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Shell-model studies of negative-parity states in nuclei with $A = 18$, 19 and 20[†]

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Abstract. A shell-model calculation of the negative-parity states in the $A = 18$, 19 and 20 nuclei is presented. Assuming the nucleus ^{16}O to be the core, an active hole is restricted to the $1p_{1/2}$ or $1p_{3/2}$ orbits, and active particles are allowed to occupy the $1d_{5/2}$ and $2s_{1/2}$ orbits. The two-body effective interaction is assumed to be a central potential which has Yukawa radial dependence. The energy spectra are calculated from a least-squares fit to the experimental data, varying the strengths of the exchange interaction and the single-particle level splittings. Spectroscopic factors and E2, E3 and M1 transition rates are calculated and compared with the observed values.

1. Introduction

It is known that low-lying levels with parity different from the ground state exist in nuclei with $A = 18$–20. These non-normal parity states can be explained on the basis of excitation of the ^{16}O core. In the last few years several calculations (Arima *et al* 1967, Johnstone *et al* 1971, McGrory 1970a, b, Benson and Flowers 1969, Elliott and Harvey 1963, Harvey 1964, Ellis and Engeland 1970, 1972, Zuker 1969, McGrory and Wildenthal 1973, Millington *et al* 1974, Flores and Moshinsky 1967, Bassichis *et al* 1965, Pedersen *et al* 1979) on the low-lying negative-parity levels of nuclei with $A = 18$, 19 and 20 have been performed where the possibility of a core nucleon jumping from the 1p shell to the 2s and 1d shells is taken into account. Ellis and Engeland (1970) treated the nuclei with $A = 16$–19 from a weak-coupling-model approach originally suggested by Arima *et al* (1967). For the negative-parity states only 1h states were considered. Most of the levels fitted favourably with experiment. Zuker (1969) has shown that a weak-coupling model is highly successful in reproducing the energy levels of ^{18}F and ^{18}O. The above works showed that the low-lying negative-parity states are predominantly 3p–1h states.

McGrory and Wildenthal (1973) used a shell-model basis of all Pauli-allowed ($1p_{1/2}$, $2s_{1/2}$, $1d_{5/2}$) configurations outside an inert ^{12}C core to calculate the low-lying positive- and negative-parity states for nuclei with $A = 18$, 19 and 20. The neglect of the $1p_{3/2}$ orbit is the most serious constraint on their model space (Reehal and Wildenthal 1973). The drawback is compensated by including multiparticle excitations from the $1p_{1/2}$ orbit.

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It is implied from these studies that if the $1p_{3/2}$ orbit is also taken to be active then considering only one-particle, instead of multiparticle, excitation from the 1p shell is probably good enough. Furthermore, new experimental information has become available since then, and therefore we believe that it is worthwhile to re-investigate this mass region and to look for a more systematical explanation of odd-parity states.

2. Assumptions

As indicated above, an ^{16}O core is assumed. Only one hole is assumed to be distributed in the $1p_{3/2}$ or $1p_{1/2}$ orbit and active particles in the $1d_{5/2}$ and $2s_{1/2}$ orbits. The omission of the $1d_{3/2}$ orbit from the model space is quite naturally based on the previous extensive studies of the problem (Zuker *et al* 1968, Reehal and Wildenthal 1973, McGrory 1970a, b, Arima *et al* 1968, Halbert *et al* 1971). Under these assumptions, the wavefunctions of eigenstates can be written as linear combinations of basis states of the form

$$\Psi = |j^{-1}, [\mathrm{d}_{5/2}^{n_1}\alpha_1 T_1 J_1, \mathrm{s}_{1/2}^{n_2} T_2 J_2] T_{12} J_{12}\rangle_{TJ}$$

where $j = \mathrm{p}_{1/2}$ or $\mathrm{p}_{3/2}$.

