612.1439	2.1771
79	124	^{203}Au	1599.816	0.003	1596.0983	3.7177
	126	^{205}Au	1611.566	-0.298	1609.5712	1.9948

2.2. ENERGY LEVELS

The objective of this study is to calculate the nuclei that lie near ^{208}Pb due to the importance of these nuclei in recent applications in astrophysics. The calculated energy levels and experimental results of low-lying states presented in Figures 1 and 2 correspond to odd-even and even-odd nuclei, respectively. Our calculations were plotted on the left and experimental data on the right for any band. Levels with '( )' correspond to cases for which the spin and/or parity of the corresponding states are not well established experimentally. The experimental data were taken from [15] for all nuclei as well as ^{205}Au nuclei, which was taken from [16].

One sees that our calculated results (in particular, yrast states) are reasonably consistent with experimental data, although the structure of odd-A nuclei is much more complicated than their even-even neighbors. On the other hand, there exist deviations between the calculated results and experimental data. In Figures 1 and 2 the calculated energies of up to the state $7/2^+$, up to the state $1/2^+$, up to the state $7/2^-$, $3/2^-$ and $7/2^-$, up to the state $9/2^-$ and up to the state $1/2^-$ except $13/2^+$ for ^{205}Tl, ^{203}Tl, ^{205}Pb, ^{203}Pb, ^{205}Hg and ^{203}Hg isotopes, respectively, are considerably higher than the experimental data. For non-yrast levels, the calculated energy levels of all odd-A nuclei are in good agreement with experimental results.

