THE EVEN PARITY STATES OF ^{94}Mo

C. DEDES
Department of Physics, University of Ioannina, Ioannina, Greece

and

L.D. SKOURAS
Tandem Accelerator Laboratory, N.R.C. Demokritos, Aghia Paraskevi Attikis, Greece

Received 24 November 1976

The even parity spectrum of ^{94}Mo is calculated in a basis constructed by coupling the $(0g_{9/2})^2$ proton to the $(1d_{5/2}, 2s_{1/2}, 1d_{3/2}, 0g_{7/2})^2$ neutron configurations. The effective interaction is calculated to second order and by allowing up to $2\hbar\omega$ excitations. The results of the calculation are in satisfactory agreement with experiment on both energy levels and transition rates.

The properties of the low-lying levels of $^{94}_{42}$Mo have been studied recently by several experimental groups [1–9]. These experiments established the presence in the spectrum of ^{94}Mo (fig. 1) of several positive parity levels below 4 MeV of excitation [1–7] and gave information about the decay properties of some of these levels [8, 9]. On the other hand only few shell-model calculations have been reported [10, 11] on the even parity spectrum of ^{94}Mo. In these calculations the simple $(0g_{9/2}p)^2$–$(1d_{5/2}n)^2$ basis was employed while the matrix elements of the effective interaction were deduced from the observed spectra of ^{92}Zr, ^{92}Mo and ^{92}Nb. Due to the limited model space employed, these calculations fail to account for the large member of levels observed above 2 MeV of excitation. Such a feature clearly indicates that other configurations play an important role in the low-energy spectrum of ^{94}Mo.

Recently a shell-model calculation has been reported [12] on the even parity states of $^{95}_{43}$Tc. In this calculation the three valence protons were considered to be in the $0g_{9/2}$ orbital but on the other hand full configuration mixing was assumed for the two valence neutrons which were allowed to occupy any of the $1d_{5/2}$, $2s_{1/2}$, $1d_{5/2}$ and $0g_{7/2}$ orbitals. This is a reasonable assumption since the experimental single-particle spectrum given by [13]

$$\epsilon d_{5/2} = 0, \quad \epsilon s_{1/2} = 1.0\ \text{MeV}, \quad \epsilon d_{3/2} = 2.5\ \text{MeV}, \quad \epsilon g_{7/2} = 3.0\ \text{MeV}, \tag{1}$$

shows that the $2s_{1/2}$, $1d_{3/2}$ and $0g_{7/2}$ orbitals are not much separated in energy from the $1d_{5/2}$ orbital and for this reason ought to be included in the model space. The success of the ^{95}Tc calculation in accounting satisfactorily for the excitation energies and decay properties of about 35 levels of this nucleus clearly suggests that the same model might also give reasonable results for the neighbouring ^{94}Mo.

The basis states considered in the present calculation for the description of the even parity states of ^{94}Mo have the general form

$$|^{94}\text{Mo}: JM\rangle = |(0g_{9/2}p)^2 J_p, (1d_{5/2}, 2s_{1/2}, 1d_{5/2}, 0g_{7/2}n)^2 J_n; JM\rangle. \tag{2}$$

As may be seen from (2) configurations describing proton excitations from the $0g_{9/2}$ orbital to the other orbitals of the sdg shell as well as excitations from the pf shell to the $0g_{9/2}$ orbital have been omitted from the model space. The arguments for introducing such an approximation have already been given with respect to the ^{95}Tc calculation [12] and need not be repeated here. Nevertheless the effects of these omitted configurations have been considered in the evaluation of the effective interaction.

Two simplifying assumptions have been made in the calculation of the effective interaction [12]. These are (a) Neglect of higher than second order terms and (b) Restriction to energy denominators of $\leqslant 2\hbar\omega$. No direct test of the validity of these assumptions

