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^{34}Si : A New Doubly Magic Nucleus ?

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Abstract

The ^{34}Al β decay was studied at the CERN on-line mass separator ISOLDE. Gamma-ray singles, β–γ, and β–γ–γ coincidence measurements, were registered with two 80% Ge detectors. A ^{34}Al β-decay scheme to ^{34}Si bound states is established. The first level scheme in ^{34}Si includes three levels at 3327.7±0.5, 4257.3±0.4 and 4382.7±0.7 keV with respectively a J^{π} assignment of 2^+, 3^- and $(4,5)^-$. The ^{34}Si level scheme is consistent with the assignment of $J^{\pi}=4^-$ for the ^{34}Al ground state. The value of P_{1n}=0.27(5) has been deduced for the ß-delayed 1n emission of ^{34}Al. The ^{34}Si level scheme is found to agree with the present shell-model predictions. In the resulting picture, ^{34}Si appears to be a new doubly magic nucleus.

[+] and IN2P3

I. INTRODUCTION

Studies [1,2] of very neutron-rich light nuclei have revealed a region of strong deformation around N=20, Z=11, which includes ^{31}Na and ^{32}Mg. The knowledge of the N=20 nucleus ^{34}Si is crucial in delineating the frontiers of this region of deformation. Despite different previous attempts to establish the ^{34}Si level scheme, the experimental information remains very scarce. The ^{34}Al isotope was first observed in the fragmentation of a uranium target by a proton beam of 800 MeV at LAMPF [3]. Recently experimental results on the ^{34}Al decay were obtained at GANIL by fragmentation of a ^{40}Ar beam at 60 MeV/nucleon [4,5]. In this latter experiment, one ß-delayed γ ray of 123.8(4) keV with a half life of 0.050(25) s was assigned to the ^{34}Al beta decay. In addition, two gamma rays were reported at 801.7 and 929.1 keV but could also be attributed to the ^{36}Si β decay [5]. In a separate experiment at GANIL, P_n and $T_{1/2}$ values have been measured for ^{34}Al with a β-neutron coincidence technique, yielding respectively P_n= 0.54(12) and $T_{1/2} = 70\pm^{30}_{20}$ ms [6]. The mass excess of ^{34}Al was determined by Vieira et al. [7] to be -3.5(0.4) MeV. With regard to the ^{34}Si excited states, Mayer et al. [8] and Fifield et al. [9] used two-proton pickup reactions on ^{36}S to form ^{34}Si. Mayer et al. reported one excited state at 3590(25) keV, which Fiefield et al. did not observe. These authors report a state at 5330(50) keV which was associated with the 2_1^+ state predicted to lie at 4888 keV [10] in the sd model space. A shell-model description of the ^{34}Al β decay was given Warburton and Becker [11] in the (2s,1d,1f,2p) configuration.

We present results on the ^{34}Al ß decay to bound levels in ^{34}Si obtained at the ISOLDE on-line separator and the comparison with new shell-model calculations in the (sd,fp) space.

II. EXPERIMENTAL PROCEDURE.

The ^{34}Al nuclei were produced by bombarding a 58 g/cm^2 uranium carbide target with the 2.5 μA proton beam of the 600 MeV CERN synchrocyclotron and afterwards ionized in a tungsten surface-ionization source[12]. The yield achieved at the ISOLDE facility for ^{34}Al was in the order of 10 atoms/s . The experimental set up for observing the decay of this short-lived isotope was arranged around the collection point located on the mylar ribbon of a tape transport system. In this way, the descendant and contaminant activities were reduced by moving the tape periodically. The collection point was surrounded by a thin cylindrical NE-102 plastic scintillator which delivered the signal attesting a beta decay and used in coincidence with two large volume Ge counters*(relative efficiency : 80 %, FWHM = 2.4 keV at 1.33 MeV). Gamma-ray singles, ß-γ and ß-γ-γ coincidence measurements were performed.

