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REPORT

TRANSITION PROBABILITIES AND ENERGY LEVELS IN HEAVY ODD-MASS ISOTOPES OF Sn (A = 119-125)

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TRANSITION PROBABILITIES AND ENERGY LEVELS IN HEAVY ODD-MASS ISOTOPES OF Sn (A = 119-125)

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Abstract. The de-excitation of levels in $^{119-125}$Sn populated in the decay of In isotopes has been studied using on-line isotope separators. Level half-lives have been measured in $^{119-123}$Sn. A near cancellation of the matrix element for $B(E2;\ g_{7/2} \to d_{3/2})$ is observed to occur in ^{121}Sn and is probably due to pairing effects. Very low lying $9/2^-$ levels have been observed in $^{121-125}$Sn and are suggested in ^{127,129}Sn. These levels have been interpreted as three quasi-particle states based on the unique parity $h_{11/2}$ level. A possible mixing of the $g_{7/2}$ level with a close lying $7/2^+$ three quasi-particle state in ^{123}Sn is discussed.

Radioactivity. $^{119-125}$In from ^{235}U(n,f) and ^{238}U(α,f), isotope separated sources; measured E_γ, I_γ, E_{ce}, I_{ce}, γγ-coin, βγ delay deduced multipolarities. $^{119-121}$Sn deduced levels, I,π, B(λ). Ge(Li), Si(Li), NaI(Tl) and plastic detectors, Ge(Li) - Ge(Li) coin, plastic detector - NaI(Tl) delay.

1. INTRODUCTION

The high stability of the tin isotopes offers the possibility to gather information on the properties of neutron energy levels in these isotopes over a wide range of mass numbers. The experimental situation is favourable, since the identification and detection of particular energy levels is naturally facilitated by the low level density due to the closed proton shell. The properties of the low lying energy levels in several of the medium mass isotopes of Sn have thus been studied thoroughly. In addition to the single quasi particle states, the level structure at low excitation energies also contain more complex levels, of three quasi particle nature. It is generally difficult to determine the composition of these states. The configurations based on the $h_{11/2}$ level are, however, easy to identify due to their negative parity. During recent years such states, based on a unique parity level, has been the subject of several studies. It is well known from shell model calculations that the (j - 1) and (j - 2) levels of $(j)^3$ configurations can be expected at fairly low energies. The amplitude of $(j)^3$ in a given low lying I = (j - 1) level is expected to be small in this case, since the corresponding amplitude of $(j)^2$ in the collective 2^+ level of the even core is small. Other descriptions of these states may therefore be more appropriate, such as particle-core coupling as discussed in sec. 3. of the text. One of the aims of the present work has been to search for the $9/2^-$, I = (j - 1) levels in the heavier tin isotopes since the presumed $7/2^-$, I = (j - 2) levels already have been suggested in a number of these isotopes. Another, closely related, aim has been the establishment of level schemes for the odd mass isotopes of Sn with mass 121 - 125. We have also put a special emphasis on a study of transition probabilities from the $g_{7/2}$ levels in $^{119-125}$Sn.

The decays of the In isotopes provide valuable means for the investigation of levels in the heavy Sn nuclei, since complex nuclear levels are very difficult to populate in stripping and pick-up reactions. The pattern of the decays of the In nuclei is similar for all the heavy isotopes. The majority of the decays of the $p_{1/2}$ isomers of In lead to the very low lying $s_{1/2}$ and $d_{3/2}$ levels in the Sn nuclei. Only a small fraction of the decays are populating higher lying, low spin states. We have put the main effort of this investigation into a study of the decays of the $g_{9/2}$ isomers of In, since these spin-flip decays very strongly populate the $g_{7/2}$ levels in the heavy odd-mass isotopes of Sn. The de-excitation properties of the $g_{7/2}$ levels, such as γ-ray multipolarities and branching and the level half-lives can thus easily be studied. Furthermore, as the presumed $7/2^-$ member of the multiplet of negative parity three quasi particle levels show up below the $g_{7/2}$ state in ^{123}Sn and ^{125}Sn, the expected still lower lying $9/2^-$ member can be populated in the γ-decay of the $g_{7/2}$ state. Similar levels are known in the Cd, Te and Xe nuclei and are in several cases populated by γ-rays from higher lying $7/2^+$ states.

The decays of In isotopes to the heavy odd-mass isotopes of Sn have so far been little studied, except for ^{117}In [ref 1] and ^{119}In [refs 2,3]. The reported investigations on the decays of ^{121}In [refs 4,5] and ^{123}In [ref 6] have suffered from weak sources and moderate resolution of the γ-ray detectors employed. No previous study of the decay of ^{125}In have been reported. As even Sn isotopes are stable up to A = 124, the odd Sn isotopes up to A = 125 have been studied in stripping and pick-up reactions. A large number of levels have been observed. This information will of course facilitate the construction of decay schemes. References to the relevant works are given in section 3 of the text.

The In activities were obtained as isotope separated fission-products from the OSIRIS and PINGIS facilities [7,8]. Source strengths in excess of 10 μC were readily obtained for all neutron rich isotopes of In up to mass number 129. The yield of In is then decreasing for still heavier isotopes, but measurable In activity persists up to mass 132. A preliminary account of the main results regarding the studies of ^{127,129,131}Sn has been given elsewhere [9]. Detailed level schemes for these isotopes are consequently not shown in the present paper.

2. EXPERIMENTAL

Measurements of γ-rays and γγ-coincidences

The activities of $^{119-125}$In were collected from the isotope separator beams onto a tape of Al with mylar backing which was used for transportation of the sources. The tape transport systems of the OSIRIS and PINGIS facilities were not identical, which made it practical to perform the γ-ray singles measurements in different ways at the two mass separators. At OSIRIS, the main measurements were made with a Ge(Li) detector viewing the tape at 110 mm away from the beam. A collected source could be rapidly transported to this position for counting while the collection of a new source was started at the beam position. By using different time intervals between the tape movements, activities with different half lives were enhanced in the spectra. At PINGIS, the detector was viewing the tape at the collection position and the different activities were enhanced by using the tape to carry away "old" activities with different time intervals. Both methods made it easy to distinguish the In γ-rays from the γ-rays due to the decay of isotopes of Ag and Cd which were also present in the sources. Weak contaminations from adjacent mass numbers were identified through parallel measurements of these spectra. A number of multi spectrum scaling experiments as well as multiscaling experiments of individual photo peaks were made to determine the half lives of the strongest γ-rays. The half lives of the In isotopes were found to agree well with the published [10] values.

The γγ-coincidence measurements were made using two Ge(Li) detectors viewing the collection position. The transport tape was used to slowly carry away old activities. In this way coincidence spectra were simultaneously recorded for more than one activity in each isobaric decay chain. The results were stored on magnetic tape by a PDP 9 computer, using a modified address-storing system permitting selection of a maximum of 12 double gates (peak and background) in the spectrum. The detectors employed were coaxial of about 30-40 cm^3 volume and were also used in the measurements of γ-ray singles spectra. Special recordings of γ-ray spectra were also made using a high resolution planar Ge(Li) detector, in order to search for low energy γ-rays.

