LEVEL SCHEME OF ^{131}Sb

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1. Experimental study

The odd mass Sb nuclei, up to A = 127, have been the subject of many experimental[1] as well as theoretical investigations[2,3] since the interplay between the proton single-particle motion in the 50<Z<82 and the quadrupole and octupole vibrations of the underlying core nuclei is manifested in a clear-cut way in these nuclei.

In the case of ^{129}Sb and ^{131}Sb for which only scarce information exists[1,4,5] limited validity of this approach is expected, due to the very strong deviations between the doubly even $^{130}_{50}Sn_{80}$ nucleus and a harmonic quadrupole vibrator[6].

An experimental effort was therefore made, in first time on ^{131}Sb, in order to check more refined one-proton-particle two-neutron-hole shell model calculation with two different proton-neutron residual interactions.

We used the Lohengrin facility[7] at the high flux reactor of the Institute Laue-Langevin in Grenoble, which separates the recoiling products of thermal neutron induced fissions within a few microseconds, to obtain pure ^{131}Sn activity. The sharing of the different gamma-transitions between the two well known beta isomers of ^{131}Sn, $11/2^-$ and $3/2^+$ whose half lives are 50 sec. and 30 sec. respectively, was performed by using the variation of the isomer formation ratio with kinetic energy in the fission, an effect which is easly exploited at Lohengrin [8]. In some earlier work, (ref. 4-5), an 50 µs excited isomeric state, was observed at 1676 keV in ^{131}Sb by performing fragment-gamma delayed coïncidences at Lohengrin. To find evidence for gamma transitions between levels above this isomeric level, and eventually fed by beta decay, delayed beta-gamma and gamma-gamma coïncidences were also performed at Lohengrin with a time-window of several microseconds.

The on-line fission-fragment separator Josef[9] at the K.F.A. Jülich was used for prompt gamma-gamma coïncidence measurements needing more intense radioactive sources.

The proposed level scheme for ^{131}Sb is shown figure 1 where spin assignment are based on beta feeding considerations as well as gamma branching ratios. An additional line of 82.3 keV (8%) could not be definitely placed in the proposed level scheme ; this line desappears in both prompt beta-gamma and delayed gamma-gamma coïncidences and was not observed by fragment-gamma delayed coïncidences performed on ^{131}Sb where 50 µs activities were identified. Nevertheless, as shown by the "Bρ" identification method performed at Josef, this line belongs to ^{131}Sb and his probable position is therefore above the isomeric level at 1675.9 keV.

In figure 2, we indicate the essential features concerning the odd-mass antimony isotopes from A = 121 up to A = 131. For ^{129}Sb, an important lack of information on excited states shows up. Moreover, we further remark a smooth increase in excitation energy, with increasing neutron number, for the $5/2^+$, $3/2^+$ and $1/2^+$ levels with respect to the $7/2^+$ level. Finally, the existence of a multiplet containing the spin states $9/2^+$, $11/2^+$ near 1200 keV is evidenced, although only in ^{131}Sb, a detailed knowledge of all members of the multiplet has been obtained.

The low lying $7/2^+$ and $5/2^+$ states probably contain most of the proton single particle states 1 g 7/2 and 2 d 5/2 respectively. The $3/2^+$ and $1/2^+$ higher lying states definitely contain important admixture of particle core compled $|1\ g\ 7/2, 2^+_1>$ configuration besides the proton single particle 2 d3/2 and 3 S 1/2 configuration.

