A shell-model analysis of the proton emission from ^{31}Cl using Gamow wave functions

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Abstract

We study the proton emission process from particle-unbound levels of ^{31}Cl . A standard shell-model calculation provides the single-particle structure of the excited states of ^{31}Cl and Gamow wave functions are used to describe the proton emission. Recent experimental data is analyzed obtaining information about spins and parities of the excited levels and the most important proton decay channels.

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1 Introduction

The development of experimental facilities for producing exotic nuclei in the last decade has opened new possibilities for studying nuclear properties in mass regions far from stability. These rare nuclei provide a good scenario to test our present knowledge of nuclear structure and nuclear dynamics in regions where the structure of the continuum and the effect of particle correlations are expected to play a dominant role.

Beta decay is the most frequent process that light and medium mass nuclei undergo to reach the stability. As we increase the proton or neutron number, the single-particle separation energy tends to decrease whereas the beta Q value tends to increase. Far enough from the valley of beta stability, the beta decay can populate particle-unbound nuclear levels of the daughter nucleus, leading to the emission of beta-delayed particles. Close to the drip lines, this process can become the most important decay mechanism, and can be used as a spectroscopic tool for the study of the structure of these exotic nuclei[1].

There are different theoretical models for the description of particle emission. Possibly the most extended approach is based on the R-matrix theory of nuclear reactions[2], although there is a wide range of microscopic formulations[3, 4, 5, 6].

In this paper we concentrate on the study of beta-delayed proton emission from particle-unbound levels of ^{31}Cl . The proton-rich nucleus ^{31}Cl is of particular interest since all the excited levels populated by the beta decay of the parent nucleus ^{31}Ar are unbound and proton emission is the most important decay channel[7]. From the analysis of the experimental data[8] we are able to identify several energy levels and spins of the states of ^{31}Cl fed by the beta decay of ^{31}Ar .

This paper is organized as follows. In section 2 we present a simple theoretical model to describe the beta-delayed nucleon emission using a standard shell-model calculation as the starting point. This model was already introduced in [9], and we will refer to it as the CSG model (Continuum-Shell-model-with-Gamow-wave-functions). In section 3 we apply the CSG model to the exotic nucleus ^{31}Cl , obtaining proton decay intensities and the energy spectrum of the beta-delayed protons. In section 4 we analyze the experimental data using our theoretical model, and discuss a tentative assignment of energy levels, spins and parities, and the corresponding mechanism for proton emission. In section 5 we summarize the results of our calculations and the analysis of the data.

2 The CSG model

We want to calculate the decay probability of a nucleus with mass A , that is initially in a nuclear state $|A; i \rangle$. This state will be typically described in a shell-model basis, neglecting the effects of the continuum. The state $|A; i \rangle$ then emits a nucleon (proton or neutron) with relative kinetic energy E_k , leaving a residual nucleus with mass $A - 1$ in a final state $|A - 1; r \rangle$. The requirement of energy conservation makes that the kinetic energy of the relative motion of the nucleon and the residual nucleus is $E_k = (E_i + Q_N - E_r)$ where Q_N is the Q -value for the emission of the nucleon from the ground state of the initial nucleus to the ground state of the residual one, and E_i, E_r are the excitation energies of the states $|A; i \rangle$ and $|A - 1; r \rangle$. The observed nucleon energy should be a fraction of E_k , i.e. $(A - 1/A)E_k$.

The decay width for nucleon emission can be obtained using the Fermi Golden Rule:

$$\Gamma(i, f, E_k) = 2\pi | \langle A; i | \hat{H} | A; f \rangle |^2 \rho(E_k) \quad (1)$$

where $\hat{H}$ is the full Hamiltonian operator. The initial states $|A; i \rangle$ are the eigenstates of $\hat{H}$ in a shell-model space, which is constructed from a set of normalizable single-particle wave functions. The final states $|A; f \rangle$ have at least one of the nucleons in a continuum single-particle wave function, which is orthogonal to the set of normalizable single-particle wave functions. Thus, the states $|A; i \rangle$ and $|A; f \rangle$ are orthogonal. Besides, $|A; i \rangle$ is not an eigenstate of $\hat{H}$ in the complete space of A particles, but only in the restricted shell-model space.

