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THE BETA DECAYS OF ^{126}Cd AND ^{126}In
TO LEVELS IN ^{126}In AND ^{126}Sn

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Based on a Ph.D. thesis submitted to Iowa State University

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to levels in ^{126}In and ^{126}Sn

by

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The beta decays of ^{126}Cd and ^{126}In
to levels in ^{126}In and ^{126}Sn

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A study of the beta decays of ^{126}Cd and ^{126}In using the TRISTAN on-line isotope separator facility is reported. Gamma-ray singles measurements were made for both decays using Ge(Li) and LEPS (low energy photon spectrometer) detectors. In addition, gamma-gamma coincidence measurements and gamma multiscale measurements were made for both decays using Ge(Li) detectors. The half-life for ^{126}Cd was determined to be 0.506 ± 0.015 sec., and the half-lives for the low- and high-spin ^{126}In isomers were determined to be 1.83 ± 0.11 sec. and 1.96 ± 0.10 sec., respectively. A total of 11 gamma rays were observed in the decay of ^{126}Cd , and all but one were placed in a level scheme for ^{126}In . A total of 48 gamma rays were observed in the decay of the low- and high-spin ^{126}In isomers and all were placed in a level scheme for ^{126}Sn . Spin and parity assignments were deduced, whenever possible, on the basis of $\log ft$ values and gamma decay selection rules. The ^{126}In decay schemes (one has been proposed for each isomer) are compared with earlier decay studies and

with results from $^{124}\text{Sn}(t,p)^{126}\text{Sn}$ reaction experiments. The systematics associated with the level schemes are discussed and a comparison is made with the nuclear shell model.

CHAPTER I. INTRODUCTION

General Motivation for these Studies

There are many reasons for studying the physics of the nucleus. The primary reason for such studies is to understand the nature of the strong forces which bind nucleons together and determine the properties of complex nuclei. Many models have been proposed to explain these poorly understood properties but as yet none has been global enough to encompass all nuclei. Much more information is needed before this problem can be solved. The principal practical application of the research reported here is to the problem of decay heats and control of fluctuations in nuclear power reactors. There are also applications in the use of isotopes in the field of medicine.

Less than one-third of the nuclei listed in the Table of the Isotopes have been thoroughly studied,¹ and most of those lie near the line of beta stability. Nuclei which do not lie near the line of stability are difficult to produce, therefore much less is known about them. These nuclei generally have short half-lives and frequently their yields in appropriate production processes are low, hence special techniques such as isotope separation are necessary for their study. In some cases fission product studies, such as those done at TRISTAN, are the only means of investigating certain

neutron-rich nuclei far from stability.

Any single experiment cannot of course provide all of the answers about a nucleus. The results of many different kinds of measurement must be combined to form a complete picture. Experiments of the type done for this study are meant to provide information about the level properties of a nucleus, specifically the energies, spins, and parities of the nuclear levels, and the energies and intensities of gamma transitions connecting these levels. Such information is necessary for verification of nuclear theories since a model calculation must predict the correct nuclear properties.

Doubly-Magic Nuclei

Nuclei in the doubly-magic regions have a particularly simple structure and hence have traditionally been the subject of extensive investigation. (A magic number refers to a neutron or proton configuration of exceptional stability in analogy to rare gas configurations in atomic physics.) Nuclei with proton and neutron numbers nearly magic are nearly spherical and exhibit the simple properties expected near closed shells. For example, these nuclei are expected to be especially well-described by the nuclear shell model, and their study has been important in the development of this model.

Of the possible doubly-magic regions the ^{208}Pb , ^{40}Ca , and ^{16}O regions have been extensively studied. These regions are near the line of stability and hence easily reached in reaction studies. Nuclei in these regions have half-lives that are long enough to make off-line studies easy, hence no special techniques are necessary.

Nuclei in the ^{132}Sn region, however, have not been studied much until recently, when on-line-isotope-separators opened this region to study. These nuclei are far from stability (see figure 1) and usually have half-lives on the order of seconds, therefore they can usually only be studied on-line. Furthermore, the fission yields of many of the nuclei in this region are low so that detailed studies are difficult. (^{126}Sn can be studied via the (t,p) reaction on stable ^{124}Sn as well as via the decay of the fission product ^{126}In . ^{126}In , however, can only be studied in one way, via the decay of the fission product ^{126}Cd .) In this work we studied the isotopes ^{126}In and ^{126}Sn as part of a systematic investigation of the neutron-rich nuclei near doubly-magic ^{132}Sn being conducted at the TRISTAN on-line mass-separator facility. Very little is known about the structure of either of these isotopes, and this is the first reported decay scheme study for ^{126}Cd . The objective of this work was to extend the systematics of In and Sn nuclei out towards doubly-magic ^{132}Sn .

$^{124}_{50}\text{Sn}_{74}$ Stable	$^{125}_{50}\text{Sn}_{75}$ $T_{1/2}(\text{LS}) = 9.6\text{m}$ $T_{1/2}(\text{HS}) = 9.7\text{d}$	$^{126}_{50}\text{Sn}_{76}$ $T_{1/2} = 10^5\text{yr}$		
	$^{124}_{49}\text{In}_{75}$ $T_{1/2}(\text{LS}) = 3.2\text{s}$ $T_{1/2}(\text{HS}) = 2.4\text{s}$	$^{125}_{49}\text{In}_{76}$ $T_{1/2}(\text{LS}) = 12.2\text{s}$ $T_{1/2}(\text{HS}) = 2.3\text{s}$	$^{126}_{49}\text{In}_{77}$ $T_{1/2}(\text{HS}) = 2.0\text{s}$ $T_{1/2}(\text{LS}) = 1.8\text{s}$	
		$^{124}_{48}\text{Cd}_{76}$ $T_{1/2} = 0.9\text{s}$	$^{125}_{48}\text{Cd}_{77}$	$^{126}_{48}\text{Cd}_{78}$ $T_{1/2} = 0.5\text{s}$

Figure 1. Section of the Chart of Nuclides showing the nuclides studied

Nuclear Shell Model and the Quasi-Particle Concept

Nuclei with a few particles more or less than a doubly-magic nucleus are described well by the nuclear shell model, which is conceptually the same as the atomic shell model. Nucleons occupy specific subshells as do the electrons in an atom, and each orbital is characterized by individual quantum numbers which determine the properties of the corresponding energy levels. Certain of the nucleons (those in the subshells with lowest energy) are assumed to form a core which is taken to be inert. These core nucleons are assumed to play only a small role in determining the low energy properties of the nucleus. Only those few valence nucleons which lie outside the core are considered active.

For the simple case of a doubly-magic core plus or minus one nucleon a shell model Hamiltonian consisting of an average potential produced by the core nucleons plus a spin-orbit force works very well.² This simple model also reproduces some of the properties of nuclei farther from closed shells. For example, the 'magic numbers' are correctly predicted with this model, and the ground state spins and parities of odd-A nuclei are those of the odd particle as predicted by the shell model.

A more refined treatment of nuclei with more than one particle (or hole) away from a doubly-magic core must take into account pairwise interactions between the valence

nucleons. These correlations are produced by the so-called residual force which is ignored in the simple shell model, and are responsible for many of the properties of nuclei with partially filled shells. This force has two parts, a long-range part, responsible for shape oscillations of the nucleus, and a short-range part, called the pairing force, which is responsible for bringing about a correlation between pairs of nucleons. The long-range part becomes dominant as mid-shell is approached (many nucleons outside a closed shell) and is characterized by the well-developed rotational bands in deformed nuclei. Closer to filled shells the pairing force becomes more important. The most important effect of the pairing force is to cause identical nucleons (protons or neutrons) to couple pairwise to zero angular momentum. Both the short-range and long-range parts of the residual interaction are always present, but the effect of one usually dominates as indicated.

Since nuclei in the ^{132}Sn region have only a few particles (or holes) outside a closed shell, it is the short-range pairing force which is most important in determining the properties of these nuclei. This short-range force is treated in the ECS or quasi-particle approximation, and this treatment has been successful in describing much of the level structure of single-closed shell nuclei, including those near ^{132}Sn . Good discussions of the quasi-particle concept are

presented in Nathan and Nilsson³ and Bohr and Mottelson⁴. Only a brief summary of the ideas will be given here.

Because of the complexity of the pairing interaction, the solution to the problem for many particles (or holes) outside a closed shell is not analytical. However, a good variational solution for the ground state exists and is given by

$$Q_0^{\text{BCS}} = \prod (U_\nu + V_\nu a_\nu^\dagger a_{\bar{\nu}}^\dagger) |0\rangle.$$

In this expression $a_\nu^\dagger$ and $a_{\bar{\nu}}^\dagger$ are the creation operators for the shell model states $\psi_{j\nu}$ and $\psi_{j-\nu}$; ν and $\bar{\nu}$ are used as short-hand notation for $(j\nu)$ and $(j-\nu)$; and $(U_\nu)^2$ and $(V_\nu)^2$ are the probabilities that the single particle level $|\nu\bar{\nu}\rangle$ is respectively completely empty or filled with a pair of protons or neutrons. (This solution is called the BCS ground state because the solution was originally suggested for the superconductor problem by Bardeen, Cooper, and Schrieffer.) Note that the particles appear only in pairs $a_\nu^\dagger a_{\bar{\nu}}^\dagger$, hence this solution refers to a nucleus with an even number of particles. The BCS ground state is described as the quasi-particle vacuum $|0\rangle$ and all excited states are obtained from it by means of the quasi-particle operators

$$\alpha_\nu^\dagger = U_\nu a_\nu^\dagger - V_\nu a_{\bar{\nu}}$$

and

$$\alpha_{\bar{\nu}}^{\dagger} = U_{\nu} a_{\bar{\nu}}^{\dagger} - V_{\nu} a_{\nu}.$$

Thus the quasi-particle can be thought of as a change in occupation for the orbit $|\nu\bar{\nu}\rangle$. One quasi-particle states appear as the low-lying excited states in odd-A nuclei; two quasi-particle states appear as the low-lying states in even-A systems. Similarly, three and five quasi-particle states occur higher in odd systems and four quasi-particle states appear higher in even-A nuclei.