The results of the measurements of γ-rays and γγ-coincidences are collected in tables 1-3. Relevant parts of the spectra are shown in figs 1-4.

A γ-ray spectrum of ^{119}In was obtained in conjunction with the conversion coefficient determinations. The results as regards energies and intensities were in good agreement with the work of Raman et al. [3]. We prefer, in the following to employ the values given by ref [3] since their γ-ray spectrum is of higher quality than ours, in not containing γ-rays from ^{119}Ag and ^{119}Cd. No tabulation is therefore given of the present results as regards γ-rays from the decay of ^{119}In. An example of a γ-ray spectrum of the A=119 isobars recorded at OSIRIS can be found in fig. 1 of ref [11].

Internal conversion electron measurements

The electron spectra from the decays of ^{119,121,123,125}In were recorded at the OSIRIS facility using a 2 mm thick cooled Si(Li) detector placed at a distance of 10-15 mm from the collection tape, in a position requiring a tape movement of about 110 mm after each collection. A Ge(Li) placed on the opposite side of the tape could view the same source as the electron detector, through a lead collimator. Values of conversion coefficients can thus be deduced from the electron and γ-ray spectra recorded with this two detector set-up after a suitable calibration has been performed. Sources of ^{85m}Kr and ^{135m}Xe, collected on-line at OSIRIS, were used for calibration of the present measurements.

The high continuous background due to β-particle events in the Si(Li) detector spectra, made necessary a special method of analysis for the determination of the intensities of weak conversion electron lines. The positions of expected lines were calculated using the transition energies obtained in the γ-ray measurements. The background, which was even and continuous, was then smoothed around the expected line positions, using some 10^2 channels for the smoothing. Care was taken in this process to avoid other possible conversion lines and Compton edges. The statistical uncertainty in the background at the expected line positions could be ignored after the smoothing. The conversion electron intensities were then obtained by summing the contents of the channels within about one line half-width on each side around the calculated line position and subtracting the corresponding smoothed background. Lines, which were barely visible in the spectrum, e.g. 1130.5 K and 1335.05 K shown in fig. 5, showed up very clearly in this analysis. The intensities of even weaker lines could also be determined with statistical significance. The method showed to give expected reproduceability in tests with spectra recorded for time intervals of different lengths. We therefore find it probable that the "true" intensities of weak conversion electron lines will fall within the limits of error given in table 4. A recent investigation [12] of conversion electrons and γ-rays following the (d,p) or (α,n) reactions leading to odd-mass isotopes of Sn gives values of α_K which are in agreement with those in table 4, in the cases where the same transitions have been observed. The author of ref [12] also report a value of α_K compatible with E2 or M1 multipolarity for the 618.8 keV transition in ^{123}Sn which was too weak to be observed in our conversion electron spectrum.

The isomeric transition in ^{121}In

The half-life of the isomeric level in ^{121}In is relatively long, 3.9 m [ref 10], which makes it possible to obtain a pure source of ^{121m}In after a decay period of a few minutes. The Si(Li) detector spectrum recorded with such a source showed prominent peaks due to the 313.6 keV isomeric transition and the 60.34 keV transition in ^{121}Sn.

The K-shell conversion coefficient of the isomeric transition was found to be 1.0±0.2 which is in agreement with the theoretical value for a M4 transition. The total L-shell conversion coefficient of the 60.34 keV transition in ^{121}Sn was determined to be 0.20±0.05 (The K-shell line was obscured by the X-rays). The theoretical values are 0.28 and 3.6 for M1 and E2 multipolarities, respectively, suggesting M1 character for this transition. By comparing the areas of the conversion lines with the total number of β-particles in the spectrum, and by using theoretical values of conversion coefficients, we deduce the branching via the isomeric transition to be (1.2±0.2) % and the β-decay feeding of the 60.34 keV level in ^{121}Sn to be (70±15) % . No isomeric transitions were observed in the heavier isotopes of In.

Delayed coincidence measurements of level half-lives

The detector system used for the delayed coincidence measurements consisted of a Naton 136 scintillator for detection of β-particles and a NaI(Tl) detector for γ-rays. Both detectors were 25 mm in diameter and 25 mm high, and both were mounted on XP 1020 photomultipliers. The stability of the system was good resulting in only small shifts of the pulse amplitudes for strong variations of the counting rate.

In the measurements, the β-particle events in coincidence with a selected photo peak were recorded at first. A narrow band around the maximum of this distribution was then selected to gate the time to pulse height converter, in coincidence with the photo peak events. All measurements were repeated two or three times and prompt spectra for comparison, were recorded, with a ^{60}Co source, after each individual measurement. It was evident from the γ-ray measurements, that no significant contributions from other transitions would be present in the energy gates used in the half life measurements. In the analysis we therefore could fit only a simple exponential decay curve to each time spectrum, after subtraction of the prompt contribution. Some of the delayed coincidence time spectra are shown in fig 6. The hindrance factors deduced from the averages of the different measurements are given in table 5.

3. DISCUSSION

Spin and parity assignments

Only a small number of levels in ^{121,123,125}Sn are populated with appreceable intensity in the β-decays of the $g_{9/2}$ isomers of the In isotopes, since most of the β-strength is exhausted by the very strong $g_{9/2} \rightarrow g_{7/2}$ β-transitions. The majority of the levels in the level schemes (figs 7, 8) constructed from the data obtained in this work, have been observed also in the extensive stripping and pick-up reaction studies, refs [12-21], of the heavy odd-mass isotopes of Sn. Assignments of the low-lying $s_{1/2}$, $d_{3/2}$ and $h_{11/2}$ states in ^{121,123,125}Sn can be regarded as well established from the work of refs [13,17,18]. The present work has merely provided more accurate values for the excitation energies of these levels. It should be remarked that we have not observed the M4 transition between the $d_{3/2}$ and $h_{11/2}$ levels. This energy difference has been deduced from the energies of feeding γ-rays from higher lying levels.

A level at about 0.6 MeV excitation energy has previously been observed [20] in ^{123}Sn. We confirm these findings and have also seen similar levels in ^{121}Sn and ^{125}Sn which are fed by γ-rays from higher lying $7/2^+$ states and decay with M1 or E2 transitions to the low lying $h_{11/2}$ states. These facts suggest $I^\pi = 7/2^-$ or $9/2^-$ for the levels considered, which is also supported by the conversion coefficient for the 618.8 keV transition in ^{123}Sn reported by Madueme et al. [12].

Levels at about 870 keV in ^{121,123,125}Sn are populated by γ-rays from higher lying $7/2^+$ levels. The M1 multipolarity of the feeding transition in ^{121}Sn and the decay to the $s_{1/2}$ and $d_{3/2}$ levels permits an unique $5/2^+$ assignment here, while $3/2^+$ cannot be ruled out for the levels in ^{123}Sn and ^{125}Sn.