The state $|A, i\rangle$ can be expanded in terms of states of the residual nucleus $|A-1; r\rangle$ coupled to single-particle wave functions $|N(B), nlj\rangle$ using the spectroscopic amplitudes (SPA). Thus, we can write:

$$|A, i\rangle = \sum_{rnlj} SPA(i; r, nlj) |A-1; r\rangle \times |N(B), nlj\rangle \quad (2)$$

where $SPA(i; r, nlj) = \langle A, i; J_i M_i | \sum_{mM'} \langle J_i M_i | j m J_r M' \rangle \hat{a}_{nljm}^+ |A-1, r; J_r M'\rangle$. Here $|N(B), nlj\rangle$ belongs to an abstract single-particle basis, as it is used in shell-model calculations. We write $N(B)$ to indicate that the nucleon is described by a bound wave function. The product $\times$ indicates that the angular momenta of J_r and j are coupled to J_i . Also, the product of the parities π_r and $(-1)^l$ have to be π_i , and the resulting wave function fully antisymmetrized.

As we want to describe the emission of one nucleon, we are only interested in final states $|A, f\rangle$ in which only one particle is promoted to an unbound single-particle state. These eigenstates of $\hat{H}$ can be written in terms of the shell-model eigenstates of the A-1 system and the extra particle as:

$$|A, f\rangle = |A-1; r\rangle \times |N(U), E_k l j\rangle \quad (3)$$

Here $|N(U), E_k l j\rangle$ is a positive energy state lying in the continuum, characterized by the values of l, j and the energy E_k . We use $N(U)$ to indicate that the nucleon is described by an unbound wave function. This final state is a scattering state that, asymptotically, corresponds to a nuclear state r of the residual nucleus coupled to an outgoing nucleon. The angular momenta and parities of the states of the residual nucleus and the outgoing nucleon couple to give a total angular momentum and parity of $|A, f\rangle$, that have to coincide with that of $|A, i\rangle$.

In our formalism, the matrix elements of the operator $\hat{H}$ that generates the decay will be approximated by those of a suitable single-particle operator $\hat{H}_{sp}$, so that $\langle A, i | \hat{H} | A, f \rangle \approx \langle A, i | \hat{H}_{sp} | A, f \rangle$. Then, we can write:

$$\langle A, i | \hat{H} | A, f \rangle = SPA(i; r, nlj) \langle N(B), nlj | \hat{H}_{sp} | N(U), E_k l j \rangle \quad (4)$$

Note that the normalizable single-particle wave function $|N(B), nlj\rangle$ is not an eigenstate of $\hat{H}_{sp}$, because if it was so, the matrix element would cancel. In writing this expression we consider only the contribution to the decay from a given n -value for each l, j . The explicit evaluation of this matrix element would require the knowledge of the continuum wave function $|N(U), E_k l j\rangle$, the bound wave function $|N(B), nlj\rangle$ as well as of the single-particle Hamiltonian $\hat{H}_{sp}$. However, we can avoid the explicit calculation by the following argument: As we want to describe the emission of a nucleon with relative energy E_k , we adjust the depth of the single-particle potential for each single-particle wave function by requiring it to have a Gamow state [10] at a complex energy $E(nlj) + i\gamma(nlj)$ so that $E(nlj) = E_k$. In this way we obtain a single-particle width for nucleon emission which will depend explicitly on the value of E_k , which we denote by $\gamma(nlj; E_k)$. This width is related to the matrix elements of the single-particle Hamiltonian and to the density of states by:

$$\gamma(nlj; E_k) = 2\pi |\langle N(B), nlj | \hat{H}_{sp} | N(U), E_k l j \rangle|^2 \rho(E_k) \quad (5)$$