Previous Studies of Odd-Odd In Nuclei

There is only one other reported study of the decay of ^{126}Cd .⁵ No decay scheme was presented in this report. The half-life was measured but only the two most intense gamma rays were observed. Also very little experimental work has been done on the lighter-mass even In nuclei except for those near stability, although some information is available on the levels in odd-odd In nuclei from $A = 106$ to $A = 124$. One notable feature of the systematics of these nuclei is the existence of two and sometimes three isomers. In most cases the low-spin isomer is the ground state with $J^{\pi} = 1^{+}$; the exception is ^{124}In which is postulated to have a 2^{+} ground state. Part of the motivation for the present work has been the desire to extend the systematics for these low-spin isomers to ^{126}In .

Studies of the decays of even-even Cd nuclei (with 0^+ ground states) can only provide information about the low-spin levels in In. Decay studies of ^{108}Sn ,⁶ ^{110}Sn ,⁷ ^{118}Cd ,⁸ ^{120}Cd ,⁹ ^{122}Cd ,⁹ and ^{124}Cd ¹⁰ have been reported, but excited states were observed only in ^{108}In , ^{110}In , and ^{124}In . Most of the beta strength is presumed to go to the ground states in the other cases, making the excited states difficult to study.⁹ This fact is presented as justification for ground state assignments of 1^+ in these cases. By analogy, Fogelberg¹⁰ used the observation of strong gamma transitions in the ^{124}Cd decay to justify a J^π of 2^+ for the ^{124}In ground state.

Levels in odd-odd In nuclei near stability from $A = 108$ to $A = 116$ have been studied using (α, n) ,^{11,12} $(^6\text{Li}, 4n)$,¹¹ (p, n) ,^{6,12,13} (d, p) ,^{14,15} (d, d) ,¹⁴ (d, t) ,¹⁴ and (n, γ) ¹⁵ reactions. Much information on high spin levels (with $J \geq 3$) was obtained from these studies. In most cases few low spin levels (with $J \leq 3$) were observed between 0 and 1 MeV.

Odd-odd In nuclei have 49 protons and it might be naively expected that the low-energy properties of these nuclei could be described as a proton hole in the closed shell of 50 protons coupled to a neutron particle between the $N = 50$ and $N = 82$ closed shells. In the case of ^{116}In , for which the most complete set of information on the levels is available, this description is adequate for low-spin levels

up to about 1 MeV. It is not, however, an adequate explanation for the level structure of ^{108}In and ^{124}In . In these cases more low-spin, positive parity states are seen than would be predicted by the above picture. It has been suggested that these additional states may be formed by coupling a proton hole to 3 neutron particles or to a phonon.¹⁵ Not enough is known about the low-spin levels in the other odd-odd In nuclei to make such a comparison with theory. The present work has been undertaken in part to examine the low-spin level structure of ^{126}In and compare it with the predictions of the shell model.

Previous Studies of Even-Even Sn Nuclei

Four studies of the level structure of ^{126}Sn have been reported previously. Two of these are decay studies, the decay of the low-spin isomer reported by Aleklett et al.,¹⁶ and the decay of the high-spin isomer reported by Fogelberg.¹⁷ The others are $^{124}\text{Sn}(t,p)$ reaction studies, reported by Bjerregaard et al.¹⁸ and Flynn et al.¹⁹ (The results of these studies will be compared with our more complete results in Chapter V.) Some interpretation of the level structure is presented by Flynn et al. More levels were observed by Flynn et al. than by Bjerregaard et al., and Flynn et al. were able to postulate specific L values for many more of the levels. There is substantial agreement be-

tween the reaction studies and the decay studies on level energies, although the J^π assignments for some of the levels are different. This study has been undertaken in part to attempt to identify more levels and to clarify the J^π assignments for the disputed levels.

Two isomers of ^{126}In have been reported by Aleklett et al.¹⁶ This is to be expected because the lower mass odd-odd In nuclei all have two, and sometimes three, isomers. The high-spin isomer of ^{126}In was reported to have a half-life of 1.55 sec. and the low-spin isomer to have a half-life of 2.1 sec.¹⁶

Much more is known about the systematics of the even-even Sn nuclei than about those of the odd-odd In nuclei. Even-even Sn nuclei have a closed proton shell at 50 and hence are much more amenable to interpretation; thus there has traditionally been more motivation for their study. (The list of references to studies done on even-even Sn levels is too extensive to include as part of this report (some information is available on the levels in even-even Sn nuclei from $A = 104$ to $A = 130$), but a complete list for any of the Sn nuclei may be found in Nuclear Data Sheets.²⁰⁻³³) Nuclear structure studies in the $Z = 50$ region have been reviewed by Baranger,³⁴ and her article contains an excellent overview of the motivation for these studies and of the results. More will be said about the systematics of the even-even Sn (as

well as the odd-odd In) nuclei in Chapter V. These systematics have been helpful in the present study in assigning specific J^π values to many of the ^{126}Sn levels.

CHAPTER II. EXPERIMENTAL PROCEDURE

The TRISTAN Separator System

Sources for this study were produced with the TRISTAN on-line mass-separator located at the Ames Laboratory Research Reactor. Figure 2 is a schematic layout of TRISTAN. The system is essentially the same as that described elsewhere,³⁵ except that TRISTAN now has a new ion source. This ion source is similar to the one developed for the separator OSIRIS,³⁶ and provides TRISTAN with the capability of producing a wide range of non-gaseous fission products. Good yields of Zn, Ga, Ag, Cd, and In are obtained with this system. Figure 3 shows a typical mass yield curve for the new ion source superimposed on the double-humped fission mass yield curve.

Figure 4 shows the new TRISTAN ion source. It is located in an external neutron beam of the reactor and is irradiated in a thermal neutron flux of 3×10^9 n/cm²•sec. The graphite cloth on the inner surface of the (graphite) anode contains a few grams of ²³⁵U at a density of approximately 100 mg/cm³. Uranium target nuclei fission when thermal neutrons are absorbed from the beam. Fission products diffuse out of the graphite anode, which is held at a positive potential, into the cavity of the ion source where they are ionized by electron bombardment and the heat of the

Figure 2. Schematic layout of the TRISTAN isotope separator facility

Figure 3. Mass yield curve for TRISTAN in-beam ion source

Figure 4. TRISTAN in-beam ion source

plasma. The electrons are emitted from a heated filament (the cathode) on the axis of the ion source. Surrounding the ion source is a series of Helmholtz coils which provides an axial field to increase the path length of the ionizing electrons. The operating temperature for this ion source has typically been 1500 °C. Water at room temperature is used to cool the outer layers of the ion source housing. Such a high operating temperature is usually necessary to insure rapid diffusion of the fission products out of the graphite. A support gas consisting of He with Kr and Xe mass markers is continuously injected into the ion source to maintain the plasma and provide stable masses for beam location.

Following ionization the fission products are extracted from the ion source by a 50-kV accelerating potential. Electrostatic lenses then focus the beam and direct it into the separating magnet. After mass separation the beam enters the focal plane of the collector box and is viewed on a fluorescent screen. There are also two copper strips in the collector box which can be positioned on either side of a mass neighboring the one being studied to provide beam stabilization. These stabilization pins are connected to a feedback network which prevents the beam from drifting. At the downstream end of the collector box is a narrow slit which is aligned with the entrance to the switch magnet. The selected mass beam is sent through the slit to the switch magnet where

it is directed to one of the experimental areas.

A moving tape collector (MTC) is available at each of the experimental stations to allow enhancement of selected activities; figure 5 is a schematic illustration of an MTC. The ion beam is deposited at the parent port of the MTC. Counting may be done at this port either at the same time that the beam is being deposited or for a period of time afterwards by deflecting the beam with an electric field. Counting may also be done at the shielded daughter port by depositing a sample on the tape at the parent port and moving it to the daughter port. Counting at either port may be delayed to allow parent activities to die away, leaving only the daughters. Movement of the tape is controlled by a daughter analysis system (DAS), which also controls the data acquisition system.

Operation of the System for $A = 126$

Optimum running conditions during these measurements were typically obtained with the settings listed in Table I. Usually the yields of Cd and In improved as the temperature of the ion source was increased. Cd, with a short half-life of 0.5 sec., was especially enhanced by operating at a higher temperature. Filament current and anode voltage determine the operating temperature of the ion source. As these parameters are increased the temperature increases. (Ion source

Figure 5. Schematic illustration of moving tape collector

design characteristics prevented one from operating at settings much higher than those listed in Table I.) These typical settings represent about half a kilowatt of power generation in the source. Aside from operating at high temperatures, the ion source usually had to be outgassed for a long time, typically two or three days, before the desired activities reached acceptable strengths. This outgassing was necessary because the graphite anode contains organic material which spoils the vacuum and decreases the efficiency of the ion source. During these measurements the strength of the activity at the tape collector was typically about 300 cps, which seemed to be the maximum activity attainable for this mass.

Table I. Typical separator settings for $A = 126$

Filament	45 amps
Anode	8 amps; +40 volts
Source Magnet	15 amps
Accelerating Potential	50 kV
Extractor Potential	5 kV
Ion Source Vacuum	5 microtorr

Data Acquisition

During this experiment three different kinds of measurement were performed. Gamma singles measurements were made to determine the energies and intensities of the gamma rays and to separate parent from daughter activities. A gamma-gamma coincidence measurement was performed to determine gamma placements, and a gamma multispectrum analysis was made to determine half-lives. Gamma rays were observed using Ge(Li) and LEPS (low energy photon spectrometer) detectors. Table II lists the characteristics of the detectors used in these studies.

