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1970 J. Phys. A: Gen. Phys. 3 390

(http://iopscience.iop.org/0022-3689/3/4/009)

J. Phys. A: Gen. Phys., 1970, Vol. 3. Printed in Great Britain

An intermediate coupling model for Br isotopes

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MS. received 15*th December* 1969

Abstract. The low-lying levels of ^{79}Br and ^{81}Br are studied in an intermediate coupling model. The main modification to the classical model consists in a microscopic description of the core, where the degeneracy of the second phonon vibrational triplet is removed. The calculated energy levels and transition rates compare well with recent results from Coulomb excitation experiments.

1. Introduction

The low-lying nuclear states of ^{79}Br and ^{81}Br have recently been investigated in some detail (Langhoff *et al.* 1966, Robinson *et al.* 1967, 1968, Salomon and Hojvat 1969). In particular, the negative parity spectra of the two nuclei show considerable similarity in both level ordering and decay properties. Some theoretical attempts to explain the results have been made along the lines of the model of Kisslinger and Sorensen (1963). In their study of ^{79}Br, Robinson *et al.* (1967) suggest that the core excitation model of Lawson and Uretski (1957) and De-Shalit (1961) may be applicable to this nucleus. In this model, the ^{79}Br nucleus would consist of an even–even core (equivalent to ^{78}Se) whose 2^+ first excited state is coupled to a $p_{3/2}$ proton state. The states at 306 keV ($\frac{1}{2}^-$), 523 keV ($\frac{5}{2}^-$), 606 keV ($\frac{3}{2}^-$) and 761 keV ($\frac{7}{2}^-$) are likely candidates for the weak-coupling multiplet. The centre-of-gravity theorem of Lawson and Uretski (1957) is indeed very well satisfied: the spin-weighted average energy of these 4 levels is 613 keV, as compared with the energy of 614 keV measured for the 2^+ state in ^{78}Se. Application of such a model to ^{79}Br and ^{81}Br would only give a partial description of the complex low-lying spectra of these nuclei. It suggests, however, that these nuclei could well be described by coupling $p_{3/2}$ and $f_{5/2}$ protons to various excited states of the respective ^{78}Se and ^{80}Se cores.

It is known that ^{78}Se and ^{80}Se fall within a region of vibrational nuclei. The intermediate coupling unified model (Bohr and Mottelson 1953) in which an odd mass nucleus is described by coupling one last nucleon or hole to an even–even core performing harmonic quadrupole vibrations about a spherical equilibrium shape may therefore be applicable to the nuclei ^{79}Br and ^{81}Br. It is found, however, that this model in its usual form is quite unable to explain the ordering of states observed in these nuclei. In particular, the calculated first $\frac{7}{2}^-$ state is always much too low in energy. The core Se nuclei are by no means pure harmonic vibrators, however. Notable among their anharmonic properties is the fact that the 2-phonon 0^+, 2^+, 4^+ multiplet of the pure oscillator is considerably split; the 4^+ state, if it is present at all, being much above the 0^+ and 2^+ states. In § 2 we describe a modification of the usual model which takes these features of the core spectra into account. In §§ 3 and 4 we discuss the application of this model to ^{79}Br and ^{81}Br respectively. The results are discussed in § 5.

2. Intermediate coupling formalism

2.1. *The Hamiltonian*

In this sub-section we set up the total Hamiltonian of the coupled system, paying particular attention to the part which differs from the pure harmonic form previously used. As usual in this model the Hamiltonian is written as the sum of three distinct terms,

$$H = H_c + H_p + H_{int}. \qquad (1)$$

We take into account the anharmonic nature of the collective oscillations of the core by writing this part of H as

$$H_c = \hbar\omega \sum_{\mu} (b_\mu{}^* b_\mu) + \tfrac{1}{4} \sum_{J=0,2,4} \eta_J \hbar\omega (b_\mu{}^* b_\mu{}^*)^J (b_\mu b_\mu)^J. \qquad (2)$$

Here $b_\mu{}^*$ and b_μ are the creation and annihilation operators for the surface vibration phonons of spin 2 and z component μ, and $\hbar\omega$ is the phonon vibration energy. The parameters η_J provide the mechanism for splitting the degeneracy of the 2-phonon triplet and are always chosen to give the experimentally observed splitting of these states in the core nucleus. We do not consider it necessary to provide for 3 or more phonon excitations. There is no clear evidence for these in the core spectra. Further, such states would have only a second-order effect on the spectra, since all the states of Br to be considered are predominantly coupled to 0- or 1-phonon excitations.

