Investigation of the neutron rich zirconium(A=92,94) nuclei with the interacting boson model

بحث نوى الزركونيوم (A=92-94) الغنية بالنيترونات بنموذج البوزونات المتفاعلة

Shetha Farhan AboAlhose
Kufa University/Education college for girls/ Physics department

Abstract:

The low lying levels structure and electric quadrupole transitions of $^{92,94}Zr$ nuclei have been studied by using the Interacting Boson Model-1 (IBM-1).

The calculated results are in good agreement with recent experimental data. The results obtained and the values of parameters used in this calculations indicated that Zr isotopes have a vibrational properties.and determined energy level 6_1^+ for tow nuclei Zirconium(94,92) by values (2.574MeV,2.580MeV) which did not specified earlier.

الخلاصة:

تمت دراسة مستويات الطاقة الواطئة والانتقالات رباعية القطب الكهربائية لنوى $^{92,94}Zr$ باستخدام نموذج البوزونات المتفاعلة الأول IBM-1 .

أظهرت النتائج توافقا جيدا مع القيم العملية الحديثة وأظهرت قيم المعاملات المستخدمة في هذه الحسابات ان نظائر الزركونيوم تمتلك صفات اهتزازية .

وقد تم تحديد مستوي الطاقة 6_1^+ لنواتي الزركونيوم (94,92) بالقيم (2574 MeV و 2580 MeV) حيث لم تكن محددة مسبقا .

Introduction:

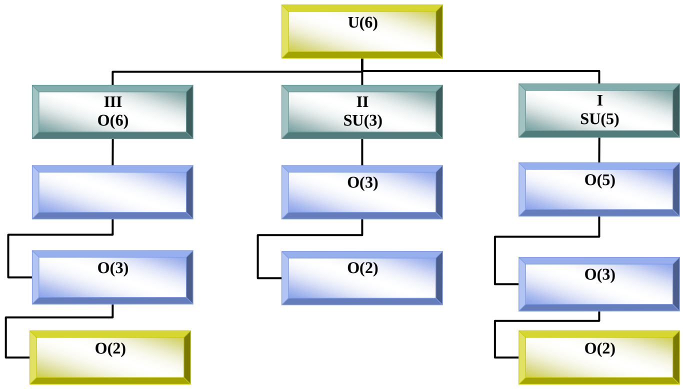
In 2006 the neutron and proton single-particle energies and the occupation probabilities for the valence states of the even-even isotopes $^{90,92,94,96}Zr$ were determined by matching data on nucleon-stripping and nucleon-pickup reactions on the same nucleus by O. V. Bespalova et. al. [1]. In 2010 Gamow-Teller strength distributions, β-decay half-lives, and β-delayed neutron emission were investigated in neutron-rich Zr and Mo isotopes within a deformed quasiparticle random-phase approximation by P. Sarriguren and J. Pereira where the approach was based on a self-consistent Skyrme Hartree-Fock mean field with pairing correlations and residual separable particle-hole and particle-particle forces[2].

Interacting Boson Model (IBM):-

Interacting Boson Model (IBM) had been introduce by Iachello [3]and then developed by Arima and Iachello [4-7]in the field of nuclear low –energy phenomena .The model has already gained a significant success in both single particle and collective behaviuor of nuclei[4].

Countless interaction boson approximation (IBM)calculations have been done over the last 30 years ,and the model has proved to be a valuable interpretive and predictive aid in understanding nuclear structure and its evolution as a function of N,Z and A .the model has entered the lexicon of standard approaches to nuclear structure [8,9].