The Hamiltonian in this space has the form

$$H = H_0 + H_{\mathrm{pp}} + H_{\mathrm{ph}}$$

where H_0 represents the single-particle energies for $2s_{1/2}$, $1p_{1/2}$ and $1p_{3/2}$ relative to the $d_{5/2}$ orbit, H_{pp} is the effective interaction between active particles in the $1d_{5/2}$ and $2s_{1/2}$ orbits outside the ^{16}O core and H_{ph} represents the effective interaction between the active particles in the ($1d_{5/2}$, $2s_{1/2}$) and the hole in $1p_{1/2}$ or $1p_{3/2}$ orbits. McGrory and Wildenthal (1973) used two different effective residual interactions in their calculation. They found that the results are not dependent on any fine details of the residual interaction. In our calculation, we used the usual central potential of the form

$$V_0(W + MP_x + BP_\sigma - HP_\tau)\frac{e^{-r/r_0}}{r/r_0}$$

where $W + M + B + H = 1$ and the range parameter $r_0 = 1.415$ fm. Harmonic oscillator wavefunctions are used with the oscillator constant $\nu = 0.96\,A^{-1/3}$ fm^{-2}, where $A = 16$. The interaction strengths consist of the $T = 0$, singlet-odd (SO) and triplet-even (TE) and $T = 1$, singlet-even (SE), triplet-odd (TO) components for both pp and ph. These eight interaction strengths and three single-particle energy spacings, i.e. $\varepsilon(2s_{1/2}-1d_{5/2})$, $\varepsilon(1d_{5/2}-1p_{1/2})$ and $\varepsilon(1d_{5/2}-1p_{3/2})$ are treated as free parameters in the least-squares fit. For the selection of energy data, in principle we included all the available low-lying states with reliable J^π assignments up to the point that the first level with an uncertain J^π assignment appeared. But the high-spin states were all included. The total number of levels used is 54. The overall RMS deviation is 0.45 MeV. The single-particle energy spacings obtained are $\varepsilon(2s_{1/2}-1d_{5/2}) = 1.35$ MeV, $\varepsilon(1d_{5/2}-1p_{1/2}) = 10.35$ MeV and $\varepsilon(1d_{5/2}-1p_{3/2}) = 17.47$ MeV, which are close to the experimental values of 0.87, 11.52 and 17.82 MeV obtained from data on the nuclei ^{15}O, ^{16}O and ^{17}O. The calculated exchange interaction strengths and the coefficients for the relative contributions of the various potentials are listed in table 1. The centre-of-mass spurious-state problem has not been treated in any way here.

Table 1. The interaction strengths (in MeV) and mixing coefficients.

Interaction strengths (MeV)		
	pp	ph
SO	−62.95	−21.38
TE	−43.96	−38.04
SE	−42.04	−24.01
TO	26.24	22.02
Mixing coefficients	pp	ph
W	0.70	0.40
M	0.28	0.41
B	−0.50	−0.19
H	0.52	0.38

3. Results

3.1. Energy levels

The excitation energies of the negative-parity states relative to the ground state were made to fit the observed values. The ground-state energy is defined as

$$E_g = -[E_B(N, Z) - E_B(^{16}\mathrm{O}) - (Z + N - 16)(E_B(^{17}\mathrm{O}) - E_B(^{16}\mathrm{O}))]$$

where N and Z are the total numbers of neutrons and protons in the nucleus. The calculated energy spectra together with observed ones for nuclei with $A = 18$–20 are shown in figures 1–6. Experimental data are taken from Ajzenberg–Selove (1978) and the recent experimental studies (Mairle *et al* 1978, Davis and Abegg 1978, Sens *et al* 1977, 1978,

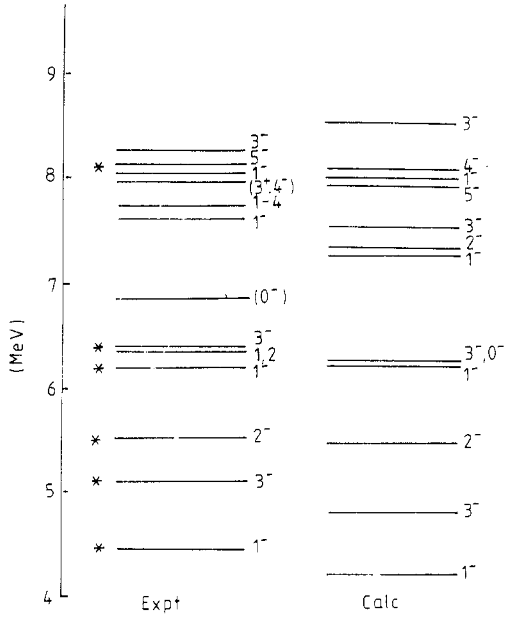

Figure 1. Experimental and theoretical energy spectra for ^{18}O.