Table II. Detectors used in these measurements

Detector	Ge(Li) A	Ge(Li) B	LEPS
Manufacturer	EGT	Ortec	Ortec
Resolution	1.8 keV FWHM @ 1332 keV	2.1 keV FWHM @ 1332 keV	0.5 keV FWHM @ 122 keV
Efficiency	15%	15%	
Bias Voltage	3500 volts	4000 volts	1500 volts

Singles measurements

Figure 6 shows a schematic block diagram of the apparatus used in a typical singles measurement. The detector was mounted at the appropriate port of the MTC and a battery pack was used to provide the bias voltage in order to insure stability of operation. All of the other apparatus was mounted in NIM bins nearby which also supplied the power for the detector preamplifiers. Table III lists the apparatus used in the singles measurements. The operation of this apparatus is explained in the following paragraphs.

Table III. Apparatus used in singles measurements

Detector	LEPS	Ge(Li) A
Preamplifier	Ortec 117A	Ortec 120-4
Linear Amplifier	Tennelec 205A	Tennelec 205A
Biased Amplifier		Canberra 1460
ADC	Geoscience 8050	Geoscience 8050
Multichannel Analyzer	Geoscience 7000	TMC 446

Gamma rays in the range 0 - 300 kev were measured with the LEPS detector and gamma rays in the range 100 - 7500 kev were measured with a large-volume Ge(Li) detector (detector A

Figure 6. Schematic block diagram of apparatus used in singles measurements

in Table I). The Ge(Li) spectra for each measurement were split into two parts, each an 8K spectrum. One of the Ge(Li) preamplifier outputs (each preamplifier has two) was connected to a linear amplifier. This amplifier was connected to an 8K ADC (analog-to-digital converter) and set to yield a spectrum covering the range 100 - 4000 kev. The other preamplifier output was connected to a linear amplifier which was in turn connected to a biased amplifier. The biased amplifier was connected to an 8K ADC and set to provide a spectrum which covered the range 2500 - 7500 kev. In this way both the low- and high-energy gamma rays could be measured with the same detector, without decreasing the resolution. Only one of the LEPS preamplifier outputs was used. This was connected to a linear amplifier which in turn was connected to an 8K ADC. The ADC was set to provide a 4K spectrum.

All of the ADC's were used in the pile-up rejection and logarithmic restoration modes with a time constant of 12.8 microseconds. Ge(Li) and LEPS spectra were stored in 16K and 4K multichannel analyzers respectively. These spectra were recorded on seven-track magnetic tape for later computer analysis.

Four different types of singles measurement were made, one with the A=126 activity only (hereafter called the unknown activity), one with both unknown and calibration ac-

tivities to determine least-squares values for the unknown energies, one with calibration activities only to determine the nonlinearities of the detectors, and one with background activities only to identify contaminants. These measurements are described in the following paragraphs.

Two different measurements of the unknown spectra were made, one to enhance the parent ^{126}Cd and one to enhance the daughter ^{126}In . The parent enhanced spectra were obtained with the detectors (LEPS and Ge(Li)) at the parent port of the MTC. For this measurement beam deposition and counting were done simultaneously, and the tape was moved every 2 seconds. This cycle was repeated for a period of about 15 hours. The ^{126}In enhanced spectra were obtained with the detectors at the daughter port. For this measurement the beam was deposited for 6 seconds at the parent port, the tape was moved to the daughter port, counting was delayed for 3 seconds to allow the shorter-lived ^{126}Cd to die away, and then counting was done for 6 seconds. During counting a fresh sample was deposited at the parent port, thus making the most economical use of time. This cycle was repeated continuously for a total of approximately 15 hours. During these unknown runs spectra were recorded periodically (about every 4 hours) on magnetic tape to prevent any difficulties which might be caused by gain shifts. These spectra were later added together during computer analysis.

Mixed spectra were obtained with the detectors at the parent port. Standard sources of ^{182}Ta , ^{133}Ba , ^{226}Ra , and ^{56}Co were placed at the parent port between the detectors (LEPS and Ge(Li)) to provide the calibration activities. At the same time the beam was deposited on the tape. Beam deposition and counting were done simultaneously, and the tape was moved every 3 seconds. This cycle was repeated for a total of about 6 hours.

Calibration spectra were also obtained with the detectors at the parent port. Standard sources of ^{56}Co , ^{22}Na , ^{133}Ba , ^{182}Ta , ^{57}Co , and ^{226}Ra were placed between the detectors to provide the calibration activities. During this run the separator was turned off to decrease the background as much as possible. Total run time in this case was about 3 hours.

Finally, the background spectra were obtained, again with the detectors at the parent port. During this run the separator was operating but a valve between the collector box and the switch magnet was closed to prevent the beam from reaching the MTC. The background spectra were obtained in this way to simulate as much as possible the background present during an actual run. Total time for this measurement was about 12 hours, which represents approximately the same counting time as that during the parent unknown run, taking into account time for tape movement.

Multispectrum scaling

A block diagram of the apparatus used for half-life measurements in this study is shown in figure 7. Table IV is a listing of the apparatus used in the half-life measurements. A large-volume Ge(Li) detector was used for these measurements. No LEPS multiscaling was done. The operation of this apparatus is described in the following paragraphs.

Table IV. Apparatus used in multispectrum analysis

Detector	Ge(Li) A
Amplifier	Tennelec Model 205A
Two-Parameter Input Unit	TMC Model 242
Multiscalar Logic Unit	TMC Model 204
ADC	TMC Model 217A
Region Selector	TMC Model 252

During these measurements the ion beam was deposited on the tape at the parent port of the MTC for two or three half-lives, long enough to allow the activity to nearly reach saturation. Then the beam was deflected and counting begun. During the counting cycle a separate spectrum was obtained in each time bin, and these spectra were stored in separate

Figure 7. Schematic block diagram of apparatus used in half-life measurements

parts of the analyzer memory. (A time bin is a segment of the counting cycle, usually small compared to the half-life.) At the end of the counting cycle the tape was moved, a fresh sample was deposited, and a new counting cycle was started. This process was repeated until a satisfactory number of counts was stored in each time bin. The spectra for each time bin were added together in the analyzer memory, and later transferred to magnetic tape.

Signals from the Ge(Li) detector were amplified and then processed by the ADC which is part of the two-parameter input unit. The other part of this unit is the spectrum multiscaler logic unit. This unit controls operation of the two-parameter unit and also determines the number and duration of time bins. Control of the two-parameter unit can be either internal or external. For these measurements the control was external, provided by the DAS: the ACC signal from the DAS was inverted and fed into the EXT START BNC of the spectrum multiscaler, thus turning on the two-parameter unit whenever the DAS was in the accumulate mode. The spectrum multiscaler provides routing signals of up to 6 bits binary (allowing $2^6 = 64$ time bins). This routing signal was combined with the energy signal from the ADC in a region selector. This combined signal then served as an address for storage in the 16K analyzer. The most significant bits of the total signal contain the routing information and the least significant bits

the energy information. The routing bits change as the counting progresses from one time bin to another, thus directing different time bins into different parts of the analyzer memory. (Patch cables on the front of the region selector determine how the energy and routing signals are combined.) Figure 8 is an illustration of the two-parameter input unit and region selector set up for 32 time bins of .2 sec. duration each.

For the decay of ^{126}Cd 16 time bins of duration .1 sec. were used. Previous studies had shown that the half-life of this isotope was 0.5 sec,⁵ hence a range of 1.6 sec. was considered adequate. Each spectrum was 1K and covered 0 - 500 keV. (The two strongest Cd gamma rays are at 260 keV and 428 keV.) Total running time was 16 hours.

Sixteen time bins were also used for the In decay; each bin was 0.4 sec. Two ^{126}In isomers with half-lives of 1.6 and 2.1 seconds had been reported,¹⁶ so for this reason a multispectral range of 6.4 sec. was chosen. Each spectrum was again 1K and covered 2500 keV. During this run the beam was collected for 6 sec. before counting was started. Total running time in this case was 11 hours.

Gamma-gamma coincidence measurements

Figure 9 is a block diagram of the apparatus used for the coincidence measurements. The two large-volume Ge(Li) detectors which have been described in Table I (Ge(Li) A and

Figure 8. Schematic illustration of two-parameter input unit and region selector

Figure 9. Schematic block diagram of apparatus used in coincidence measurements

Ge(Li) B) were used for these measurements. No LEPS-Ge(Li) coincidence measurements were made because of a lack of time. Other equipment used for the coincidence measurements is listed in Table V. A brief description of the operation of this apparatus follows.

Table V. Apparatus used in coincidence measurements

Timing Filter Amplifier	Ortec Model 454
Constant-Fraction Timing Discriminator	Ortec Model 463
Time-to-Pulse-Height Converter	Ortec Model 437
Single Channel Analyzer	Ortec Model 420

Each detector preamplifier has two outputs. One is used for energy analysis and the other is used to determine when a coincidence event has occurred. When a coincidence event occurs the latter output from each detector, also called the timing pulse, is amplified and shaped by the timing filter amplifier and used as the input to a constant-fraction timing discriminator (CFTD). (Constant-fraction timing is used to obtain a timing pulse independent of the energy of the gamma ray. This method minimizes time jitter due to differences in

pulse size.) One of the CFTD's then provides the START signal for the time-to-pulse-height converter (TPHC), and the logic signal from the other CFTD, delayed by approximately 60 ns., is used as the STOP signal for the TPHC. The output of the TPHC, which is a pulse whose height is proportional to the time between the start and stop signals, is then fed into the SCA. The window of the SCA is set to accept a suitable range of pulses, and any events occurring within this time range (usually the window is about 50 ns.) are coincidence events. Each ADC is gated by the output of the SCA when a coincidence event occurs (i. e. when two gammas are detected (by different detectors) within 50 ns. of one another). Both ADC's were set for 8K spectra with a compression ratio of 2 to 1; hence, the resulting coincidence array was 4K by 4K. The coincidence information was stored in a buffered memory event by event and periodically transferred to magnetic tape.

