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EXPERIMENTAL STUDY OF NUCLEI NEAR N = 20

STUDY OF ^{32,31}Na, ^{31}Mg, ^{33,34}Al BETA DECAY

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Work in collaboration with : P. Baumann, A. Huck, G. Klotz, A. Knipper (CRN, Strasbourg), G. Marguier (IPN, Lyon), H.L. Ravn (CERN-ISOLDE), C. Richard-Serre (IN2P3/CERN-ISOLDE), A. Poves and J. Retamosa (Univ. Autonoma, Madrid)

Contribution to the Workshop
"Nuclear Structure of Light Nuclei Far From Stability : Experiment and Theory"
OBERNAI (France) November 27-29, 1989

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The fundamental interest of studies of neutron-rich nuclei in the region of the N,Z plane centered at Z=11, N=20 has been stimulated by recent theoretical works1) and by new possibilities of producing n-rich nuclei and collecting spectroscopic information by γ or neutron measurements.

In this contribution, we present experimental results obtained at the ISOLDE on-line separator where the n-rich Na, Mg, Al isotopes are produced by bombarding a uranium carbide target with the proton beam of the 600 MeV CERN synchrocyclotron and afterwards ionized in a tungsten surface ionization source.

The region of light n-rich nuclei is represented in Fig.1 and the different nuclei which have been studied are indicated.The knowledge of the interface between the (sd) and (fp) shell is only fragmentary in nuclei for which protons occupy the $d_{5/2}$ sub-shell. Previous studies2-4) had revealed a region of strong deformation including ^{31}Na and ^{32}Mg which present anomalies in binding energies and nuclear spectra. The aim of the present study was to delineate the region of deformation where properties could not be described by sd shell model calculations and to locate intruder states for which $1\hbar\omega$ or $2\hbar\omega$ excitation from sd to fp shells are found lower than $0\hbar\omega$ excitation. This presentation will be limited to the experimental results, as other contributions to the workshop give a detailed discussion of the theoretical interpretation.

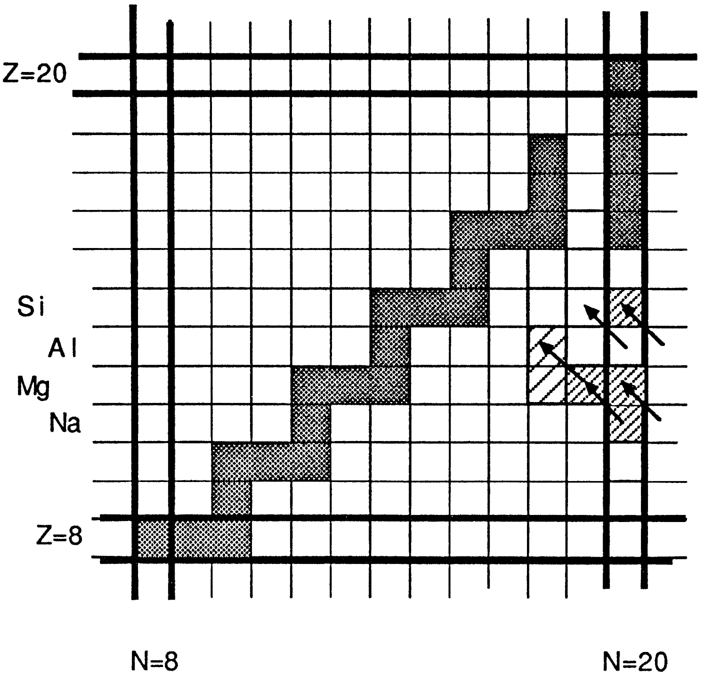

Fig.1 Portion of the (Z,N) plane where β decays (arrows) were investigated to study the region of deformation around N=20.

^{32}Na → ^{32}Mg β decay [Z-N : 11-21 → 12-20]

This study was undertaken with a twofold aim : first, a return to the ^{32}Mg bound level structure was deemed practical because of the recent improvements in γ detection efficiency, and second, the investigation of the 1n-channel was important to complement available data on ^{31}Mg.

In spite of the gain of detection efficiency, properties of bound levels of ^{32}Mg are found similar to those reported in the first studies[3,4] of the Orsay group. In particular, from the analysis of γ–γ coincidences, the first excited level is found at 885 keV with no measurable β feeding. If we assume $J^{\pi}=2^+$ for this level, only populated by the cascade of γ rays from high lying levels, we expect $J \geq (4)^-$ for the ^{32}Na ground state (the negative parity being dictated by the 21th neutron). Taking into account the large β decay energy, a first forbidden ($3^- \rightarrow 2^+$) transition should correspond to a measurable branch. Finally, a previously observed, but non assigned, γ ray of 1436 keV has been found in our experiment in coincidence with the 885 keV line and tentitavely assigned by us to the decay of a new level at 2321 keV in ^{32}Mg.

The analysis of the β–n–γ coincidences in the A=32 decay has been very successful, providing the first evidence for a set of levels at low energy in ^{31}Mg distinct from those populated in the ^{31}Na β decay.In that case, we have recorded the γ spectra in coincidence with a neutron filter consisting in two hexagonal cells (3750 cm^3/cell) filled with NE213. From the results, the 240 keV γ ray is unambiguously assigned to the ^{31}Mg level scheme. If in the n-γ–γ spectra, we put a gate on this 240 keV peak, we observe (Fig.2) different transitions (50, 171 and 929 keV) with clear evidence for a sequential decay involving levels in ^{31}Mg. The non-appearance of most of these levels in the ^{31}Na β decay (^{31}Na g.s.,J=(3/2)$^+$) and their selective population in the decay of ^{32}Na through the 1-n channel (^{32}Na g.s. J≥4$^-$), suggest that the γ cascade with the 929, 240 and 171 keV lines corresponds to the decay of a set of levels of negative parity located at 1390 keV (J ≥ 3/2$^-$), 461 keV (J ≥ 3/2$^-$) and 221 keV (J ≤ 5/2).