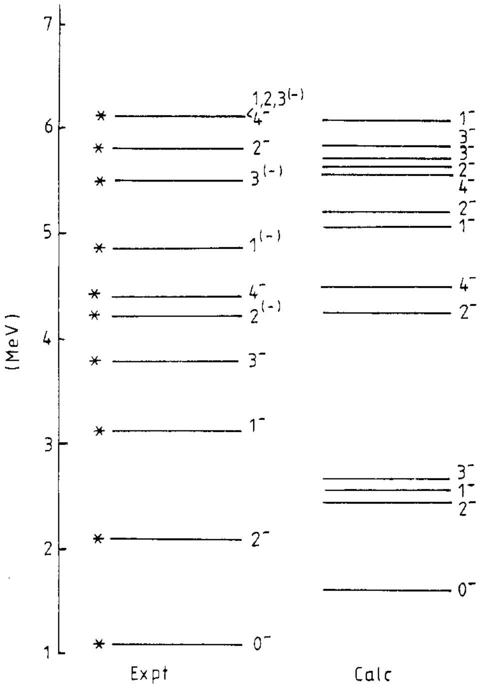

Figure 2. Experimental and theoretical energy spectra for ^{18}F.

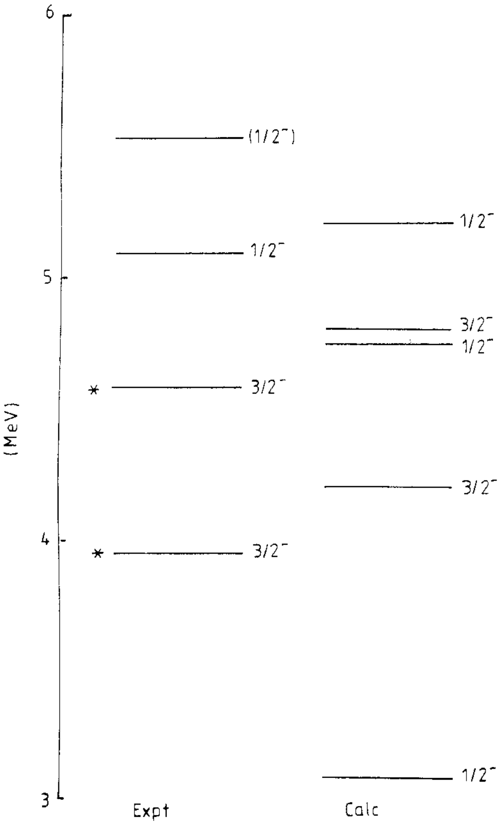

Figure 3. Experimental and theoretical energy spectra for ^{19}O.

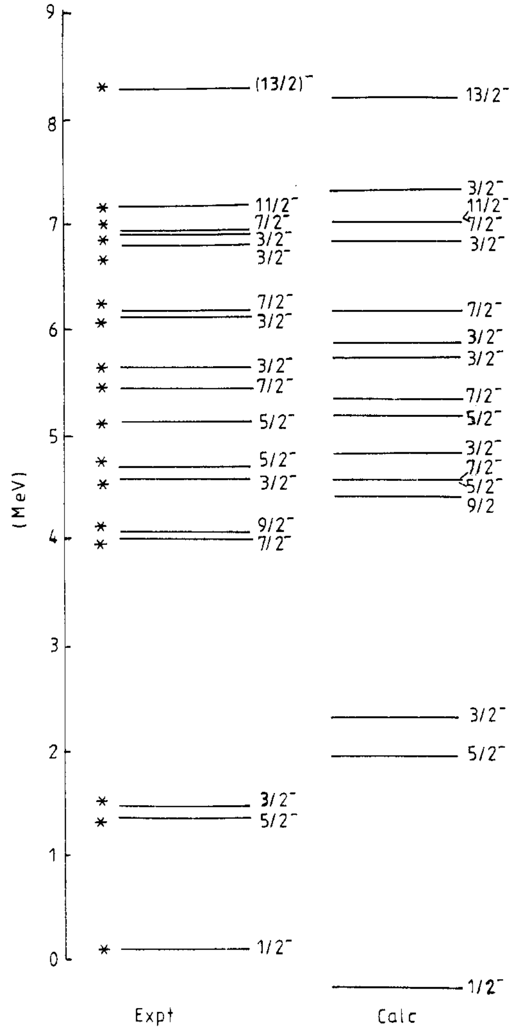

Figure 4. Experimental and theoretical energy spectra for ^{19}F.