III. EXPERIMENTAL RESULTS

Selected parts of the coincident β–γ spectrum observed in the A=34 decay are shown in fig.1. The identified peaks belong to the decay of the A=34 chain or to the decay of the contaminants (mainly ^{136}I and ^{68}Cu) also arriving at this mass position due to their multiple charge (4+ and 2+ respectively).

A number of γ lines, likely due to unknown nuclei in the A=136 chain, remain unassigned.

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* manufactured by Enertec-Intertechnique.

A level scheme is established on the basis of our β–γ–γ coincidence data (fig. 2) which includes 4 transitions listed in Table 1. One of these, 125.4±0.5 keV, is identified with the one reported previously [4,5] in the study of the ^{34}Al β decay by projectile fragmentation. The energy and intensity values for the transitions are reported in Table 1 along with the corresponding assignments in ^{34}Si. In Table 2 are listed gamma-ray branching ratios in ^{34}Si and tentative spin and parity assignments for the ^{34}Si excited states. In the ß-γ spectrum (fig. 1) we observe lines corresponding to the ^{33}Si ß decay and fed by the ß-delayed 1n emission of ^{34}Al. This allows us to determine a P_{1n} value of 0.27(5) for ^{34}Al, taking into account the ^{33}Si β-decay scheme [13]. We note a discrepancy between our value and the value (P_n=0.54±0.12) reported by Bazin et al. [6]. We do not expect a strong P_{2n} process as only two states in ^{32}Si (g.s.,0^+ and 1941 keV, 2^+) are available in the open energy window. Furthermore, in our experiment, the deexcitation of the 1941 keV level was not observed ($I_{1941}/I_{3327} < 1\%$). Excitation energies, β intensities and the corresponding logft values for bound levels in ^{34}Si populated in the decay of ^{34}Al are listed in Table 3. The intensities of the β branches are deduced from the imbalances of the gamma intensities connected with each level. Our P_{1n} determination and values of $T_{1/2}$ = 50(25) ms (ref. [4]) and $Q_ß$ = 16450(400) keV (ref. [7]) have been used for the beta transition rate determination.

The established ^{34}Al β-decay scheme to particle bound states in ^{34}Si is represented in fig.3. Two levels (4257.3 and 4282.7 keV) are related to ^{34}Al negative parity ground state by strong beta transitions and therefore a negative parity is inferred for these two levels. On the basis of the γ-ray branching ratio and the lifetime upper limit (τ < 300 ns) deduced from our β–γ timing measurement, a 3^- assignment is proposed for the 4257 keV level. Using the same arguments, the J^π value of the 4383 keV level is restricted to $J^\pi=(4,5)^-$. For the first excited state (E_X=3328 keV), the $J^\pi=2^+$ value is assigned, 0^+ and 3^- being excluded by the γ decay mode and the absence of β feeding respectively. Our interpretation of the 125 keV transition $((4^-,5^-)\rightarrow 3^-))$ agrees with the expectations given in ref. [11]. None of the excited states found in ^{34}Si can be related to the levels reported previously in transfer reaction studies [8,9].

IV. DISCUSSION

We describe ^{34}Al and ^{34}Si with the theoretical model of ref. [14]. The effects of the truncations of the shell-model space are approximately taken into account by means of a weak coupling evaluation [15]. The calculation shows how the $(sd)^{-2}(fp)^2$ intruder states, which in ^{32}Mg dominate the ground state due to their deformation energy, are pushed up in ^{34}Si, whose ground state is dominated by the normal (sd) configurations. The main reason of this sharp change of regime is the fact that the 2p-2h intruder states of ^{34}Si are not deformed [14].