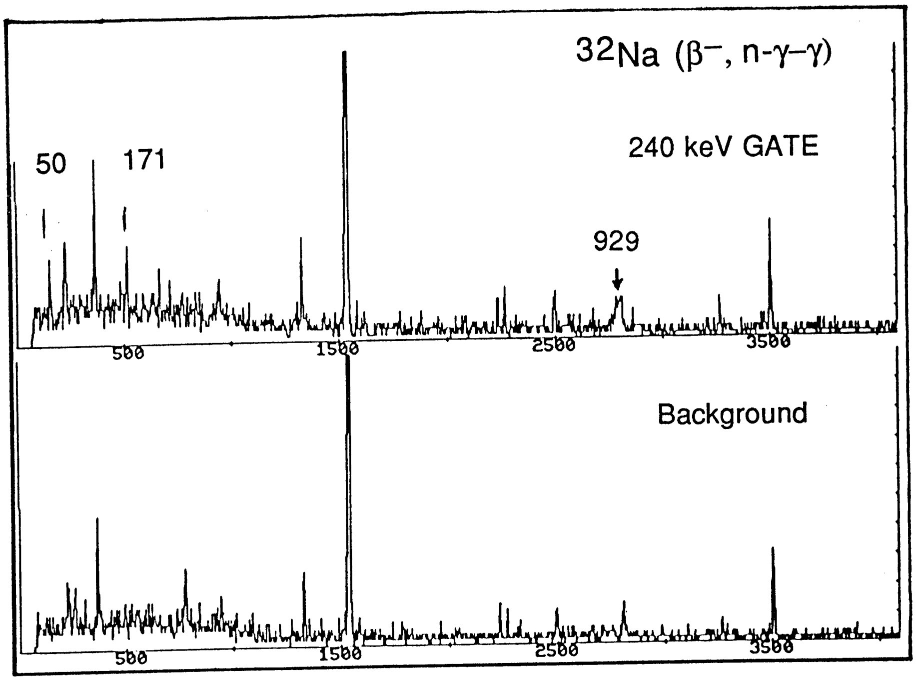

Fig.2 Portions of γ spectra, in coincidence with neutrons and with the 240 keV transition in ^{31}Mg

The formation of intruder configurations via the delayed neutron channel has already been observed in the case of ^{29}Mg levels populated in the 1n-decay of ^{30}Na$^{5)}$. In that case, the selectivity of the delayed neutron emision leading to negative parity states was understood as resulting from favoured transmission coefficients for l=1 waves in this mass region. In the ^{31}Mg case, neutron transmission coefficients, calculated using either a local or a non-local optical potential$^{8)}$, are still higher for l=1 in the 0.1 MeV ≤ En ≤ 4 MeV range, but it should be noted that

- at very low energy (E_n < 100 keV), l=0 waves are always favoured,
- at high energy (E_n ≥ 3 MeV) transmission of l=2 neutrons becomes appreciable for the l+1/2 channel ($T_{5/2}$)