The Hamiltonian H_p describes the motion of the last proton in an effective average potential generated by the core. We shall work in the usual angular momentum representation labelled by states of the form $|j; NR; IM\rangle$.

The Hamiltonian $H_0 = H_c + H_p$ is diagonal in this basis, and satisfies

$$H_0 |j; NR; IM\rangle = (E_j + E_{NR}) |j; NR; IM\rangle \qquad (3)$$

where $\boldsymbol{j}$ is the angular momentum of the last proton and E_j is its energy. The number of phonons of surface excitations is N, R is the angular momentum of the surface and $\boldsymbol{I} = \boldsymbol{R} + \boldsymbol{j}$ is the total angular momentum of the nucleus, with z component M. The energy of surface excitation is given by E_{NR}, where $E_{12} = \hbar\omega$ and $E_{2R} = (2+\eta_R)\hbar\omega$.

The Hamiltonian of the particle–surface interaction can be written

$$H_{int} = -\xi\hbar\omega \left(\frac{\pi}{5}\right)^{1/2} \sum_{\mu} \{b_\mu + (-)^\mu b_\mu{}^*\} Y_{2\mu}(\Theta, \Psi) \qquad (4)$$

where ξ is a parameter describing the strength of the coupling. The off-diagonal elements of the symmetric matrix H_{int} are well known, being given by

$$\langle j'; N'R'; IM | H_{int} | j; NR; IM\rangle = (-)^{I+R'+\frac{1}{2}} \xi\hbar\omega \times \left\{\frac{(2j+1)(2j'+1)(2R+1)}{4}\right\}^{1/2} \begin{pmatrix} j & 2 & j' \\ \frac{1}{2} & 0 & -\frac{1}{2} \end{pmatrix} (N'R' \| b \| NR) \begin{Bmatrix} I & R & j \\ 2 & j' & R' \end{Bmatrix} \qquad (5)$$

where $N' < N$ and the reduced matrix elements of b are tabulated by Choudhury (1954). The $3j$ and $6j$ symbols are as defined by Edmonds (1960). The Hamiltonian H may now be diagonalized in a basis $|E; IM\rangle$, giving

$$H|E; IM\rangle = E \sum_{jNR} A(jNRI) |j; NR; IM\rangle. \qquad (6)$$

2.2. *Electromagnetic transitions and moments*

Since they depend not only on the eigenvalues of H but also on the structure of its eigenvectors, the calculated electromagnetic transition rates and moments form a much more critical test of a nuclear model than do the energy levels. The basic expressions for the transition rates and moments were worked out in the papers of

Bohr and Mottelson (1953) and Choudhury (1954). As the necessary formulae have since been clearly set out on numerous occasions (e.g. Heyde and Brussaard 1967, Rustgi *et al.* 1968, Choudhury and O'Dwyer 1967, Choudhury and Clemens 1969), we think it unnecessary to quote them here. However, a few remarks are in order concerning the various physical parameters contained in these formulae.

The radial integrals $\langle l'j'|r^2|lj\rangle$ between single-particle states $|lj\rangle$ are as usual equated to $3R_0^2/5$, where $R_0 = 1{\cdot}2\,A^{1/3}$ (and A is the atomic mass number). The magnetic dipole operator involves three g-factors. The core g-factor is always taken to be $g_R = Z/A$, and the orbital g-factor (for a proton) is $g_l = 1$. For the proton-spin g-factor we have followed Choudhury and Clemens (1969) in choosing an effective value $g_s^{\text{eff}} = 0{\cdot}58\,g_s^{\text{free}} = 3{\cdot}24$.

The electric quadrupole operator depends on the effective charge of the proton, which we take to be $e_p = 2e$. It also involves the value of C, the 'stiffness' parameter for the core surface oscillations. This is related to the coupling strength ξ and the coupling constant k by $\xi = k(5/2\pi\hbar\omega C)^{1/2}$. The values of C adopted for ^{78}Se and ^{80}Se are discussed in the following sections.

3. Results for ^{79}Br

In the present model the nucleus ^{79}Br is described by coupling one last proton to vibrations of the ^{78}Se core. Since we are to build in the properties of the low-lying states of this core it is necessary to consider the low-energy spectrum of ^{78}Se. This shows (Artna 1966) a 2^+ (one phonon) state at 0·61 MeV and a second 2^+ state at 1·31 MeV. The status of the next (1·51 MeV) state is not certain—it has been assigned spins of 0^+ and 4^+. Since the analogous states in ^{80}Se and ^{80}Kr (the latter is of course an alternative core for ^{79}Br) are both 0^+, we have used this value. Since no other 4^+ state is known, the only parameters used are $\eta_0 = 0{\cdot}5$ and $\eta_2 = 0{\cdot}1$.