The predicted level scheme of ^{34}Si is given in fig. 3. The excited states at 3.78 (2^+), 4.05 (0^+) and 4.40 MeV (4^+) are 2p-2h intruders. The first non-intruder excited state will appear at ~ 5.5 MeV excitation energy and will be dominated by the sd 2^+ excited state predicted by the sd calculation [10] at 4.9 MeV. The ^{34}Al ground state is predicted to have $J^\pi = 4^-$. The β decay will proceed through the 3^-,4^- and 5^- excited states of ^{34}Si. The calculation predicts a 70 % beta intensity to the first 3^- and 25 % beta intensity to the first 4^- excited states in excellent agreement with the experimental results. The calculation of ref. [11] gives a good description of the negative parity states of ^{34}Si; on the contrary the 2^+ excited state is not reproduced because the 2p-2h configurations are absent from the calculation.

The main features of the γ decays can also be qualitatively understood in our model. On the basis of the calculation, one expects an M1 transition $4^- \rightarrow 3^-$ with a 100% branching ratio, both a retarded E1, $3^- \rightarrow 2^+$, and an enhanced E3, $3^- \rightarrow 0^+$ and finally a retarded E2, $2^+ \rightarrow 0^+$ transition.

The very good agreement between theory and experiment supports our interpretation of the nature of the ^{34}Si levels. The non observation in this experiment of the 0^+ state predicted at 4.05 MeV is well understood in terms of relative transition probabilities to this state compared to transition probabilities to the 2^+ excited state.

The resulting ^{34}Si spectrum is then strikingly similar to that of the doubly magic nucleus ^{40}Ca. The excitation energies of the lowest excited states are in both cases $\sim$ 3.5 MeV and in the two nuclei we found almost degenerated 0^+,2^+ and 3^- excited states. Furthermore both in ^{40}Ca and in ^{34}Si these states are intruders. The mass formula based on α lines [16] predicts a shell closure for Z=14, N=20 even stronger than for Z=20, N=20. One is tempted to conclude that ^{34}Si is doubly magic, in the same sense as ^{40}Ca. We have reported in fig. 4 the systematics of the first excited states for N=20, $T_z \geq 0$ nuclei which display the ^{34}Si, ^{36}S and ^{40}Ca similarities. One should note, however, that the ^{36}S 2^+ state is well reproduced in the sd model space whereas this not the case for ^{34}Si [11].

The N=20 isotones have again given an example of rich structure. Starting with ^{40}Ca , one of the paradigms of magic nuclei, we have then the very deformed ^{32}Mg and now the evidences pointing to new magic numbers far from stability with the new doubly magic nucleus ^{34}Si and perhaps ^{36}S.

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TABLE CAPTIONS

Table 1 : Energy, intensity and assignment of gamma transitions in the ^{34}Al beta decay.

Table 2 : Gamma-ray branching ratios in ^{34}Si and proposed J^{π} values for the ^{34}Si excited states.

Table 3 : Beta intensities and log ft values in the ^{34}Al beta decay to ^{34}Si excited states.

FIGURE CAPTIONS

Figure 1: Portions of the Ge spectrum taken in coincidence with the beta counter and showing the lines attributed to the ^{34}Al decay.

Figure 2 : Beta-γ–γ coincidence spectrum gated by the 3328(a) and 929 keV (b) ^{34}Si transitions (background subtracted).

Figure 3 : Experimental ^{34}Al beta-decay scheme and comparison with theoretical predictions in the (sd,fp) model space.

Figure 4 : Low energy level structure of the N=20 ($T_z \geq 0$) isotones. Results for ^{32}Mg are from ref. [2], for ^{36}S from ref. [5], and for ^{34}Si from this work.