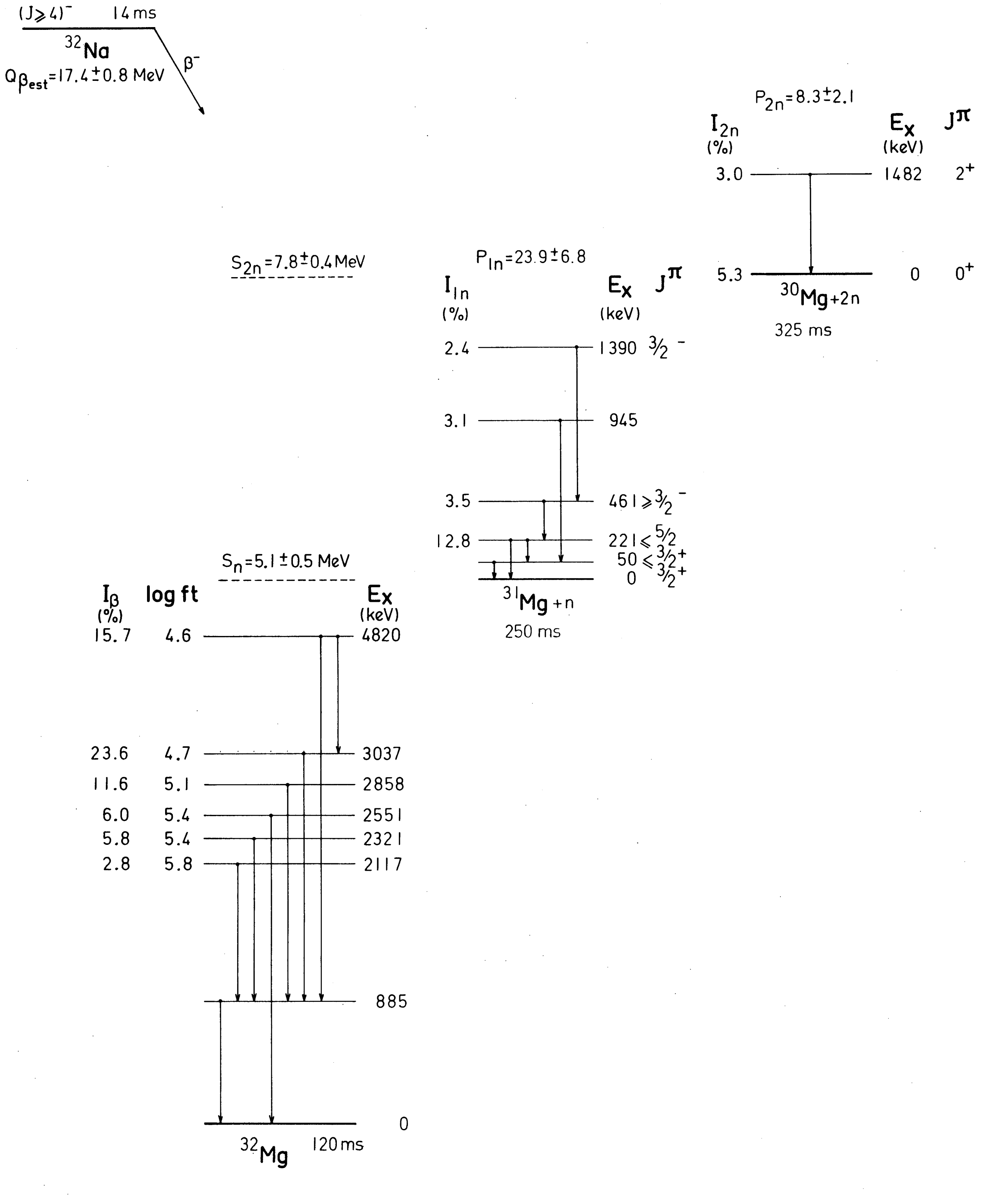

Fig. 3 Decay scheme for ^{32}Na → ^{32}Mg and the competing delayed neutron emission

Therefore, the population of negative parity states in ^{31}Mg can be explained by (l = 0,2) neutron emision from high excited levels (J = 3$^-$, 4$^-$, 5$^-$) in ^{32}Mg. An evaluation of neutron transmission coefficients which takes into account the nuclear deformation, would be very valuable.
The ^{32}Na β decay is illustrated in Fig.3. where the new levels assigned in ^{32}Mg and ^{31}Mg are reported.

^{31}Na → ^{31}Mg β decay [Z-N : 11-20 → 12-19]

Using γ–γ measurements with two large Ge detectors (300 cm^3), information on positive parity states of ^{31}Mg, populated by the Gamow-Teller decay of ^{31}Na ($J^\pi = 3/2^+$) has been extended (Fig.4). For the two lower levels (E_x = 50 and 221 keV), lifetime measurements$^{6)}$ give values or upper limits and transitions at low energy are found consistent with E1 or M1 deexcitations with the probable assignments reported in Fig.4. The anomalous high density of excited states at low energy in ^{31}Mg is now well established (from direct β decay for positive parity states and through 1-n delayed emission for negative states) and has to be compared to theoretical calculations. Such density has not been observed previously in a light even-odd nucleus and uncovers a severe disagreement with the sd shell model calculations$^{7)}$ where only the 5/2$^+$ level at 1550 keV is predicted in the 0-2MeV range. This situation is in sharp contrast with the ^{29}Mg case$^{9)}$ and the level structure of ^{31}Mg is therefore an important test for calculations which take into account configurations with one or two nucleons in the fp shells.

For ^{31}Na, the production yield was about 120 at/s and a correlated neutron and γ energy measurement could not be performed, preventing the determination of the Gamow-Teller strength above the neutron separation energy. Positive-parity states at low energy in ^{30}Mg are populated in the 1-n channel. Yet for the two states at 3760 and 3814 keV in ^{31}Mg [J^π= (1/2-5/2)$^+$] a neutron emission to the ^{30}Mg is energetically possible but the observation of the radiative decay may be explained if a l=2 neutron transfer is involved [J^π = (3/2,5/2) $^+$ for E_x = 3760 and 3814 MeV].

^{31}Mg → ^{31}Al β decay [Z-N : 12-19 → 13-18]

Our interest in the spectroscopy of ^{31}Mg → ^{31}Al results from the need to explore the interface betwen ^{31}Mg, where (fp)^n configurations are important and ^{31}Al which appears, at least at low energy, to be very well described in a sd model space. Our concern was also to provide information of value for the J^π assignement of ^{31}Mg ground state. As it appears that the low energy levels of ^{31}Mg are nearly degenerate, an inversion of the regular ground state(J^π=3/2$^+$, d3/2 state) with intruder configurations could occur and be responsible for the discrepancy between observed and calculated β branches in the ^{31}Mg → ^{31}Al decay.