In the IBM ,Axially symmetric rotors and spherical vibrators are schematically described in the IBM [8]by the analytically solvable dynamical symmetries SU(3)and U(5) .Besides these there exists a third analytical solution of dynamical symmetry O(6) with schematically describes γ –soft nuclei [9] .The three possible chains are as shown



The Hamiltonian for IBM-I is given by[5]

$$H=\varepsilon_s n_s+\varepsilon_d n_d+\sum_{L=2,4,6}\frac{1}{2}(2L+1)^{1/2}C_L\left\{\left[d^\dagger\times d^\dagger\right]^{(L)}\times[d\times d]^{(L)}\right\}^{(0)}$$
$$+\frac{1}{2^{1/2}}\upsilon_2\left\{\left[d^\dagger\times d^\dagger\right]^{(2)}\times[d\times s]^{(2)}+\left[d^\dagger\times s^\dagger\right]^{(2)}\times[d\times d]^{(2)}\right\}^{(0)}$$
$$+\frac{1}{2}\upsilon_0\left\{\left[d^\dagger\times d^\dagger\right]^{(0)}\times[s\times s]^{(0)}+\left[s^\dagger\times s^\dagger\right]^{(0)}\times[d\times d]^{(0)}\right\}^{(0)}$$
$$+u_2\left\{\left[d^\dagger\times s^\dagger\right]^{(2)}\times[d\times s]^{(2)}\right\}^{(0)}$$
$$+\frac{1}{2}u_0\left\{\left[s^\dagger\times s^\dagger\right]^{(0)}\times[s\times s]^{0}\right\}^{(0)}\ldots\ldots\ldots\ldots(1)$$

where n_s and n_d are number operators, ε_s and , ε_d are single boson energies for s- and d boson respectively. The C_L, V_2, V_0, u_2 and u_0 are corresponding interaction parameters.

This form of Hamiltonian is the most direct form which includes all allowed one-body and two-body interactions in the second quantization formalism. Alternatively, another form of Hamiltonian which emphasizes its multipole character is also adopted [9].

$$H=\varepsilon+a_0P^\dagger.P+a_1L.L+a_2Q.Q+a_3T_3.T_3+a_4T_4.T_4\ldots\ldots\ldots(2)$$

where P, L,Q,T_3 and T_4 are the pairing, angular momentum, quadrupole, octopole and hexadecapole operators respectively.

A successful nuclear model must yield a good description not only of the energy spectrum of the nucleus but also of its electromagnetic properties.

The one body transition operator which has the second quantized form is [8] :

$$T_m^{(l)}=\alpha_2\delta_{l2}\left[d^\dagger\times s+s^\dagger\times d\right]_m^{(l)}+\beta_l\left[d^\dagger\times d\right]_m^{(l)}+\gamma_0\delta_{l0}\delta_{m0}\left[s^\dagger\times s\right]_0^{(0)}\ldots\ldots\ldots\ldots(3)$$

Where α_2,$\beta_l$and γ_0 are coefficient of the various terms in the operator .this equation yields transition operator for E0,M1,E2,M3 and E4 transitions with appropriate values of the corresponding parameters. The most important electromagnetic features are the E2 transitions. The B(E2) values were calculated by using the E2 operator. The E2 transition operator must be a hermitian tensor of rank two and therefore the number of bosons must be conserved. Since, with these constraints the general E2 operator can be written as [7]

$$T_m^{(E2)}=\alpha_2\left[d^\dagger\times s+s^\dagger\times d\right]_m^2+\beta_2\left[d^\dagger\times d\right]_m^2\ldots\ldots\ldots\ldots(4)$$

The $T_m^{(E2)}$ operator ,which has enjoyed a widespread application in the analysis of γ-Ray transitions .

Calculation :

Calculation were performed in the complete Hamiltonian using the IBM -1 computer code for energies and IBMT-cod for B(E2) values.

For $^{92,94}Zr$ there are (6,7) active bosons ,the values of the parameters which are giving the best fit to experimental data [10-12] are listed in table(1) and fig.(1). In figs.(2) the calculated energy levels were compared with the experimental data.

The parameters in E2 operator eq.(4) are determined by fitting the experimental $B(E2;2_1^+ \rightarrow 0_1^+)$ data [10-12], and the parameters are listed in table(1),where $E2SD = \alpha_2, E2DD = \sqrt{5}\beta_2$ And $\beta_2 = \frac{-0.7}{5}\alpha_2, -\sqrt{7/2}\alpha_2$ *and* $=0$ in SU(5), SU(3) and O(6) respectively[4]. and the converter coefficient between (e^2b^2) and (W.u) is $B(E2)w.u = \frac{B(E2)e^2b^2}{5.943\times10^{-6} A^{4/3} e^2b^2}$ and B(E2) transitions are given in tables (2)

Table(1):The parameters obtained from the programs IBM-1 code.