Therefore, the width for nucleon emission from the state $|A, i\rangle$, leading to a final state $|A-1, r\rangle$ coupled to an outgoing nucleon with relative energy E_k and angular momenta l, j can be written as:

$$\Gamma(i; r; l j; E_k) = |SPA(i; r, nlj)|^2 \gamma(nlj; E_k) \quad (6)$$

This expression is valid assuming that we know not only the residual state $|A-1, r\rangle$ but also the angular momentum l, j of the outgoing nucleon. The experimental situation is usually that one does not know l, j . Then, we have

$$\Gamma_P(i, r; E_k) = \sum_{lj} \Gamma(i; r; l j; E_k) = \sum_{lj} |SPA(i; r, nlj)|^2 \gamma(nlj; E_k) \quad (7)$$

which gives the partial width for the decay of the emitter state $|A, r\rangle$ to a final state consisting of a residual nucleus $|A-1, r\rangle$ and a nucleon with relative kinetic energy E_k . From this expression, and

assuming that the decay of the state $|A; i\rangle$ occurs mainly through particle emission, one can calculate the natural width of the state:

$$\Gamma_T(i) = \sum \Gamma_P(i, r; E_k) = \sum_{rlj} |SPA(i; r, nlj)|^2 \gamma(nlj; E_k) \quad (8)$$

Also, one can calculate the branching ratios

$$b_p(i, r) = \Gamma_P(i, r; E_k) / \Gamma_T(i) \quad (9)$$

In the case of beta-delayed particle emission, the nucleon activity arising from the beta decay of the parent nucleus to a state i of the emitter, leaving the residual nucleus in a final state r can be obtained as

$$I_p(i, r) = I_\beta(i) b_p(i, f) \quad (10)$$

where $I_\beta(i)$ is the corresponding beta-decay intensity from the parent nucleus to the state i of the emitter.

It should be noticed that any CSG calculation requires two basic ingredients:

- *The spectroscopic amplitudes.* These can be taken from suitable shell-model calculations. Although the calculated values of the SPA's might not be reliable for highly excited states, usually one will be interested in beta-delayed particle emission, and then the relevant states would be those that have a strong overlap with the parent nucleus. We expect that for these states the shell-model description should be adequate.
- *The widths of the single-particle states.* These will have a certain dependence on the choice of the single-particle potential. However, it should be noticed that the depth of the potential should be determined by the requirement of having the resonance energy at E_k . Thus, if one fixes the geometry of the single-particle potential to the standard values required in shell-model calculations (for example, using Woods-Saxon forms with $a=0.65$ fm, $r_0=1.27$ fm), the widths of the single-particle states are uniquely determined. It should be noticed that the single-particle potentials, and also the single-particle widths, will depend on the residual state, because the kinetic energy E_k depends on it.

3 CSG calculations for ^{31}Cl

The drip-line nucleus ^{31}Ar is the lowest member of the $T = 5/2$ isospin multiplet, with a half-life of 14.1(7) ms and a large Q-value of 18.49(10) MeV[8]. It has a ground state spin of $J=5/2$ [11] and although the parity is still unknown, we will assume in the present work to be the same as the one of its mirror nucleus ^{31}Al (positive). Thus, the beta decay of ^{31}Ar should mainly populate ^{31}Cl positive parity states of $J=3/2, 5/2$, and $7/2$. As the lowest excited levels of the residual nucleus ^{30}S have isospin $T=1$, proton decay will occur only for the $T=3/2$ states of ^{31}Cl in the absence of isospin mixing. However, it has been reported that the isobaric analog state of ^{31}Cl at 12322 keV does actually decay by proton emission through small isospin impurities of its wave function[7, 12, 13, 14, 15, 16], which otherwise would have been forbidden by isospin conservation. A shell-model calculation including isospin-breaking terms has been recently used to study this exotic decay process[7]. In the present work we will not consider this decay mechanism, which in any case only accounts for a small fraction (4.25(30)%) of the total proton intensity.