We shall consider only negative parity states of ^{79}Br in the present calculation. The last proton is expected to occupy the $p_{3/2}$ and $f_{5/2}$ orbits. It seems likely, however, that the $p_{3/2}$ single-particle strength is not entirely in the ground-state level in ^{79}Br. In the calculation we have considered one $I = \frac{5}{2}$ and two $I = \frac{3}{2}$ single-particle states. The second $I = \frac{3}{2}$ single-particle state is supposed to arise either from a one-particle–one-hole excitation or from a seniority-three coupling, an assumption already used in the intermediate-coupling formalism (Choudhury and Clemens 1969). We label the $\frac{3}{2}$ orbits as $(\frac{3}{2})_1$ and $(\frac{3}{2})_2$ and write the energy differences of the single-particle states in terms of the parameters $\alpha\{(\frac{5}{2})-(\frac{3}{2})_1\}$ and $\beta\{(\frac{3}{2})_2-(\frac{3}{2})_1\}$. The Hamiltonian H may now be diagonalized for any values of the parameters α, β, ξ and $\hbar\omega$. The parameters α, β and ξ were adjusted to give the best fit to the relative spacing of the experimental spectrum, and $\hbar\omega$ was then chosen to fit the scale of the spectrum. The values of these parameters obtained were $\alpha = 117$ keV, $\beta = 585$ keV, $\xi = 3{\cdot}35$, $\hbar\omega = 0{\cdot}390$ MeV. For these values of α and β the energy levels were drawn as a function of ξ, as shown in figure 1. In figure 2 we compare the experimental and calculated spectra of ^{79}Br. The agreement is good, although the upper part of the spectrum is somewhat compressed. The suggested assignments (Robinson *et al.* 1967, 1968) of $I = \frac{1}{2}$ and $\frac{7}{2}$ to the states at 306 keV and 761 keV, respectively, are supported. It will be noted that there are two low-lying $\frac{3}{2}$ states in the experimental spectrum which are not reproduced by this calculation. It is suggested following Kisslinger and Sorensen (1963) that these are seniority-three states of a kind which should not mix strongly with the other levels. The observed decay scheme seems to support this view.

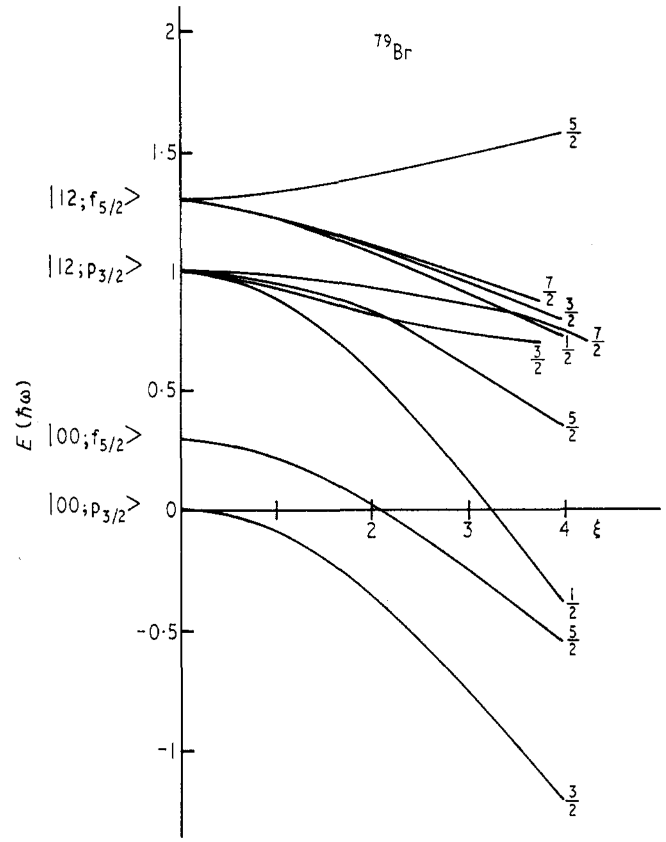

Figure 1. Energy levels of the coupled system of one proton and the quadrupole oscillations of the core of the nucleus are plotted as a function of ξ. The proton may occupy the $2p_{3/2}$ or $1f_{5/2}$ states. The separations of these states are those used for the ^{79}Br calculation.