Isotopes	Parameters in(MeV)								
	Eps.	P.P	L.L	Q.Q	T3.T3	T4.T4	$B(E2:2_1^+\rightarrow0_1^+)(e^2b^2)$	E2SD(eb)	E2DD(eb)
^{92}Zr	0.7	0.0	0.009	0.0	0.0089	0.0098	0.0153	0.036	0.0
^{92}Zr	0.76	0.04	0.012	0.0	0.0089	0.0098	0.0122	0.032	0.0

Table (2) Comparison between present values of B(E2)(in unit e^2b^2) for even-even $^{92,94}Zr$ isotopes (Theo.) and experimental ones (Exp.) [10-12]. The quadrupole moment of 2_1^+ state listed in last line.

i→f	$B(E2)e^2b^2$			
	^{92}Zr		^{94}Zr	
	Th.	Exp.	Th.	Exp.
$2_1^+ \rightarrow 0_1^+$	0.0161	0.0153	0.0128	0.0122
$0_2^+ \rightarrow 2_1^+$	0.027	0.034	0.021	0.0232
$4_1^+ \rightarrow 2_1^+$	0.02	0.0096	0.019	0.002
$Q21^+$	0.0	-	0.0	-

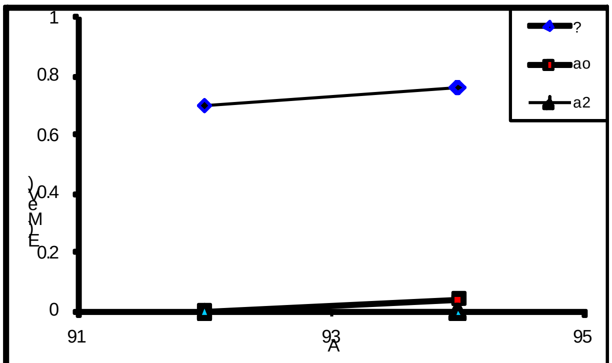


Fig.(1):The values of the (Eps., a0 and a2) parameters which give the best fit to the expermental [10-12] data.