The shell-model calculations for ^{31}Ar , ^{31}Cl and ^{30}S were performed with the computer code ANTOINE[17]. We have used the Wildenthal effective sd-shell interaction USD[18] which is isospin conserving. In the case of ^{31}Cl we have extended our calculations up to an excitation energy of 12.7 MeV, obtaining Gamow-Teller matrix elements and the corresponding beta intensity for isospin $T=3/2$ and $T=5/2$. Our calculations predict $J=5/2+$ for the ground state of ^{31}Ar , which agrees with the experimental value of [11], and the one

Figure 1: Shell-model calculations for $T=3/2$ levels in ^{31}Cl and the experimental levels of the mirror nucleus ^{31}Si . Energy levels are given in MeV.

of its mirror nucleus ^{31}Al . We get a half-life for ^{31}Ar of 10.6 ms, somewhat smaller than the experimental value of 14.1(7) ms cited above. The quotient of these values gives the well known quenching factor of ≈ 0.7 expected for sd-shell nuclei [19] and reported in previous shell-model calculations [7]. This effect can be attributed to three factors: the differences between the theoretical and the experimental values of the Q_β , the energy distribution of the $B(\text{GT})$ and the corresponding total strength. In any case, we do not include any quenching factor in the present study.

In Figure 1 we show the calculated low-lying levels of $T=3/2$ of ^{31}Cl together with the experimental ones of the mirror nucleus ^{31}Si . In general terms we get a reasonable agreement between the energy levels and the spin sequence. Our shell model gives a beta feeding of 28.5% for the ground state of ^{31}Cl and $B(\text{GT})=0.127$. The calculation reveals that most of the beta intensity ($\approx 86\%$) is concentrated in the first few levels of $T=3/2$. Therefore these levels will give the main structure of the beta-delayed proton spectrum. We also find that the $B(\text{GT})$ strength is particularly strong for two highly excited states: one at $E=12.065$ MeV with $J=3/5+$ and $B(\text{GT})=.148$, and another at $E=12.536$ MeV with $J=5/2+$ and $B(\text{GT})=.159$. These states give strong peaks in the high energy part of the theoretical energy spectrum of the beta-delayed protons (see Figure 3). The $T=5/2$ levels obtained in our calculation lie above 12 MeV excitation energy and only the IAS appears with a relevant beta intensity. Our calculation gives for the IAS an excitation energy of $E=12.061$ MeV, a $B(\text{GT})=.126$ and a beta intensity of 4.2%. The value of $B(F)=5$ can be obtained in a model-independent calculation. Thus our results are consistent

Figure 2: Shell-model calculations for $T=1$ levels in ^{30}S , the experimental values and the levels of the mirror nucleus ^{30}Si . Energy levels are given in MeV.

within the experimental errors with the value of $B(F)+B(GT)=4.9(4)$ and with the beta intensity of $4.25(30)\%$ given in [8]. The $T=5/2$ levels will give no contribution to the proton emission due to isospin conservation. The result of our shell-model calculations for the low energy levels of ^{30}S is shown in Figure 2 together with the experimental values and the ones of the mirror nucleus ^{30}Si . We see that we reproduce properly the sequence of spins and energies.