Table 1. The amplitudes $A(jNRI)$ of the wave functions for low-lying negative parity states of ^{79}Br

I		$\frac{3}{2}$	$\frac{3}{2}$	$\frac{5}{2}$	$\frac{5}{2}$	$\frac{1}{2}$	$\frac{7}{2}$
E_{calc} (keV)		0	635	217	557	334	679
E_{exp} (keV)		0	606	217	523	(306)	(761)
Basis states j	NR						
$(\frac{3}{2})_1$	00	0·7376	−0·6086				
	12	−0·4650	−0·5028	−0·3321	0·7300	0·6722	0·8827
	20	0·1244	0·1565				
	22	−0·0352	−0·0018	−0·0956	0·4095	−0·4430	−0·1160
$\frac{5}{2}$	00			0·8161	0·1851		
	12	0·2568	0·0059	−0·4177	−0·4030	0·3653	0·3053
	20			0·1066	−0·0119		
	22	0·0622	0·1415	−0·0227	−0·1648	−0·2713	0·3215
$(\frac{3}{2})_2$	00	0·2781	0·5646				
	12	−0·2605	−0·0788	−0·1574	0·1771	0·2771	0·0885
	20	0·0866	0·0850				
	22	−0·0235	−0·0008	−0·0593	0·2101	−0·2610	−0·0535

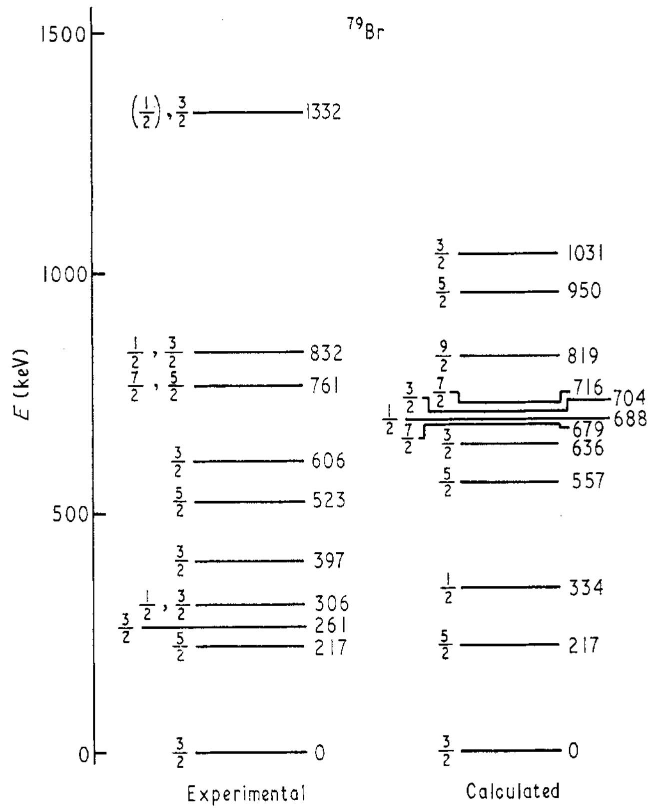

Figure 2. Comparison of the experimental and theoretical spectra of ^{79}Br. The parameters used in the calculation are $\alpha\{\frac{5}{2}-(\frac{3}{2})_1\} = 117$ keV, $\beta\{(\frac{3}{2})_2-(\frac{3}{2})_1\} = 585$ keV, $\xi = 3{\cdot}35$, $\hbar\omega = 390$ keV.

Table 2. Transition rates and branching ratios in ^{79}Br

Initial state I_1	Final state I_f	Energy (keV) $E_i - E_f$	$B(E2)$ (W.u.)† Theory	$B(E2)$ (W.u.)† Experiment‡	$B(M1)$ (W.u.)† Theory	$B(M1)$ (W.u.)† Experiment‡	Branching ratio Theory	Branching ratio Experiment‡
$\frac{5}{2}$	$\frac{3}{2}$	217	18·5	13·1 ±1·1	0·23	$0{\cdot}10\pm^{0{\cdot}13}_{0{\cdot}05}$	100	100
$\frac{1}{2}$§	$\frac{5}{2}$	117	9·2	—			0	0
$\frac{1}{2}$	$\frac{3}{2}$	334	30·1	20·9 ±2·3	0·05	0·10 – 0·30	100	100
$\frac{5}{2}$*	$\frac{1}{2}$	223	0·7	—			0	0
$\frac{5}{2}$*	$\frac{5}{2}$	340	10·2	—	0·02	—	15	10
$\frac{5}{2}$*	$\frac{3}{2}$	557	18·1	31·4 ±3·0	0·02	$0{\cdot}26\pm^{0{\cdot}18}_{0{\cdot}09}$	85	90
$\frac{3}{2}$*	$\frac{1}{2}$	345	0·2	—	0·01	0·06 ±0·01	1	0
$\frac{3}{2}$*	$\frac{5}{2}$	419	0·3	—	0·06	0·03 ±0·01	12	17
$\frac{3}{2}$*	$\frac{3}{2}$	636	7·7	7·5 ±1·1	0·12	0·04 ±0·01	87	83
$\frac{7}{2}$	$\frac{5}{2}$*	122	<0·1	—	0·20	—	2	6
$\frac{7}{2}$	$\frac{5}{2}$	462	3·24	—	0·14	0·05 – 0·47	84	59
$\frac{7}{2}$	$\frac{3}{2}$	679	21·6	31·7 ±5·4			14	35