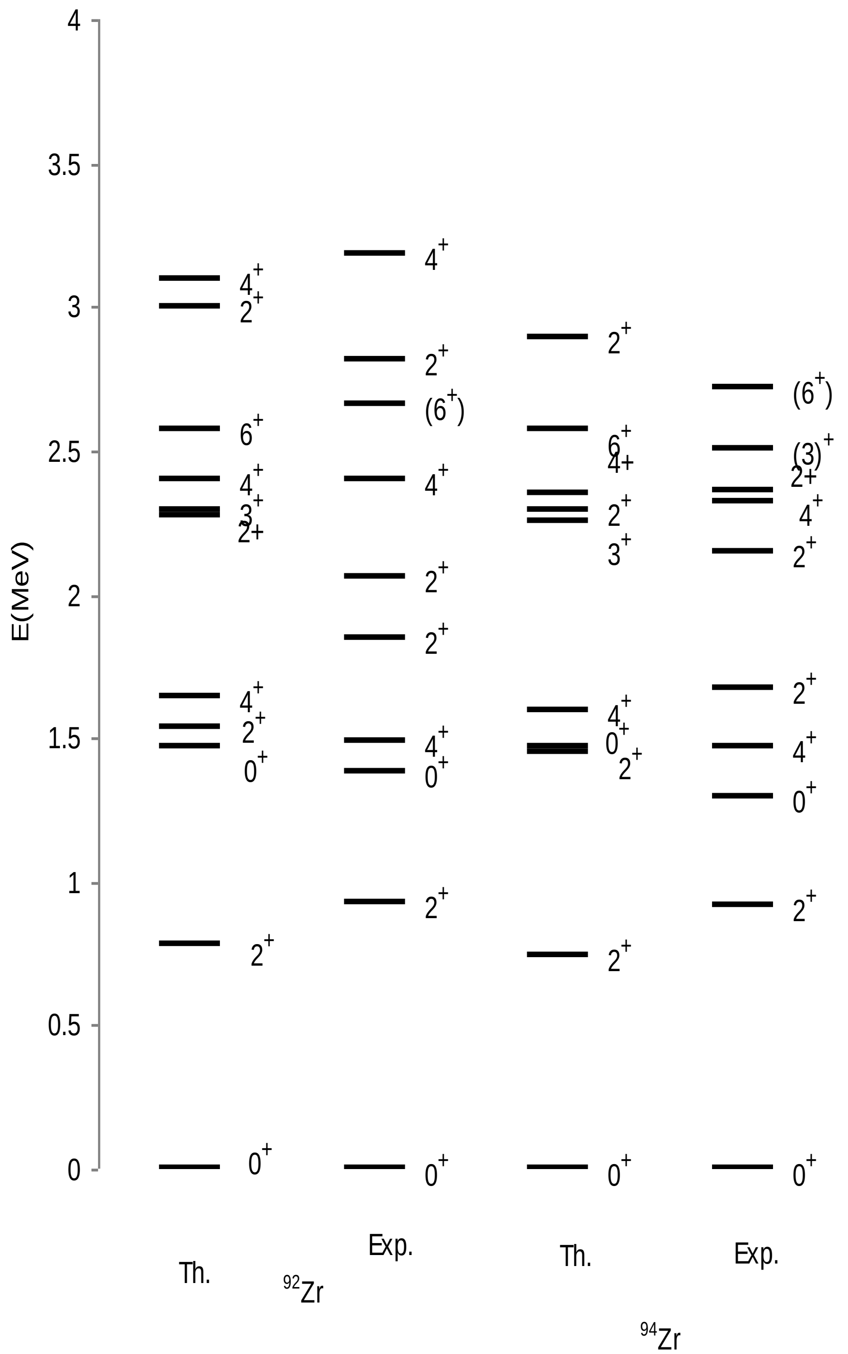


Fig. (2): Comparsion of experemental [10-12] and theortical energy levels of $^{92,94}Zr$ tsotopes.

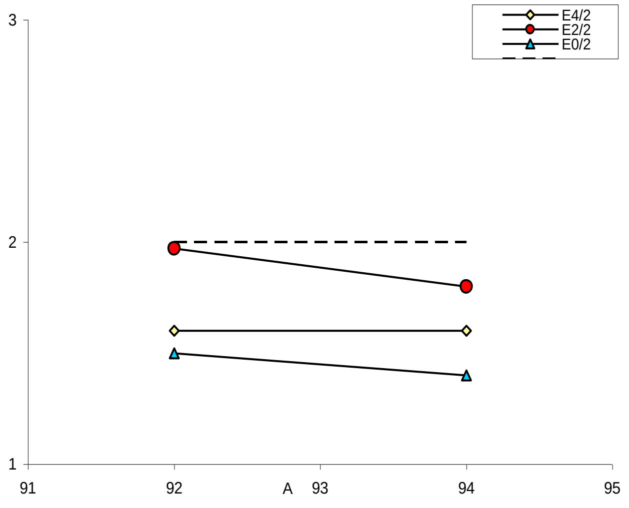


Fig.(3):Experimental [10-12] ratios $E4_1/2_1$,$E2_2/2_1$ and $E0_2/2_1$ for $^{92,94}Zr$ isotopes with SU(5) prospects the dotty line[4].