During the coincidence measurement the detectors were located at the parent port of the MTC. Beam deposition and counting were done simultaneously, and the tape was moved every 5 minutes. A total of approximately 3×10^6 events were recorded, and total running time for the coincidence experiment was 36 hours.

CHAPTER III. DATA ANALYSIS

Transition Energies and Intensities

As indicated previously, data was transferred periodically to magnetic tape during the unknown runs. These spectra were added together where necessary using the code DISKRITE, and then stored on a private disk using the same code. Disk storage was chosen because it greatly simplifies later data handling. DISKRITE as well as the other codes used in this analysis are also stored on disk and can be accessed easily with a few job control statements.

Once the spectra had been stored on disk, the code UNIPLOT was used to obtain a plot of each spectrum. UNIPLOT can be used to plot the data either as a function of energy or channel number and has a variety of vertical scale options, including log and square root which were used most often in this analysis. By comparing the plots of the parent unknown, the daughter unknown and the background spectra it was possible to identify most of the Cd and In peaks and also to identify the major sources of contamination. Some of the Cd and In peaks were too weak to be identified in the singles spectra and could only be identified in the coincidence spectra. Most of the contamination was due to neutron activation of the detectors because of the large fast neutron component in the background. Ge capture peaks are clearly

present in all of the spectra. Very little contamination from neighboring masses was apparent.

Spectra were analyzed to determine the peak centroids and areas using the codes PEAKFIND³⁷ and SKEWGAUS³⁸ which are iterative fitting routines. PEAKFIND searches the data, determines the locations of peaks in the spectrum, fits each peak with a gaussian, and calculates the centroid, area, and other parameters for each peak. An individual plot of each peak may be generated with this code, and punched cards containing the values of the fit parameters may be obtained.

SKEWGAUS usually provides a higher quality fit than PEAKFIND and is used for the final fitting. The punched cards generated with PEAKFIND may be used as input for SKEWGAUS.

SKEWGAUS fits each peak with a gaussian skewed on both the high and low energy sides with exponential tails. These parameters as well as others which determine the fit can be varied during the iteration process or set to some finite value if desired. Again the centroid and area for each peak are calculated with SKEWGAUS. Multiplets containing up to nine peaks can be analyzed with this code and individual plots obtained for each. A plot of each peak generated by SKEWGAUS is usually used to determine the quality of the fit. Punched cards with the fit parameters are also provided by SKEWGAUS, and they may be used as input to other codes used in the analysis.

Energies of most of the peaks were obtained from the singles spectra using the code DRUDGE. First, a nonlinearity curve for each detector was determined from the calibration spectra. A weighted least-squares straight line for the energy as a function of channel number was determined for each spectrum (LEPS and Ge(Li) calibration spectra) using the strongest peaks for the fits. Later analysis was simplified by choosing the peaks for the fits from within the regions known to be approximately linear in energy for each detector (300-2500 keV for the large-volume Ge(Li) and 50-150 keV for the LEPS). The least-squares energy of each peak was then calculated and subtracted from the true energy to obtain the nonlinearity as a function of energy. A weighted least-squares fit to the linear region was used to determine the nonlinearity as a function of energy in this region, and smooth curves drawn through the nonlinearity points above and below this region were used to determine the nonlinearity as a function of energy in these regions. Figure 10 shows the nonlinearity curve for the Ge(Li) detector; the LEPS curve is similar. The nonlinearity curves determined from the calibration spectra were assumed to be the same for the other (mixed and unknown) spectra.

Next, a weighted least-squares straight line for the energy as a function of channel number was determined for each of the mixed spectra. The same peaks that were used for the

Figure 10. Nonlinearity curve for Ge(Li) detector A

least-squares fits in the calibration spectra were also used in the mixed spectra so as to insure that the nonlinearity is properly mapped onto the mixed spectra. Least-squares values for the energies of these peaks determined from the fits of the calibration spectra were used for this fit. The least-squares values for the energies of the unknown (Cd and In) peaks in the mixed spectra were then calculated and the true energies determined by correcting these values for nonlinearities using the curves determined from the calibration spectra.

Finally, a weighted-least squares straight line for the energy as a function of channel number was determined for each of the unknown spectra. Least-squares values for the energies of a few of the strong peaks in each spectrum (determined from the mixed spectra) were used for these fits. The least-squares energies for the remaining unknown peaks were then calculated and the final true energies obtained by correcting for the nonlinearity, again using the nonlinearity curve determined from the calibration spectrum. The uncertainties in these final energies were determined from the uncertainties in the nonlinearity and the centroid.

Energies of gamma rays above 3.3 MeV were obtained from the high-energy spectrum (that extending from 2.5 to 7.5 MeV). These energies could not be determined in the same manner as for lower energies because the nonlinearity curve

could not be extended above 3.25 MeV. (The highest energy calibration gamma rays are those of ^{56}Co at about 3.5 MeV but statistics in the calibration run were not good enough to justify extending the nonlinearity curve above 3.25 MeV.) The energies of those gamma rays which were strong enough and low enough in energy to have appreciable escape peaks below 3 MeV were determined by taking a weighted average of the escape peak energies. The energies of the remaining peaks were obtained by determining a least-squares straight line for the energy as a function of channel number above 2.6 MeV using the energies of full energy and escape peaks between 2.6 and 3.25 MeV. (The energies of the peaks used for this calibration were determined from the low energy spectrum using the method described previously.)

The energies of those peaks which were too weak to appear in the singles spectra were determined from the coincidence spectra. A weighted least-squares straight line for the energy as a function of channel number was obtained from the coincidence profile (the spectrum of all coincidence events seen by one of the detectors) of detector A. Peaks for which the energy had already been determined from the singles spectra were used for the fit, and the energies of the weak peaks were calculated from the least-squares line.

Relative intensities for the unknown gamma rays were calculated from relative efficiency curves for the detectors.

The code DRUDGE was used to convert the areas of the unknown peaks to relative intensities. Standard sources of ^{56}Co , ^{182}Ta , and ^{226}Ra were used to measure the detector efficiencies. The relative efficiency for each detector was determined as a function of energy by taking the ratio of the peak area to the relative intensity of calibration peaks properly normalized to take into account the different source strength of each standard isotope. The logs of these values were plotted as a function of the logs of the energies, and smooth curves drawn through the points to obtain the efficiencies. Figure 11 is the efficiency curve for Ge(Li) detector A. The efficiency curve for the LEPS detector is similar.

The relative efficiencies of high-energy peaks were determined by assuming that the efficiency on a log-log plot is linear above 3.2 MeV. The relative intensities of most of the peaks were determined from the singles spectra. The relative intensities of the very weak gamma rays were determined from the gated coincidence spectra.

Multiscale Data

Multiscale data were recorded first on magnetic tape as 8K data sets and then transferred to disk. The strongest transitions in each case were used to determine the half-life. The peaks corresponding to these transitions in each time bin were fit using the code SKEWGAUS to determine their

Figure 11. Efficiency curve for Ge(Li) detector A

areas. A weighted least-squares straight line for the log of the area as a function of time was then determined for each transition and from this the half-life was calculated. These areas were normalized to take into account live time differences for the different time bins.

All of the decay curves were fit with a straight line of the form

$$\ln A = \ln A_0 - (\ln 2 / T_{1/2}) \cdot t.$$

The uncertainties in the half-lives were calculated from

$$\sigma_{T_{1/2}} = (T_{1/2})^2 \cdot \sigma_b / \ln 2$$

where σ_b is the uncertainty in the slope b of the least-squares line, and

$$T_{1/2} = -\ln 2 / b$$

is the half-life.³⁹ It was expected that the ground state transition in ^{126}Sn (1141 keV) might show two components, reflecting the different half-lives of the In isomers, but statistics were not good enough to extract two half-lives from the 1141-keV decay curve.

Coincidence Data

Coincidence data were stored in a memory buffer as two-word pairs during the experiment, each word containing an ad-

dress from one of the detectors. When the memory buffer was filled (2K coincidence events) the data were transferred to magnetic tape. Each data set on the tape, which represents one full memory buffer, is called a "buffer". A full tape contains 1700 buffers.

The computer code BUFTAPES was used to analyze the data stored on the buffer tape. This program is used to set a "gate" on a certain region of the 4K channels referenced by one of the detectors, say detector A. A coincidence profile, containing all coincidence events seen by one of the detectors, was used to determine where these gates should be set. All coincidence events which have the channel A address within this gate contribute to that coincidence spectrum. A 4K spectrum is then created from the second half of these two-word pairs and this spectrum is written on another magnetic tape.

In order to determine which transitions are in coincidence with a certain transition, for example, a gate would be set around the peak corresponding to this transition in the coincidence profile for detector A. BUFTAPES then finds all coincidence events for which address A falls within this gate. All transitions in coincidence with the transition of interest then appear in the gated coincidence spectrum. Some of the peaks in the spectrum gated by the transition will correspond to transitions in coincidence with the Compton

background of peaks with energy higher than the energy of the gating transition. These are found by setting a gate on the Compton distribution slightly above the full-energy peak of the gating transition. The spectrum of events in coincidence with the gating peak is then compared to the spectrum of events in coincidence with the Compton background to determine which transitions are actually in coincidence with the ground state transition. Those peaks appearing in the former and not the latter spectrum correspond to transitions in coincidence with the ground state transition. This comparison was made by visual inspection of the spectra.

