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Calculation reduced transition probabilities (BE2 ↓) for two holes in 64Ni within modified surface-delta interaction

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Abstract

Reduced electric quadruple transition probabilities (BE2 ↓) in the mixed configuration of ^{64}Ni with two holes have been calculated within the nuclear shell model. In the present work modified surface delta interaction MSDI within the model space $(1P_{3/2}\ 0f_{5/2})$ has been used for two holes neutrons The closed nuclear core is represented by the Ni- 66 nucleus. We have used a theoretical study to find a relationship between the semi-classical coupling angle $\theta_{a,b}$ and the energy levels at different orbital within (hole- hole) configuration. we observed good agreement between theoretical energy levels with experimental data, new values have been specified for both the excited energy levels and the reduced electric quadruple transition probabilities (BE2 ↓), these values are considered as a proposal, that grows theoretical understanding, of the energy levels and the expected transition probabilities through, this work.

Keywords: Modified surface delta interaction, ^{64}Ni, Reduced Transition Probabilities (BE2) ↓

1. Introduction

Nickel-64 nucleus has been the original subject of theoretical attention and restorative experimental since they lie far from the stability valley, thus allowing to recognize the evolution of the shell structure when approaching the neutron drip line. This has result in a major number of experiments in this, part [32, 28, 33, 25, 41, 31] directing explore the evolution of the single particle orbitals theoretically describing the spectroscopic properties of these nuclei the shell model with various two-body

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effective interactions has been widely used recently. Through the last years, shell model effective interactions without any experimental modifications have proved to be able to describe with remarkable accuracy the spectroscopic properties of nuclei in several mass regions [6, 7, 8]. Having nuclear shell model SM in notion ,Talmi applied SDI the surface delta interaction to estimate feature of nuclear cases with few particle on a closed core [13]. It uses presumption, initially there exists an inert core of (closed shell) ,which acts within forces on to valence particles ; another presumption, there exists a residual-interaction by means of 2-body forces acting between the valence particles. Schiffer [29] opinion the nuclei where 2 (hole, particle)there exists an inert core model of close shell ,which acts with central forces upon valence nucleons; another, there exists a residual interaction caused by two-body forces acting between the valence nucleons. Schiffer [29] considered only those nuclei where two (particle or hole) are present in addition to closed shell ,and move in the orbits ja and jb of a self -consistent field. Schiffer pointed out the universal behavior of the effective interaction in terms of the angle between the angular momenta of the interacting nucleons, property which was later shown to be related to the short-range character of the effective interaction [38, 39]. The angle between the protons and neutrons (holes , particles) spin vector ja and vector jb were determined in Ref. [4, 34]. Several of theoretic study explaining nuclear SM , by using MSDI [20, 30, 27]. J. Kostensalo and J.Suhonen [23] clarified a calculation of the properties pairing interaction for (even-even)reference nuclei in the mass region A =50 to 102 .K. Kaki [24] studied the elastic scattering for 48–82 Ni .In Ref. [22] explain beta decay of 62,64,68 Ni .In Ref. [35] explain optical model Ni –isotopes . In the recent years ,we studied the energy levels for different states within shell model [17, 14], the excitation energies for state hole –hole [15], particle–hole [13, 16] and particle- particle [18, 19] by using MSDI and surface delta interaction. Previous studies encourage the aim of the present study by application of MSDI predicting low-lying levels structure of 64Ni nuclei. We have used a theoretical process to find link between the classical coupling angle and energy levels at different orbital and determined the reduced electric quadruple transition probabilities (BE2 ↓).

2. Theory

Among the hypothesis of the shell model, there is a remaining interaction which are resulting between two valence nucleons , defining as the collision force between the nucleons which occurs as a cause of the perturbation in the Hamiltonian operation and equal to the sum of two basic parts . This is clarified as the following [2, 5]:

$$H = \sum_{k=l} H_0 + \sum_{k \leq l} V_{kl} \tag{1}$$

Where $\sum_{k<l} V_{kl}$ is expressed on residual 2-body interactions and can be re-written as:

$$\sum_{k<l} V_{kl} = \sum_{IM} \sum_{j_a \geq j_b} \sum_{j_c \geq j_d} \langle j_a j_b | V | j_c j_d \rangle_I a^{+}_{IM}(j_a j_b) a^{+}_{IM}(j_c j_d) \tag{2}$$

If δ_j is the energy of single particle state j relative to the closed core and $\langle j_a j_b | V | j_c j_d \rangle = V^{IT}_{abab}$ is the matrix element [26] the interaction energy when the 2 particle couple to angular momentum I the energy of this state relative to the closed shell

$$\langle H \rangle = 2\delta_j + \langle j_a j_b | V | j_c j_d \rangle \tag{3}$$