Fortune and Bishop 1977, 1978, Mosley and Fortune 1977, Fortune and Bingham 1977). Levels marked with an asterisk are included in the least-squares fit. Most of the calculated excitation energies agree reasonably well with the data, except for a few levels. In general, the second level for each J is fitted better on average than the yrast level. Those levels for which the discrepancies are larger than 1 MeV are the first excited 3^- level at 3.79 MeV for ^{18}F, the first excited 2^- level at 4.97 MeV and the first excited 6^- level at 10.61 MeV for ^{20}Ne. These discrepancies may be ascribed to our space truncation and the oversimplified effective two-body interaction. Davis and Abegg (1978) measured the tensor analysing power T_{20} for the reaction ^{20}Ne($\vec{d}$, α) ^{18}F for $E_x(^{18}F) \leqslant 6.48$ MeV. They could not resolve the 6.096 MeV (4^-) and 6.108 MeV $J = \{1, 2, 3^{(-)}\}$ states; however, their T_{20} extracted for the doublet shows the presence of at least one unnatural parity state. Our calculation predicts a 4_2^- level at 5.56 MeV and a 3_3^- level at 5.83 MeV which can be assigned as the theoretical counterparts of the two levels above. The level at 7.96 MeV for ^{18}O was assigned as a (3^+, 4^-) doublet and our calculated 4^- state at 8.08 MeV agrees very well with the observed one.

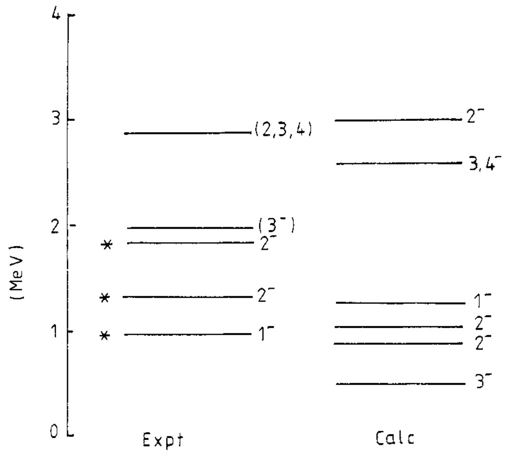

Figure 5. Experimental and theoretical energy spectra for ^{20}F.

A $\frac{1}{2}^-$ state is known to exist at 5.09 MeV for ^{19}O, but it seems unlikely that the shell-model calculations could miss the first $\frac{1}{2}^-$ state by 1.99 MeV. Furthermore, there are two theoretical states remarkably close to the known $\frac{1}{2}^-$ state at 5.09 MeV. It was pointed out by Fortune and Bingham (1977) that a simple weak-coupling consideration would imply

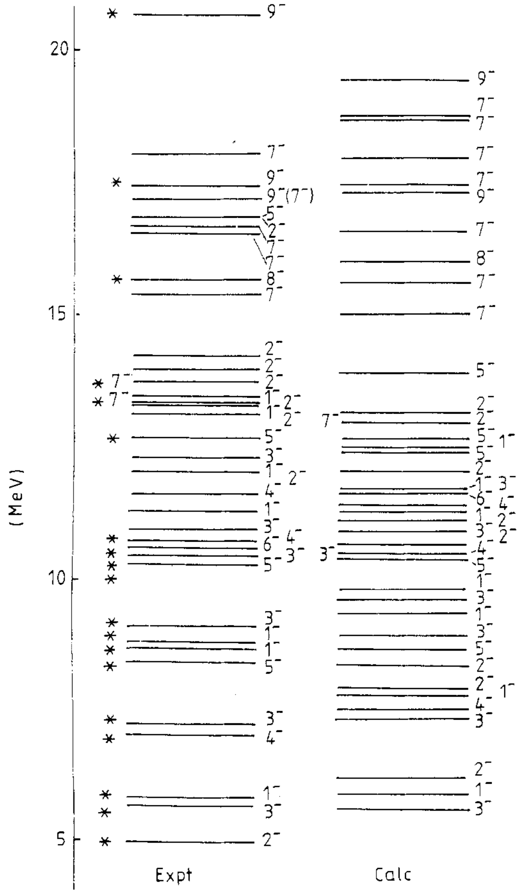

Figure 6. Experimental and theoretical energy spectra for ^{20}Ne.