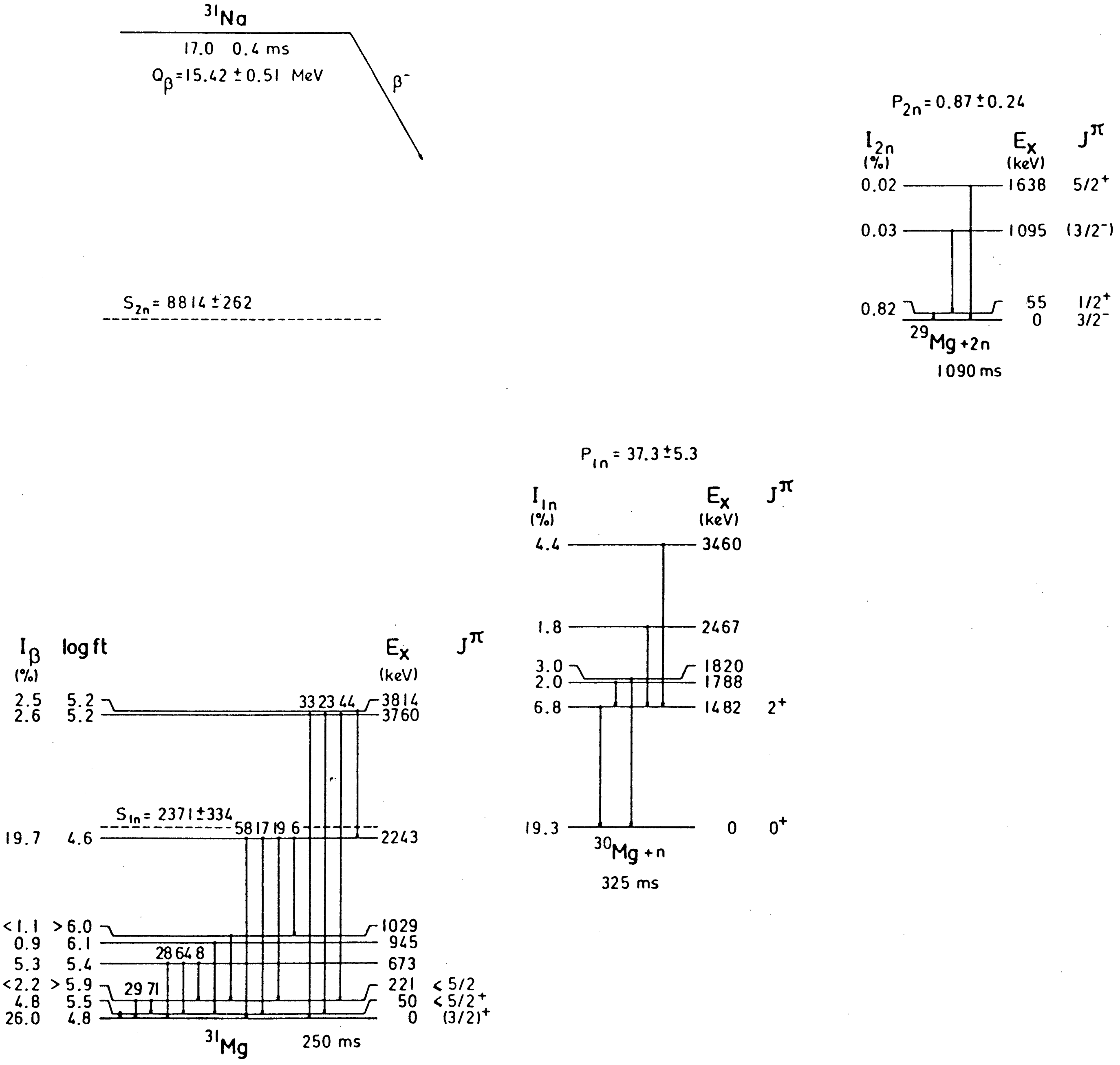

Fig.4 Decay scheme for ^{31}Na → ^{31}Mg and the competing delayed neutron emission

The nucleus ^{31}Al has been previously studied via the ^{31}Mg β decay[3,4] and via the multistep reaction ^{30}Si(^{18}O,^{17}F)^{31}Al[10]. It has also been observed in the ^{15}N(^{18}O,2p)^{31}Al reaction[11], but with a very small cross-section. From these measurements , a detailed comparison has been made with complete sd-shell model calculations[7] and counterparts have been found for the first 0hω model states[10]. Notice particularly that, at low energy, the agreement between the calculation (g.s., $J^\pi=5/2^+$; E_x=944 keV, $J^\pi=1/2^+$ and E_x 1744 keV, $J^\pi = 3/2^+$), and the experiment (g.s. $J^\pi =5/2^+$; E_x=947 keV and E_x=1613 keV) is excellent and illustrates the predictive power of the theory.

At higher energies, Cl.Woods et al[10] have assigned the experimental levels found at 2530, 3239, 3623 and 4809 keV with sd-shell model states respectively at 3171($5/2^+$), 3951($5/2^+$), 4052($3/2^+$) and 4782($5/2^+$). Comparison between experimental and calculated γ-decay branching ratios reveals an excellent agreement for all levels but the last one (4782 keV). If we now consider the beta decay matrix elements, experimental values are completely at variance with the calculated ones and as a result the total half-life of ^{31}Mg is quite anomalous in the context of sd systematics. In particular, the ($3/2^+ \rightarrow 5/2^+$) spin-flip β transition to the ^{31}Al ground state, predicted to correspond to a 80% branch was found[2,3] very low (10±18 %). On the contrary, the strong allowed transition measured to the 3239 keV level (24±7%) is predicted -granting identification with the level calculated at 3951 keV- with a much lower intensity (12%). A return to the ^{31}Mg → ^{31}Al decay was therefore necessary to set more precise limits on these discrepancies and extend the comparison with shell model calculations.