The Gamow eigenvalues are obtained using the computer code GAMOW[20]. They are generated from real Saxon-Woods potentials of a fixed geometry ($a=0.65$ fm, $r_0=1.27$ fm). The depth of the central potential V_c is then varied to reproduce a single-particle state with quantum numbers ' nlj ' and energy eigenvalue ϵ_{nlj} such that $\text{Re}(\epsilon_{nlj}) = E_k$. For the depth of the spin-orbit potential we adopt a simple ansatz $V_{sp}=-0.2 V_c$ [3]. As the kinetic energy E_k increases the proton widths become too large and the computation of the energy eigenvalues becomes difficult due to the numerical precision required to achieve convergence. To overcome this problem we have used a parameterization based on a simple barrier penetration model. We write the width for particle emission as:

$$\Gamma(E_k) = \hbar\nu(E_k)P(E_k) \quad (11)$$

where $P(E_k)$ is the penetrability for a given potential barrier and $\nu(E_k)$ is the number of attempts per

unit time of the particle to penetrate through the barrier[21]. For a parabolic barrier we have

$$P(E_k) = \frac{1}{1 + \exp \frac{E_B - E_k}{\omega_B}} \quad (12)$$

where E_B is the barrier height and ω_B the barrier width. We can estimate $\nu(E_k)$ considering a particle inside an infinite square well of depth V_0 and radius R_B , the barrier radius. Then we get:

$$\nu(E_k) = \sqrt{\frac{E_k + V_0}{2\mu R_B^2}} \quad (13)$$

where μ is the reduced mass of the system. Thus we are left with:

$$\gamma(E_k) = \sqrt{\frac{E_k + V_0}{2\mu R_B^2}} \frac{\hbar}{1 + \exp \frac{E_B - E_k}{\omega_B}} \quad (14)$$

The barrier radius can be estimated from $R_B \approx 1.2M^{1/3}$, where M is the mass of the daughter nucleus ^{30}S . The values of E_B , V_0 and ω_B are fitted to the calculated values of the single-particle widths. We use this parameterization above 3 MeV excitation energy for $2s_{\frac{1}{2}}$ orbitals and above 7 MeV for the $1d_{\frac{3}{2}}$ and $1d_{\frac{5}{2}}$ ones.

Beta-delayed proton transition intensities have been obtained including all the 151 theoretical states of ^{31}Cl and the first 7 states of ^{30}S . We do not expect to reproduce the exact values of the experimental energy levels due to residual interactions and the limited size of our shell-model space. Thus, to analyze the experimental data, we have taken the experimental values of the energy levels of ^{30}S , keeping the theoretical values for the corresponding spins, parities and SPA's. Although the shift in energy would also modify the values of the SPA's, we expect this change to be negligible for small modifications of the energy levels. The calculated proton widths are in most cases much smaller than the typical energy resolution of the experiment[8]. Therefore we have chosen Gaussian shapes of 12 keV width, re normalizing our theoretical spectrum to the height of the most intense experimental proton peak at 2080 keV. The results of a preliminary calculation have already been discussed in [9].

The energy levels of ^{31}Cl are still unknown, but they can be obtained from the analysis of the energy spectrum of the beta-delayed protons. Here we proceed to vary the calculated values of the ^{31}Cl energy levels to place the theoretical proton peaks under the experimental ones. Once again, in this method one neglects the possible effects that this level shift would produce on the values of the corresponding SPA's and B(GT)'s. We found that small changes in the level scheme of ^{31}Cl produced strong modifications in the calculated beta-delayed proton spectrum. This effect can be understood from the strong dependence of the beta intensity and the single-particle width on the available decay energy. For example, if one moves up one of the energy levels, the corresponding beta feeding will decrease, and the decay energy of *all* the proton transitions originated in that level will increase. Thus the overall height of the corresponding proton peaks will decrease, and the proton widths will increase, modifying the decay branching ratios.