TABLE 1

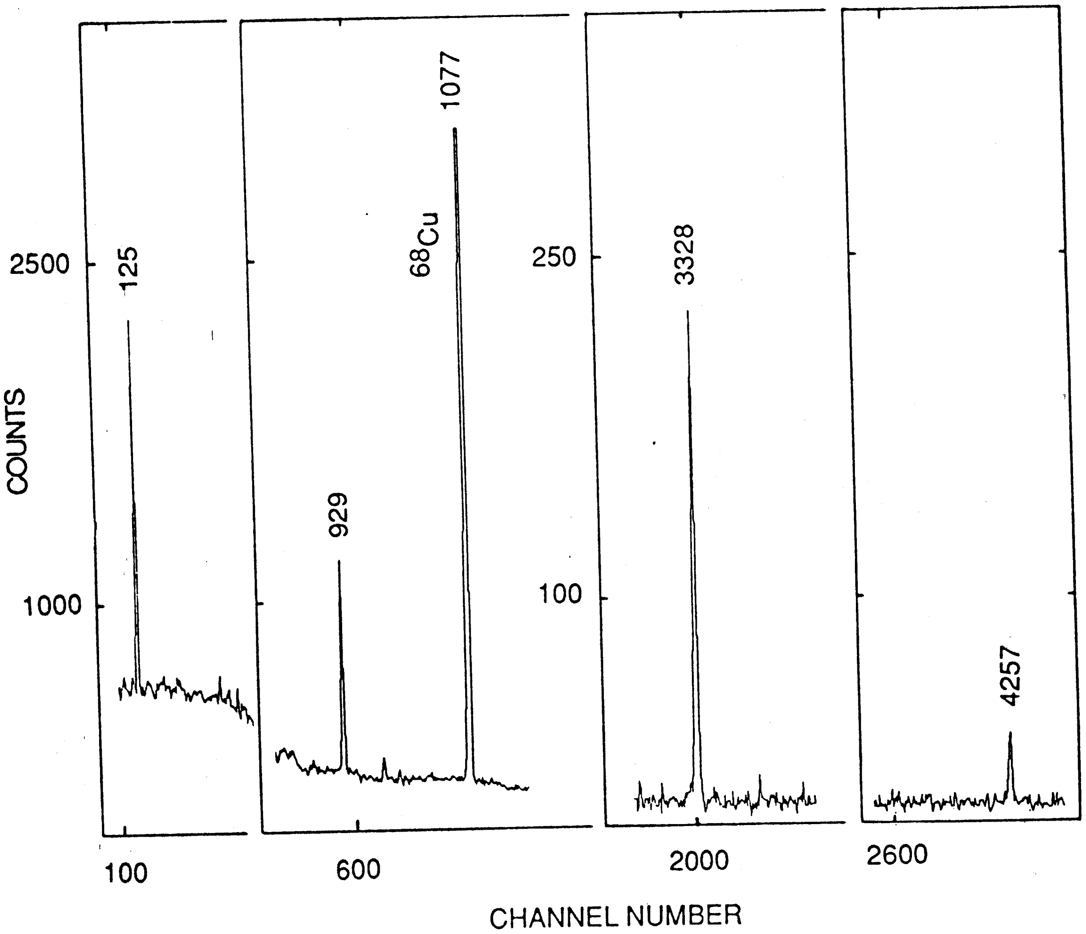
E_γ (keV)	I_γ (relative)	I_γ (per 100 β decays)	$E_i \to E_f$ (keV)
125.4±0.5	42.7±39	25.6±4.1	4382.7±0.7→4257.3±0.4
929.5±0.3	93.5±8.2	56.1±8.7	4257.3±0.4→3327.7±0.5
3327.5±0.5	100	60±9	3327.7±0.5→0
4257.1±0.5	20.5±3.5	12.3±3.0	4257.3±0.4→0

TABLE 2

E_i (keV)	E_f (keV)	Gamma branching ratios (%)	$J_i^\pi \to J_f^\pi$
4383	4257	100	$(5,4)^- \to 3^-$
4257	3328	82 ± 3	$3^- \to 2^+$
4257	0	18 ± 3	$3^- \to 0^+$
3328	0	100	$2^+ \to 0^+$

TABLE 3

E_x (keV)	I_β (per 100 decays)	log ft
3328	< 11.7	> 5.2
4257	45.6	4.6
4383	27.4	4.7



