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An Application of Coupled Clusters Expansion to generate the complete ground state due to n-n interaction

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ABSTRACT

This topic deals with the study of correlation of ground and excited states of even nuclei like ^{16}O and ^{4}He. The main objective of present work is to develop more theoretical techniques applicable in nuclear physics. The work is also extended to discrete excited states as well as odd even nuclei. The work is useful for the calculation of nuclear many body problems for spherically symmetric nuclear quantization representation. The ground state calculation of ^{16}O and ^{4}He are done using G matrix, which also help in calculation of ground state binding energy and one body two body densities.

Key Words :- Correlated & uncorrelated wave-function, one body density, Excited states, Discrete excited states, Odd even nuclei, G-matrix.

INTRODUCTION

Many attempts have already been made to understand complex behavior of even nuclei and to propose a suitable model based on certain approximation and to calculate various parameters of these nuclei. Present attempt is not only advancement of these attempts but also knock out reaction to discrete states all have in same way supported the mean field approach, as the lowest order in the description of nuclear structure. The form factor for the excitation of high single particle stated in ^{208}Pb were described extremely, well in shape be mean field wave function general conclusion of observables e.g. binding energy, one body density or two body densities. They do not change actual shape of the wave function but simply modify the strength due to deoccupation of orbits below the fermi surface and partial occupation of orbits above the fermi surface. Therefore, we have to take into account the correlation largely due to hard repulsive core of nucleon nucleon interaction.

To account for the correlation, there are different ways. One way is to introduce correlation function in many body wave functions in real space. It has been quite successful for small nuclei [1] and has resulted in reasonable description of ^{16}O. Another approach is added in configuration space to the uncorrelated ground state multipartite multi holes configurations. These two approaches can be related to each other.

MATERIALS AND METHODS

2.1 In the present study the exp(s) method also known as coupled cluster expansion to generate the complete ground state correlations due to the nucleon nucleon interaction is used. To solve G-matrix inside the nucleus, there are two types of functions one is uncorrelated and other is correlated.

The quantities to be compared to experiment are calculated to be evaluating the mean value of corresponding operators fixed at the minimum of the energy function.

$$(Q) \quad = \frac{\langle \emptyset_0 | F^* QF | \emptyset_0 \rangle}{\langle \emptyset_0 | F^* F | \emptyset_0 \rangle}$$

Here Q is indicated as generic operator associated to on observable.

2.2 Uncorrelated Function: An uncorrelated ground state can be constructed as a single Slater determinant which indicates all the occupied orbits and is written as $|o\rangle$. It is introduced as the vacuum of reference state of the many body system. The vacuum must play [2] the basic role of cycle victor, with respect to which may be defined two mutually communicating sub algebras called Abe lion. There are multi configurationally creation operator C_n^* and their Hermit ion adjoin destruction operator C_n. Therefore

$$|\tilde{\Psi}< = \sum \tilde{\Psi}_n C^*_n |0>$$
$$\text{and} < \tilde{\Psi} | = \sum \tilde{\Psi}_n < 0 | C_n$$

Where n is set index, a general multiparticle cluster configurations. The single particle wave functios, are expanded easily in a set of orthonormal functions such as harmonic oscillator function, Bessel's functions and others. Thus each orbit is represented by a set of expansion coefficients and single particle energy. In second quantization[3], this translates into :

$$\mathbf{a_h^* |0>=0; a_p| 0>=0}$$

2.3 Correlated functions: Correlated function can be obtained using variation approach and shall further assume that there exist at least one set of wave function. This set is the set of single particle mean field wave functions. With that basis lowest order or correlation are the two particle tow hole (2p2h) correlated. A variation $\delta|\tilde{o}>$ orthogonal to the correlated ground state can be constructed from any operator C^*_n representing any n-p, n-h excitation as

$$\delta|\tilde{o} >= e^{-s}C^* e^{-s^*}|\tilde{o} > = e^{-s} C^*_n|\tilde{o} >$$

3. Results and Discussion

According to the variational principle the Hamiltonian between ground state and such a variation vanishes therefore we have the following equation :

$$<\tilde{o}|HS|\tilde{o}> = < o|e^{-s}He^{-s} C^*_n|o >$$

the term $e^{-s}He^{-s}$ represents effective Hamiltonian. Thus the term $e^{-s}He^{-s}$ repute effective Hamiltonian to show that a system of above equation is equivalent with the previos coupled cluster method [2, 4]

All the individual components of S commute with each other, so that each element of S is linked directly to the Hamiltonian. Exact ground state Schrödinger equations are followed as:

$$\mathbf{H | \tilde{o} >= E | \tilde{o} >}$$

in transformation, it may be written as

$$\mathbf{e^{-s}He^{-s} |o >= E |0>}$$

The particle orbit has been changed into hole orbit in order to get the matrix elements between particle and hole orbit and the detail contribution in the mean field has been taken into account [5].