2. Theoretical predictions

A more detailed description for the excited states in ^{131}Sb can be obtained by treating all one-proton two-neutron-hole configuration with residual interaction, within a shell-model approach. Starting from the general formalism, developed in order to treat m-proton n-neutron nuclei[10,11], we have obtained in the specific case of a one-proton two-neutron hole nucleus (such as ^{131}Sb), the expression :

$$<p',C'_nJ'_n;JM|V_{pn}|p,C_nJ_n;JM> = \sum_\lambda \chi_\lambda (-1)^{j_p+J'_n+J} \begin{Bmatrix} J_n & \lambda & J'_n \\ j' & J & j_p \end{Bmatrix}$$

$$<p'||Q_\lambda||p> \times <C'_nJ'_n||Q_\lambda||C_nJ_n> \quad , \qquad (1)$$

as the residual proton-neutron interaction[12]. This expression is formally equivalent with the macroscopic particle-core coupling matrix element. The core matrix elements (1) however, are defined in terms of their shell-model description. Therefore, first carrying out the two-hole shell-model calculation for ^{130}Sn [6] supplie the wave-functions necessary to calculate the $<C'_nJ'_n||Q_\lambda||C_nJ_n>$ reduced matrix elements.

The proton-neutron residual interaction consists of a quadrupole + octupole expansion with strength

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parameters (see also ref.2) χ_2 = -0.08 MeV, χ_3 = -0.06 MeV, giving a good agreement with the ^{131}Sb experimental level scheme. Calculations with δ interaction have also been rather succesful in describing nuclei near ^{132}Sn (ref.[13]). Proton and neutron single-particle and single-hole energies respectively, were discussed in ref.3. The neutron residual interaction was a Gaussian interaction also fully described in ref.3.

Carrying out the calculations of energy spectra -shown figure 3- and electromagnetic transition rates (M1,E2,M2,E3,..) the following interesting results occur (see also fig.3 and table 1) :

- besides the low-lying single-particle states $1g_{7/2}$, $2d_{5/2}$ and the quadrupole-coupled configuration $|1g_{7/2},2^+_1\,;\,J^\pi>$, near $E_x \cong$ 1.6 MeV, negative parity levels result from coupling the $1g_{7/2}$ proton single-particle orbit with the $J^\pi_1 = 7^-_1, 5^-_1, 4^-_1$, ... negative parity states in ^{130}Sn. The latter levels cannot result from a purely macroscopic approach,

- some more positive parity levels are obtained by coupling the proton single-particle states to non-collective levels obtained from the two-hole shell model calculation describing levels in ^{130}Sn i.e. $J^\pi_i = 2^+_2, 0^+_2, 0^+_3$,

- Above $E_x \cong$ 2 MeV, the level density, both experimentally and theoretically, becomes so large such as to make precise assignments impossible.

Electromagnetic M2 and E3 calculations point out that, in going from the $|1g_{7/2}, 7^-_1>$ towards the $|1g_{7/2},2^+_1>$ configurations, the core wave function is undergoing an important change and thus nuclear isomerim can result. The theoretical calculation point out that the only candidates, compatible with the experimental data, are the $J^\pi_1 = 13/2^-_1$ or $13/2^-_2$ levels. The theoretical excitation energy favours the $J^\pi_1 = 13/2^-_1$ assignment for the isomeric level. The precise values for the half-lifes, calculated using a δ-interaction and a multipole interaction are given in Table 1. Finally, we can conclude that, up to $E_x \cong$ 2 MeV, a good theoretical description of the experimental data in ^{131}Sb is obtained by the one-proton two-neutrons hole shell-model calculation. Moreover, we point out that no important nuclear features are missing in a description of the nucleus ^{131}Sb.

Table 1

$J^\pi_i \rightarrow J^\pi_f$	δ-interaction M2	E3	Multipole interaction M2	E3
$13/2^-_1 \rightarrow 7/2^+_1$		97		25
$\rightarrow 11/2^+_1$	573		260	
$\rightarrow 9/2^+_1$	14		7.4	
$\rightarrow 7/2^+_2$	-		-	
$13/2^-_2 \rightarrow 7/2^+_1$		140		10
$\rightarrow 11/2^+_1$	13		8	
$\rightarrow 9/2^+_1$	3.1		3300	
$\rightarrow 7/2^+_2$	-		-	

Theoretical partial $T_{1/2}(\gamma)$ values for the $13/2^-_1$ and $13/2^-_2$ levels. Half-life are given in μsec.