COUNTS
2500
1000
125
929
68Cu
1077
250
100
3328
4257
100
600
2000
2600
CHANNEL NUMBER

Fig. 1

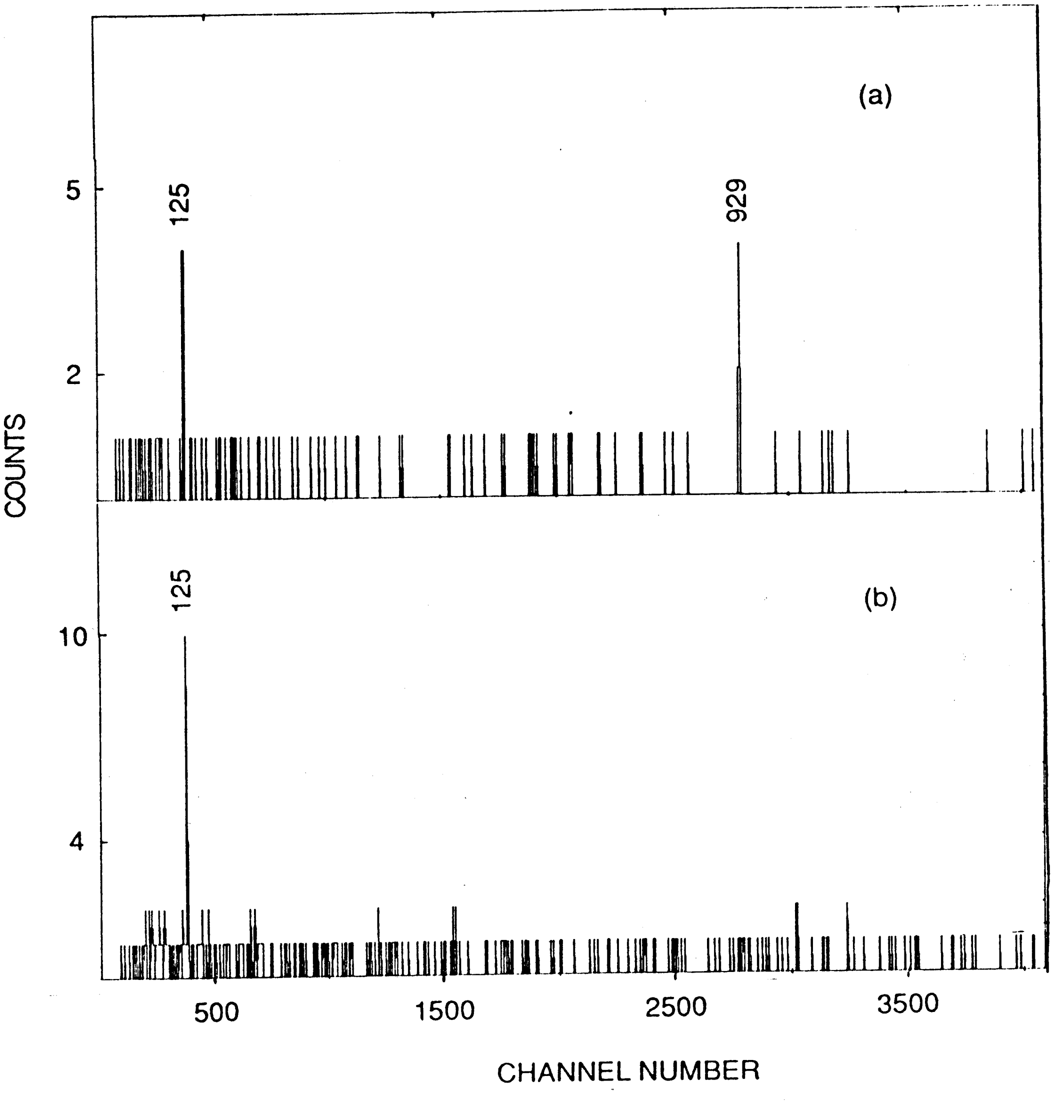

(a)
125
929
5
2
COUNTS
(b)
125
10
4
500
1500
2500
3500
CHANNEL NUMBER

Fig. 2

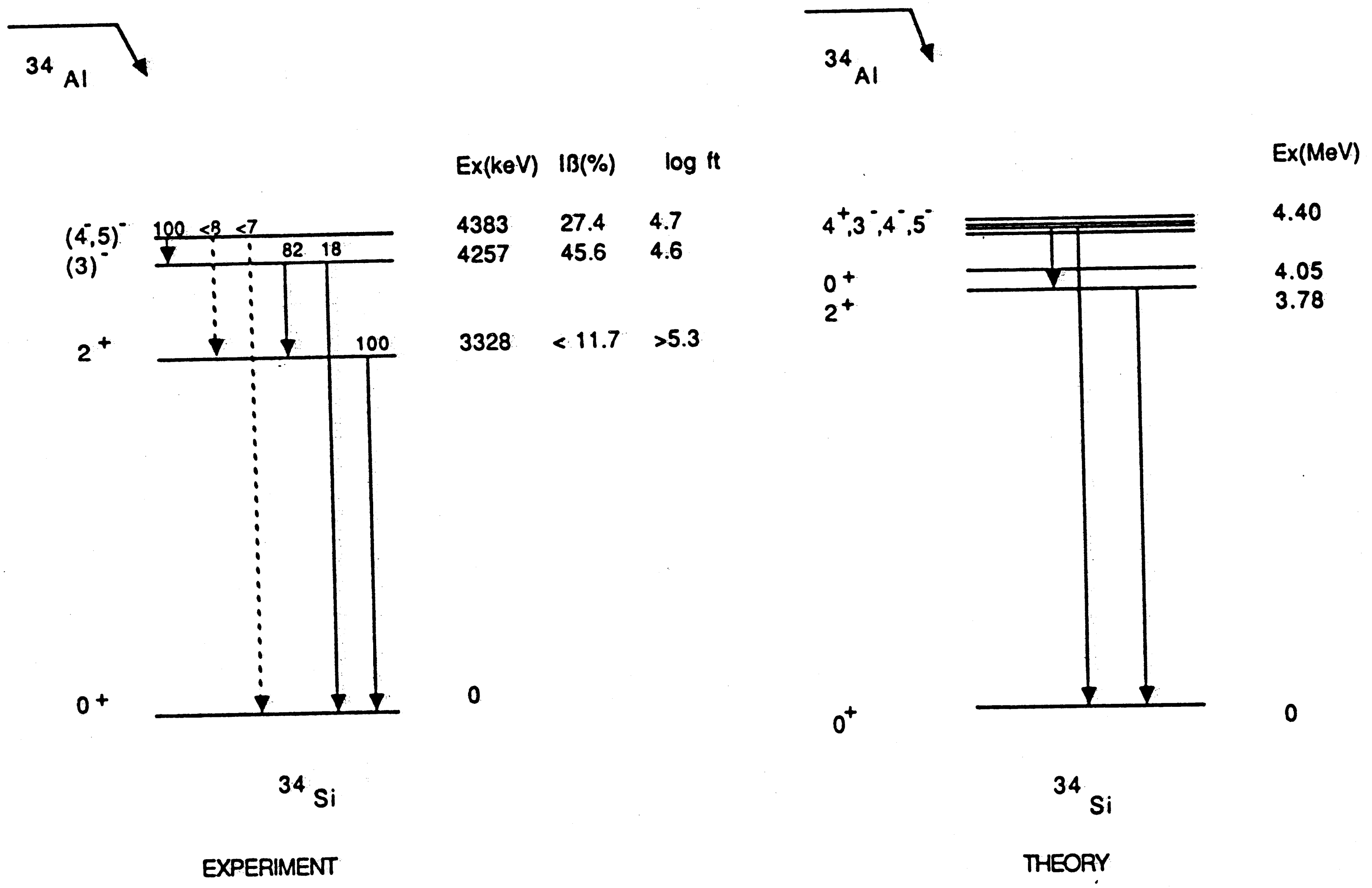

