SHELL-MODEL CALCULATION OF TRANSITION PROBABILITIES BETWEEN $A = 31$ EVEN-PARITY STATES *

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Shell-model wave functions, incorporating particles in the $2s_{\frac{1}{2}}$ and $1d_{\frac{3}{2}}$ sub-shells and up to two holes in the $d_{\frac{5}{2}}$ sub-shell, have been used to calculate M1 and E2 transition probabilities in ^{31}P, the log *ft* values for the ^{31}S and ^{31}Si beta decay, and the ^{31}P magnetic moment μ. Very good agreement with experiment is obtained for the largest M1 strengths, for the log *ft* values and for μ, if the isovector part of the matrix element is quenched, and for the E2 strengths (standard deviation 20%) if the average effective charge $\frac{1}{2}(e_p + e_n)$ is allowed to increase linearly with average excitation energy. All E2 transitions are highly fragmented, whereas the strong M1 transitions derive their strength from just one or two components.

Recently, many-configuration shell-model wave functions have become available for even-parity states in the $A = 30$-33 region [1]. Particles in the $2s_{\frac{1}{2}}$ and $1d_{\frac{3}{2}}$ sub-shells were taken along and up to two holes in the $d_{\frac{5}{2}}$ sub-shell, and the residual interaction was assumed to be of the surface-delta type. In the present paper these wave functions have been used to compute γ and β transition probabilities for $A = 31$ and the ^{31}P magnetic moment.

For given J and T the number of many-particle basis states may be up to 265 resulting in several thousands of contributions to a particular M1 and E2 matrix element.

The experimental material (with errors for the transition rates between 5 and 30%) is given in ref. 2, supplemented with data in refs. 3-5. The branching ratio (1.4%) for the 3.13 → → 1.27 MeV transition stems from a recent unpublished measurement in this laboratory by Wolff.

A comparison with the experimental data shows that the M1 transitions calculated with free-nucleon g-factor on the average come out too fast, which can be remedied by some quenching of the g-factors. It was thought best to quench only the g-factor differences for spin and orbital angular momentum, because the free-nucleon g-factor sums very well reproduce the known magnetic moments of self-conjugated nuclei and the average magnetic moments of mirror nuclei [6]. A quenching factor 0.63 exactly reproduces the ^{31}P magnetic moment, and yields very good agreement for the relatively strong 3.13 → 0 MeV and 7.14 → 0 MeV M1 transitions.

The E2 transitions calculated with charges $e_p = e, e_n = 0$, (and radial integrals obtained from harmonic oscillator wave functions with $\hbar\omega = 13$ MeV) on the average come out too slow. To account for the limited configuration space one then can take some sort of effective charges. Excellent agreement is obtained (for $e_p - e_n = e$) if the average effective charge $\bar{e}_{eff} = \frac{1}{2}(e_p + e_n)$ is taken to increase linearly with the average excitation energy $\bar{E}_x = \frac{1}{2}(E_i + E_f)$, such that $\bar{e}_{eff} = e\{1.35 + 0.37\, \bar{E}_x(\mathrm{MeV})\}$. This seems not unreasonable, because the configuration space taken is expected to be closer to reality for the lower than for the higher excited states. The effective charge taken here is somewhat larger than the one needed in a complete sd-shell space for the $A = 18$-22 region [7].

The β transitions were treated, in principle, like the M1 strengths, i.e., the Gamow-Teller matrix element was quenched with a factor 0.63. The final results are compared with experiment in fig. 1. Because the lifetime of the 6.38 MeV level is unknown, for this state only branching ratios can be compared. Two known mixing ratios are also taken along, mainly to show that the calculated signs come out right.