the existence of several low-lying negative-parity states beginning at about 3–4 MeV. Unless more of the known states are doublets, there is no experimental state corresponding to such a low $\frac{1}{2}^-$ state. It was concluded that it was likely that the lowest $\frac{1}{2}^-$ state remained to be identified. For ^{19}F, our calculated levels agree quite well with those observed experimentally. The levels at 10.69 and 11.53 MeV for ^{20}Ne are both assigned as a $(3^+, 4^-)$ doublet. Our calculated 4_2^- and 4_3^- states at 10.45 and 11.34 MeV strongly manifest the existence of the negative-parity state in these doublets. The experimental energy spacing between the 2_1^- and 2_2^- states of ^{20}Ne is known to be 6.6 MeV, but our calculation predicts two 2^- states that do not have experimental counterparts in this interval.

To investigate the importance of the inclusion of the $1p_{3/2}$ orbit, we calculate the intensities of the hole in $1p_{1/2}$ and $1p_{3/2}$ orbits. The result shows that the intensity of the $1p_{3/2}$ orbit for the first level of each J is generally around 10% or less, with only two exceptions, i.e. the $\frac{7}{2}^-$ level at 4.00 MeV of ^{19}F and the 1_1^- level at 5.79 MeV of ^{20}Ne. For these two states, the intensities of the $p_{3/2}$ orbit are 27% and 35% respectively. For the second excited level for each J, the $p_{3/2}$ intensity is in general larger than 20%. This shows that the inclusion of the $1p_{3/2}$ orbit for 1h excitation in this mass region is necessary.

In conclusion, the energy spectra for the negative-parity states in the mass region $A=18$–20 can be reproduced reasonably well by considering 1h excitation from the $1p_{1/2}$ and $1p_{3/2}$ orbits. The importance of the $1p_{3/2}$ orbit is manifested in the second or higher excited states for each J.

3.2. Spectroscopic factors

The calculated and observed spectrocopic factors C^2S of ^{18}O and ^{18}F for $l=1$ pick-up reactions on ^{19}F are listed in table 2. The ground-state wavefunctions are adopted from previous calculation (Arima *et al* 1967). The theoretical values are in general smaller than the observed ones except for the 1^- level at 4.45 MeV for ^{18}O. The experimental values seem too large. For example, the maximum theoretical C^2S values for the 0^- level at 6.86 MeV of ^{18}O and the 0^- level at 1.08 MeV and 1^- level at 3.13 MeV of ^{18}F are only 0.75, 0.25 and 0.75 respectively. Our calculated C^2S values for these states are very close to the maximum theoretical values. Therefore there is a very large overlap between our

Table 2. The experimental and theoretical spectroscopic factors of ^{18}O and ^{18}F for $l=1$ pick-up reactions on ^{19}F.

Residual nucleus	T	J_f^π	E_x^{exp} (MeV)	C^2S Theory	C^2S Experiment
^{18}O	1	1^-	4.45	1.84	1.31
	1	2^-	6.19	0.02	0.70
	1	0^-	6.86	0.71	1.03
	1	1^-	7.62	0.27	0.42
^{18}F	0	0^-	1.08	0.23	0.41
	0	2^-	2.10	0.003	<0.13
	0	1^-	3.13	0.69	0.88

The experimental data are taken from Ellis and Engeland (1970, 1972), Ajzenberg-Selove (1978) and Sens *et al* (1977, 1978).

Table 3. The experimental and theoretical spectroscopic factors of ^{19}F and ^{19}Ne for $l=1$ pick-up reactions on ^{20}Ne.

				C^2S		
					Experiment	
Residual nucleus	T	J_f^π	E_x^{exp} (MeV)	Theory	[a]	[b]
^{19}F	$\frac{1}{2}$	$\frac{1}{2}^-$	0.11	1.74	1.7	1.8
	$\frac{1}{2}$	$\frac{3}{2}^-$	1.46	0.19	0.30	0.21
	$\frac{1}{2}$	$\frac{3}{2}^-$	4.56	0.33	0.69	0.57
	$\frac{1}{2}$	$\frac{3}{2}^-$	5.62	0.03	—	—
	$\frac{1}{2}$	$\frac{3}{2}^-$	6.09	0.48	1.0	1.4
	$\frac{1}{2}$	$\frac{3}{2}^-$	6.79	0.86	0.96	1.5

The experimental data are taken from Ajzenberg-Selove (1978) and Fortune and Bingham (1977).