In order to depict the low-lying states, one should consider a situation where several single-particle levels are the basis ; if there are two states denoted by $|j_a j_b IM\rangle$ and $|j_c j_d IM\rangle$ then their energies with respect to the (core) are given by [26, 3].

$$\langle H\rangle_{11} = \delta_{ja} + \delta_{jb} + V^{IT}_{abab} \tag{4}$$
$$\langle H\rangle_{22} = \delta_{jc} + \delta_{jd} + V^{IT}_{abab} \tag{5}$$
$$\langle H\rangle_{12} = \langle H\rangle_{21} = V^{IT}_{abab} \tag{6}$$

To calculate the matrix element by using MSDI potential for the residual nucleon -nucleon interaction [13, 15].

$$V_{a,b} = -4\pi A_T \delta\Omega_{a,b}\delta(\hat{r}(a)) - R_0)\delta(\hat{r}(b)) - R_0) + B\tau_a\tau_b \tag{7}$$

The $\hat{r}(a), \hat{r}(a)$ are the position of vectors, R0 represent nucleus radius [11, 9, 19] A_T represent strength the interaction .The magnitude, $B\tau_a\tau_b$ represent o amount for the split between the levels with various angular momentum. $V_{a,b}$ is represent MSDI. Matrix element of is written [26, 21, 12].

$$\begin{aligned} V^{IT}_{abab} = &-\frac{A_T}{2(2I+1)} \times \sqrt{\frac{(2j_a+1)(2j_b+1)(2j_c+1)(2j_d+1)}{(1+\delta_{ab})(1+\delta_{cd})}} \\ &\times \left[(-1)^{l_a+l_b+j_c+j_d} h_I(j_a j_b) h_I(j_c j_d)\right]\left[1-(-1)^{l_c+l_d+I+T}\right] \\ &- \left[k_I(j_a j_b) k_I(j_c j_d)\right]\left[1+(-1)^T\right] + \{[2T(T+1)-3]B + C\}\, \delta_{a,c}\delta_{b,d} \end{aligned} \tag{8}$$

Where it is $h_I(j_a j_b) = \langle j_b - \frac{1}{2} j_a \frac{1}{2}|I0\rangle, k_I(j_a j_b) = \langle j_a \frac{1}{2} j_b \frac{1}{2}|I1\rangle$; Where $\langle|\rangle$ is the Clebsh-Gordon coefficients

The behavior of $(2h)$ nuclei is very much the same that nuclei except that the single particle energy $e_{h(hole)} = -e_{p(particle)}$ [13, 16, 3] The comportment of diagonal ion 2 - body matrix element as a function of the angular momentum I of (hole - hole) case is special when their data are plot in advantage way The major source of facts about total angular momentum and parity is the study of electromagnetic transfers, because electromagnetic interaction is a well know phenomenon different nuclear forces [26, 3]. The survey of gamma radiation emission has become associated with nuclear interactions, internal transformation, and nuclear decay. The decay rate of the emission gamma ray photon that results from the multipolar transitions from the initial state I_i to the final state I_f.The reduced transition probabilities can be calculated from the following equation [26].

$$\begin{aligned} B(EL: Ii \to If) = &\frac{1}{(2l_i+1)} \sum_{M_i M_f M} |\langle\psi_{I_f M_f}|T^{(E)}_{LM}|\psi_{I_i M_i}\rangle|^2 \\ &(\frac{2I_f+1}{2I_i+1})|\langle\psi_{I_f}||T^{(E)}_{L}||\psi_{I_i}\rangle|^2 \end{aligned} \tag{9}$$

where I_i and I_f represents the angular momentum of the initial and final states while $T^{(E)}_{LM}$ represents the multipolar electric effect .Gamma decay is expressed in Weisskopf units, and in order to judge whether the transition is relatively weak or strong, the B value of the single particle is often given in Weisskopf units in practical values. This unit is an estimate of the B value of the single particle (proton or neutron), and the following equations show how it depends on the mass number [26, 36].

$$B_\omega(E\lambda) = (\frac{1}{4\pi})[\frac{3}{(3+\lambda)}]^2(1.2A^{\frac{1}{3}})^{2\lambda} e^2 fm^{2\lambda} \tag{10}$$

whereλ is the gamma ray photon of the transition, and A is the mass number. The most commonly used equations are

$$B_\omega(E_1) = 0.0645A^{\frac{2}{3}} e^2 fm^2$$

$$B_\omega(E_2) = 0.0594A^{\frac{4}{3}} e^2 fm^4$$

when hole - hole in orbits j_a and j_b with $I = j_a + j_a$ one can write [40].