The levels at about 930 keV in ^{123,125}Sn can most probably be identified as the $7/2^-$ states observed by De Barros et al. [15]

Regarding the higher lying levels, in $^{121-125}$Sn , which receive substantial feeding by β-transitions, we propose $I^\pi = 7/2^+$ in all cases where the logft values are smaller than 6.5, (first forbidden β-transitions with such small logft values are very rare) and the subsequent γ-decay of the level proceeds to the $d_{3/2}$ level. This proposition is supported by the ℓ-values for particle transfer to the 925 keV level in ^{121}Sn [refs 13, 21], the 1155 keV level in ^{123}Sn [refs 16,20] and the 1362 keV level in ^{125}Sn [refs 14,19].

The levels at about 2 MeV in ^{123}Sn and ^{125}Sn are also strongly populated by β-branches with logft values below 6. There are no γ-transitions from these levels to the $d_{3/2}$ levels which makes $7/2^+$ assignments less likely. A transition to the 870.1 keV level in ^{123}Sn excludes the $11/2^+$ alternative for the 2 MeV state in this nucleus. We therefore propose the assignments shown in fig. 8.

The $7/2^+$ levels

Regarding the transition probabilities from the $g_{7/2}$ levels, one find the hindrance factors of the $g_{7/2} \rightarrow h_{11/2}$ M2 transitions in ^{119,121}Sn (shown in table 5) to be very similar to the values of 4.5 and 3.9 found in ^{115}Sn and ^{117}Sn respectively [1,22]. Also the hindrance factor for the E1 transition to the $9/2^-$ state in ^{121}Sn is close to the value of $1.2 \cdot 10^5$ found for the corresponding transitions in both ^{117}Cd and ^{119}Cd [refs 23,24].

The E2 transition to the $d_{3/2}$ level in ^{121}Sn is found to be very slow, which is rare in odd-mass spherical nuclei. An explanation may be offered by the pairing theory in which the transition probabilities are given as proportional to the pairing factor, $(U_{I_i} \cdot U_{I_f} - V_{I_i} \cdot V_{I_f})^2$, which is close to zero when the fermi-level is midway between the initial and final states. The E2 transition probabilities in odd-mass nuclei have been calculated within the pairing plus quadrupole model by Reehal and Sorensen [25], who find a minimum in the $g_{7/2} \rightarrow d_{3/2}$ transition probability for ^{117}Sn. These authors point out that the exact isotope for which the minimum occurs is sensitively dependent on the choice of single particle energies. A minimum for ^{121}Sn does not therefore contradict the model. The purity of the $g_{7/2}$ and $d_{3/2}$ states is high according to the calculations of Reehal and Sorensen, i.e. the collective contributions to the transition rates are almost negligible and there is a fair proportionality between B(E2) and the pairing factor, except for very small transition rates. It may therefore be appropriate to compare the experimentally determined transition probabilities in odd-mass isotopes of Sn with values of the pairing factor, as shown in table 6. The B(E2) values for the corresponding transitions in ^{115}Sn and ^{117}Sn, deduced from the half-lives given in refs [1,22], have been included in table 6 for the sake of completeness. The half-lives of the $7/2^+$ levels in isotopes of Sn heavier than A = 121 are not known. (The present investigation did only give hardly significant upper limits of the half-lives in ^{123}Sn). It is, however, possible to estimate the half-lives of the $7/2^+$ levels in ^{123}Sn and ^{125}Sn by assuming that the M2 and E1 transition probabilities to the $11/2^-$ and $9/2^-$ states are the same as in the lighter isotopes of Sn. This assumption may, for the M2 transitions, be justified by the constant values of $F_w(M2)$ in $^{115,117,119,121}Sn$. The E1 transition probability is known only for ^{121}Sn. The corresponding transition rate is constant [23,24] in ^{117}Cd and ^{119}Cd which helps to justify the assumption from the systematics point of view. Another indication of constant transition rates of the M2 and E1 transitions is given by the ratios of B(M2) to B(E1) for transitions from the 1155.2 keV level in ^{123}Sn and the 1362.51 keV level in ^{125}Sn. These numbers agree within a factor of four with the ratio found for the transition rates in ^{121}Sn, where the half life of the $7/2^+$ level is known. It is therefore probable that the estimated values of B(E2) shown in table 6, are fairly close to the true numbers. Table 6 also contains values of the pairing factor deduced from experimental occupation numbers [13]. These values reproduce the general increase with increasing mass number which is predicted theoretically, but do not show the minimum at ^{121}Sn which is expected from the small B(E2) value at this point. This may be due to the relatively large uncertainties in the experimental occupation numbers reported by Schneid et al. [13].

The purity of the $g_{7/2}$ level in ^{123}Sn may, however, be questioned since there is another close-lying strongly populated $7/2^+$ level in this nucleus. (The decay properties of both these levels are included in tables 5 and 6). In this connection, it is interesting to note that the $7/2^+$ level, expected from a coupling of the $d_{3/2}$ quasiparticle to a 2^+ phonon of the core, has not previously been identified in any isotope of Sn although carefully searched for, in particular in ^{121}Sn, ref [21]. From the point of view of the core-excitation model, such a state would be expected to mix strongly with the $g_{7/2}$ level in case the two levels are fairly close lying. One consequence of the mixing is a division of the collective B(E2) strength between the levels. It is tempting to ascribe the presence of two strongly populated $7/2^+$ states in ^{123}Sn to such a mixing of the $g_{7/2}$ level and a core-particle state. The estimated (see table 6) B(E2) strength of the two levels should then be compared to the B(E2↓) of about $4\ e^2 \cdot 10^{-50}\ cm^4$ found [26] for the $2^+ \rightarrow 0^+$ transitions in the even isotopes of Sn. The estimated values of B(E2) in ^{123}Sn are high enough to lend support to this interpretation, and furthermore suggest that the lower lying of the two states is the more collective one.

Further information on the structure of the $7/2^+$ states in ^{123}Sn is given by the log*ft* values of the feeding β-transitions. In the other heavy isotopes, ^{119,121,125}Sn, where the $g_{7/2}$ state seem to be relatively pure, a log*ft* of about 4.4 is observed for the spin flip β-transition from the $g_{9/2}$ state in the In isotopes. We find that the *sum* of the β-strengths to the two $7/2^+$ levels in ^{123}Sn agrees well with this value of log*ft*, which is an indication that the single particle character is divided between the states. The higher level, which has the smaller value of log*ft*, should then carry the greater part of the $g_{7/2}$ single particle amplitude. This is in good agreement with the implications of the estimated B(E2) values which show that the higher lying $7/2^+$ state is the less collective of the two levels.

In the present work we observe an additonal $7/2^+$ state at 1059 keV in ^{125}Sn too. Similar levels have been found [9] at 1053 and 1054 keV in ^{127}Sn and ^{129}Sn,respectively. The β-transitions feeding these levels are about an order of magnitude weaker than the transitions feeding the $g_{7/2}$ levels. It is likely that also these levels can be interpreted as members of the multiplet formed by a coupling of the $d_{3/2}$ quasi-particle to a phonon of the core.