[a] Experimental data for ^{20}Ne(t, α)^{19}F.

[b] Experimental data for ^{20}Ne(^{3}He, α)^{19}Ne.

wavefunction and the ground-state target wavefunction. Table 3 shows the theoretical and experimental spectroscopic factors of ^{19}F and ^{19}Ne for $l=1$ pick-up reactions on ^{20}Ne. Two sets of experimental results labelled [a] and [b] are listed. The column labelled [a] is the result obtained from the reaction ^{20}Ne(t, α)^{19}F and that labelled [b] is obtained from the reaction ^{20}Ne(^{3}He, α)^{19}Ne. The $\frac{1}{2}^-$ level at 0.11 MeV for ^{19}F is predominantly a pure $p_{1/2}^{-1}$ state (97%). The excitation energy and the C^2S value for this state agree very well with the observed ones. The theoretical C^2S values for the other levels selected are somewhat underestimated. The spectroscopic factors obtained for the pick-up reactions ^{21}Ne(d, ^{3}He)^{20}F and ^{21}Ne(d, t)^{20}Ne are compared with the experimental values (Millington *et al* 1974) in table 4. Clearly, the calculated 1^- state at 8.84 MeV and the 3^- states at 10.39 and 10.88 MeV agree with the observed ones reasonably well. These three levels contain a significant $p_{3/2}^{-1}$ component with intensity 36.7%, 17.8% and 26.9% respectively.

In conclusion, the overall results show that the calculated spectroscopic factors are, in general, slightly smaller than the experimental observations.

Table 4. The experimental and theoretical spectroscopic factors of ^{20}F and ^{20}Ne for $l=1$ pick-up reactions on ^{21}Ne.

				C^2S	
Residual nucleus	T	J_f^π	E_x^{exp} (MeV)	Theory	Experiment
^{20}F	1	1^-	0.98	0.96	0.84
	1	2^-	1.31	0.48	0.86
	1	2^-	1.84	1.14	0.69
^{20}Ne	0	3^-	5.62	0.002	0.02
	0	1^-	5.79	0.005	0.03
	0	1^-	8.84	0.30	0.33
	0	3^-	10.39	0.06	0.08
	0	3^-	10.88	0.11	0.13

The experimental data are taken from Millington *et al* (1974), Ajzenberg-Selove (1978), Fortune and Bishop (1977) and Mosley and Fortune (1977).

3.3. EM *transition rates*

We calculated E2, E3 and M1 transition rates to provide a more sensitive test of the wavefunctions. The reason that the E1 transition rates are left out is because the spurious states due to the motion of the centre of mass are not removed in our calculation. The radial integrals are evaluated between harmonic oscillator wavefunctions with $\hbar\omega =$ 14.0 MeV (Hsieh *et al* 1975). The reduced width Γ is very sensitive to the γ-ray energies. In actual calculation, we used the experimental values for the γ-ray energies. For electric multipole transitions effective charges of $e_p = 1.5$ and $e_n = 0.5$ are assumed. For M1 transitions, the free gyromagnetic factors are used.

Table 5 shows the calculated and experimental EM transition rates. The calculated results are in reasonably good agreement for most of the transitions. The $4_2^- \rightarrow 3_1^-$ M1 transition for ^{18}F and the $3_1^- \rightarrow 0_{GS}^+$ E3 transition for ^{20}Ne are too small compared with the observed values. This may be due to the neglect of the octupole vibration. However, only small changes in the amplitudes may improve the results.

Most of the M1 transitions agree reasonably well with the observed ones. In general, our calculated M1 transition rates are slightly smaller than the experimental data. This defect may be improved if the effective magnetic moment is taken into account.

Table 5. The experimental and theoretical EM transition rates for nuclei with $A = 18$, 19 and 20.