Construction of the Level Scheme

A preliminary level scheme for ^{126}Sn was constructed from the results of previous studies on this nucleus. No such scheme could be followed for ^{126}In because of the lack of information. The coincidence information was used to establish most of the other levels. There were very few transitions seen in the case of ^{126}In , and this level scheme was constructed solely by inspection. Likewise, most of the levels in ^{126}Sn were established by inspection. The code LVLSURCH was used as a check to determine if any placements had been missed in the inspection process and also to determine if any alternate placements were possible. (LVLSURCH makes a thorough search of coincidence information, transi-

tion energies, and known levels to determine all possible placements.) In some cases the lack of coincidence data was used to propose the existence of a level. Strong gamma rays that were not seen in the coincidence profiles were assumed to correspond to transitions directly to the ground state from levels fed only by beta transitions. Level energies were determined from the transition energies, weighted by their uncertainties. These calculations were done with the code LEAF, which determines the level energies iteratively. The confidence with which a level is held to exist is indicated by line type. A solid line is used for a level which is well-established and a dashed line is used for a level established by a minimal amount of information only.

Spin and Parity Assignments

Spin and parity assignments for the levels were made on the basis of $\log ft$ calculations using the code LOGFT. This code determines the $\log ft$ from the percent beta decay to a level, the Q -value for this beta transition, and the half-life of the beta decaying nucleus. Also called the comparative half-life, the $\log ft$ for a level is directly related to the strength of the beta transition to that level: the stronger the beta transition to a level the lower the $\log ft$. A list of possible spin and parity changes for beta transitions and their related $\log ft$ values is given in Table VI.⁴⁰

Table VI. Rules for spin and parity assignments based on $\log ft$ values

	Spin Change	Parity Change
$Z < 80$		
$\log ft < 5.9$	$J = 0, 1$	No
$\log f_{1,t} < 8.5$	$J = 0, 1$	Yes or No
$\log ft < 11.0$	$J = 0, 1$ $J = 2$	Yes or No Yes
$\log ft < 12.8$	$J = 0, 1, 2$	Yes or No

Spin and parity assignments cannot be made uniquely on the basis of $\log ft$ values but the possible assignments can usually be limited to one or two values when the spin and parity of the beta-decaying state are known. In the case of no beta feeding to ground state, the amount of beta feeding to an excited level was taken to be the total gamma strength leaving a level minus the total gamma strength entering the level. (Corrections for internal conversion were made where appropriate.) In the case of nonzero beta feeding to the ground state, the beta feeding to an excited level was also determined from the net gamma strength leaving the level, taking into account the amount of ground state feeding.

CHAPTER IV. EXPERIMENTAL RESULTS AND DECAY SCHEMES

Decay of ^{126}Cd ^{126}Cd experimental results

The multiscale data were used to determine the half-lives for ^{126}Cd and ^{126}In . Figure 12 shows the decay curves for the two strongest gamma transitions in ^{126}In . The value of the ^{126}Cd half-life calculated from the 260-keV decay curve is 0.509 ± 0.01 sec., and the value calculated from the 428-keV decay curve is 0.504 ± 0.01 sec. The proposed half-life for ^{126}Cd is therefore 0.506 ± 0.015 sec.

All of the gamma rays which have been assigned to the decay of ^{126}Cd (except the 277- and 325-keV gamma rays which were seen only in the coincidence spectra) are shown in the singles spectra of figures 13 and 14. Both the Cd enhanced spectrum (which was obtained at the parent port during beam deposition) and the In enhanced spectrum (which was obtained at the daughter port following a short delay after beam deposition to allow the Cd to die away) are shown in these figures. Figure 13 shows the LEPS spectra and figure 14 shows the Ge(Li) spectra. Note that the Cd peaks are completely gone from the In enhanced spectra, reflecting the short half-life of ^{126}Cd .

Analysis of the 325-keV peak was hampered by background contamination. This peak is masked by a background peak at

Figure 12. Decay curves for the 260- and 428-keV ^{126}Cd gamma rays

Figure 13. Parent and daughter spectra of gamma rays from the decays of ^{126}Cd and ^{126}In with energy less than 120 keV

Figure 14. Parent and daughter spectra of gamma rays from the decays of ^{126}Cd and ^{126}In with energy from 80 keV to 720 keV

the same position, therefore its energy and intensity were determined from the coincidence spectra. The 277-keV peak is too weak to be seen in the singles spectra, and it too had to be analyzed from the coincidence data. Two other peaks were masked somewhat by ^{126}In peaks. The one at 260 keV was influenced only negligibly by the weak 258-keV transition in ^{126}Sn . The peak at 366 keV is part of a triplet, which has been resolved as is shown in figure 15. There was no interference from background contamination in any of the other ^{126}Cd peaks.

Table VII is a listing of the gamma rays resulting from the decay of ^{126}Cd . For each transition the energy, intensity, and placement is given. Intensities have been normalized to 1000 for the 260-keV transition. Eleven gamma rays have been assigned to the decay of ^{126}Cd , and all except for the 653-keV gamma ray have been placed in the proposed decay scheme. Only the gamma rays at 260- and 428-keV had been reported previously.⁵

Sample coincidence spectra gated by the 260- and 428-keV gamma rays are shown in figure 16. Events in coincidence with the appropriate Compton distribution have not been subtracted from these spectra. Some of the peaks appearing in these spectra therefore are due to coincidences with the Compton distribution of other transitions and do not correspond to actual coincidences with the gating transition.

Figure 15. Triplet of peaks at approximately 365-keV, showing the 366-keV ^{126}Cd peak resolved

Table VII. Gamma transitions observed in the ^{126}Cd decay

Energy (keV)	Intensity ^a	Placement
62.93 $\pm$ 0.20	16 $\pm$ 3	688 - 626
102.8 $\pm$ 0.3	12 $\pm$ 4	688 - 585
260.09 $\pm$ 0.09	1000 $\pm$ 50	260 - 0
277.4 $\pm$ 0.5 ^b	6 $\pm$ 2 ^c	585 - 308
325.3 $\pm$ 0.4 ^b	6 $\pm$ 3 ^d	585 - 260
365.80 $\pm$ 0.20	23 $\pm$ 6	626 - 260
428.11 $\pm$ 0.06	837 $\pm$ 28	688 - 260
555.40 $\pm$ 0.09	48 $\pm$ 6	555 - 0
585.6 $\pm$ 0.6	9 $\pm$ 3	585 - 0
653.08 $\pm$ 0.19	15 $\pm$ 4	unplaced
688.24 $\pm$ 0.10	59 $\pm$ 4	688 - 0

^aIntensities normalized to 1000 for the 260-keV gamma ray.

^bvalues obtained from the coincidence profile.

^cvalue obtained from the spectrum in coincidence with the 103-keV gamma ray.

^dvalue obtained from the spectrum in coincidence with the 260-keV gamma ray.

Table VIII is a summary of the coincidence relationships observed in the ^{126}Cd study.

Figure 16. Gamma spectra in coincidence with the (a) 260- and (b) 428-keV gamma rays from ^{126}Cd

Table VIII. Coincidences observed in the ^{126}Cd decay

Gating Energy (keV)	Definite Coincidences (keV)	Possible Coincidences (keV)
63	366	260
103	277, 325, 586	260
260	63, 103, 325, 366, 428	586 ^a
277	103	
325	103, 260	
366	63, 260	
428	260	
555		
586	103	260 ^a
653		
688		

^aNot consistent with placement proposed in this work.

Discussion of the ^{126}In levels

Figure 17 is the proposed level scheme for the decay of ^{126}Cd . Definite coincidences in this level scheme are indicated by dots. Definite J^π assignments cannot be made for the levels in ^{126}In because the beta feeding to the ^{126}In ground state is not known. The ground state feeding is dif-

difficult to measure due to uncertainties in the relative yields of Cd and In from our ion source. Logft values for the ^{126}In levels were calculated using various assumed values for the ground state beta feeding, and consistency arguments were used to determine the most reasonable J^π assignments in each case. Table IX is a summary of these calculations. In these calculations a Q-value of 4.6 MeV from Garvey-Kelson was used.⁴¹ A discussion of the ^{126}In levels follows Table IX.

Table IX. Logft calculations for the ^{126}Cd decay

Energy Level (keV)	Logft with a Ground State Feeding of				
	0%	1%	50%	90%	99%
0	---	5.8	4.1	3.9	3.8
260	4.7	4.7	5.0	5.7	6.7
555	5.0	5.0	5.3	6.0	7.0
688	3.6	3.6	3.9	4.6	5.6

Ground state ^{126}Cd has a 0^+ ground state. Odd-odd In isotopes from ^{112}In through ^{122}In all have 1^+ ground states. These states are described as primarily $(\pi g_{9/2}, \nu g_{7/2}) 1^+$. The ^{124}In ground state is proposed to be 2^+ and to have the same configuration as in the lower mass even-A In nuclei.

Figure 17. Proposed decay scheme for ^{126}Cd

Based on systematics, the ground state of ^{126}In is expected to be 1^+ or 2^+ and to be described as $(\pi g_{9/2}, \nu g_{7/2})$. Furthermore, there is strong beta feeding to the first excited 2^+ state in ^{126}Sn and no feeding to the first excited 4^+ state (see below for the discussion of the ^{126}In decay). This implies that the J of the ^{126}In ground state is less than 3. (Negative parity states are rejected on the basis of systematics.) The value of 1^+ is less likely because of the strong gamma transitions associated with the ^{126}Cd decay. A 1^+ ground state would be expected to be fed strongly in the beta decay of the 0^+ ^{126}Cd ground state, leaving little beta strength to the excited levels. Such strong ground state beta feeding would make strong gamma transitions unlikely. (Strong ground state beta feedings in the ^{120}In and ^{122}In cases (which have 1^+ ground states) have been used to explain the absence of observable gammas in the decays of ^{120}Cd and ^{122}Cd ,⁹ and the strong gamma transitions associated with the ^{124}Cd decay were taken as evidence for a ground state spin assignment greater than 1 in that case.¹⁰) An assignment of 0^+ for the ground state is unlikely if this state has a simple proton hole-neutron particle configuration because no 0^+ state can be formed from the available shell model states. Thus, an assignment of 1^+ or 2^+ is favored for the ^{126}In ground state.