The negative parity levels

Low-lying negative parity three quasi-particle states are expected in the odd-mass heavy isotopes of Sn due to a coupling of the $h_{11/2}$ quasi-particle to a phonon of the even core, see e.g. refs [15,27] The $7/2^-$ state of the one-phonon multiplet has been observed [14,15] in several odd Sn isotopes through charged particle reactions. The conversion coefficients and γγ-coincidences measured in the present work, show that negative parity states also exist at about 0.6 MeV in ^{121}Sn and ^{125}Sn. The modes of feeding and decay indicate $I^\pi = 7/2^-$ or $9/2^-$ of which the latter alternative is strongly supported by level systematics in close-lying isotopes of Cd ref. [23] and Te ref. [28] and also by the theoretical calculations of ref. [27]. The conversion coefficient reported by ref [12] for the 619 keV transition in ^{123}Sn show that the parity of the 619 keV level in this nucleus also is negative. A $9/2^-$ assignment is very plausible also here. As in the Cd and Te nuclei one finds that the $7/2^-$ and $9/2^-$ levels are mainly populated through γ-ray cascades from higher lying $7/2^+$ states. An attempt to identify the $7/2^-$ and $9/2^-$ states also in ^{127}Sn and ^{129}Sn, where no conversion electron data are at hand [9] can thus be made, using the known modes of population and γ-decay as criteria. Obvious candidates [9] for a $9/2^-$ assignment are found at 646 and 764 keV and for $7/2^-$ at 963 and 1044 keV in ^{127}Sn and ^{129}Sn, respectively. These candidates do also fit nicely into the energy level systematics, which is shown in fig. 9.

It has been shown by Soares [28], that the properties as regards transition probabilities and magnetic moments of the $9/2^-$ levels in ^{125}Te and ^{127}Te are in good agreement with the predictions of Kuriyama _et_ _al_.[27]. These properties are difficult to study in the Sn isotopes due to the weak feeding and expected short half-lives of the $9/2^-$ states. One may, however, remark that the excitation energies of the $9/2^-$ levels are only about half as high as the predicted energies. This indicates that the magnitude of the quadrupole force strength has been underestimated in the calculations reported in ref [27].

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TABLE 1

Properties of γ-rays following the decay of the 23.1 s isomer of ^{121}In

Energy (keV)		γ-intensity[a)] (percent per decay)		Coincidence relations
56.35	± 0.02	0.19	± 0.02	
60.34	0.02	b)		
261.96	0.03	7.9	0.5	657
657.32	0.07	7.1	0.5	262
808.7	0.2	0.22	0.04	
869.31	0.10	1.1	0.1	
919.28	0.07	4.2	0.3	
925.57	0.07	87.	6.	
1092.8	0.4	0.34	0.03	

a) The intensities have been normalized by assuming that the β-particle feeding of the 925.57 keV level is ~ 100 %.

b) The greater part of the intensity of this γ-ray follows the decay of the 3.9 min isomer [10] of ^{121}In

TABLE 2

Properties of γ-rays following the decay of the 5.98 s isomer of ^{123}In

Energy (keV)		γ-intensity a) (percent per decay)		Coincidence relations
125.76	± 0.04	b)		
174.18	0.06	0.19	± 0.03	
175.01	0.08	0.13	0.03	
223.5	0.5	0.12	0.04	
284.7	0.2	0.17	0.04	
425.4	0.7	0.17	0.08	
536.4	0.3	0.90	0.08	619
618.8	0.3	2.6	0.2	425, 536, 1382
845.5	0.2	1.3	0.2	285, 1131
931.2	0.8	0.3	0.1	
957.3	0.5	0.4	0.1	1020
1019.7	0.2	32	2	957
1130.5	0.2	63	4	
1131.	2.	≤0.2 c)		
1155.2	0.8	0.04	0.02	
1382.3	0.2	1.12	0.07	619
2001.2	0.4	0.27	0.06	

a) The γ-ray intensities have been normalized by assuming that the $h_{11/2}$, $d_{3/2}$ and $s_{1/2}$ levels in ^{123}Sn are not directly populated in the β-decay of the $g_{9/2}$ isomer of ^{123}In, and by using the intensity balance in the level scheme.

b) This γ-ray follows the decay of the 47.8 s isomer [10] of ^{123}In.

c) The intensity and energy are estimated from the coincidence experiment as the peak is not resolved from the strong 1130.5 keV peak in the singles measurements.

TABLE 3

Properties of γ-rays following the decay of the 2.33 s isomer of ^{125}In

Energy (keV)	γ-intensity[a)] (percent per decay)	Coincidence relations
187.63±0.03	b)	
318.7 0.4	0.12±0.03	
426.03 0.10	2.5 0.2	936
507.7 0.2	0.5 0.1	
617.88 0.10	8.0 0.4	745, 1558
744.62 0.10	5.6 0.5	618
827.15 0.10	2.5 0.2	508
936.50 0.10	3.0 0.2	426
1031.75 0.10	10.3 0.6	
1335.04 0.10	76 4	
1362.5 0.3	0.25 0.05	
1558.2 0.4	1.0 0.1	

a) The γ-intensities have been normalized by using the intensity balance in the level scheme and by assuming that there is no β-particle feeding of the $s_{1/2}$, $d_{3/2}$ and $h_{11/2}$ levels from the $g_{9/2}$ isomer of ^{125}In.

b) This γ-ray follows the decay of the 12.2 s isomer [10] of ^{125}In.

TABLE 4

Internal conversion coefficients for some transitions in ^{119,121,123,125}Sn

Nucleus	Transition energy (keV)	Relative K-electron intensity	K-shell internal conversion coefficients				Assigned multipolarity
			Exp$^{a)}$x10^2	Theory $^{b)}$x10^2			
				E1	E2	M1	
^{119}Sn	763.14	1.3±0.3	0.23±0.06	0.083	0.26	0.22	M1 or E2
^{121}Sn	261.96	0.67±0.25	0.8 ±0.4	1.1	4.7	3.7	E1
	657.32	0.63±0.25	0.9 ±0.5	0.11	0.30	0.36	M1 or E2
	925.57	1.10±0.25	0.12±0.04	0.056	0.14	0.17	M1 or E2
^{123}Sn	125.76	30.2±3.0	25.0±3.0	8.2	54	23	M1
	1019.7	1.5±0.8	0.21±0.11	0.046	0.11	0.13	M1 or E2
	1130.5	1.6±0.5	0.11±0.04	0.039	0.088	0.11	M1 or E2
^{125}Sn	187.63	22.4±3.0	11.2±2.0	2.6	14	8.4	M1 (+ E2?)
	426.03	<0.3	<0.9	0.29	0.98	1.0	-
	617.88	0.5±0.3	0.40±0.25	0.13	0.36	0.41	M1 or E2
	1335.04	0.77±0.33	0.065±0.028	0.029	0.062	0.074	M1 or E2

a) The normalization constant of the experimental ICC is not the same for all the spectra.

b) Interpolated from the tables of Hager and Seltzer [31]

TABLE 5

Hindrance factors for transitions from $7/2^+$ levels in ^{119,121,123}Sn as obtained in the present work