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References

1) C.M. Lederer and V.S. Shirley, Table of Isotopes - John Wiley & Sons Inc. New-York, 7th edition (1978).

2) L.S. Kisslinger and R.A. Sorensen, Rev. Mod. Phys. 35, 853 (1963).

3) G. Vanden Berghe and K. Heyde, Nucl. Phys. A163, 478 (1971).

4) F. Schussler, J. Blachot, J.P. Bocquet, E. Monnand, Z. Physik A281, 229-232 (1977).

5) K. Heyde, J. Sau, R. Chery, F. Schussler, J. Blachot, J.P. Bocquet, E. Monnand, K. Sistemisch, Phys. Rev.C 16 (1977) 2437-2441.

6) B. Fogelberg, K.Heyde, J. Sau, Nuclear Physics A 352 (1981) 157-180.

7) E. Moll, H. Schrader, G. Siegert, M. Asghar, J.P. Bocquet, G. Bailleul, J.P. Gautheron, J. Greif, G.I. Crawford, C. Chauvin, H. Ewald, H. Wollnik, P. Armbruster, G. Fiebig, H. Lawin, K. Sistemich, Nucl. Instr. 123, 615 (1975) ; Institut Laue-Langevin, Grenoble report 75-A-51.

8) J.P. Bocquet, F. Schussler, E. Monnand, K. Sistemisch, International Symposium on Physics and Chemistry of Fission, Jülich May-1979 IAEA - SM/241 -F10 -

9) H. Lawin, J. Eidens, P. Armbruster, J.W. Grüter, K. Hübenthal and K. Sistemich, Proc. Int. Conf. on electromagnetic isotope separators and the techniques of their applications, Marburg 1970, ed. H. Wagner and W. Walcher, report BMBW-FB K 70-28 (1970) 270 ;
H. Lawin, J. Eidens, P. Armbruster, J.W. Grüter, M. Rajagopalan, K. Rashid, G. Sadler and K. Sistemich, Proc. 8th Int. EMIS Conf. on low-energy ion accelerators and mass separators, Skövde 1973, ed. G. Andersson and G.Holmen,p.239.

10) J. Sau and K. Heyde, Phys. Rev. C21 (1980) 419

11) J. Sau and K. Heyde, Phys. Rev. C23 (1981) 2315

12) K. Heyde, J. Sau and J. Van Maldeghen, hese Proceedings.

13) J. Sau, K. Heyde and R. Chery, Phys. Rev. C21 (1980) 405.