260.10 $\pm$ 0.08-keV level The strongest gamma ray and the one with the richest coincidence spectrum is at 260 keV. Thus the first excited state is postulated to be at 260 keV. If the ground state beta feeding is less than 90% then the $\log ft$ for the 260-keV level is less than 5.9, indicating an allowed transition. The gamma strength of the ^{126}Cd decay is probably inconsistent with a ground state beta feeding of more than 90%, therefore an allowed transition to the 260-keV level is plausible, and a J^π assignment of 0^+ or 1^+ for this level is reasonable. Again, 0^+ is less likely if most of the low-lying states can be described as simple shell model configurations.

308.0 $\pm$ 0.6-keV level The existence of this level is based on definite coincidences between the 277- and 103-keV gamma rays. It has been indicated by a dashed line because of the paucity of evidence supporting its existence. The 277-keV gamma ray is placed the one at 103 keV because there is no evidence of coincidences between the 277-keV gamma ray and any of the other gamma rays depopulating the 688-keV level. No gamma rays other than the one at 103 keV are observed in coincidence with the 277-keV gamma ray, and hence no gamma rays are shown depopulating the 308-keV level. A spin value greater than 2 is postulated for this level because no gamma rays were observed depopulating it. (A more detailed interpretation of this level will be given in

Chapter V.)

555.40 $\pm$ 0.10-keV level The existence of this level is based on the absence of gamma rays in coincidence with the 555-keV transition. This gamma ray is fairly strong, and hence is expected to proceed directly to the ground state. No strong gamma rays are expected to feed the 555-keV level because of the absence of coincidences in the 555-keV gate. If the ground state beta feeding is less than 90%, the $\log ft$ for the 555-keV level is less than 6.0. Again, ground state feeding is not likely to be greater than 90%, so the beta transition to the 555-keV level is probably allowed. Hence, the J^π for this level is postulated to be 0^+ or 1^+ .

585.4 $\pm$ 0.2-keV level This level is well-established by coincidences between the 260- and 325-keV gamma rays, between the 586- and 103-keV gamma rays, and by the existence of the crossover transition at 586 keV. Determination of the beta feeding to this level is complicated not only by the uncertainty of the ground state beta feeding but also by the possibility of internal conversion of the 102-keV gamma ray which feeds this level. Total gamma intensity entering this level is 12 ± 4 and total gamma intensity leaving the level is 21 ± 5 . If the 102-keV transition is E1 ($\alpha = .17$),⁴² then the total intensity entering the 585-keV level would be 14, leaving the possibility that this level is fed. If, however, the transition is M1 ($\alpha = .52$),⁴² then the total intensity

entering the level is 18, and the possibility of beta feeding is unlikely. Any higher order transitions are unlikely because the conversion coefficients in those cases make the total intensity entering the 585-keV level greater (by 50% or more) than the intensity leaving it. Hence, the multipolarity of the 102-keV transition is probably E1 or M1, although E2 is possible (the conversion coefficient is 1.3 in this case). Since the 688-keV level is postulated to be 0^+ or 1^+ (see discussion of 688-keV level below), the assignment of $J \leq 3$ for the 585-keV level is plausible.

625.6 $\pm$ 0.3-keV level This level is established by coincidences between the 260-, 366-, and 63-keV gamma rays, and by the crossover transition at 428 keV. Again there is a possibility of internal conversion, this time for the 63-keV gamma ray. Examination of the intensity balance for the 626-keV level for various multipolarities shows that only an E1 transition is possible. If the transition were M1 or higher, then the total intensity entering the 626-keV level would be 50% or more, greater than that leaving the level. An E1 transition implies that the 626-keV level has negative parity. Furthermore, since the 688-keV level is 0^+ or 1^+ , the 626-keV level must be 0^- , 1^- , or 2^- .

688.23 $\pm$ 0.08-keV level Most of the beta strength populates this level. It is well-established by coincidences and a good energy match between all but one of the depopulat-

ing cascades. (The sum of the gamma ray energies in the cascade which includes the 63-keV gamma ray differs by 0.6 keV from the sums of the other cascades. This is two standard deviations from the norm of the other sums and could be evidence for a level doublet at 688 keV.) If the ground state beta feeding is less than 99% then the $\log ft$ for the 688-keV level is less than 5.9. As indicated earlier, the ground state beta feeding is not likely to be as large as 99%. Hence, the beta transition to the 688-keV level is probably allowed, and the J^π for this level is most likely 0^+ or 1^+ .

Decay of ^{126}In

Much more information on the level structure of ^{126}Sn than on that of ^{126}In has resulted from these studies. Many gamma rays extending over a wide energy range have been assigned to the ^{126}In decay. This situation is due in part to the large Q-value in the ^{126}In case (approximately twice that of ^{126}Cd) and to the existence of at least two isomers of ^{126}In .

Half-life measurements

Figure 18 shows the decay curves for four of the strongest gamma transitions in ^{126}Sn (the 112-, 909-, 970-, and 1141-keV gamma rays). The 112-keV gamma ray depopulates a high-spin ($J \geq 5$) level at 2162 keV (see discussion of this

Figure 18. Decay curves for the 112-, 909-, 970-, and 1141-keV ^{126}In gamma rays

level below). Since the low spin ^{126}In isomer has been shown to be 1^+ or 2^+ , this level can only be beta fed by the high-spin isomer. (The spin of this isomer is postulated to be 6; see discussion below.) Furthermore, all of the gamma strength feeding this level comes from levels which will be shown to be beta fed only by the high-spin isomer, therefore the decay curve for the 112-keV gamma ray should yield the half-life of the high-spin isomer. Likewise, the decay curve for the 909-keV gamma ray should also yield the half-life of the high-spin isomer because the 909-keV gamma ray depopulates a level which is fed only by the 112-keV gamma ray (no beta feeding to this level). The half-life calculated from the 112-keV decay curve is 2.00 ± 0.06 sec., and the half-life calculated from the 909-keV decay curve is 1.88 ± 0.08 sec. The proposed value for the half-life of the high spin isomer is thus 1.96 ± 0.10 sec., which was obtained from a weighted average of the two above values.

Both the 1141- and 970-keV gamma rays are expected to be produced mainly in the decay of the low-spin isomer, and therefore their decay curves should yield the half-life of this isomer. The 1141-keV gamma ray depopulates the first excited 2^+ level which can only be beta fed by the low-spin isomer. Furthermore, most of the gamma strength feeding this level is from levels which are beta fed only by the low-spin isomer. Similarly, the 970-keV gamma ray depopulates a low-

spin level which is fed mainly by the low-spin isomer. The half-life determined from the 1141-keV decay curve is 1.82 ± 0.06 sec., and that calculated from the 970-keV decay curve is 1.84 ± 0.09 sec. The proposed value for the half-life of the low-spin isomer is thus 1.83 ± 0.11 sec.

Gamma singles measurements

Singles spectra up to 700 keV are shown in the previous section on the decay of ^{126}Cd . Figure 13 shows the LEPS unknown spectra from 20 to 120 keV, and figure 14 shows the Ge(Li) unknown spectra from 100 to 700 keV. The Ge(Li) singles unknown spectrum from 700 to 4400 keV is shown in figure 19. This spectrum was obtained at the parent port during beam deposition. All peaks in this figure, except those labelled as background, are ^{126}In peaks. The highest energy Cd peak observed is that at 688 keV, hence only the spectrum obtained at the parent port is shown in figure 19. The daughter spectrum is essentially the same with regard to the ^{126}In gamma rays except that the total number of counts is less and some of the weak peaks are not as clearly visible. Most of the background peaks in these spectra are due to neutron activation of the detectors or surrounding materials. The fast neutron background during these experiments was very high, and there was thus much activation of the Ge(Li) detectors. The highest and lowest energy gamma rays assigned to the decay of ^{126}In are 4304 and 57 keV re-

Figure 19. Spectrum of gamma rays from the decay of ^{126}In from 700 keV to 4400 keV

spectively.

Table X is a list of the energies, intensities, and placements of the gamma rays assigned to the decay of ^{126}In . Three different intensity normalizations are given in this table. In column A under Intensity the intensities are normalized to 1000 for the total gamma intensity of the 1141-keV gamma ray. In column B the gamma rays assigned to the low-spin decay are normalized to 273 for the 970-keV gamma ray. This normalization has been chosen so that the strength of the 1141-keV gamma ray attributed to the low-spin decay is 1000. In column C the intensities of the gamma rays assigned to the high-spin decay are normalized to 1000 for the 909-keV gamma ray. In order to eliminate confusion, whenever an intensity is given in the text following, it will be from A. Two of these transitions (1053 and 1136 keV) have been placed twice, and their alternate placements have been indicated in Table X. The 1053-keV gamma ray is seen strongly in coincidence with itself and hence is placed connecting both the 3247- and 2195- and the 2195- and 1141-keV levels. The total intensity of the 1053-keV gamma ray determined from the singles spectrum is 29 which is twice that of the 549-keV gamma ray in the spectrum gated by the 1053-keV gamma ray. Since the 549-keV gamma ray has an intensity of 1, the intensity of the 1053-keV gamma ray depopulating the 3247-keV level is taken to be 2, and the intensity of the 1053-keV

gamma ray depopulating the 2195-keV level is taken to be 27. Likewise, the 1136-keV gamma ray is placed connecting both the 3965- and 2829- and the 3247- and 2111-keV levels. This transition has a total intensity of 37 in the singles spectrum and an intensity of 13 relative to 27 for the 632-keV transition in the spectrum gated by the 970-keV gamma ray. Hence, the strength of the 1136-keV gamma ray placed between the 3247- and 2111-keV levels is taken to be 13 and that between the 3965- and 2829-keV levels is taken to be 24.