To apply the above formalism to the ground state the binding energy, the ground satate expectation value for arbitrary operator are evaluated first. This can be done by introducing operator $\mathbf{S^*}$, as described in the normal coupled cluster method[2]. The ground state has been taken as :

$$\mathbf{| \tilde{o} >= e^{s^*} |0>}$$

The equation for the energy implies that all the correlations are present and the above procedure is applied to the ground state one body density. According to the definition the ground state one body density is introduced as :

$$\mathbf{\rho(\check{r})=\sum_{k=1}^{A} < \tilde{o} | \delta(\check{r}- r_k) | \tilde{o} >}$$

In order to be consistent with phase convention of two body potential matrix elments, the two body density matrix elements is coupled with ph angular matrix coupling conventions[6].

Evaluation of ground state of ^{16}O: In the present study coupled cluster exp (s) method is used to calculate the ground state of ^{16}O. The equation is solved so it determines the 2p2h amplitude and thus essentially the ground state G-matrix for ^{16}O is a space of 35hw with a harmonic oscillator length parameter b= 0.8 fm, excluding those orbits with l and 13. Further correlation for 3p3h as corrections are included in a reduced space of 30hw and l and 6. In the last correctors due to 4p4h corrections are included in full space.

3.2 Binding energy: To apply the above formalism to ground state binding energy; let us first evaluate the ground state expectation values for arbitrary operators, which can be evaluated by introducing the operator $\tilde{S}^*$, which is defined by its decomposition in terms of ph-correlation operators :

$$\tilde{S}^* = \sum \frac{1}{n!} \tilde{S} C_n^*$$

Bragrand state wave function is given as

$$\langle \tilde{o} | = \langle o | \tilde{S}\, e^{-s^*}$$

On application of this procedure to the ground state binding energy the expectation value of Hamiltonian can be written as

$$\langle E \rangle = \langle o | e^{-s} H e^{-s} (1+S^*) | o \rangle$$

the term invaling $\tilde{S}^*$ vanishes and energy becomes

$$\langle E \rangle = \langle o | e^{-s} H e^{-s} | o \rangle$$

Assuming that H is almost two body operator and taking in to account that S, vanishes, we write this as

$$\langle E \rangle = \langle o | H | o \rangle + \langle o | S_2 V_2 o | o \rangle$$

When expectation value of operator H is evaluated in the above equation, it is considered that the whole orbits are not denoted with respect to only of these operators. Also, this expression needs to be modified if three nucleon interactions are preset. This expression does not give the upper limit of the ground state of the energy unless it is exactly at the minimum.

Table I Strength parameter of various three nucleon interactions of the urbana series

Sl. No.	Potential	Two pion exchange	Short range potential
1.	Urbana V	- 0.0333	0.0030
2.	Urbana VII	- 0.0333	0.0038
3.	Urbana VIII	- 0.0280	0.0050
4.	Urbana IX	- 0.0293	0.0048

Where $A^*_{2\pi} = - f \left(\frac{f^* m\pi}{12\pi 9 E_{av}} \right) 2$

f and f* are π NN and π NΔ coupling constant E_{av} is the mean energy.

Table II Resulting binding energy (E), r.m.s. charge radii (r) and occupation probabilities.

Sl. No.	Potential	Binding energy (E) (Mev/nucleon)	R.M.S charge radii (r)(fm)	$1d_{5/2}$ %	$2S_{1/2}$ %
01	V_8	- 6.44	2.843	2.08	4.26
02	V_{14}	- 5.66	2.839	1.86	4.98
03	V_{18}	- 4.79	2.840	1.77	3.83
04	V_{14}+urbanaV	- 7.00 (+0.27)	2.832	2.40	7.33
05	V_{18}+urbana IX	- 5.90 (+0.27)	2.805	2.65	6.57
06	Experimental	- 8.0	2.73	2.27	1.78
			±0.025	±0.12	±0.36

CONCLUSION

A reasonable description of the ground that of ^{16}O that explicitly accounts for realistic correlations use the coupled cluster expansion (exp (S) method) to solve the many body Schrödinger equations in configuration space. While the coupled cluster expansion is exact it carried out to all orders, the present results are obtained with truncations. In this study efforts are made in two ways. First we intend to apply the procedure described in this paper for more realistic interaction. Second we have used the equality of motion technique to calculate excited states of ^{16}O nucleus.

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