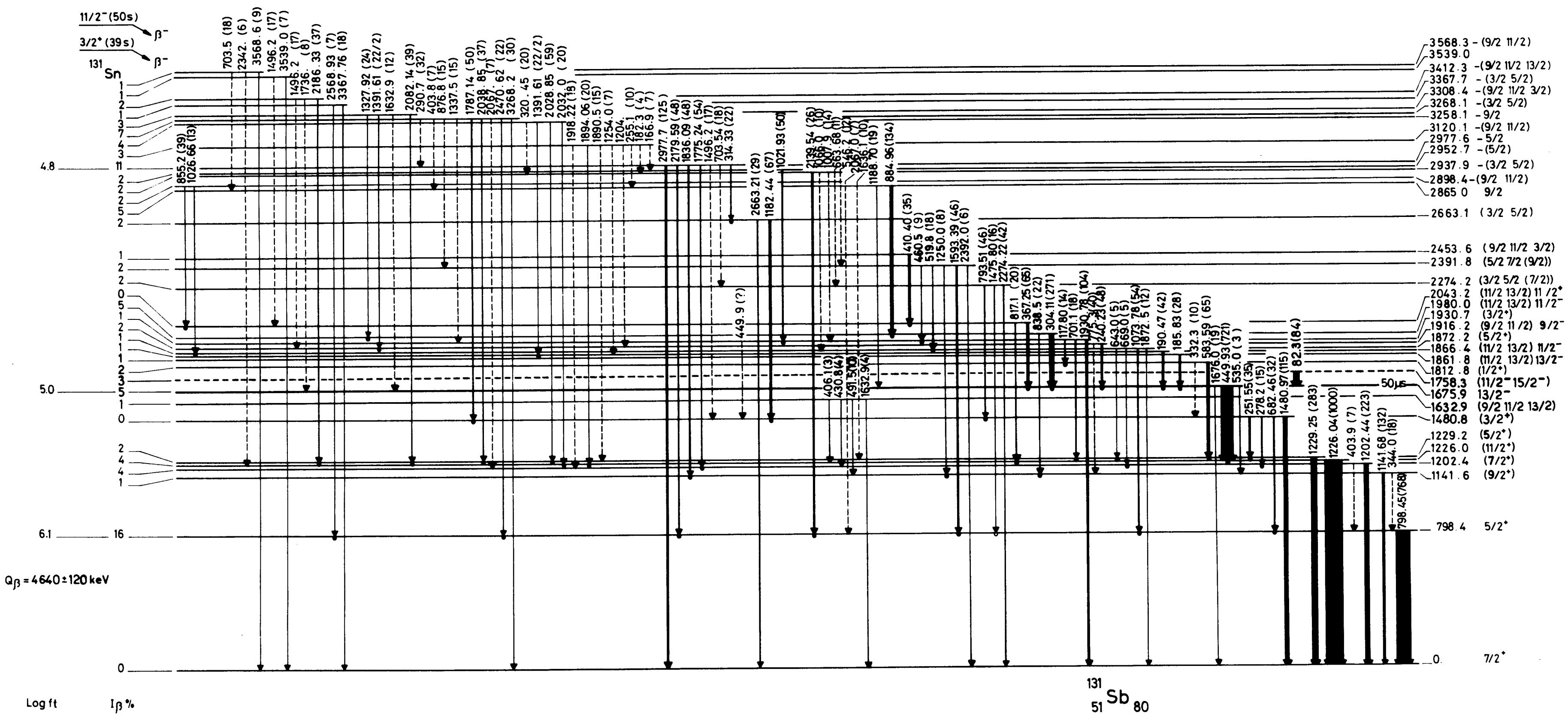

Fig.1 - Proposed level scheme for ^{131}Sb.
Spin assignements have to be considered as temptative.

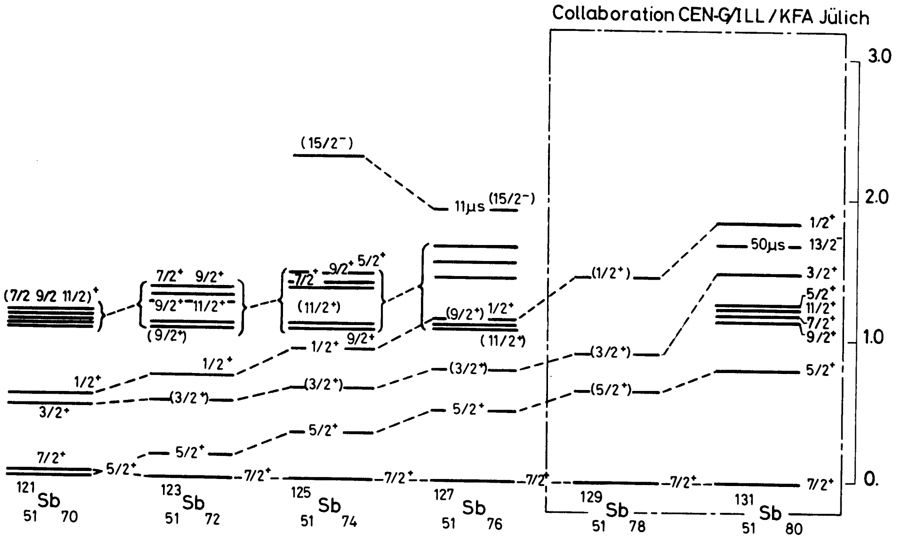

Fig.2 - Systematic of excited states in odd antimony isotopes.