4 Discussion

In the present work we have concentrated on the analysis of the most intense proton transitions obtained in a recent experiment[8]. A summary of the results of our analysis is given in Table 1, where the energy levels of ^{31}Cl are just taken to reproduce the centroid of the most intense proton decay branch. The final theoretical spectrum is shown in Figure 3 and the proposed proton decay mechanism after a tentative assignment of proton transitions is shown in Figure 4. Some of our energy levels and level decay mechanisms will differ to some extent from those given in previous analyses[7, 8]. This is because in the present work we have a CSG theoretical calculation that involves the relevant elements for the proton decay, providing a reasonably good starting point to study the proton energy spectrum. In the previous

Figure 3: Experimental energy spectrum of the beta-delayed protons (down)[8] and the final theoretical spectrum (up) after adjustment of level energies. The theoretical proton peaks have a Gaussian shape of 12 keV width.

studies the energy matching between the emitted protons and the few observed gamma coincidences were the only available guidelines for the analysis of the experimental data.

Once the experimental values of the ^{30}S energy levels have been included in our CSG calculations, the calculated proton spectrum makes possible a straightforward identification of the proton decay branches of the levels $5/2_1^+$, $3/2_2^+$, $3/2_3^+$, $7/2_1^+$, $7/2_3^+$, $5/2_4^+$, $7/2_4^+$, $3/2_5^+$ and $7/2_7^+$ of Table 1. In the following we discuss some particular cases where the initial level in ^{31}Cl cannot be directly identified from the energy spectrum of the beta-delayed protons.

Our calculations show that levels $5/2_2^+$ and $7/2_2^+$ will decay to the ground state and first excited state of ^{30}S . These are the only theoretical levels able to produce a large proton intensity around the experimental values of 2253(2) keV and 2327(4) keV. No gamma-proton coincidences have been detected for these transitions, and therefore we cannot fix the final state in ^{30}S . We can only conclude that the proton decay of these levels is seen in the experiment, but with an energy uncertainty as given by the observed proton transition energy difference (74 keV).

There are two level candidates $3/2_4^+$ and $5/2_3^+$ which can reproduce the intense proton peak observed at 1643(2) keV. We conclude that one or both of these levels are seen in the experiment, with a spin uncertainty (3/2, 5/2).

We pay particular attention to the observed proton transition at 4030(3) keV as it was suggested to proceed via the ^{30}S first excited state in [7] and via the ground state in [8]. For this transition we have only two possible candidates: the $7/2_5^+$ and the $7/2_6^+$ which decay via the 1st excited state of ^{30}S . This result agrees with [7] and not with [8]. As a matter of fact, in our calculations these levels can never decay to the ground state of ^{30}S due to angular momentum conservation. We propose level $7/2_6^+$ as the candidate for the 4030(3) keV transition due to the large proton intensity in comparison with the other. Moreover, with this assumption we also get the observed proton transition at 2881(3) keV with an intensity close to the experimental value. The proton decay mechanism of level $7/2_5^+$ is consistent with

Figure 4: Proposed level scheme and decay mechanism for ^{31}Cl . Energy levels are given in MeV, relative to the ground state of ^{31}Cl . (*) = ambiguous assignment; see text for details.

the observed proton transition of 3902(4) keV to the 2nd excited state of ^{30}S .

Our theoretical model predicts a proton transition from the level $5/2_5^+$ to the first excited state of ^{30}S . This decay mechanism is not consistent with the one proposed in [7] nor with the one of [8]. However the calculated natural width of the corresponding energy peak is $\Gamma=30.8$ keV, which is almost twice the energy resolution of the experiment. An estimate of the expected width for this broad proton peak can be obtained as

$$\sigma \approx \sqrt{\sigma_e^2 + \Gamma_p^2} \approx 36 \text{ keV}$$

which is consistent with the peak width analysis given in [22].

5 Summary and conclusions

In this paper we present a simple model to describe the beta-delayed nucleon emission. In our approach a standard shell model is used to obtain the nuclear structure of the parent, emitter and daughter nuclei, and the corresponding beta intensity. The single-particle widths are obtained from the Gamow eigenfunctions of an effective single-particle potential which we assume to induce the transition process.