Our final results are summarized in our proposed decay scheme of Fig.5. Several observations can be made:

- For the three first levels of ^{31}Al, we confirm the strong discrepancy between calculated and experimental beta decay rates, the feeding of the 947 keV ($J^\pi=1/2^+$) being nevertheless reduced from 17 to 5.2%, in better agreement with the sd calculation. The β decay to the level at 1613 keV in ^{31}Al, identified to the first $3/2^+$ model state, involves a normal parity for the ^{31}Mg ground state [$J=(3/2)^+$].
- The previously reported level at 2530 keV, which has been identified with the 2nd $5/2^+$ model state, is ruled out by the present γ–γ measurements. The corresponding γ decay is now attributed to a new level at 4143 keV for which three γ branches are found.
- Appreciable beta strength is found to proceed to two new levels, established at 4562 and 5148 keV.

Finally, it appears that the new measurements locate an important fraction of the GT strength at higher energy and the resulting density of levels is in better agreement with the sd predictions. Nevertheless the unexpected anomaly in the distribution of the β strength is still present and should be attributed, as noted previously by C.LWoods et al.[10], to the failure of the

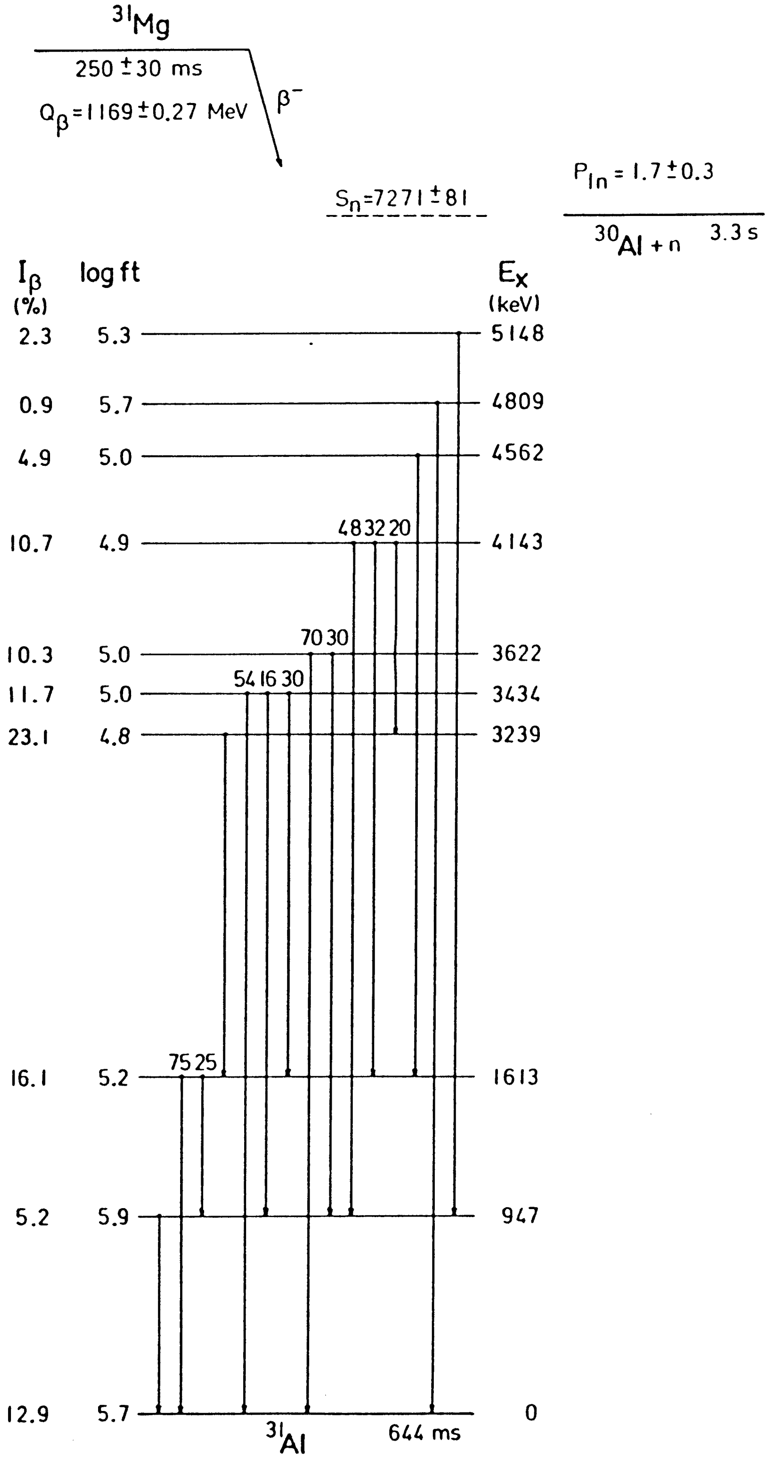

Fig. 5 Decay scheme for ^{31}Mg → ^{31}Al

sd calculation to reproduce the ^{31}Mg ground state wave function.

^{33}Al → ^{33}Si β decay [Z-N : 13-20 → 14-19]

For ^{33}Si, 6 levels have been located in the 0-5 MeV range by heavy ion transfer reactions[12-14], but the paucity of the data prevails to make a comparison with theoretical results. No information relative to the β decay of ^{33}Al is available in the litterature. A first test measurement made at ISOLDE has indicated a low production yield (≈ 30 at./s) in the mass separated beam resulting from the Uranium carbide target fragmentation and subsequent surface ionization of the thermalized fragments. A preliminary value for the ^{33}Al half-life has been measured ($T_{1/2}$ =115 ±15 ms). Determination of partial β branches is planned in a future experiment. The main transition is expected to be the ^{33}Al (g.s.) → ^{33}Si (g.s.) $d_{5/2} \rightarrow d_{3/2}$ spin-flip transition, which according to sd shell model calculations[7], amounts to 89% of the β decay. Is this prediction true, or do we have an anomaly similar to the ^{31}Mg → ^{31}Al analog case where the spin-flip component was found very weak ? The enlarging of the systematics is clearly needed.