$$I^2 = (j_a + j_a)^2 = j_a^2 + j_b^2 + 2 \times (j_a j_b) cos\theta_{a,b} \tag{11}$$

$\theta_{a,b}$ is the angle between the vectors j_a and j_b. Since the length of vector j is given by $\sqrt{j(j+1)}$ one obtains from eq (12) in a classical picture [10]. Where $\theta_{a,b}$ is the angle between the vectors j_a and j_b. Since the length of vector j is given by $\sqrt{j(j+1)}$ one obtains from eq (12) in a classical picture [10].

$$Cos\theta_{a,b} = \frac{I(I+1) - j_a(j_a+1) - j_b(j_b+1)}{2\sqrt{j_a(j_a+1)j_b(j_b+1)}} \tag{12}$$

The I-dependence of the matrix element V_{abab}^{IT} can thus be plotted as a function of the angle $\theta_{a,b}$. The radial overlaps of the particle orbits for light nuclei differ from those for heavy nuclei. The proton -neutron configurations correspond to nucleon pair having mixed isospin and one find [15, 16].

$$E_I(p,n) = \frac{1}{2}\{(V_{abab}^{IT})_{T_I=1} + (V_{abab}^{IT})_{T_I=0}\} \tag{13}$$

Plotting the excitation energy of these states as a function of the corresponding angle $\theta_{a,b}$ determined as specified by Eq.(12). For neutron and proton in various orbits the absolute value of average two body energy is given by [19]:

$$\bar{E} = |\sum_I (2I+1)E_I \{\sum_I (2I+1)\}^{1/2}| \tag{14}$$

With E_I defined by Eq. (13).

3. Results and discussion

Some properties of nuclear structure for ground bands of ^{64}Ni nuclei have been calculated using MSDI. Hole nucleons of these nucleus are distributed in: $(1P_{3/2}0f_{5/2})$ model space. In these calculations MSDI have been utilized to estimate the energy levels and classical coupling angles $\theta_{a,b}$ for 2 neutrons hole. Thus, ^{64}Ni nuclei are discussed the following. There are 2 neutrons hole less then closed shell $N = 38$. In this case, the original MSDI Hamiltonian is adjusted to properly the ground state energy. It is found that the acceptance with the experimental value is very good. In order to involve the neutrons contribution, configurations mixing between the orbit is applied. The spectrum of this nucleus was calculated by using Eq.(4,5,6 and 8). Energy levels can be obtained by using the single particle energy [1]. Where: $\delta_{0f_{5/2}} = 8.8061$ MeV and $\delta_{1P_{3/2}} = 9.1162$ MeV. Table 1show a comparison between a theoretical, Theor.Res. and experimental, Exp.Res., excitation energies, MeV, for ^{64}Ni nucleus by using Model Space $(1P_{3/2}0f_{5/2})$. From table 1 it can be concluded the model space considered predict results in agreement with the observed data especially at low-excited energy levels. The MSDI calculations of the energies, and parity are in good agreement with the experimental values [37]. Good agreement between theoretical energy levels with experimental data. The new energy levels, which are expected for this nucleus in the states ($4_1^+, 2_2^+$ and 1_1^+ were not well established experimentally. Plotting excitation energy of these states as a function of the identical angle determined according to Eq. (12). Table 2 show (according to states of angular momentum I, all possible cases of the classical coupling angle data within configuration ($1P_{3/2}0f_{5/2}$) Table 3. show reduced transition probability $B(E2;\downarrow)$ for ^{64}Ni nucleus with the experimental value [37]. Fig. 1 show the behaviour for even states $j_a + j_b + I = even$ and odd states $j_a + j_b + I = odd$ of effective interaction for ^{64}Ni. Curvature is a measure of a short- range attractive force. The highest spin I values correspond to least possible angle $\theta_{a,b}$ and contrariwise. The energy levels seem to follow 2-universal functions which depend on the classical- coupling angles $\theta_{a,b}$.

Table 1: Comparison between a theoretical, Theor.Res. and experimental, Exp.Res., excitation energies, MeV, for ^{64}Ni nucleus

I^π	$\frac{Energy}{(MeV)}$	$\frac{Energy}{(MeV)}$	I^π
Theor. Res.		Exp. Res. [37]	
0_1^+	0.000	0.000	0+
2_1^+	1.3351	1.3457	2+
4_1^+	1.4448	...	...
2_2^+	1.849	...	...
1_1^+	1.9809	...	...
0_2^+	2.2968	2.2765	(2)+
4_2^+	2.3946	2.6101	4^+
3_1^+	2.7170	2.867	(0)+
2_3^+	3.647	3.6478	2^+

Table 2: According to states of angular momentum I , all possible cases of the classical coupling angle data.