We apply this model to study the energy spectrum of beta-delayed protons emitted in the beta decay of ^{31}Ar . We have carried out a shell-model calculation using the effective sd-shell interaction proposed by Wildenthal[18]. In our calculations we get a description of the ground state of ^{31}Ar and the nuclear structure of ^{31}Cl and ^{30}S which is consistent with the available experimental data. The single-particle widths are obtained from Gamow wave functions generated using real Saxon-Woods form factors of fixed geometry ($a=0.65$ fm, $r_0=1.27$ fm), for which the potential depth is varied in order to reproduce the Q value for the proton decay.

The calculated proton transition probabilities and the corresponding proton energy spectrum describe the general features of the experimental results. If we vary the shell-model energy levels to reproduce the experimental values it is possible to make a clear assignment of many of the observed proton transitions to various levels of ^{31}Cl , allowing for spin and parity assignment. We also find that the calculated

proton widths provide useful information to make the correct proton transition assignment when the experimental values are available. Our calculations suggest that only a few excited levels in the emitter nucleus are needed to describe the main structure of the beta-delayed proton spectrum of ^{31}Ar . Thus we conclude that the CSG model can be a useful tool for spectroscopic studies of exotic nuclei.

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J_{Cl}^{π}	E_{Cl}	$B(GT)(th)$	J_S^{π}	$E_p(exp)$	$I_p(th)$	$I_p(exp)$	$\Gamma(th)$
$5/2_1^+$	1753	0.053	0_1^+	1416(2)	27.1	34.0(3)	0.02
$3/2_2^+$	2443	0.243	0_1^+	2084(2)	100	100.0(6)	0.4
$5/2_2^+$	2618	0.004	0_1^+	2253(2)	1.6	4.0(3)	0.8
$7/2_1^+$	3752	0.004	2_1^+	1211(4)	1.1	1.7(5)	0.11
$3/2_3^+$	4045	0.028	0^+	3634(3)	4.4	6.1(8)	9.8
			2_1^+	1504(2)	2.3	6.2(2)	5.1
$7/2_2^+$	4905	0.014	2_1^+	2327(4)	2.4	5.1(4)	1.7
$5/2_3^+$	5390	0.011	2_2^+	1643(2)	1.1	2.88(14)	3.4
$7/2_3^+$	5621	0.057	2_1^+	3020(3)	7.4	1.08(14)	3.1
$3/2_4^+$	5658	0.010	1_1^+	1643(2)	0.8	2.88(14)	3.8
$5/2_4^+$	5767	0.360	0_1^+	5276(5)	11.5	17.6(3)	7.4
			2_1^+	3153(4)	12.2	0.44(10)	7.8
			2_2^+	2008(2)	20.9	10.0(2)	13.4
$7/2_4^+$	6047	0.022	2_1^+	3432(3)	2.1	0.89(11)	9.8
$5/2_5^+$	6180	0.047	2_1^+	3561(11)	4.5	3.6(8)	30.8
$7/2_5^+$	6533	0.044	2_1^+	3902(3)	3.4	2.22(14)	11.3
$3/2_5^+$	6640	0.023	0_1^+	6145(7)	0.5	0.51(12)	5.4
$7/2_6^+$	6665	0.186	2_1^+	4030(3)	14.7	7.0(2)	4.6
			2_2^+	2881(3)	0.4	0.99(13)	0.13
$7/2_7^+$	7050	0.050	2_2^+	3249(4)	1.9	1.17(15)	2.6
			3_2^+	1300(13)	0.9	0.7(11)	1.3

Table 1: Results of the analysis of the beta-delayed proton energy spectrum. The different columns represent the spin and parity of the ^{31}Cl excited states, the excitation energy (keV), the Gamow-Teller strength to that state, the spin and parity of the ^{30}S states to which they decay by proton emission, the energy of the observed proton (keV), the proton intensity normalized to the strongest proton transition at 2084(2) keV, calculated and experimental, and the calculated width for proton decay (keV).