^{34}Al → ^{34}Si β decay [Z-N : 13-21 → 14-20]

The level structure of the N=20 nucleus ^{34}Si is important to understand the evolution of deformation with the proton number. Previous attempt to investigate the ^{34}Al decay at GANIL[15-17] have allowed the $T_{1/2}$ ($T_{1/2}$=70 +30/-20 ms) and the P_n determinations as well as the identification of a β-delayed γ-ray (E_γ= 123.8 keV). Studies of ^{34}Si by different heavy ion transfer reactions have provided conflicting results which give the experimental counterpart for the first 2^+state, predicted at 4.9 MeV in the sd model space[7], either at 3590(25) keV[12] or at 5330(50) keV[13]. In addition to the sd calculations, predictions including 1ħω 1fp and 2ħω 2fp states were available[16].

With the same experimental conditions as for ^{33}Si, a weak production yield (≈10 at/s) has been measured at ISOLDE and an experimental strategy has been worked out to collect the information on ^{34}Si in spite of the low yield and the strong contamination (mainly ^{136}I and ^{68}Cu with charge 4^+ and 2^+ respectively) selected at the mass separator with the A=34 settings. We have used a β–γ–γ device involving a β plastic scintillator ($\Omega \approx 4\pi$) and two large volume Ge detectors (rel.eff. 80 %, FWHM = 2.4 keV). In these conditions, the absolute γ efficiency was about 1.5 10^{-2} at 1 MeV for each Ge counter and a successful γ–γ measurement could be performed in a reasonable time (8h).

Four γ lines were attributed to the ^{34}Al activity and found to correspond to a cascade with

