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A Quasi Shell Model Calculation of 0^{16*}

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MASTER

ABSTRACT

The even parity spectrum of 0^{16} is calculated using the $(0+2)\hbar\omega$ shell model functions as a basis. RPA techniques are employed to decouple the core state without eliminating ground state correlations. By suitably choosing the strength of the interaction, the observed spectrum can be fitted remarkably well. Work is in progress to obtain transition rates and other nuclear properties.

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A Quasi Shell Model Calculation of 0^{16} *

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We give here a preliminary report of a calculation of the even parity energy spectrum of 0^{16} using RPA techniques. Other properties have not been extracted as yet, but the results of the energy comparison are encouraging. An extended account of this work is in preparation.

Recent shell model calculations¹ of 0^{16} have shown that when the core state $|s^4p^{12}\rangle$ ($\equiv |0\rangle$) is included, the calculated ground state suffers an unusually large depression relative to the average energy of all the other levels. If the core state is not coupled in this fault is removed, but at the expense of suppressing all ground state correlations. We have attempted to resolve this dilemma by making recourse to an RPA interpretation, a brief description of which follows.

It is easily demonstrated² that any operator $\Gamma^\dagger$ satisfying

$$[\mathcal{H}, \Gamma^\dagger] = \omega \Gamma^\dagger \quad (1)$$

where $\mathcal{H}$ is the Hamiltonian and ω is a positive number, can be used as an energy raising operator. Hence energies ω obtained from (1) are actually the excitation energies of the system described by $\mathcal{H}$. If we attempt to solve (1) in terms of particle conserving products (normally ordered with respect to $|0\rangle$) of fermion creation and annihilation operators ($1, a_\alpha^\dagger, a_\beta$, etc.)

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we arrive at an infinite set of coupled equations. If the equations are broken somewhere by neglecting all groups containing more a -operators than a certain fixed number, the remaining equations can in principle be solved. We have chosen to neglect all groups containing more than four a -operators, and also all groups which give zero both when acting on $|0\rangle$ to the right and when acting on $\langle 0|$ to the left. Apart from the unit operator, the surviving operators are just the state creation operators $S_q^\dagger$ and their hermitian conjugates S_q . $S_q^\dagger$ has the property that $S_q^\dagger|0\rangle = |q\rangle$ where $|q\rangle$ is a shell model state labelled by q . Had we chosen to retain only the $S_q^\dagger$, the energy determining equations would have reduced to those of a standard shell model calculation with the core state uncoupled. When both $S_q^\dagger$ and S_q are retained, the equations have an RPA structure but include two-hole two-particle (2h-2p) as well as lh-lp excitations. To avoid confusion with the higher RPA³ (which strictly speaking should retain some of the terms we have discarded), we refer to this method as the quasi shell model approximation (QSMA). We note that, within this approximation, properties other than the energy must be calculated in a manner consistent with the RPA interpretation.

For the parameters used in our numerical work, it turns out - as may be verified a posteriori - that the positive parity states of interest contain very little contribution generated from the operators S_q . It is therefore sufficiently accurate to neglect the S_q and set up the equivalent shell model eigenvalue problem.

In our calculation, interaction matrices were set up using harmonic oscillator single particle orbits with $v = m\omega/\hbar = 0.323$ (fermis)⁻². For the basis states $|q\rangle$ we took the set of all possible states at $2\hbar\omega$

excitation above the core. We used a Rosenfeld central force with Gaussian radial dependence of range $r_0 = 1.85$ fermis. The depth V_0 was varied to fit the known $J=0+$ and $2+$, $T=0$ levels of O^{16} , resulting in a value of -51 MeV. For the single particle energies we used essentially the values listed by Jolly.⁴ The effects of spurious center of mass motion were eliminated. The values chosen for the parameters are all reasonable. Indeed, if we use the shell model states at low excitation and calculate the odd parity levels with these parameters, we obtain a spectrum similar to that of Elliott and Flowers⁵.

The results for the even parity states are exhibited in Figures 1 and 2 and Table 1. Although the strength of the force was the only free parameter in the calculation, there is a remarkable agreement with experiment for a wide range of energy levels. Most $T=0$ states are properly reproduced by the calculation, although we do find a $J=4+$ and a $J=6+$ state at energies much lower than observed experimentally. The calculated $T=1$ states are somewhat low, but still within $1 - 1.5$ MeV of their experimental counterparts. The $T=2$ states fall well into place, the lowest predicted $J=0+$ and $2+$ states being both about 1 MeV lower than the observed levels.

Unfortunately, there still remains much which has to be done before we can know how effective this approach to the O^{16} problem really is. Formulae for the nuclear moments and transition rates will have to be set up and evaluated for comparison with experiment. With regard to the QSMA method itself, it would be desirable to know more about the effect of the neglected terms. We propose to continue investigation along these lines.

At this point we have shown only that the shell model is capable of simultaneously giving a fairly good description of both the even and odd parity spectra of O^{16} and that within the QSMA concept it is possible to retain the effects of correlations in the ground state. But the success of this preliminary work suggests that this approach may go a long way towards a valid description of many of the states of O^{16} .

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TABLES

Table 1

The T=2 States of O^{16}

J π	Calc. (MeV)	Exp. (MeV)
0+	22.12	22.9
2+	23.75	24.7

Figure Captions

- Fig. 1 Even parity $T=0$ energy levels of O^{16} . For each spin, the first column shows the calculated energy levels while the second column shows the experimental levels. Brackets denote experimental levels whose spins have not been confirmed.
- Fig. 2 Even parity $T=1$ energy levels of O^{16} . For each spin, the first column shows the calculated energy levels while the second column shows the experimental levels. Brackets denote experimental levels whose spins have not been confirmed.