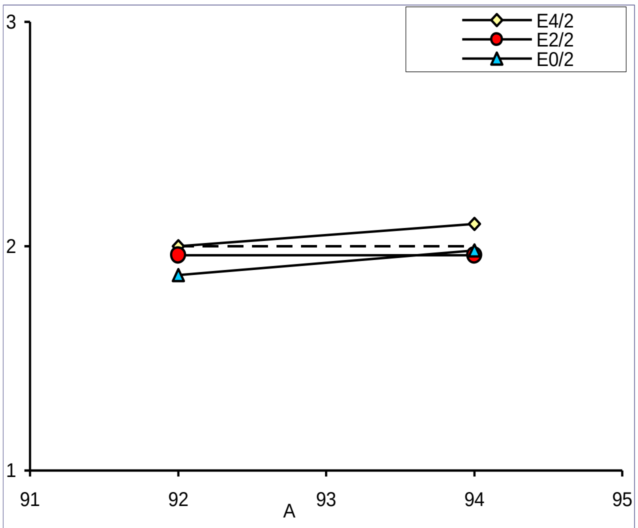


Fig.(4):Calculated ratios E 41/21,E22/21 and E02/21 for 92,94Zr isotopes with SU(5) prospects the dotty line[4].

Discussion and conclusion:

The even-even Zirconium(92,94) isotopes have been calculated by the IBA-1 Hamiltonian yields a good description of the energy levels in addition to the excitation energies and the electric quadrupole transition probability B(E2; Ii →If) of the $^{92,94}Zr$ isotopes. The $^{92,94}Zr$ nuclei have 5 bosons proton (hole) and (1-2) boson neutron (particles) which occur near the magic number 50, then the total number of bosons is (6-7) respectively. Figure (1) shows the values of the (Eps., a_0 and a_2) parameters and it is clear that the effect of Vibrational limit is increased with A.

In the present work and from the first sight, the Zirconium isotopes have the SU(5) behaviors because of the experimental and calculated ratio values E^+_{41}/E^+_{21}, E^+_{22}/E^+_{21} & E^+_{02}/E^+_{21} which occur near SU(5) characteristics see figs.(2-3) [5].

demonstrates that a microscopically based vibrational picture is quite successful to explain many aspects of the structure pure phonon structure. The experimental and theoretical values of 2^+_2 ,0^+_2 and 4^+_1 states which are commonly considered as members of the two phonon triplets are well descried in the framework of the IBM ,

then , the quadrupole moments values will be give the same impression where $Q2_1^+$ which measures the deviation of the nuclear charge distribution equal to zero.

References:

[1] O. Bespalova, I. Boboshin, V. Varlamov, T. Ermakova, B. Ishkhanov, E. Romanovsky, T. Spasskaya and T. Timokhina," Investigation of special features of the neutron and proton shell structure of the isotopes $^{90,92,94,96}Zr$ ",physics of atomic nuclei ,**69**,796,(2006).

[2] P. Sarriguren and J. Pereira , "β-decay properties of neutron-rich Zr and Mo isotopes " ,PHYSICAL REVIEW C **81**, 064314 (2010).

[3] F.Iachello, Collective aspects of the shell –model ,Proc. Int. Conf. on Nucl. Structure and Spectroscopy, Amsterdam , 1974 .

[4] F. Iachello , A. Arima," The interacting boson model", Cambridge University Press ,1987.

[5] A. Arima, F. Iachello ,Ann. Phy.**99**,293 (1976).

[6] A. Arima,F. Iachello ,Ann. Phy.**111**,201 (1978).

[7] O.Scholten, F. Iachello , A. Arima, Ann. Phy.**115**,325 (1979).

[8] A. Arima,F. Iachello ,Ann. Phy.**123**, 468 (1976).

[9] R.Casten and P. Brentano ,Phys.Lett.,**152B**,22,(1985).

[10] V.Werent, D.Belic, P.van Brentano, C.Fransen ,A.Gade ,H. von Garrel ,J.Jolie, U. Kneissl ,C.Kohstall,A.Linnemann, A.Lisetskiy, N.Pietrealla, H.Pitz, M.Scheck, K.Speidel ,F. Stedile and N.Yates, "Proton –netron structure of N=52 nucleus ^{92} Zr", Physics letters B, **550**, 140,(2002).

[11] M. Baglin, Nuclear Data Sheets **91**, 423, (2000).

[12] D. Abriola, and A. Sonzogni, Nuclear Data Sheets, **107**, 2423 (2006).

[13] N.J.Stone “Table of Nuclear Magnetic Dipole and Electric Quadrupole Moments”OXFORD OX1 3PU ,U.K.,(1998).