Nucleus	Initial level		Final level	E_γ	Partial $T_{1/2}$	Hindrance factors relative the Weisskopf estimates[a]	
	Energy (keV)	$T_{1/2}$ (ns)	I^π	(keV)	(ns)		
^{119}Sn	787.01	0.19±0.07	$3/2^+$	763.14	0.19±0.07	3.1	(E2)
			$11/2^-$	697.47	40±15	5.3	(M2)
^{121}Sn	925.57	0.25±0.06	$3/2^+$	925.57	0.29±0.07	12.6	(E2)
			$11/2^-$	919.28	6.0±1.6	3.1	(M2)
			$9/2^-$	261.96	3.2±0.8	$2.1 \cdot 10^5$	(E1)
			$5/2^+$	56.35	132±32	$1.1 \cdot 10^3$	(M1)
^{123}Sn	1044.3	< 0.1	$3/2^+$	1019.7	< 0.1	< 7.2	(E2)
			$9/2^-$	425.4	< 20	$< 5.3 \cdot 10^6$	(E1)
			$5/2^+$	174.18	< 11	$< 2.7 \cdot 10^3$	(M1)
	1155.2	< 0.1	$11/2^-$	1155.2	< 150	< 250	(M2)
			$3/2^+$	1130.5	< 0.1	< 12	(E2)
			$9/2^-$	536.4	< 7.3	$< 4.1 \cdot 10^6$	(E1)
			$5/2^+$	284.7	< 40	$< 4.2 \cdot 10^4$	(M1)

a) See ref |29|

TABLE 6

Properties of the $g_{7/2} \rightarrow d_{3/2}$ E2 transitions in odd-mass heavy isotopes of Sn.

Nucleus	E_γ (keV)	Exp value of B(E2) ($e^2 \cdot 10^{-50} cm^4$)	Estimated value of B(E2)	$(U_{3/2} \cdot U_{7/2} - V_{3/2} \cdot V_{7/2})^2$ exp a)	theory b)
^{115}Sn	115.6	0.047±0.001		0.044	0.020
^{117}Sn	552.9	0.11±0.01		0.130	0.000009
^{119}Sn	763.14	0.11±0.04		0.130	0.022
^{121}Sn	925.57	0.028±0.007		0.160	0.085
^{123}Sn	1019.7	> 0.05	1.3 c)		0.178
^{123}Sn	1130.5	> 0.03	0.6 c)		0.178
^{125}Sn	1335.04	-	0.2 c)	0.328	0.301

a) Calculated from the experimental occupation numbers given by ref [13] for $^{115-121}$Sn and by ref [14] for ^{125}Sn. No values are available for the occupation numbers of the $7/2^+$ levels in ^{123}Sn.

b) Calculated by the use of parameters and equations given in ref [30]

c) Values obtained from estimates of the half-lives of these levels made by using the observed γ-ray branching via M2 and E1 transitions and by assuming that the hindrance factors of these transitions relative the Weisskopfs estimates are 4.2 and 2.1×10^5 respectively. Averages have been used where possible. See also the text.

FIGURE CAPTIONS

Fig. 1 A Ge(Li) detector spectrum showing γ-rays from the A = 121 isobaric decay chain as obtained at OSIRIS. The spectrum was recorded under conditions which enhance activities with $T_{1/2} \approx 20$ s. The γ-rays which are labelled with the transition energy follows the decay of ^{121}In. Not labelled γ-rays are due to the decay of ^{121}Ag and ^{121}Cd.

Fig. 2 A γ-ray spectrum obtained for the A = 123 isobaric decay chain The γ-rays which are labelled with transition energies were observed to follow the decay of ^{123}In.

Fig. 3 A γ-ray spectrum obtained for the A = 125 isobaric decay chain at OSIRIS. The γ-rays which are labelled with transition energies were observed to follow the decay of ^{125}In.

Fig. 4 Examples of γγ-coincidence spectra with gates set on the 618.8 keV transition in ^{123}Sn and the 617.88 keV and the 936.50 keV transitions in ^{125}Sn, respectively. Background coincidences have been subtracted.

Fig. 5 Parts of the Si(Li) detector spectra showing conversion lines in ^{121,123,125}Sn. The gain settings are not the same for all the spectra. For details of the analysis, see the text, section 2.

Fig. 6 Some of the time spectra obtained in the measurement of delayed coincidences. All measurements were repeated two or three times and prompt distributions were recorded after each individual measurement. The prompt spectra are drawn with full lines in the fig. The broken lines show exponential decay curves which were fitted to the spectra after subtraction of the prompt component. The fig. shows the half-lives obtained at a particular measurement while the averages are given in table 5. The time spectra obtained for the 1019.7 keV line (not shown in the figure) and the 1130.5 keV line in ^{123}Sn were indistinguishable from the prompt spectra and we conclude that the half-lives of these lines are less than 0.1 ns.

Fig. 7 Energy levels of ^{119}Sn and ^{121}Sn. The γ-ray intensity is given within brackets for each transition. Observed coincidence relations are indicated by dots. The γ-ray energies and branching in ^{119}Sn and the β-particle feeding of the 787.0 keV level, have been taken from ref [3]. Multipolarity assignments shown have been decuded from the presently measured conversion coefficients, except for the 56.3 keV transition in ^{121}Sn. The conversion coefficient of this transition was estimated from the intensity balance with the 869.3 keV level. The values of log*ft* for β-transitions feeding levels in ^{121}Sn have been calculated using the β-decay energies of ref [32]

Fig. 8 Proposed decay schemes of ^{123}Sn and ^{125}Sn. The γ-ray intensity is given within brackets for each transition. Observed coincidence relations are indicated by dots. Multipolarity assignments shown have been deduced from the presently measured conversion coefficients except for the 618.8 keV transition in ^{123}Sn which is taken from ref [12]. The log*ft* values have been calculated by using the intensity balance with each level to get the β-branching ratios and by using the Q_β-values given in ref [32].

Fig. 9 Energy level systematics in odd-mass heavy isotopes of Sn. In addition to the $s_{1/2}$, $d_{3/2}$, $h_{11/2}$ and $g_{7/2}$ levels are shown the $7/2^-$ [refs 14,15] and the presently observed $9/2^-$ anomalous coupling states. These two latter levels are observed to follow closely the trend obtained by adding the phonon energy of the nearest lighter even isotope to the energy of the $h_{11/2}$ level, which is indicated by dots in the figure. A $7/2^+$ level present at about 1.05 MeV in ^{123,125,127,129}Sn can most probably be explained as the three quasi particle state obtained by a coupling of the $d_{3/2}$ particle to a phonon of the core.