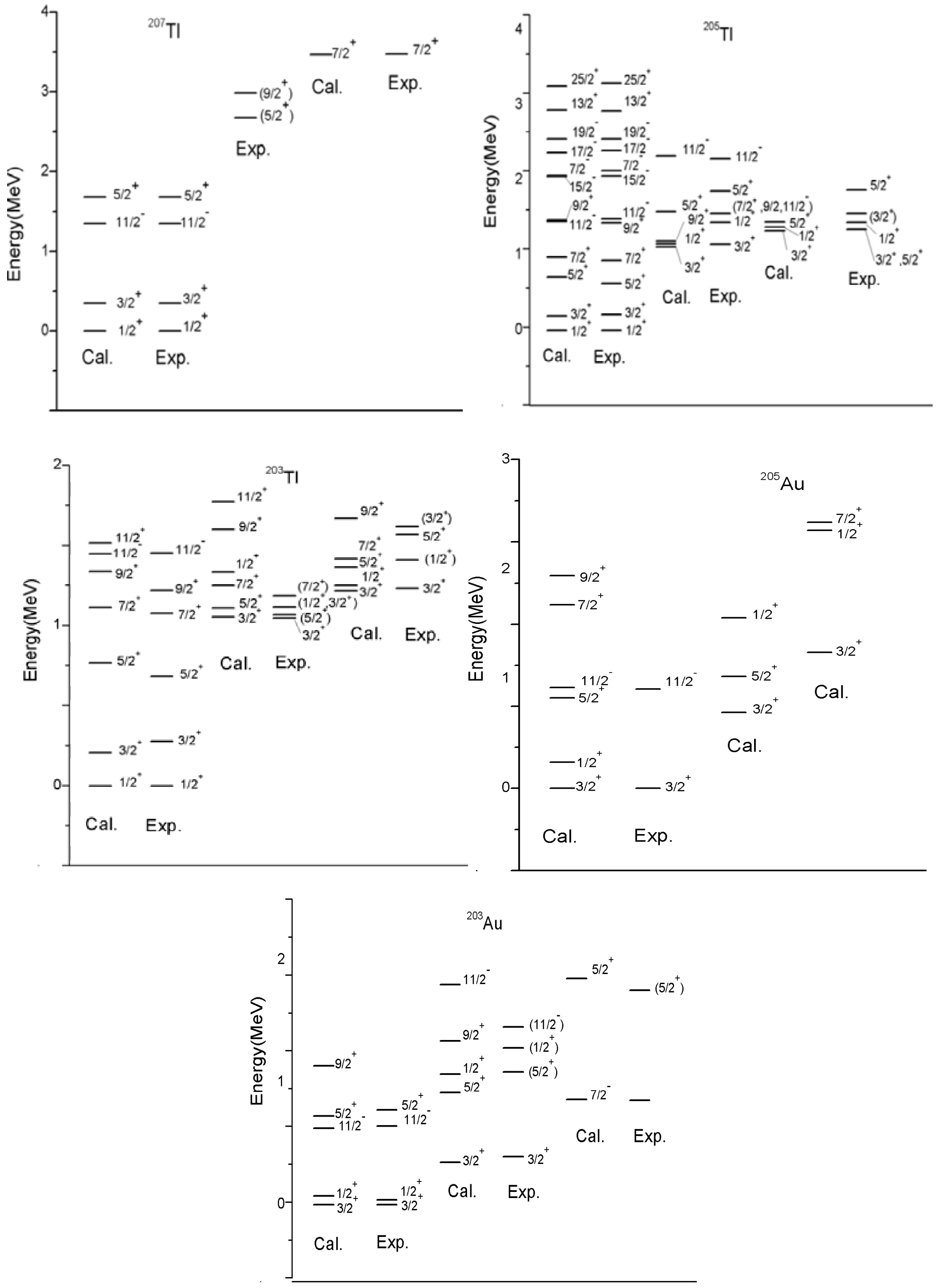

Fig. 1 – Comparison of calculated spectra with experimental ones for odd-even nuclei. The experimental data are taken from [15] and for ^{205}Au from [16].