34 Al
(4⁻,5)⁻
(3)⁻
2 +
0 +
100 <8 <7
82 18
100
Ex(keV) Iß(%) log ft
4383 27.4 4.7
4257 45.6 4.6
3328 < 11.7 >5.3
0
34 Si
EXPERIMENT
34 Al
4⁺,3⁻,4⁻,5⁻
0 +
2 +
0+
Ex(MeV)
4.40
4.05
3.78
0
34 Si
THEORY

Fig. 3

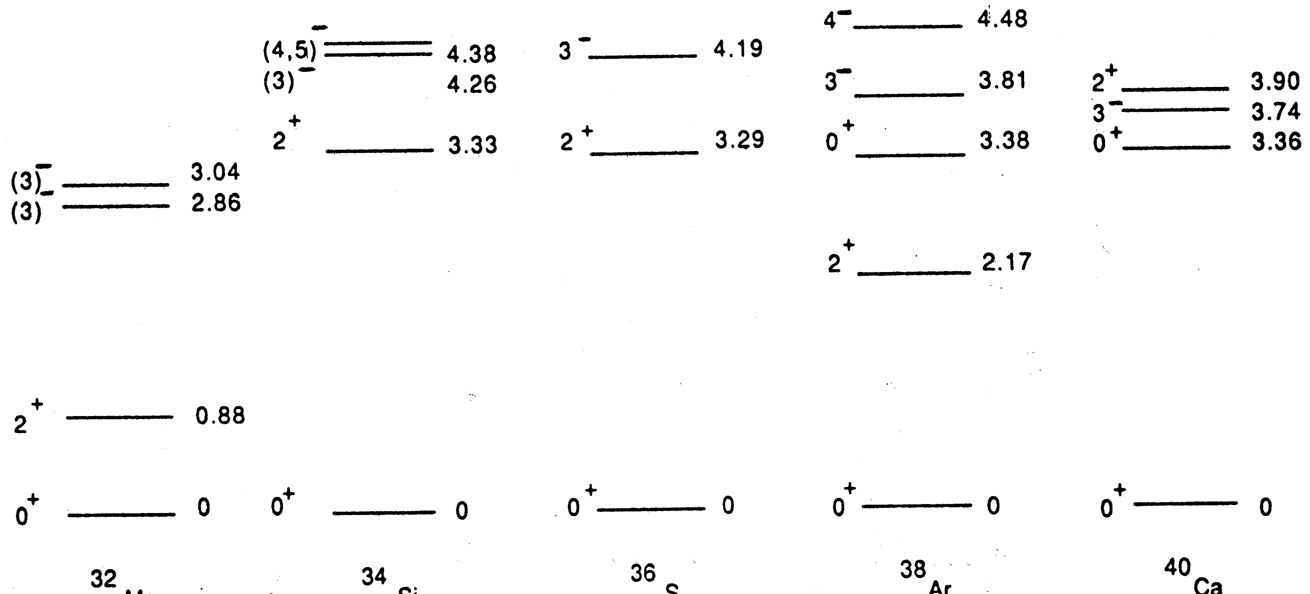

(3)$^-$ 3.04
(3)$^-$ 2.86
2^+ 0.88
0^+ 0
^{32}Mg
(4,5)$^-$ 4.38
(3)$^-$ 4.26
2^+ 3.33
0^+ 0
^{34}Si
3^- 4.19
2^+ 3.29
0^+ 0
^{36}S
4^- 4.48
3^- 3.81
0^+ 3.38
2^+ 2.17
0^+ 0
^{38}Ar
2^+ 3.90
3^- 3.74
0^+ 3.36
0^+ 0
^{40}Ca

Fig. 4