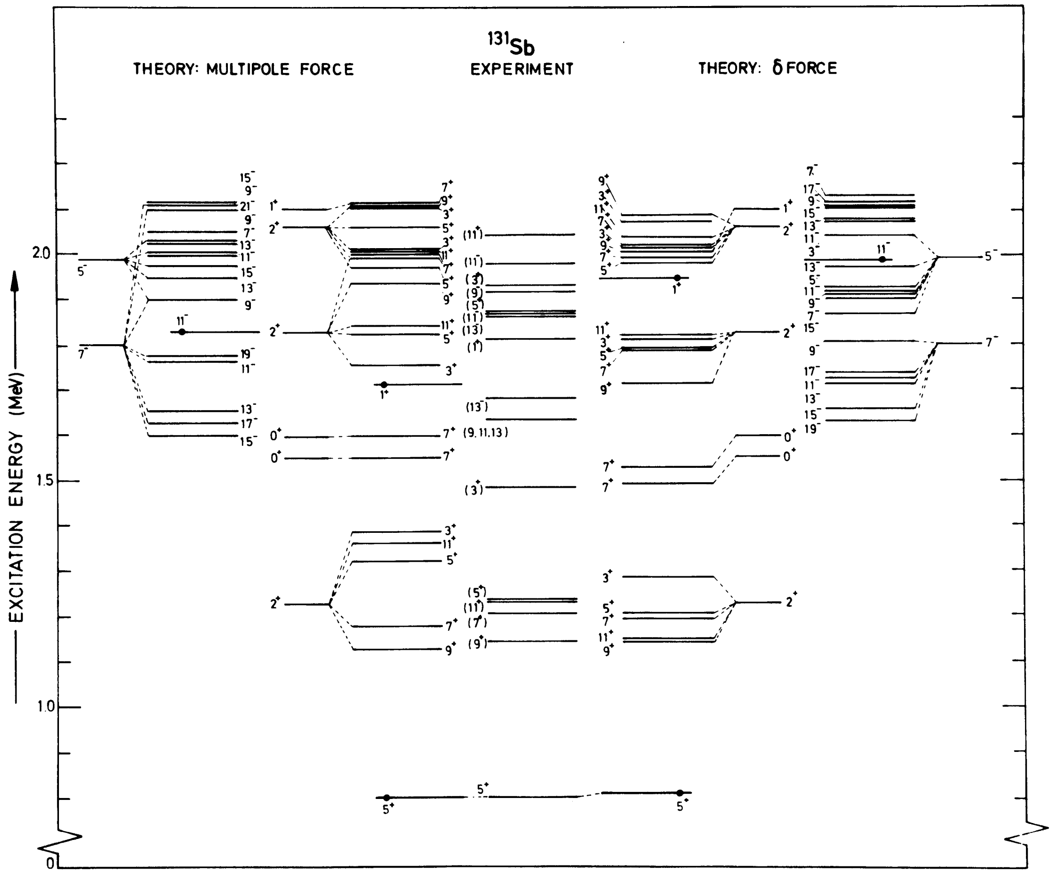

Fig.3 - Comparison of theoretical calculations, using a δ-interaction or a quadrupole + octupole interaction as proton-neutron interaction, with experimental data. Angular momenta we denoted as 2J. The parentage (if very pronounced) on 2 hole levels of ^{130}Sn is also indicated. Dotted levels contain most of the corresponding proton single-particle configuration.