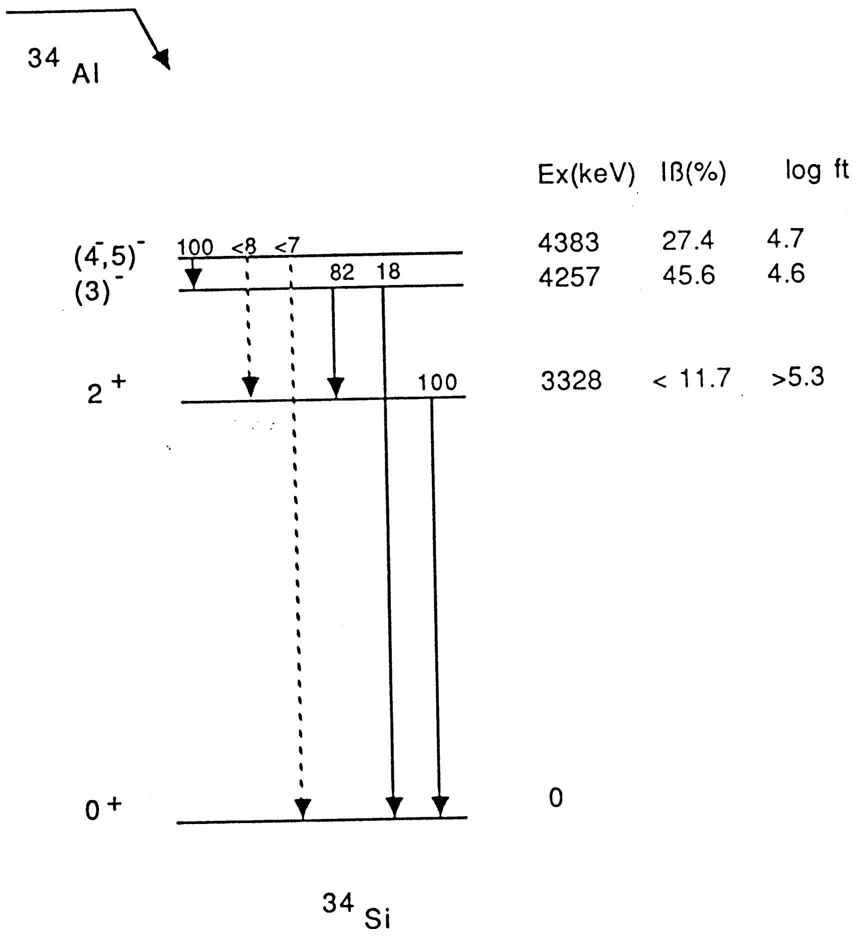

Fig. 6a Decay scheme for ^{34}Al → ^{34}Si

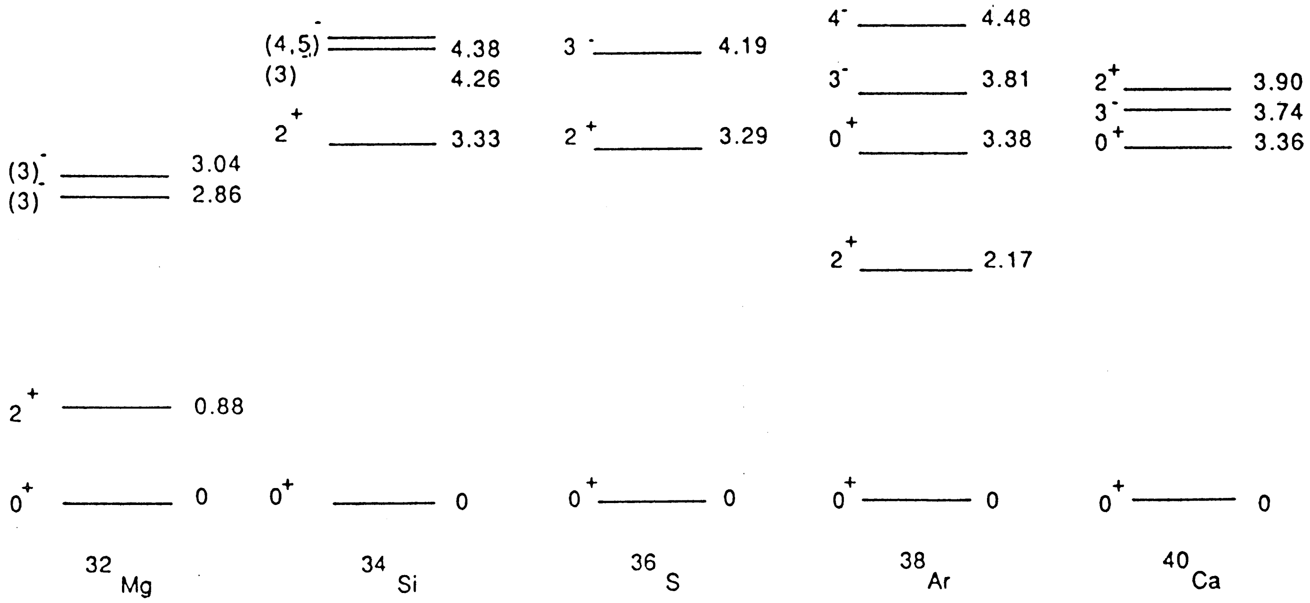

Fig.6b Low energy level structure of N=20 isotones from the litterature and this work (^{34}Si).

one cross-over (Fig.6a). The experimental β decay branches are in agreement with the predictions of E.K.Warburton and J.A.Becker[18]) who accounted for the decay of ($J^{\pi}=4^-$) ^{34}Al by two strong transitions (to the first 3^- and 4^- ^{34}Si states). Yet the γ cascade locates unambiguously the first 2^+ state of ^{34}Si at 3327.7(0.5) keV, lower than the predictions corresponding to the sd configurations whereas the 2p-2h configuration used in ref.19) gives a good agreement ($E_x(2^+)=3.78$ MeV).

It is now possible to follow up the low energy level structure of N=20 isotones (Fig.6b) between the very deformed ^{32}Mg and ^{40}Ca. This comparison illustrates the similarities between ^{40}Ca and ^{34}Si and the sharp discontinuity when Z changes from 12 to 14. From the body of information which now exists for nuclei around N=20 several observations can be made :

- The γ decay of the first 3^- state of the N=20 isotones reveals a systematic trend in the transition strength of E1 and E3 decays. For ^{34}Si, the lifetime of the 4248 keV, 3^- state is unknown, but the γ branching ratio [18 % for the E1 ($3^- \rightarrow 2^+$), 82% for the E3 ($3^- \rightarrow 0^+$)] shows a strong enhancement of the E3 and a retardation for the E1 transition with a ratio $\Gamma(E1)/(\Gamma(E3) \approx 1.2\ 10^{-5}$. For the corresponding 3^- states of ^{36}S (E_x=4192 keV) and ^{38}Ar (E_x=3810 keV), where the absolute values of the E1 and E3 transitions are known, we find for the same ratio $\Gamma(E1)/(E3) = 4\ 10^{-5}$ and $1.6\ 10^{-4}$ respectively. The lifetime of the 4248 keV ^{34}Si level may reveal a very strong reduced electric octupole transition probability.
- Experimental values of $E_x(3^-)$ states are ploted in Fig.7a versus A for the Mg, Si, S and Ar isotopes. For the sake of comparison, corresponding plots of $E_x(2^+)$ are shown in Fig 7b. Shell structure effects at N=20 for $E_x(2^+)$ are evident for Si and S, very weak for Ar and completely modified by the strong deformation for Mg. It is striking that the $E_x(3^-)$ data show no peaks at N=20. This observation, already made by R.H.Spear[20]), is now documented by the new results on Mg and Si isotopes.

We note also that the N=21 experimental beta decays, studied previously in ^{35}Si and ^{36}P by J.P.Dufour et al[15]) and here in ^{32}Na and ^{34}Al, present specific features related to the shell model configurations :

- allowed beta transitions to high excited negative parity levels, followed by γ cascades through positive parity states,
- weak first forbidden decay to the low energy positive parity states
- delayed neutron decay inhibited by a low barrier transmission probability.

For all these cases, the description of the level structure in the daughter nucleus is not yet complete and detailed γ–γ and γ–γ–n spectroscopy is still necessary to test the nuclear interaction in the two (sd and fp) major shells.