Nucleus	J_i^π	E_{xi} (MeV)	J_f^π	E_{xf} (MeV)	$\Gamma(10^{-n}$ eV)			
					Experiment	Theory	n	
^{18}O	1^-	6.20	1^-	4.46	1.2 ± 0.4	1.8	2	M1
^{18}F	2^-	2.10	0^-	1.08	4.7 ± 1.6	1.6	5	E2
	1^-	3.13	0^-	1.08	5.3 ± 1.8	2.8	4	M1
	3^-	3.79	2^-	2.10	2.0 ± 0.4	0.22	3	M1
	3^-	3.79	2^-	2.10	1.0 ± 0.4	0.21	4	E2
	2^-	4.23	0^-	1.08	1.9 ± 0.7	1.9	4	E2
	2^-	4.23	2^-	2.10	9.0 ± 3.6	1.2	4	M1
	2^-	4.23	1^-	3.13	5.4 ± 4.0	0.08	5	M1
	4^-	4.40	2^-	2.10	3.0 ± 0.8	0.60	3	E2
	1^-	4.86	0^-	1.08	7.4 ± 5.8	760	6	M1
	1^-	4.86	1^-	3.13	3.7 ± 2.8	23	6	M1
	2^-	5.79	0^-	1.08	2.6 ± 1.7	0.09	2	E2
	4^-	6.10	2^-	2.10	1.4 ± 0.3	0.91	2	E2
	4^-	6.10	3^-	3.79	7.0 ± 2.0	0.01	4	M1
	4^-	6.10	4^-	4.40	4 ± 2	0.63	4	M1
^{19}F	$\frac{5}{2}^-$	1.35	$\frac{1}{2}^+$	GS	5.3 ± 0.9†	3.0	10	E3
	$\frac{5}{2}^-$	1.35	$\frac{1}{2}^-$	0.11	1.3 ± 0.2	0.82	4	E2
	$\frac{3}{2}^-$	1.46	$\frac{1}{2}^-$	0.11	6.1 ± 1.2	4.6	3	M1
	$\frac{3}{2}^-$	1.46	$\frac{1}{2}^-$	0.11	9.8 ± 3.0	1.3	4	E2
	$\frac{7}{2}^-$	4.00	$\frac{5}{2}^-$	1.35	3.5 ± 2.0	2.0	2	M1
	$\frac{7}{2}^-$	4.00	$\frac{3}{2}^-$	1.46	6 ± 5	1.0	3	E2
	$\frac{9}{2}^-$	4.03	$\frac{5}{2}^-$	1.35	9.3 ± 1.0	3.3	3	E2
	$\frac{3}{2}^-$	4.56	$\frac{1}{2}^-$	0.11	1.0 ± 0.3	0.17	1	M1
	$\frac{3}{2}^-$	4.56	$\frac{5}{2}^-$	1.35	9 ± 8	8.4	3	M1
	$\frac{5}{2}^-$	4.68	$\frac{5}{2}^-$	1.35	$\geqslant 0.39$†	0.67	1	M1
	$\frac{5}{2}^-$	4.68	$\frac{3}{2}^-$	1.46	6.0 ± 1.2	1.2	4	M1
	$\frac{5}{2}^-$	5.11	$\frac{3}{2}^-$	1.46	9	1900	4	M1

Table 5. (continued)