All but 14 of the gamma rays assigned to ^{126}In were observed clearly in the singles parent spectra. These 14 weak transitions are the ones at 258, 419, 444, 463, 502, 517, 549, 717, 788, 906, 1068, 1328, 1368, and 1755 keV. The 258-keV gamma ray is masked by the much stronger Cd peak at 260 keV in the parent spectrum. This gamma ray, however, is clearly present in the daughter spectrum (see figure 20), and its energy and intensity were determined from this spectrum. The other 13 transitions not observed in the singles spectra were clearly identified in the coincidence spectra, and their energies and intensities were determined from these spectra. (The spectra used to determine the energies and intensities of these weak transitions are identified in Table X.) Two of the weak transitions have only upper limits listed for their intensities. These are the 463- and 1368-keV transitions which were seen only in the spectrum gated by the 269-keV

gamma ray. Since these transitions are the only transitions entering the 2488-keV level their intensities could only be determined relative to each other. Since the intensity of the 269-keV gamma ray is 16, and since this transition is the only one leaving the 2488-keV level the sum of the intensities of the 463- and 1368-keV transitions cannot be greater than 16. This implies that the intensity of the 463-keV transition must be at most 3 and the intensity of the 1368-keV transition at most 13 since the intensity of the 1360-keV transition in the spectrum gated by the 269-keV gamma ray is 4 times that of the 463- keV gamma ray. Hence, the upper limits of 3 and 13 have been listed in Table X for the 463- and 1368-keV gamma rays, respectively.

Coincidence measurements

Coincidence spectra for the 909- and 1141-keV gates are shown in figure 21. Again, events in coincidence with the Compton background have not been subtracted from these spectra, so that some of the peaks represent coincidences with transitions other than the gating transitions. The spectrum gated by the 1141-keV gamma ray is the richest. (The 1141-keV gamma ray depopulates the first excited 2^+ state in ^{126}Sn and thus has many gamma rays in coincidence with it.) The 909-keV gate is the richest spectrum gated by a transition from a high-spin level. Table XI is a summary of the coincidence data.

Table X. Gamma transitions observed in the ^{126}In decay

Energy (keV)	Relative Intensity		Placement (keV)
	A ^a	B ^b	
57.36 $\pm$ 0.16	11 $\pm$ 2		2220 - 2162
111.79 $\pm$ 0.07	220 $\pm$ 20		2162 - 2050
258.5 $\pm$ 0.2 ^d	25 $\pm$ 8 ^d		2478 - 2220
269.26 $\pm$ 0.13	16 $\pm$ 2		2489 - 2220
316.03 $\pm$ 0.16	28 $\pm$ 5		2478 - 2164
363.3 $\pm$ 0.4	9 $\pm$ 3		2525 - 2162
418.6 $\pm$ 0.5 ^e	2 $\pm$ 1 ^e	3 $\pm$ 1	3247 - 2829
444.2 $\pm$ 0.5 ^f	4 $\pm$ 2 ^f		2663 - 2219
462.9 $\pm$ 0.5 ^g	$\leq$ 3 ^g		2951 - 2488

^a Intensities normalized to 1000 for the 1141-keV gamma ray.

^b Intensities normalized to 273 for the 970-keV gamma ray.

^c Intensities normalized to 1000 for the 909-keV gamma ray.

^d Energy and intensity determined from daughter singles spectrum.

^e Energy and intensity determined from the spectrum in coincidence with the 1687-keV gamma ray.

^f Energy and intensity determined from the spectrum in coincidence with the 1193-keV gamma ray.

^g Energy and intensity determined from the spectrum in coincidence with the 269-keV gamma ray.

Table X. (continued)

Energy (keV)	Relative Intensity			Placement
	A	B	C	
501.5 $\pm$ 0.4 ^h	11 $\pm$ 4 ^h		45 $\pm$ 16	2663 - 2162
517.5 $\pm$ 0.5 ^e	4 $\pm$ 2 ^e	5 $\pm$ 3		3345 - 2829
548.6 $\pm$ 0.5 ^h	1.0 $\pm$ 0.5 ⁱ	1.2 $\pm$ 0.6		2743 - 2195
631.94 $\pm$ 0.09	27 $\pm$ 3	36 $\pm$ 4		2743 - 2195
716.9 $\pm$ 0.5 ^j	4 $\pm$ 1 ^j	5 $\pm$ 1		2829 - 2111
788.4 $\pm$ 0.51 ^h	12 $\pm$ 5 ^k		49 $\pm$ 20	2951 - 2162
905.8 $\pm$ 0.5 ^l	2 $\pm$ 1 ^l		8 $\pm$ 4	3856 - 2951
908.71 $\pm$ 0.08	243 $\pm$ 13		1000 $\pm$ 53	2050 - 1141
969.74 $\pm$ 0.08	207 $\pm$ 11	273 $\pm$ 13		2111 - 1141
1053.39 $\pm$ 0.17	29 $\pm$ 4	35 $\pm$ 7		2195 - 1141
		3 $\pm$ 1		3247 - 2195
1068.3 $\pm$ 0.4	14 $\pm$ 6	18 $\pm$ 8		2210 - 1141

^hEnergy determined from the coincidence profile.

ⁱIntensity determined from the spectrum in coincidence with the 1141-keV gamma ray.

^jEnergy and intensity determined from the spectrum in coincidence with the 970-keV gamma ray.

^kIntensity determined from the spectrum in coincidence with the 112-keV gamma ray.

^lEnergy and intensity determined from the spectrum in coincidence with the 789-keV gamma ray.

Table X. (continued)

Energy (keV)	Relative Intensity			Placement
	A	B	C	
1135.88 $\pm$ 0.19	37 $\pm$ 7	32 $\pm$ 10 17 $\pm$ 4		3965 - 2829 3247 - 2111
1141.36 $\pm$ 0.07	1000 $\pm$ 50	1000 $\pm$ 66	1000 $\pm$ 53	1141 - 0
1192.80 $\pm$ 0.14	10 $\pm$ 2		41 $\pm$ 8	3856 - 2663
1229.61 $\pm$ 0.14	19 $\pm$ 4	25 $\pm$ 5		2371 - 1141
1252.1 $\pm$ 0.2	29 $\pm$ 5	38 $\pm$ 7		3965 - 2712
1327.7 $\pm$ 0.4 ^h	9 $\pm$ 3 ⁱ	12 $\pm$ 4		3965 - 2637
1367.6 $\pm$ 0.5 ^g	$\leq$ 13 ^g		$\leq$ 53	3856 - 2488
1378.35 $\pm$ 0.13	56 $\pm$ 6		230 $\pm$ 25	3856 - 2219
1495.4 $\pm$ 0.3	16 $\pm$ 3	21 $\pm$ 4		2637 - 1141
1571.24 $\pm$ 0.13	33 $\pm$ 4	44 $\pm$ 5		2712 - 1141
1594.0 $\pm$ 0.3	17 $\pm$ 4	22 $\pm$ 5		3965 - 2371
1601.8 $\pm$ 0.3	24 $\pm$ 4	32 $\pm$ 5		2743 - 1141
1636.89 $\pm$ 0.11	57 $\pm$ 5		235 $\pm$ 21	3856 - 2219
1687.27 $\pm$ 0.17	3 $\pm$ 4	40 $\pm$ 5		2829 - 1141
1755.0 $\pm$ 0.5 ⁱ	4 $\pm$ 2 ⁱ	5 $\pm$ 3		3965 - 2210
2105.9 $\pm$ 0.3	30 $\pm$ 5	40 $\pm$ 7		3247 - 1141
2111.4 $\pm$ 0.2	47 $\pm$ 5	62 $\pm$ 7		2111 - 0
2203.95 $\pm$ 0.16	36 $\pm$ 6	48 $\pm$ 8		3345 - 1141
2371.1 $\pm$ 0.3	25 $\pm$ 5	33 $\pm$ 7		2371 - 0
2637.2 $\pm$ 0.4	9 $\pm$ 3	12 $\pm$ 4		2637 - 0

Table X. (continued)

Energy (keV)	Relative Intensity			Placement
	A	B	C	
2745.9 $\pm$ 0.4	11 $\pm$ 4	15 $\pm$ 5		3887 - 1141
2822.7 $\pm$ 0.4	10 $\pm$ 4	13 $\pm$ 5		3965 - 1141
3247.3 $\pm$ 0.3	28 $\pm$ 5	37 $\pm$ 7		3247 - 0
3345.5 $\pm$ 0.5	300 $\pm$ 16	396 $\pm$ 21		3345 - 0
3887.6 $\pm$ 0.5	64 $\pm$ 6	85 $\pm$ 8		3888 - 0
3964.7 $\pm$ 0.5	38 $\pm$ 6	50 $\pm$ 8		3965 - 0
4240.3 $\pm$ 0.7	21 $\pm$ 4	28 $\pm$ 5		4240 - 0
4304.2 $\pm$ 0.6	31 $\pm$ 4	41 $\pm$ 5		4304 - 0

Level schemes

Figures 22 and 23 are the proposed level schemes for the ^{126}In low-spin and high-spin decays, respectively. (Dots in these decay schemes again indicate definite coincidences and circles indicate possible coincidences.) Levels which have connecting transitions to the 0^+ ground state were assumed to be low-spin levels and were assigned to the low-spin decay. Similarly, levels which do not have connecting transitions to the ground state but which only depopulate to high-spin levels were assumed to belong to the high-spin decay. Spins

Figure 20. Segment of daughter spectrum showing 258-keV ^{126}In peak

Figura 21. Gamma spectra in coincidence with (a) 909- and (b) 1141-keV gamma rays from ^{126}In