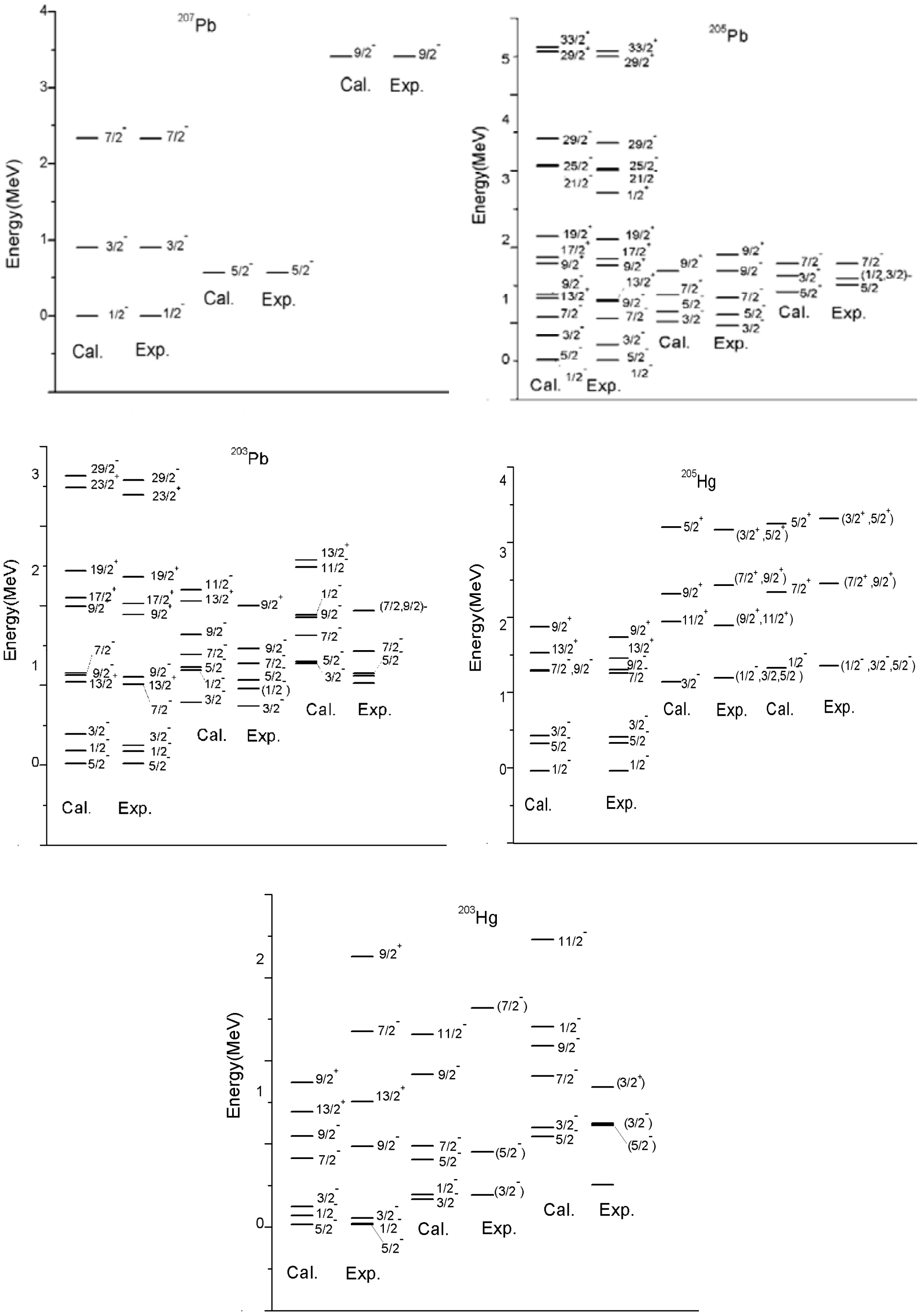

Fig. 2 – Same title of figure one but this is even-odd nuclei. The experimental data are taken from [15].

2.3. THE B(E2) VALUES

The transition rates represented a sensitive test for the most modern effective interactions that have been developed to describe the nuclei near ^{208}Pb. Transition strengths were calculated in this study using the harmonic oscillator potential (HO, x), where $x < 0$ for each in-band transition by assuming pure E2 transition. In this section, the calculated results of the B(E2) have been presented and the comparison of calculations B(E2) values with experimental data [17-19] were shown given in Tables 2 and 3 for the (proton number-neutron) odd-even and even-odd nuclei, respectively. In general, all of the calculated results are reasonably consistent with available experimental data.

Table 2

B(E2) values for odd-even nuclei (in W.u.)

	Cal.	Exp.[17-19]	Cal.	Exp.[17-19]	Cal.	Exp.[17-19]
	^{207}Tl		^{205}Tl		^{203}Tl	
$1/2^+ \rightarrow 3/2^+$	4.047	2.7(7)	5.935		7.000	7.6(3)
$5/2^+ \rightarrow 1/2^+$	2.023		2.233		6.185	9.7(15)
$5/2^+ \rightarrow 3/2^+$	0.624		0.666		0.717	0.80(17)
$7/2^+ \rightarrow 5/2^+$	0.185		0.428		4.636	
	^{205}Au		^{203}Au			
$1/2^+ \rightarrow 3/2^+$	1.417		4.3277			
$5/2^+ \rightarrow 1/2^+$	0.719		2.9802			
$5/2^+ \rightarrow 3/2^+$	4.864		7.4688			
$7/2^+ \rightarrow 5/2^+$	0.084		0.4491			

Table 3

B(E2) values for even-odd nuclei (in W.u.)

	Cal.	Exp. [17-19]	Cal.	Exp. [17-19]	Cal.	Exp. [17-19]
	^{207}Pb		^{205}Pb		^{203}Pb	
$3/2^- \rightarrow 1/2^-$	0.0205	0.0242(3)	0.002			
$5/2^- \rightarrow 1/2^-$	0.174	0.639(21)	0.008		0.045	
$5/2^- \rightarrow 3/2^-$	0.049		0.058		0.019	
$7/2^- \rightarrow 3/2^-$	0.224		0.001		0.089	
	^{205}Hg		^{203}Hg			
$3/2^- \rightarrow 1/2^-$	8.010		0.258			
$5/2^- \rightarrow 1/2^-$	5.442		1.227			
$5/2^- \rightarrow 3/2^-$	2.668		7.003			
$7/2^- \rightarrow 3/2^-$	3.045		1.440			

3. CONCLUSION

The present study demonstrated the binding energy of the ground state, low excited energy levels and the reduced probability for E2 transitions, B(E2) values, with positive and negative parities for Au, Hg, Tl and Pb odd isotopes. Good agreements were obtained by comparing these calculations with the recently available experimental data for binding energy, the level spectra and transition probabilities for nuclei near of ^{208}Pb.

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