Nucleus	J_i^π	E_{xi} (MeV)	J_f^π	E_{xf} (MeV)	$\Gamma(10^{-n}$ eV)			
					Experiment	Theory	n	
	$\frac{7}{2}^-$	5.43	$\frac{5}{2}^-$	1.35	7.4	5.7	2	M1
	$\frac{7}{2}^-$	5.43	$\frac{3}{2}^-$	1.46	1.4	1.4	2	E2
	$\frac{7}{2}^-$	5.43	$\frac{7}{2}^-$	4.00	1.1	1.3	2	M1
	$\frac{7}{2}^-$	5.43	$\frac{9}{2}^-$	4.03	6.3	1.5	3	M1
	$\frac{3}{2}^-$	5.62	$\frac{5}{2}^-$	1.35	1.1 ± 0.3	0.35	1	M1
	$\frac{3}{2}^-$	6.09	$\frac{1}{2}^-$	0.11	1.4 ± 0.3	0.89	0	M1
	$\frac{7}{2}^-$	6.16	$\frac{5}{2}^-$	1.35	3.9 ± 1.0	1.6	1	M1
	$\frac{7}{2}^-$	6.16	$\frac{3}{2}^-$	1.46	7.8 ± 4.0	14	3	E2
	$\frac{7}{2}^-$	6.16	$\frac{7}{2}^-$	4.00	9.6 ± 4.8	7.4	3	M1
	$\frac{7}{2}^-$	6.16	$\frac{9}{2}^-$	4.03	1.4 ± 0.5	6.7	2	M1
	$\frac{3}{2}^-$	6.79	$\frac{1}{2}^-$	0.11	2.1 ± 0.4	1.3	0	M1
	$\frac{3}{2}^-$	6.79	$\frac{1}{2}^-$	0.11	8.6 ± 3.0	2.1	3	E2
	$\frac{3}{2}^-$	6.79	$\frac{5}{2}^-$	1.35	2.9 ± 0.7	0.17	1	M1
	$\frac{3}{2}^-$	6.79	$\frac{3}{2}^-$	1.46	1.4 ± 0.3	0.02	0	M1
	$\frac{3}{2}^-$	6.89	$\frac{5}{2}^-$	1.35	1.9 ± 0.5	0.11	0	M1
	$\frac{3}{2}^-$	6.89	$\frac{3}{2}^-$	1.46	9.2 ± 3.0	2.2	1	M1
	$\frac{7}{2}^-$	6.93	$\frac{5}{2}^-$	1.35	5.3 ± 1.0	2.7	1	M1
	$\frac{7}{2}^-$	6.93	$\frac{7}{2}^-$	4.00	3.2 ± 1.3	8.5	2	M1
	$\frac{7}{2}^-$	6.93	$\frac{9}{2}^-$	4.03	3.2 ± 1.3	0.06	2	M1
	$\frac{11}{2}^-$	7.17	$\frac{7}{2}^-$	4.00	8.0 ± 2.5	1.6	3	E2
	$\frac{11}{2}^-$	7.17	$\frac{9}{2}^-$	4.03	1.5 ± 0.2	0.08	0	M1
	$\frac{13}{2}^-$	8.29	$\frac{9}{2}^-$	4.03	6.6 ± 0.7	2.4	2	E2
	$\frac{11}{2}^-$	9.87	$\frac{7}{2}^-$	4.00	3.5 ± 0.7	5.1	2	E2
	$\frac{11}{2}^-$	9.87	$\frac{9}{2}^-$	4.03	1.4 ± 0.3	4.5	1	M1
^{19}Ne	$\frac{5}{2}^-$	1.51	$\frac{1}{2}^-$	0.28	1.5 ± 0.7†	0.82	4	E2
	$\frac{3}{2}^-$	1.62	$\frac{1}{2}^-$	0.28	3.2 ± 0.8	4.2	3	M1
^{20}F	1^-	6.65	1^-	0.98	2.9 ± 1.0	1.0	1	M1
^{20}Ne	2^-	4.97	2^+	1.63	2.5 ± 1.0	3.7	7	E3
	3^-	5.62	0^+	GS	2.5 ± 0.7	0.13	4	E3

The experimental data are taken from Ajzenberg-Selove (1978).

† Experimental data taken from Ellis and Engeland (1970) and the references included therein.

4. Conclusion

A central potential which has a Yukawa radial dependence is used in a least-squares fit to energy level data of negative-parity states in nuclei with $A = 18$, 19 and 20. One nucleon is assumed to be excited from the $1p_{1/2}$ or $1p_{3/2}$ orbit of the ^{16}O core. Most of the calculated energy spectra are in good agreement with the observed values. A few levels deviate by about 1 MeV from the observed ones. This may be ascribed to the fact that an oversimplified effective two-body interaction is assumed, and the multiparticle excitation is neglected in this calculation.

The first excited state for each J contains only about 10% or less of the intensity of the $p_{3/2}$ orbit. However, the $p_{3/2}$ intensity increases to a significant fraction in the second excited state for each J. This seems to justify the necessity to include the $1p_{3/2}$ orbit in the configuration space.

The spectroscopic factors are in satisfactory agreement with the experimental results. The observed electromagnetic transition rates can also be reasonably well explained using the experimental values for γ-ray energies and a reasonable set of effective charges. The predicted values are slightly underestimated for most of the transitions. These discrepancies may be improved by enlarging the model space and taking the octupole vibration and the effective magnetic moments into account.

In conclusion, the structure of the negative-parity levels observed in nuclei with $A = 18$, 19 and 20 can be explained quite well by assuming a simple central potential with a model space including the $1p_{3/2}$, $1p_{1/2}$, $1d_{5/2}$ and $2s_{1/2}$ orbits.

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