† The Weisskopf units are as defined by Moszkowski 1966.
‡ The experimental results are from Robinson *et al.* 1967, 1968.
§ The results quoted for the $\frac{1}{2}$ and $\frac{7}{2}$ states are those measured for the 306 keV and 761 keV levels.

The wave functions obtained from the diagonalization are displayed in table 1. These permit the calculation of the electromagnetic transition rates and moments, using the formulae discussed in § 3.2. The stiffness parameter C was chosen to fit the total $B(E2)$ from the multiplet of one-phonon states to the ground state. A value of $C = 12$ MeV was obtained. The reduced $E2$ and $M1$ transition rates (in Weisskopf units) and the branching ratios for the decay of the calculated first five excited states are shown in table 2. In tables 2 and 3 the experimental properties quoted for the

Table 3. Total lifetimes of states in ^{79}Br

State		Total lifetime(s)	
I	E (keV)	Theory	Experiment
$\frac{5}{2}$	217	$1{\cdot}34\times10^{-11}$	$(3{\cdot}7\pm2{\cdot}3)\times10^{-11}$
$\frac{1}{2}$†	334	$1{\cdot}70\times10^{-11}$	$(6\pm3)\times10^{-12}$
$\frac{5}{2}$*	557	$6{\cdot}41\times10^{-12}$	$(9\pm4)\times10^{-13}$
$\frac{3}{2}$*	636	$8{\cdot}56\times10^{-13}$	$(2{\cdot}6\pm0{\cdot}3)\times10^{-12}$
$\frac{7}{2}$	679	$1{\cdot}86\times10^{-12}$	$(1{\cdot}2\pm0{\cdot}3)\times10^{-12}$

† The lifetimes quoted for the $\frac{1}{2}$ and $\frac{7}{2}$ levels are those measured for the 306 keV and 761 keV levels by Robinson *et al.* 1967.

306 keV ($\frac{1}{2}^-$ or $\frac{3}{2}^-$) and 761 keV ($\frac{7}{2}^-$ or $\frac{5}{2}^-$) correspond to the former assignment in each case. Unmeasured experimental quantities are indicated by dashes. The $B(E2)$ and $B(M1)$ agree well with experiment. The calculated branching ratios show particularly good agreement. The total lifetimes of these states are compared with experiment in table 3, and the moments of the two lowest states are shown in table 4. The quadrupole moment is rather large, but the dipole moment agrees very well with experiment.

Table 4. Nuclear moments in ^{79}Br and ^{81}Br

		Electric quadrupole moment (ebn)		Magnetic dipole moment (μ_n)	
Nucleus	State	Theory	Experiment†	Theory	Experiment†
^{79}Br	ground state	0·43	0·31	1·94	2·11
	first excited state	0·45		1·68	
^{81}Br	ground state	0·28	0·26	2·11	2·27
	first excited state	0·33		1·76	

† Experimental data from Fuller and Cohen 1969.

The state observed at 832 keV has been assigned $J^\pi = \frac{1}{2}^-$ or $\frac{3}{2}^-$, and it is of interest to compare its decay properties with those of the calculated $\frac{1}{2}^-$ state at 688 keV and the $\frac{3}{2}^-$ state at 704 keV. The 832 keV state has a lifetime of $(1{\cdot}2\pm0{\cdot}4)\times10^{-13}$ s. The calculated lifetimes of the $\frac{1}{2}^-$ and $\frac{3}{2}^-$ states referred to are $4{\cdot}2\times10^{-13}$ s and $2{\cdot}3\times10^{-13}$ s respectively. The observed branching ratio of the 832 keV state for decay to the $\frac{5}{2}$*, $\frac{1}{2}$, $\frac{5}{2}$ and $\frac{3}{2}$ states is 0 : 20 : 10 : 70. The calculated ratios are 0 : 5 : 1 : 94 for the $\frac{1}{2}^-$ state and 2 : 23 : 69 : 6 for the $\frac{3}{2}^-$ state. Further, the $B(M1)$ of 0·22 μ_n^2 for the ground-state decay of the $\frac{1}{2}^-$ state agrees much better with the observed (Robinson *et al.* 1967) $B(M1)$ of $0{\cdot}41\pm0{\cdot}14$ μ_n^2 for a $\frac{1}{2}^-$ state at 832 keV than does the $B(M1)$ of 0·02 μ_n^2 for the ground-state decay of the $\frac{3}{2}^-$ state. This calculation therefore tends to favour a $\frac{1}{2}^-$ assignment to the 832 keV level. This indeed was the value favoured by Langhoff *et al.* (1966).