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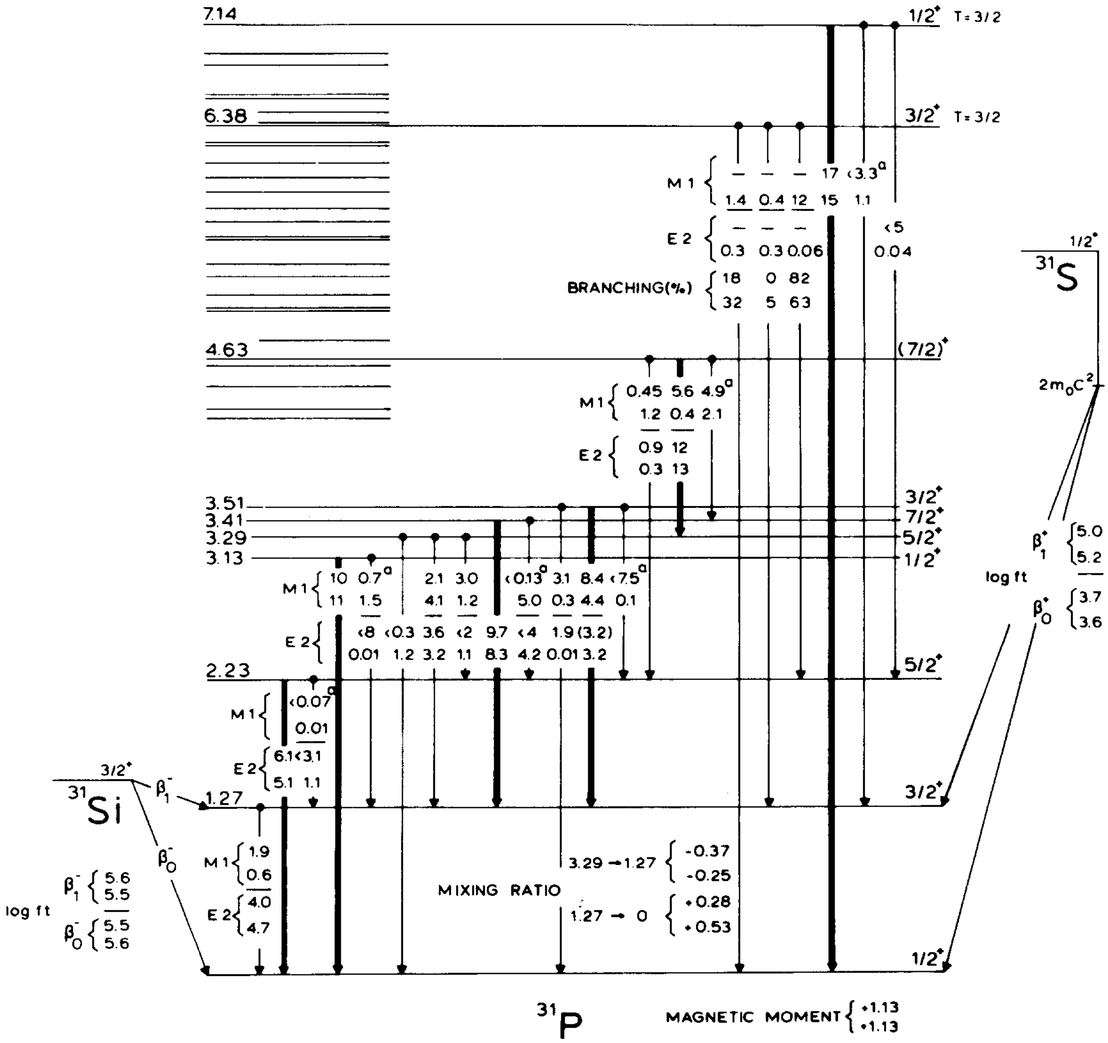

Fig. 1. Comparison of theoretical and experimental values (lower and upper numbers respectively) for β and γ transition probabilities and for the ^{31}P ground-state magnetic moment. The E2 strengths are in W.u., the M1 strengths 10^{-2} W.u. For the M1 strengths marked a) it is assumed that the E2/M1 mixing ratio is negligibly small.

It is seen that the E2 strengths agree remarkably well. The standard deviation (for 10 transitions) is only 1.0 W.u. for an average strength of 5.0 W.u. This is the more surprising because the E2 strengths are much fragmented (or very collective). The largest components in the largest two matrix elements contribute only 10% in intensity.

On the whole, the agreement for the M1 transitions is not quite so good (standard deviation for 12 transitions 2.8×10^{-2} W.u. for an average strength of 5.0×10^{-2} W.u.). The largest deviations are seen to occur for two $\frac{7}{2}^+ \to \frac{5}{2}^+$ transitions, viz. 3.41 → 2.23 MeV and 4.63 → 3.29 MeV, which were both found to be highly fragmented. However, most strong M1 transitions (and the ground-state magnetic moment) derive their strength from just one large component in the matrix element. An analysis of the large components shows that for all of them the M1 operator has to operate on the $s_{\frac{1}{2}}$ particle. This is in agreement with the rule derived by Maripuu [8] that single-particle $l_j \to l_j$ M1 transitions are strong for $j = l + \frac{1}{2}$ and weak for $j = l - \frac{1}{2}$. The rule was derived for the γ decay of analogue states (where only the isovector part contributes because $\Delta T = 1$), but it is found here to hold also for transitions between $T = \frac{1}{2}$ states, which is understandable because the isovector part will always dominate.

Finally, it is seen that the four calculated log ft values agree beautifully with experiment.

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