I^π	Configuration ^{64}Ni	state	$\theta^\circ_{a,b}$
0_1^+	$(\frac{5}{2},\frac{5}{2},\frac{5}{2},\frac{5}{2})$	Odd	180
2_1^+	$(\frac{5}{2},\frac{5}{2},\frac{5}{2},\frac{5}{2})$	Odd	131.0823
4_1^+	$(\frac{5}{2},\frac{5}{2},\frac{5}{2},\frac{5}{2})$	Odd	81.78679
2_2^+	$(\frac{3}{2},\frac{3}{2},\frac{3}{2},\frac{3}{2})$	Odd	101.537
1_1^+	$(\frac{5}{2},\frac{5}{2},\frac{3}{2},\frac{3}{2})$	Odd	156.4218
0_2^+	$(\frac{3}{2},\frac{3}{2},\frac{3}{2},\frac{3}{2})$	Odd	180
4_2^+	$(\frac{5}{2},\frac{5}{2},\frac{3}{2},\frac{3}{2})$	Even	49.10661
3_1^+	$(\frac{5}{2},\frac{5}{2},\frac{3}{2},\frac{3}{2})$	Odd	92.50139
2_3^+	$(\frac{5}{2},\frac{5}{2},\frac{3}{2},\frac{3}{2})$	Even	124.5668

Table 3: Reduced transition probability $B(E2;\downarrow)$ for ^{64}Ni nucleus with the experimental value [37]

Transition n levels	Theoretical $B(E2), e^2fm^4$	Experimental $B(E2), e^2fm^4$
$2_1^+ \to 0_1^+$	117.6924	117.6863±37.96
$2_2^+ \to 0_1^+$	52.59697	...
$2_3^+ \to 0_1^+$	11.21293	...
$2_3^+ \to 0_2^+$	240.6839	...
$4_1^+ \to 2_1^+$	79.15135	101.7417±16.7039
$4_2^+ \to 2_1^+$	79.15135	212.5947±16.7039
$4_2^+ \to 2_2^+$	194.7856	...
$3_1^+ \to 2_1^+$	66.05897	...
$3_1^+ \to 2_2^+$	68.96398	...
$1_1^+ \to 2_1^+$	22.02019	...
$1_1^+ \to 2_2^+$	11.54148	...

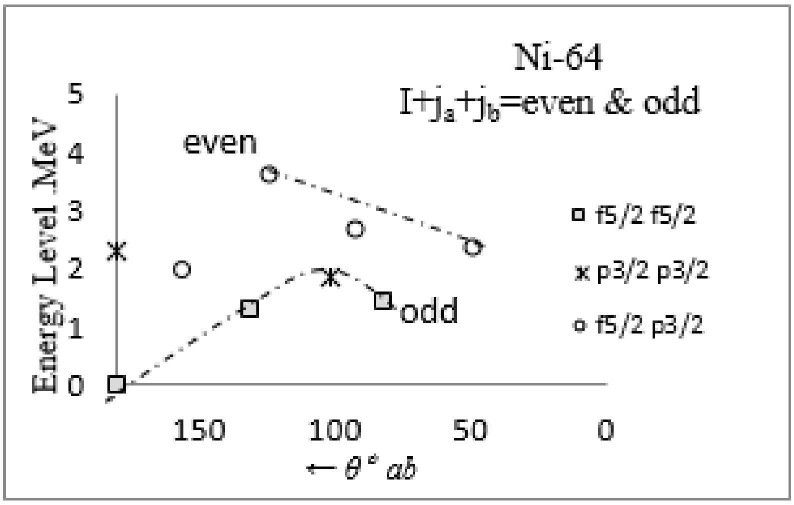

Figure 1: The value of theoretical energy levels for states as (hole –hole) a function of the classical coupling angles $\theta_{a,b}$

4. Conclusion

The current theoretical calculations give the data of the energy levels, by using the MSDI potential for Ni nuclei The shell model used in the present study predicts most of the energy levels and their systematics with their total angular momentum. Comparing the experimental results with the shell-model calculations shows that the level structures exhibit mainly the single-particle character. The most important results of calculations can be summarized as follows:

- The agreement between theoretical and experimental levels is satisfactory for excitation energies and transition probabilities $B(E2;\downarrow)$. New values for $B(E2;\downarrow)$ not indicated by the experimental data.

- We observe the energy levels appear to follow two overall functions which depend on the classical coupling angles but are unconstrained of angular momentum I .The minimum angular momentum I values correspond to maximum angle and vice versa.

- The theoretical calculations in the nuclear shell model by using the MSDI reasonably agree with the experimental data. This indicates that the shell model is very good to describe the nuclear structure for 2-hole in Ni nuclei

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