Finally, a comment on the $\frac{3}{2}^-$, ($\frac{1}{2}^-$) state at 1332 keV is in order. The only decay property of this state so far measured is the branching ratio. The state decays to lower states at 606 keV, 523 keV, 306 keV, 217 keV and 0 keV in the ratio 4, 8, 10, 33 and 30 respectively, with the remaining 15% going to the $\frac{3}{2}^-$ states at 397 and 261 keV. The calculated decay of the $\frac{3}{2}^-$ state at 1031 keV is remarkably similar, the branching ratio to the corresponding five states being 4 : 6 : 9 : 56 : 24. This $\frac{3}{2}^-$ state has a very complex wave function, the principal components being $|jNR\rangle = |(\frac{3}{2})_1 12\rangle$, $|(\frac{3}{2})_2 00\rangle$ and $|(\frac{3}{2})_2 12\rangle$ in almost equal strengths. It is very tempting to identify this state with the observed 1332 keV state.

4. Results for ^{81}Br

The treatment of ^{81}Br is in most respects closely analogous to that of ^{79}Br. In this case the proton is coupled to an ^{80}Se core. The first excited state is (Artna 1966) 2^+ at 0·67 MeV, followed by 2^+ at 1·45 MeV and 0^+ at 1·48 MeV. There is again

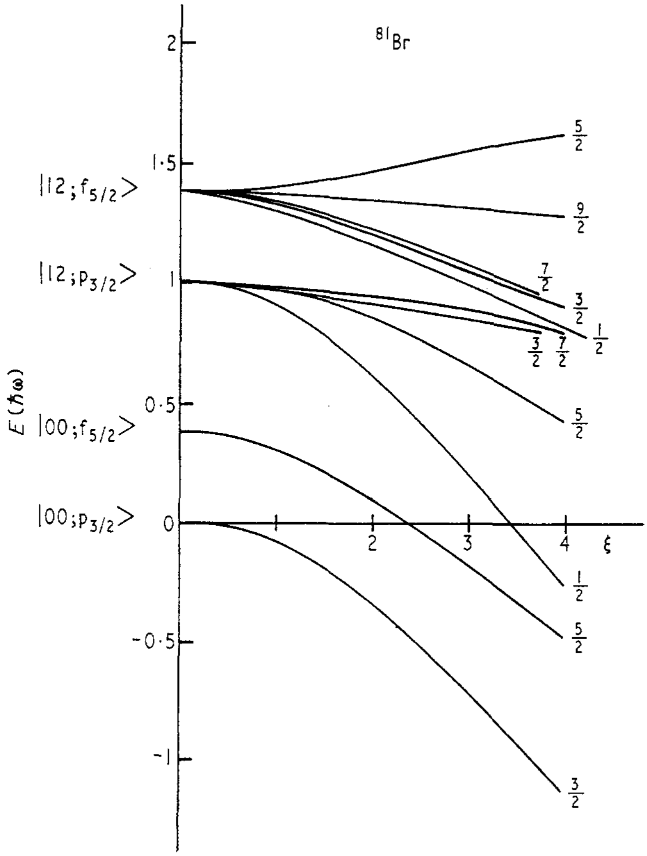

Figure 3. Energy levels of the coupled system of one proton and the quadrupole oscillations of the core of the nucleus are plotted as a function of ξ. The proton may occupy the $2p_{3/2}$ or $1f_{5/2}$ states. The separations of these states are those used for the ^{81}Br calculation.

no probable assignment of a 4^+ state and we adopt the parameters $\eta_0 = \eta_2 = 0{\cdot}2$.