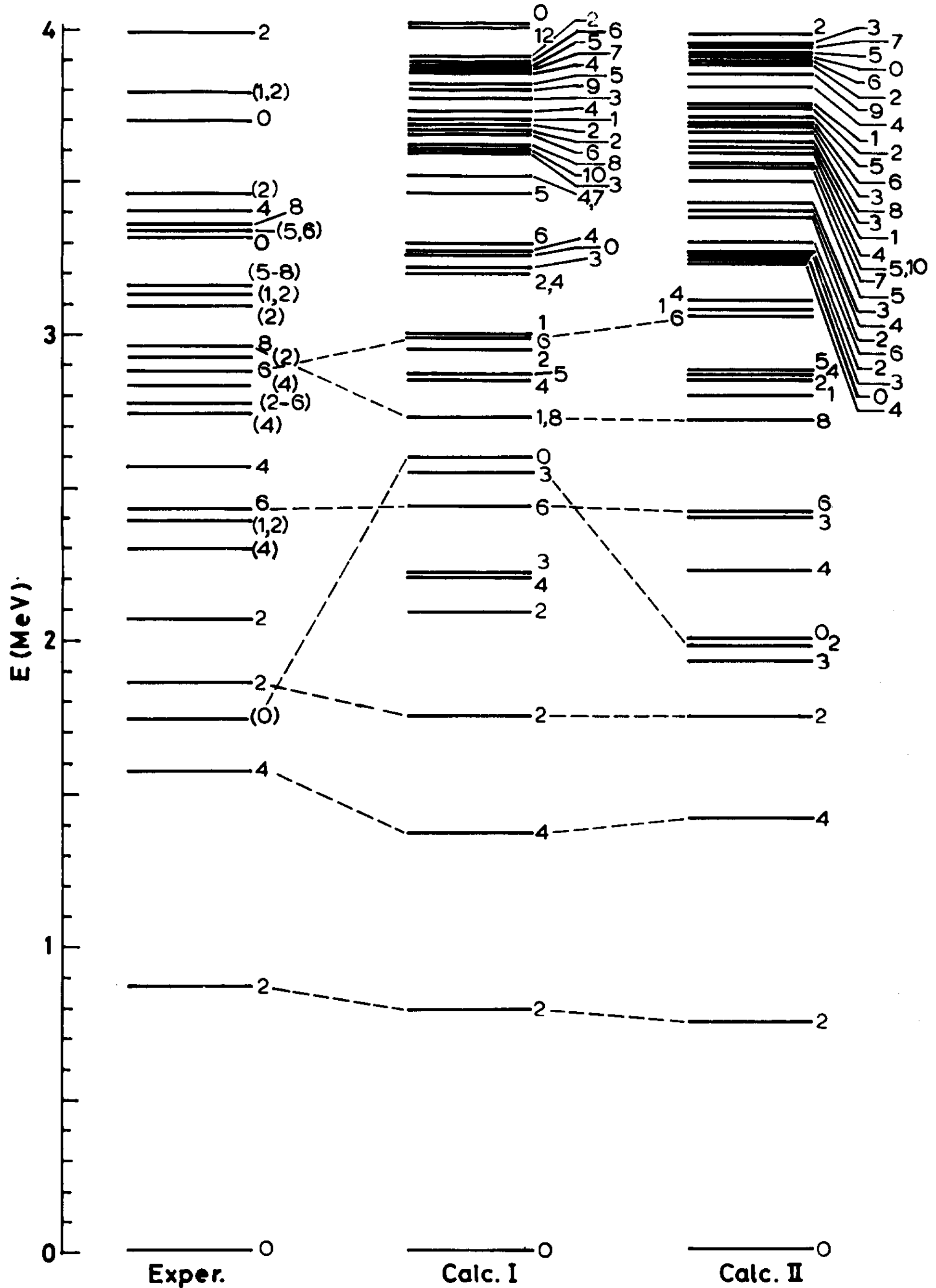

Fig. 1. Experimental [1–7] and calculated even parity spectra of ^{94}Mo. The two theoretical spectra differ in the choice of $\epsilon s_{1/2}$ which is 1.0 and 0.5 MeV for calculations I and II respectively. Broken lines connect the states that are discussed in the text.

has been made. However, the calculated energy spectra of ^{92}Mo, ^{93}Tc, ^{94}Ru [14] and ^{95}Tc [12] provide an indirect justification of the approximations adopted here. As bare G matrices the "Sussex" [15] and "Yale" [16] interactions have been considered. The results of the present calculation are not significantly interaction dependent and for this reason we quote in the following only the results obtained with the Sussex interaction. Like in the ^{95}Tc case [12] we have adopted here the approximation of neglecting the effective three-body interaction. The effects of this interaction have been studied recently in connection with the energy spectra of ^{95}Tc, ^{94}Ru, and ^{93}Mo [17] and found to be extremely small.

It was found during the calculation that some of the properties of the low-lying states are sensitive to the choice of the $\epsilon s_{1/2}$ single-particle energy. In the following we present results obtained with $\epsilon s_{1/2}$ values of 1.0 (as in (1)) and 0.5 MeV and we shall distinguish in the following these two cases by I and II respectively. For the other single-particle energies we use the values given in (1). Harmonic oscillator wavefunctions are used throughout the calculation and the oscillator parameter has been given the value of 2.1 fm.

The calculated even parity spectra of ^{94}Mo are compared in fig. 1 with the experimental spectrum [1–7]. It may be seen from fig. 1 that up to 2.4 MeV excitation the calculation accounts for all the observed even parity states of ^{94}Mo and in most cases the agreement between experimental and calculated excitation energies is very satisfactory. For higher than 2.4 MeV excitations the comparison between experimental and calculated spectra is difficult due to the many uncertainties that exist in the spin assignments of the observed levels.