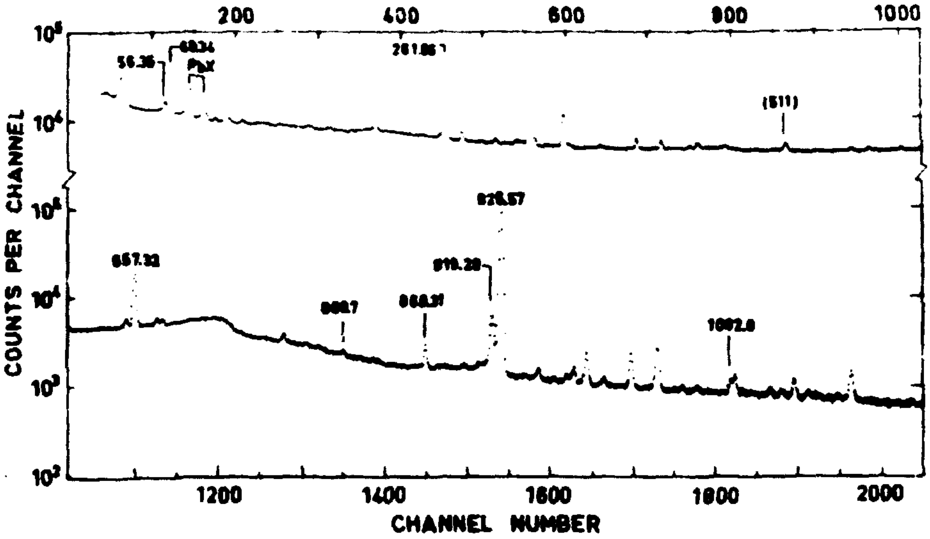
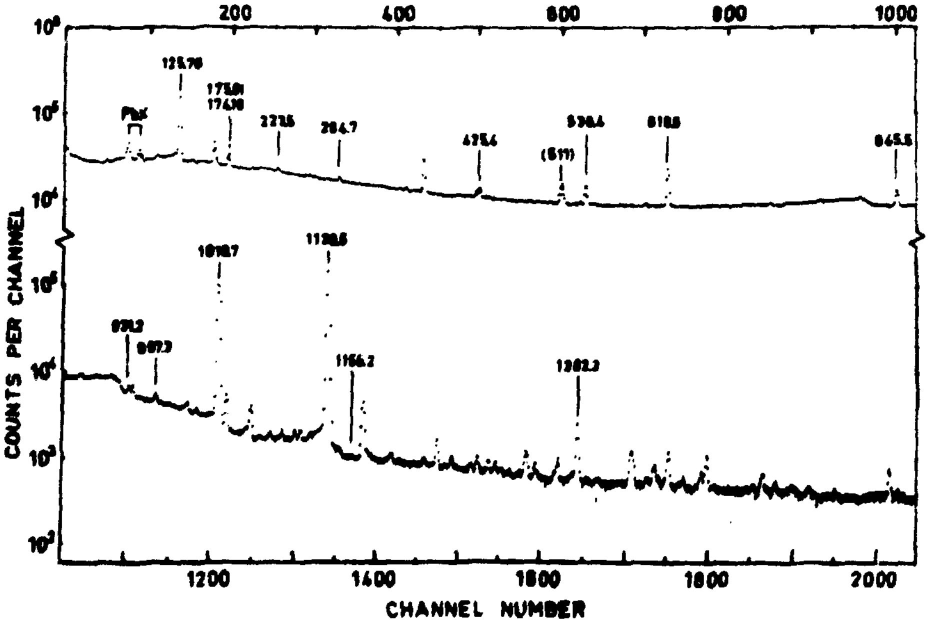

200
400
600
800
1000
56.36
60.34
PbX
261.86
(511)
926.57
657.32
919.28
860.7
868.31
1002.8
10^5
10^4
10^5
10^4
10^3
10^2
COUNTS PER CHANNEL
1200
1400
1600
1800
2000
CHANNEL NUMBER

Fig 1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400
600
800
1000
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175.01
174.10
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284.7
475.4
(511)
530.4
616.6
645.5
1018.7
1128.5
931.2
987.3
1156.2
1302.3
10^6
10^5
10^4
10^5
10^4
10^3
10^2
COUNTS PER CHANNEL
1200
1400
1600
1800
2000
CHANNEL NUMBER

Fig 2

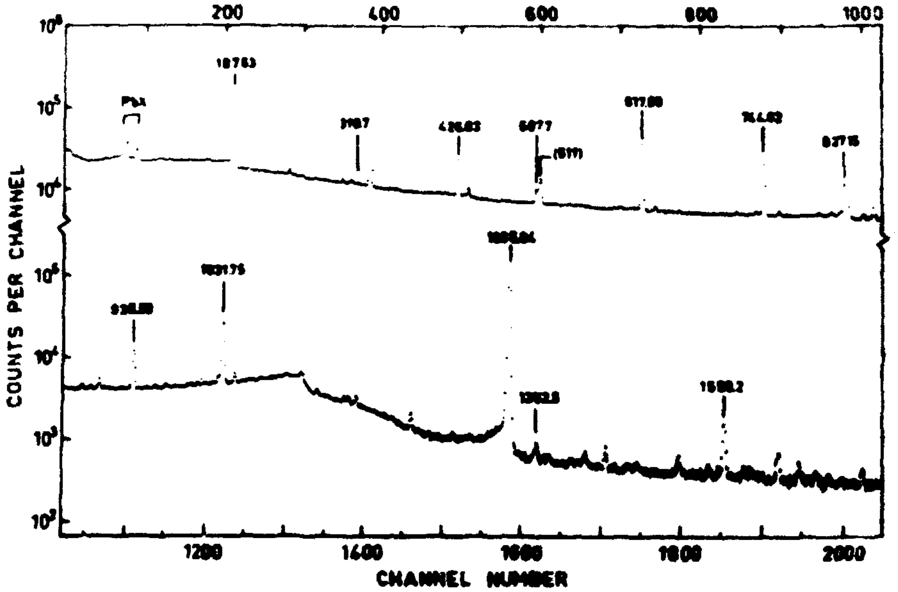
200
400
600
800
1000
10^6
10^5
10^4
10^5
10^4
10^3
10^2
COUNTS PER CHANNEL
Pbx
(511)
1200
1400
1600
1800
2000
CHANNEL NUMBER

Fig 3

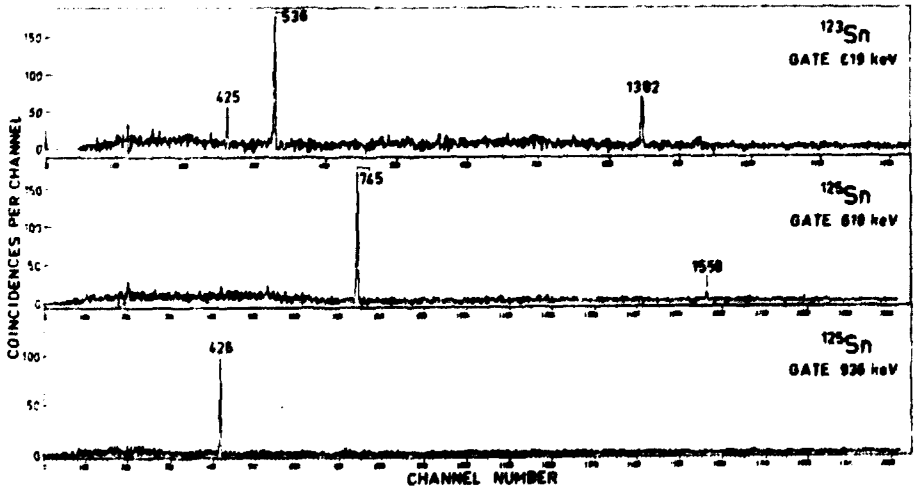
536
425
1302
^{123}Sn
GATE 619 keV
765
1550
^{125}Sn
GATE 618 keV
426
^{125}Sn
GATE 936 keV
150
100
50
0
COINCIDENCES PER CHANNEL
CHANNEL NUMBER