The same single-particle orbits were used as in ^{79}Br, and a best fit to the spectrum was obtained for

$$\alpha\{(\tfrac{5}{2})-(\tfrac{3}{2})_1\} = 225\ \text{keV}; \qquad \beta\{(\tfrac{3}{2})_2-(\tfrac{3}{2})_1\} = 1152\ \text{keV}; \qquad \xi = 2{\cdot}54$$

and $\hbar\omega = 591$ keV. Figure 3 shows the dependence of the energy levels on ξ for these values of α and β, and figure 4 compares the experimental and calculated spectra

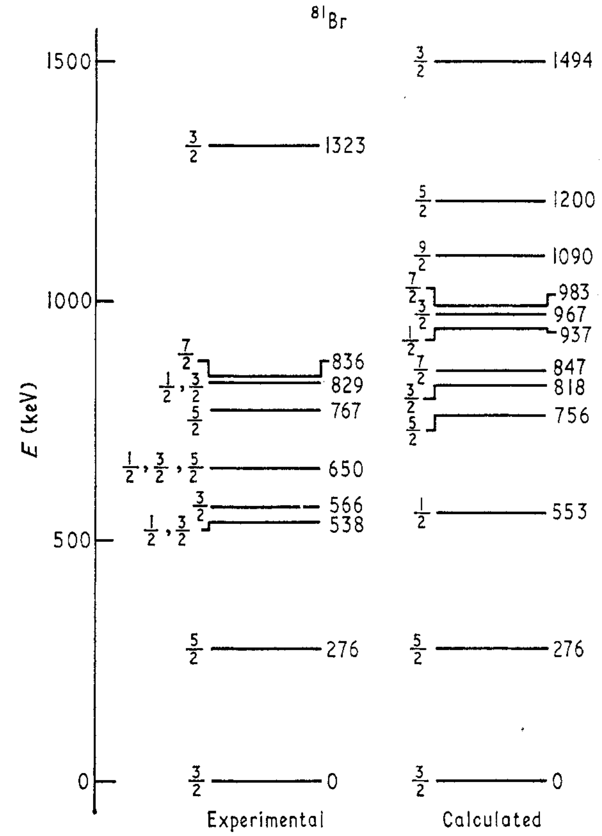

Figure 4. Comparison of the experimental and theoretical spectra of ^{81}Br. The parameters used in the calculation are $\alpha\{\tfrac{5}{2}-(\tfrac{3}{2})_1\} = 225$ keV, $\beta\{(\tfrac{3}{2})_2-(\tfrac{3}{2})_1\} = 1152$ keV, $\xi = 2{\cdot}54$, $\hbar\omega = 591$ keV.

of ^{81}Br. Apart from the states at 566 and 650 keV, which we suggest are analogous to the $\tfrac{3}{2}^-$ states at 261 and 397 keV in ^{79}Br, the observed spectrum up to 850 keV has been fitted almost exactly. There is again very strong support for the suggestion that the states at 538, 767, 829 and 836 keV form a $\tfrac{1}{2}$, $\tfrac{3}{2}$, $\tfrac{5}{2}$, $\tfrac{7}{2}$ mutliplet.

The correct spin assignment to the 538 keV state is not yet clear. Robinson *et al.* (1968) assign it $\tfrac{1}{2}^-$ or $\tfrac{3}{2}^-$, but Rao and Fink (1967) did not observe it to be fed in the β-decay of ^{81}Se, and accordingly considered it to be $\tfrac{5}{2}^-$ or $\tfrac{7}{2}^-$. The strong $E2$ ground-state transition from this state indicates that it should be a member of the multiplet, and the centre-of-gravity theorem then suggests a $\tfrac{1}{2}$ assignment. Further, both the harmonic and anharmonic versions of this model indicate that the $\tfrac{1}{2}$ member of the multiplet must lie lowest in energy.

In table 5 the wave functions of the first six calculated states are set out. The value $C = 40$ MeV for the stiffness parameter was used in the calculation of the electromagnetic transition rates and moments. The results appear in tables 4, 6 and 7.

Table 5. The amplitudes $A(jNRI)$ of the wave functions for low-lying negative parity states of ^{81}Br

I		$\frac{3}{2}$	$\frac{3}{2}$	$\frac{5}{2}$	$\frac{5}{2}$	$\frac{1}{2}$	$\frac{7}{2}$
E_{calc} (keV)		0	818	279	756	553	847
E_{exp} (keV)		0	(829)	279	767	(538)	837
Basis states							
j	NR						
$(\frac{3}{2})_1$	00	0·8320	0·4953				
	12	−0·4239	0·7235	−0·3104	0·8302	0·7828	0·9713
	20	0·0998	−0·2053				
	22	−0·0251	−0·0041	−0·0661	0·3399	−0·4055	−0·1394
$\frac{5}{2}$	00			0·8551	0·1937		
	12	0·2183	0·0172	−0·3836	−0·3373	0·3235	0·0657
	20			0·0869	−0·0265		
	22	0·0422	−0·1432	−0·0182	−0·1205	−0·2201	0·1683
$(\frac{3}{2})_2$	00	0·1735	−0·3991				
	12	−0·1854	0·0453	−0·1082	0·0892	0·1793	0·0389
	20	0·0582	−0·0833				
	22	−0·0146	−0·0016	−0·0354	0·1440	−0·1934	−0·0554