It is interesting, however, to note from fig. 1 that the calculation predicts a higher density of levels than that observed experimentally. Such a feature indicates that many levels of ^{94}Mo have not yet been observed. experimentally. Such a feature indicates that many levels of ^{94}Mo have not yet been observed.

As fig. 1 shows calculations I and II, which as discussed above differ in the choice of the $\epsilon s_{1/2}$ value, predict similar excitation energies for most levels. The most important difference appears in the case of the first excited 0^+ state which is predicted to be at about 2.6 MeV by calculation I and at about 2.0 MeV by calculation II. This energy difference is evidently due to significant $s_{1/2}$ admixtures that are contained in the w wavefunction of this state. Since recent experimental information [7] places the position of the first excited 0^+ state at 1.74 MeV the spectrum obtained from calculation II appears to be in closer agreement with experiment. However, before conclusions may be drawn about the parameters of the effective Hamiltonian the identification of the 1.74 MeV level with the theoretical 0_2^+ states need to become definite. For this, obviously, further experimental information is required especially regarding the decay of the 1.74 level.

Table 1
Experimental and calculated transition rates of the even parity states of ^{94}Mo.

$J_i \to J_f$	Multi-porality	Experiment W.u.	Calculation I W.u.	Calculation II W.u.
$2_1 \to 0_1$	E2	17.2	17.6	16.7
$4_1 \to 2_1$	E2	26.0	16.7	14.7
$2_2 \to 0_1$	E2	0.25	0.29	0.18
$2_2 \to 2_1$	M1	$(11 \pm 4) \times 10^{-3}$	184×10^{-3}	47×10^{-3}
$2_2 \to 2_1$	E2	45	20.9	20.6
$8_1 \to 6_1$	E2	3.85×10^{-3}	0.411	0.364
$8_1 \to 6_2$	E2	3.75	8.02	9.36

The experimental information on the decay of the even parity states of ^{94}Mo is rather limited. In table 1 we make a comparison of the theoretical predictions with the available experimental data [8, 9]. In the calculation of E2 rates effective charges of 0.8 and 1.4 are used for protons and neutrons respectively. Such a choice ensures best overall agreement of the theoretical predictions with experiment. On the other hand the bare M1 operator has been used in the evaluation of M1 rates.

As table 1 shows calculations I and II produce very similar results on E2 rates. These results are also in very satisfactory agreement with experiment except in the case of the B(E2) value in the $8_1^+ \to 6_1^+$ decay which is overestimated by a factor ~100 in the theory. However, this particular B(E2) value is an extremely small quantity a feature suggesting that an improvement to the theoretical predictions might easily be affected by a suitable small change to the existing wavefunctions.

In contrast to E2 rates the two calculation differ in the predictions on the $2_2^+ \to 2_1^+$ M1 rate. In this case the larger $s_{1/2}$ admixtures contained in the wavefunctions that have been obtained with calculation II, appear to be important in producing better agreement with experiment.

From the above it may be concluded that there is an encouraging agreement between the results obtained from this calculation with the current experimental information on ^{94}Mo. It is obvious, however, that to check the validity of our model and to make the best choice of its parameters much more detailed experimental information is required.

Many helpful discussions have taken place with Dr. H.A. Mavromatis.

References

[1] N.K. Aras, E. Eichler and G.G. Chilosi, Nucl. Phys. A112 (1968) 609.
[2] C.M. Lederer, J.M. Jaklevic and J.M. Hollander, Nucl. Phys. A169 (1971) 449.
[3] H.F. Lutz, D.W. Heikkinen and W. Bartolini, Phys. Rev. C4 (1971) 934.
[4] M.R. Cates, J.B. Ball and E. Newman, Phys. Rev. 187 (1969) 1682.
[5] J.S. Larsen, J.B. Ball and C.B. Fulmer, Phys. Rev. C7 (1973) 751.
[6] J.E. Holden and W.W. Daelnick, Phys. Rev. C8 (1973) 2286.
[7] M.T. McEllistrem et al., Phys. Rev. C9 (1974) 670.
[8] J. Barette et al., Phys. Rev. C4 (1972) 1339.
[9] C.V.K. Baba et al., Phys. Lett. 48B (1974) 218.
[10] K.H. Bhatt and J.B. Ball, Nucl. Phys. 63 (1965) 286.
[11] J. Vervier, Nucl. Phys. 75 (1966) 17.
[12] L.D. Skouras and C. Dedes, to be published.
[13] J.D. Vergados and T.T.S. Kuo, Phys. Lett. 35B (1971) 93.
[14] C. Dedes and J.M. Irvine, J. Phys. G. Nucl. Phys. 1 (1975) 929.
[15] J.P. Elliott et al., Nucl. Phys. A121 (1968) 241.
[16] C.M. Shakin et al., Phys. Rev. 161 (1967) 1015.
[17] H.A. Mavromatis, L.D. Skouras and C. Dedes, to be published.