Fig 4

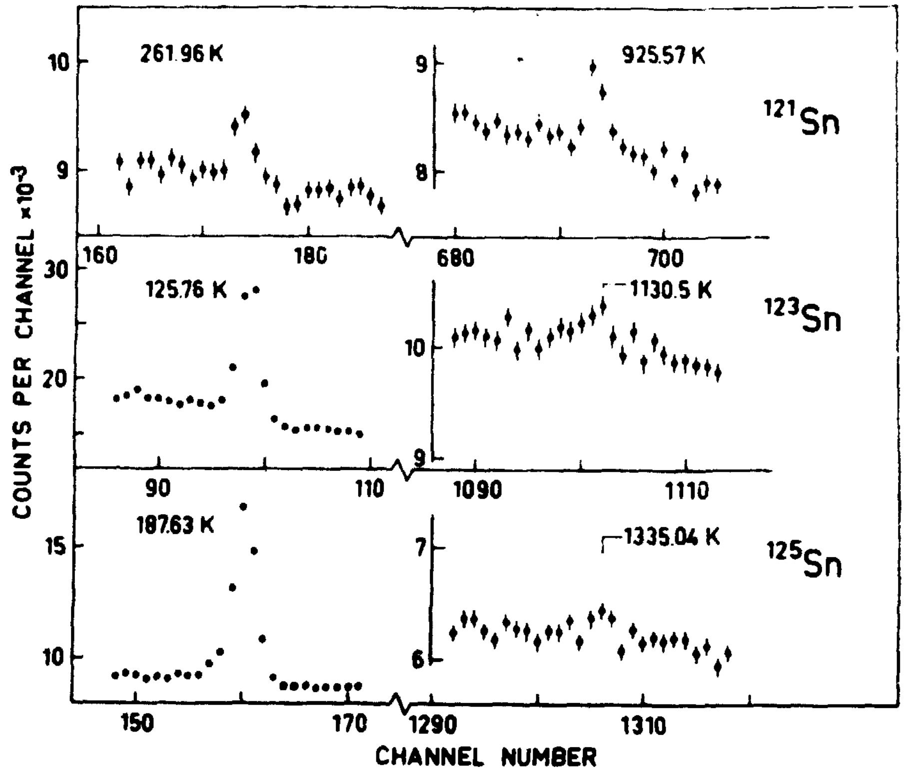
COUNTS PER CHANNEL ×10⁻³
10
9
261.96 K
9
8
925.57 K
¹²¹Sn
160
180
680
700
30
20
125.76 K
10
9
1130.5 K
¹²³Sn
90
110
1090
1110
15
10
187.63 K
7
6
1335.04 K
¹²⁵Sn
150
170
1290
1310
CHANNEL NUMBER

Fig 5

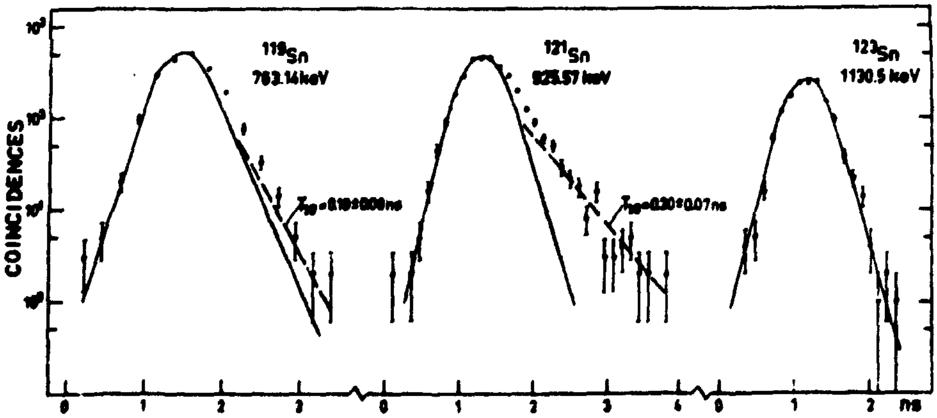
COINCIDENCES
10³
10²
10¹
10⁰
¹¹⁹Sn
763.14 keV
T1/2=0.10±0.08 ns
¹²¹Sn
925.57 keV
T1/2=0.20±0.07 ns
¹²³Sn
1130.5 keV
0
1
2
3
0
1
2
3
4
0
1
2
ns

Fig 6

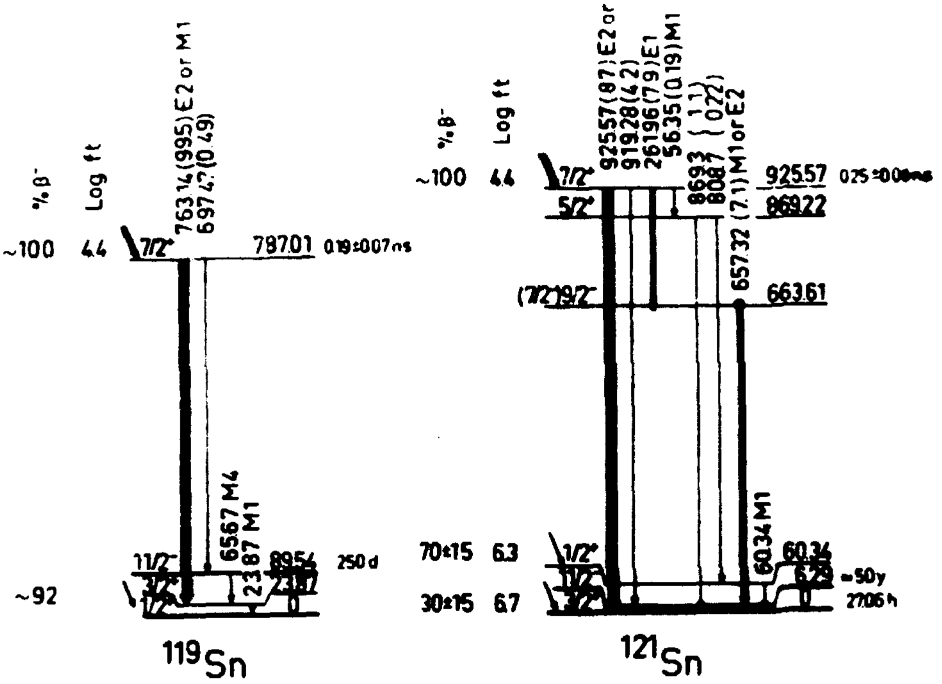
%β⁻
Log ft
~100
4.4
7/2⁺
76314(995) E2 or M1
69747(0.49)
78701
0.19±0.07ns
6567 M4
2387 M1
8954
2387
250 d
11/2⁻
3/2⁺
1/2⁺
0
~92
119Sn
%β⁻
Log ft
~100
4.4
7/2⁺
92557(87) E2 or M1
91928(4.2)
26196(7.9) E1
5635(0.19) M1
8693 (1.1)
8087 (0.22)
65732 (7.1) M1 or E2
92557
0.25±0.08ns
5/2⁺
86922
(7/2⁻)9/2⁻
66361
6034 M1
6034
6.29
≈50y
2706 h
70±15
6.3
1/2⁺
11/2⁻
30±15
6.7
3/2⁺
121Sn