Table 6. Transition rates and branching ratios in ^{81}Br

Initial state I_i	Final state I_f	Energy (keV) $E_i - E_f$	$B(E2)$ (W.u.)† Theory	Experiment‡	$B(M1)$ (W.u.) Theory	Experiment‡	Branching ratio Theory	Experiment‡
$\frac{5}{2}$	$\frac{3}{2}$	279	9·4	16·4 ± 0·9	0·14	0·23	100	100
$\frac{1}{2}$	$\frac{5}{2}$	274	2·6	—			0·7	0
$\frac{1}{2}$	$\frac{3}{2}$	553	13·3	8·2 ± 0·5	0·03	—	99·3	100
$\frac{5}{2}$*	$\frac{1}{2}$	203	0·8	—			0	0
$\frac{5}{2}$*	$\frac{5}{2}$	480	2·7	$\left(87\begin{smallmatrix}+120\\-67\end{smallmatrix}\right)$	0·02	$0·28\begin{smallmatrix}+0·26\\-0·12\end{smallmatrix}$	11	13
$\frac{5}{2}$*	$\frac{3}{2}$	756	8·7	9·6 ± 0·5	0·04	$0·6\begin{smallmatrix}+0·5\\-0·2\end{smallmatrix}$	89	87
$\frac{3}{2}$*	$\frac{1}{2}$	265	0·1	—	0·05	—	1	0
$\frac{3}{2}$*	$\frac{5}{2}$	542	0·5	—	0·08	—	10	20
$\frac{3}{2}$*	$\frac{3}{2}$	818	8·5	3·9 ± 0·6	0·19	—	89	80
$\frac{7}{2}$	$\frac{5}{2}$	571	1·3	12 ± 2	0·09	0·13 ± 0·01	80	74
$\frac{7}{2}$	$\frac{3}{2}$	847	12·3	14·2 ± 1·0			20	26

† The Weisskopf units are as defined by Moszkowski 1966.
‡ Experimental data from Robinson *et al.* 1968.

Table 7. Total lifetimes of states in ^{81}Br

State I	E(keV)	Total lifetime(s) Theory	Experiment†
$\frac{5}{2}$	279	$1·11 \times 10^{-11}$	$6·47 \times 10^{-12}$
$\frac{1}{2}$	553	$5·54 \times 10^{-11}$	
$\frac{5}{2}$*	756	$1·51 \times 10^{-12}$	$(1·1 \pm 0·5) \times 10^{-13}$
$\frac{3}{2}$*	818	$2·64 \times 10^{-13}$	
$\frac{7}{2}$	847	$1·48 \times 10^{-12}$	$(1·2 \pm 0·1) \times 10^{-12}$

† Experimental lifetimes were calculated from Robinson *et al.* 1968.

Both the quadrupole and dipole moments, shown in table 4, are in excellent agreement with experiment. Most of the $B(E2)$ and two of the four measured $B(M1)$ also compare very favourably with the observed values. The decays of the 538 and 829 keV states support the respective $\frac{1}{2}^-$ and $\frac{3}{2}^-$ assignments. There is at present little experimental evidence on the lifetimes of the low-lying states, but it has been possible to deduce lifetimes for three of these states from the measured $B(E2)$ and $B(M1)$, and these are compared with the calculated lifetimes in table 7.

5. Conclusion

The negative parity spectra of ^{79}Br and ^{81}Br have been analysed in terms of an intermediate-coupling model. The main improvement on previous studies using the same model is an attempt to describe the anharmonic properties of the 2-phonon triplet. The good general agreement obtained in comparison with recent experimental data suggests that this model could be profitably extended to other vibrational regions where the second-phonon structure is considerably split. In the complex spectra of ^{79}Br and ^{81}Br, some isolated levels remain unexplained. It is suggested, however, that additional $I = \frac{3}{2}^-$ levels would result from states of seniority three. An alternative model has been suggested in this region by Kisslinger and Sorensen (1963), who derived a rather different structure for ^{79}Br and ^{81}Br. Comparisons of their calculated transition rates with the measured ones are hampered by the fact that there seems to be no good level correspondence for energies below 1 MeV.

Acknowledgments

The authors wish to acknowledge partial financial support from the National Research Council of Canada (for B.C.) and the Atomic Energy Control Board of Canada (for K.W.C.S.). They are indebted to Mr Y. K. Tan for his help in carrying out the calculations on Queen's University IBM-360-50 computer.

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