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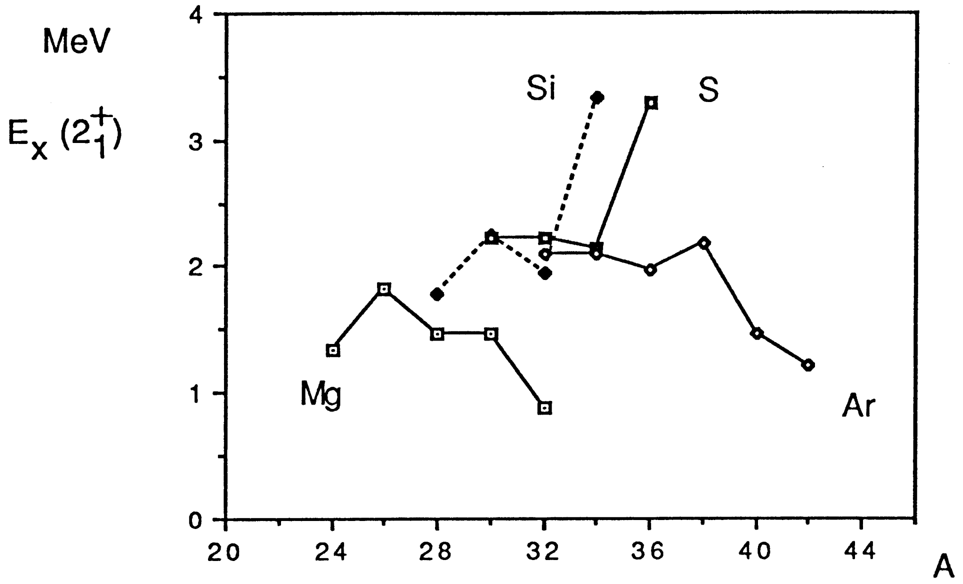

Fig.7a Experimental energy for the first 2^+ level, in even-even nuclides, as a function of the mass number A.

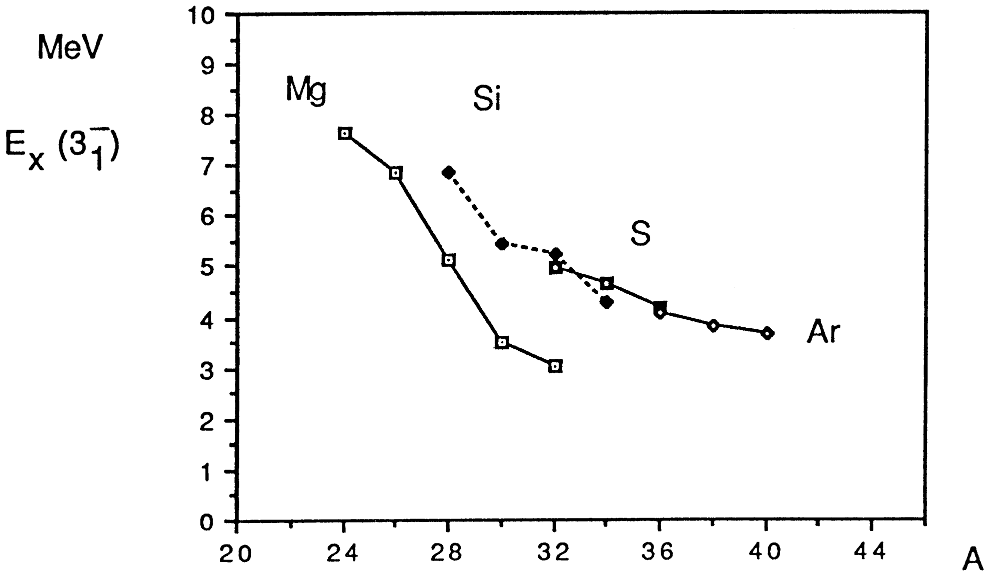

Fig 7b Experimental energy for the first 3^- level, in even-even nuclides, as a function of the mass number A.

References

1) A.Poves and J.Retamosa, Phys.Let.B 184 (1987) 311
and this workshop, contributions of B.A.Brown et al., K.Heyde, A.Poves and references therein.
2) C.Thibault et al. Phys.Rev. C12 (1975) 644
3) C.Detraz et al., Nucl.Phys. A394 (1983) 378
4) D.Guillemaud-Mueller et al., Nucl.Phys.A426 (1984) 37
5) P.Baumann et al., Phys.Rev.C39 (1989) 626
6) G.Klotz et al. (to be published)
7) B.H.Wildenthal et al., Phys.Rev.C28 (1983) 1343
B.H.Wildenthal, Prog.Part.Nucl.Phys. 11 (1984) 5
8) E.H.Auerbach and F.G.J.Perey, BNL 765 (1962) T-286
9) P.Baumann et al. Phys.Rev. C36 (1987) 765
10) Cl.Woods et al., Nucl.Phys. A476 (1988) 392
11) A.D.Panagiotou et al., Nucl.Phys. Phys.Lett. B103 (1981) 297
12) W.A.Mayer et al., Z.Phys.A319 (1984) 287
13) L.K.Fifield et al., Nucl.Phys.A440 (1985) 531
14) L.K.Fifield et al., Nucl.Phys.A453 (1986) 497
15) J.P.Dufour et al., Z.Phys. A324 (1986) 487
16) D.Jean, Thesis, Bordeaux (1986)
17) D.Bazin et al. AIP Conf.Proc. Vol.164, ed.I.Towner (AIP, New York, 1987) 722
18) E.K.Warburton and J.A.Becker, Phys.Rev.C37 (1988) 754
19) P.Baumann et al., Phys.Lett.B228 (1989) 458
20) R.H.Spear, Atomic Data and Nuclear Data Tables 42 (1989) 55