Fig 7

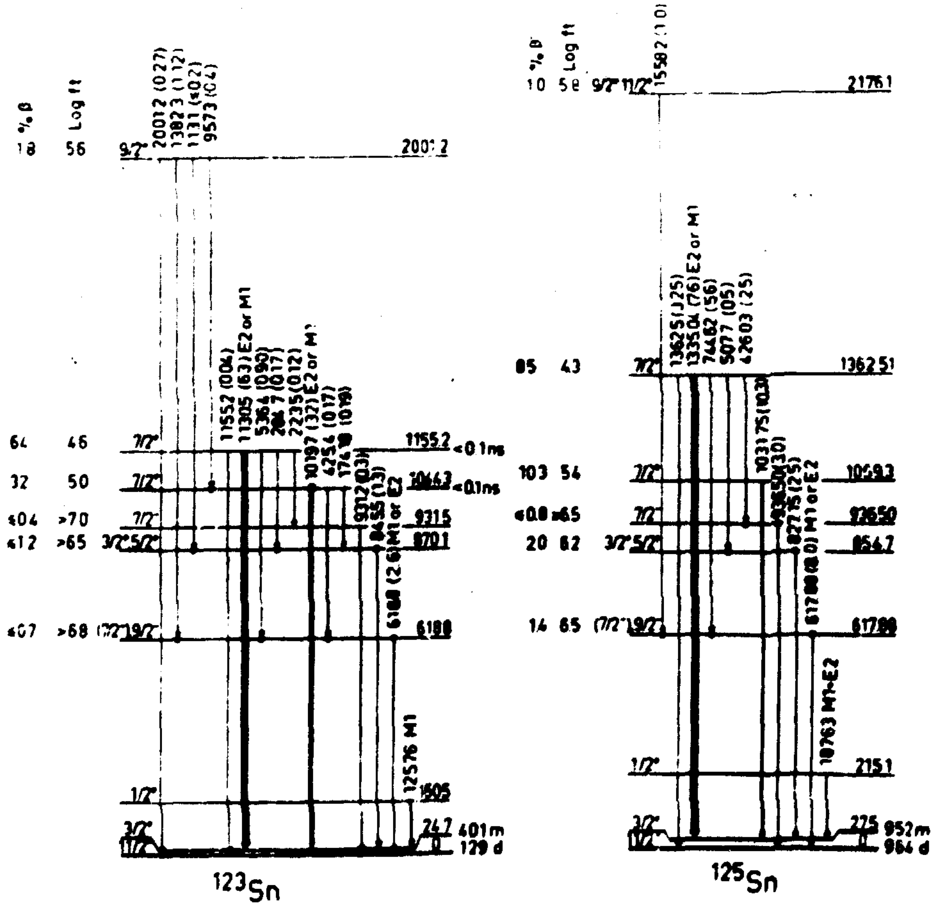
%β
Log ft
18
56
9/2⁺
20012 (0.27)
13823 (1.12)
1131 (≤0.2)
9573 (0.4)
2001.2
11552 (0.04)
11305 (63) E2 or M1
5364 (0.90)
2847 (0.17)
2235 (0.12)
10197 (32) E2 or M1
4254 (0.17)
1741 (0.19)
9312 (0.3)
8455 (1.3)
6188 (2.6) M1 or E2
12576 M1
64
46
7/2⁺
1155.2
<0.1ns
32
50
7/2⁺
1046.3
<0.1ns
≤0.4
>70
7/2⁺
931.5
≤1.2
>65
3/2⁺5/2⁺
870.1
≤0.7
>68
(7/2⁻)9/2⁻
618.8
1/2⁺
160.5
3/2⁺
24.7
401m
11/2⁻
0
129 d
123Sn
%β
Log ft
10
5.8
9/2⁺11/2⁺
15582 (1.0)
2176.1
13625 (1.25)
133504 (76) E2 or M1
74482 (56)
5077 (0.5)
42603 (2.5)
103175 (10.3)
93650 (3.0)
82715 (2.5)
61780 (8.0) M1 or E2
18763 M1+E2
85
43
7/2⁺
1362.51
103
54
7/2⁺
1059.3
≤0.8
≥6.5
7/2⁺
936.50
20
6.2
3/2⁺5/2⁺
854.7
14
6.5
(7/2⁻)9/2⁻
617.80
1/2⁺
215.1
3/2⁺
27.5
9.52m
11/2⁻
0
9.64 d
125Sn

Fig 8

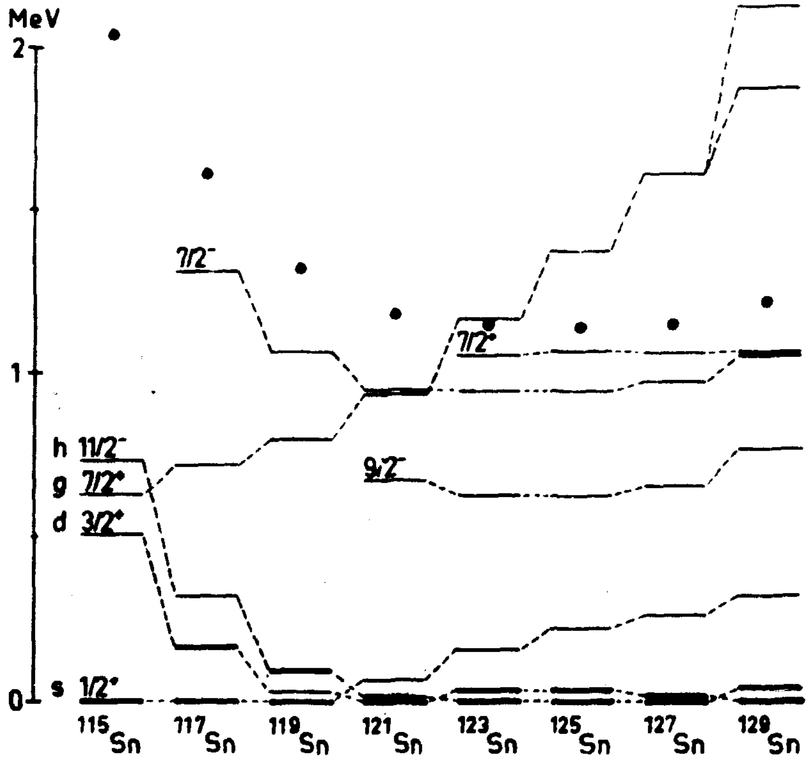
MeV
2
1
0
h 11/2⁻
g 7/2⁺
d 3/2⁺
s 1/2⁺
7/2⁻
9/2⁻
7/2⁺
115Sn
117Sn
119Sn
121Sn
123Sn
125Sn
127Sn
129Sn

Fig 9