Table XI. Coincidences observed in the ^{126}In decay

Gating Energy (keV)	Coincidences Observed (keV)	
	Definite	Possible
57	112	909
112	57, 316 363, 502, 909, 1193, 1141, 1378, 1788	906
258	1378	
269	463, 1368	
316	112, 909, 1141, 1378	
363	112, 909, 1141	
444		1193
502	909, 1193	112, 1141
549		1053, 1141
632	970, 1141, 2111	
788	112, 906, 909, 1141	
909	112, 316, 363, 502, 788, 1141, 1193, 1252, 1378	906
970	632, 718, 1136, 1141	
1053	1053, 1141	549
1068	1141, 1755	
1136	970, 1141, 1687	
1141	112, 316, 363, 502, 632, 788, 909, 1053, 1068, 1136, 1230, 1252, 1378, 1495, 1571, 1594, 1602, 1687, 2105, 2746, 2823	57, 549, 906, 1193, 1328, 1755

Table XI. (continued)

Gating Energy (keV)	Coincidences Observed (keV)	
	Definite	Possible
1193	112, 502, 909	444
1230	1141, 1594	
1252	909, 1141, 1571	
1328	1141, 1495	2637
1368	269	
1378	112, 258, 316, 909	1141
1495	1141, 1328	
1571	1141, 1252	
1594	1141, 1230, 2371	
1602	1141	
1687	1136, 1141	419, 518
1755	1068	1141
2106	1141	
2111	632	
2204	1141	
2371	1594	
2637		1328
2746	1141	
2823	1141

Figure 22. Proposed decay scheme for low-spin ^{126}In isomer

Figure 23. Proposed decay scheme for high-spin ^{126}In isomer

and parities of some of the ^{126}Sn levels had been established previously and these were used as an aid in this separation. All of the levels could be assigned to one isomer or the other in this way, and none except the 1141-keV level appears in both level schemes. Parent-daughter ratios of the areas of all but the weakest gamma rays were calculated in an attempt to separate the gamma rays into two groups based on half-life. These ratios could not be separated into two distinct groups, however, except for a few of the strongest transitions because of the closeness of the half-lives. If the half-lives had been a factor of two different from one another instead of being almost the same, then this method would have made possible an unambiguous separation in most cases.

As in the case of ^{126}Cd it is difficult to make J^π assignments for the low-spin isomeric decay on the basis of $\log ft$ calculations because the ground-state beta feeding is not known. J^π assignments for the high-spin decay are not complicated by this problem. The beta feeding to the ^{126}Sn ground state in the case of the high-spin decay must be 0 because the ^{126}Sn ground state is 0^+ . In order to limit the J^π possibilities for the low-spin levels the same procedure was followed for the In decay as for the Cd decay. A number of possible values for the ground-state feeding were assumed and $\log ft$ calculations made with these assumptions. Consistency

arguments were then applied to obtain the most reasonable J^π assignments. The Q-values for the low- and high-spin decays are 8.17 ± 0.08 and 8.06 ± 0.17 MeV, respectively.¹⁶ Table XII is a listing of the results of the $\log ft$ calculations for the low-spin isomer, and Table XIII is a listing of $\log ft$ values for the high-spin isomer.

Table XII. $\log ft$ calculations for the low-spin ^{126}In isomer

Level (keV)	$\log ft$ Assuming Ground State Feeding of					
	0%	1%	20%	50%	90%	99%
0	---	7.5	6.2	5.8	5.5	5.5
1141	5.8	5.8	5.9	6.1	6.8	7.9
2111	5.7	5.7	5.8	6.0	6.7	7.7
2195	6.6	6.6	6.7	6.9	7.6	8.6
2210	7.0	7.0	7.1	7.3	8.0	8.9
2371	6.5	6.5	6.6	6.8	7.5	8.5
2637	6.7	6.7	6.8	7.0	7.7	8.7
2743	6.1	6.1	6.2	6.4	7.1	8.1
3247	5.8	5.8	5.9	6.1	6.8	7.7
3345	5.1	5.1	5.2	5.4	6.1	7.1
3887	5.5	5.5	5.6	5.8	6.5	7.5
3965	5.2	5.2	5.3	5.5	6.2	7.2
4240	5.9	5.9	6.0	6.2	6.9	7.8

Table XII. (continued)

Level (keV)	Logft Assuming Ground State Feeding of					
	0%	1%	20%	50%	90%	99%
4304	5.7	5.7	5.8	6.0	6.7	7.8

Table XIII. Logft values for transitions to the high-spin ^{126}Sn levels

Level (keV)	% Beta Feeding	Logft
2163	18.3 ± 13.3	5.7 ± 0.3
2219	14.9 ± 10.7	5.7 ± 0.3
2525	3.4 ± 1.2	6.3 ± 0.2
2663	6.1 ± 1.9	6.0 ± 0.1
2951	5.3 ± 1.5	5.9 ± 0.1
3856	51.9 ± 3.8	4.6 ± 0.1

Discussion of the levels fed by the high-spin isomer

Two of the levels in the high-spin decay scheme, those at 2163 and 2219 keV, are strongly fed and have been used to postulate a J value of 6 for the high-spin isomer. The logft

for each of these levels is less than 5.9 indicating allowed beta transitions, although the uncertainties in these values admit the possibility of first-forbidden transitions. Two different assignments for the J^π of the 2162-keV level have been made previously. Fogelberg¹⁷ assigned 5⁻ to this level on the basis of systematics and conversion measurements. Flynn et al.¹⁹ assigned 6⁺ to this level on the basis of distorted wave fits to angular distributions from the $^{124}\text{Sn}(t,p)^{126}\text{Sn}$ reaction data. Both investigators agree that the 2219-keV level is 7⁻. This is also consistent with systematics (see Chapter V for a discussion of the systematics of levels in even-even Sn nuclei). Fogelberg measured the conversion coefficient of the 57.4-keV transition connecting the 2219- and 2162-keV levels and determined that the transition is E2 which supports the 5⁻ assignment. The uncertainty in the conversion coefficient measurement is not likely to be large enough to admit the possibility of an E1 transition because the E1 and E2 conversion coefficients are an order of magnitude different at this energy. Furthermore, Fogelberg measured the conversion coefficient of the transition from the 2162- to the 2050-keV level and determined a multipolarity of E1 for this transition. An assignment of 4⁺ (implying that the 2162-keV level is 5⁻) for the 2050-keV level is consistent with systematics and also with the single-particle estimate for the half-life of an E2 tran-

sition at 909 keV. (There is a strong transition at 909 keV which connects the 2050-keV level with the 1141-keV level.) If the level at 2050 keV is 5^- as postulated by Flynn et al. then the 909-keV transition to the 1141-keV level would be $E3$ and its half-life would be approximately 10 microseconds,⁴³ which would make it impossible to detect coincidences between the 909-keV transition and any feeding the 2050-keV level. On the other hand, if the transition is $E2$, then the half-life of the transition should be approximately 0.1 nanosecond. Since coincidences are definitely seen between the 909-keV gamma ray and gamma rays feeding this level, an assignment of 4^+ rather than 5^- is more reasonable for the 2050-keV level which favors 5^- rather than 6^+ for the 2162-keV level. Since the level at 2162 keV is probably 5^- and the level at 2219 keV is 7^- , an assignment of 6^- for the high-spin isomer is reasonable if the beta transitions to these levels are allowed.

Ground state This level is postulated to have a J^π of 0^+ as do the ground states of all even-even nuclei. Hence, this level cannot be beta fed in the decay of the high-spin isomer.

1141.38 $\pm$ 0.07-keV level This level has a J^π of 2^+ , therefore it cannot be beta fed in the decay of the high-spin isomer. The 2^+ assignment is based on systematics and the fact that all even-even Sn nuclei have a J^π of 2^+ for the

first excited state.

2050.09 $\pm$ 0.08-keV level This level is established by definite coincidences between the 1141-, 909-, and 112-keV gamma rays. If the 112-keV transition feeding it is E1 ($\alpha = .129$)⁴² as proposed by Fogelberg,¹⁷ then the intensity of this transition corrected for internal conversion just matches the intensity of the 909-keV gamma ray depopulating the level. Hence, the beta feeding to this level is 0. As indicated previously an assignment of 4⁺ is favored for this level.

2162.88 $\pm$ 0.08-keV level This level is well-established by coincidences between many transitions. It is beta fed but the uncertainty in the feeding is large because of the large conversion coefficient for the 57-keV transition feeding this level. A multipolarity of E2 for this transition is assumed (from Fogelberg), and the conversion coefficient taken to be 11.86.⁴² The $\log ft$ calculated for this level is 5.7 ± 0.3 indicating an allowed transition. As indicated above, this level has been observed in previous studies and is proposed to have a J^π of 6⁺ by Flynn et al.¹⁹ and 5⁻ by Fogelberg.¹⁷ Internal conversion measurements reported by Fogelberg favor the 5⁻ assignment and this has been adopted here.

2219.25 $\pm$ 0.11-keV level The half-life of the 57-keV transition leaving this level is long enough (approximately 1

microsecond⁴³) to make it impossible to see direct coincidences between it and any transitions entering the level, so there is no direct coincidence information to support its existence. Good energy matches for the numerous transitions going through this level support its existence, and it has also been observed in previous studies.^{17,18} As in the case of the 2162-keV level, the large conversion coefficient for the 57-keV transition introduces a large uncertainty in the beta feeding to this level. The $\log ft$ calculated for this level is 5.7 ± 0.3 , favoring an allowed transition. This level is postulated to be 7^- by both Flynn et al. and Fogelberg, and this assignment has been adopted here.

2477.88 $\pm$ 0.14-keV level This level is established by definite coincidences between the 1387- and the 258- and 316-keV gamma rays. Coincidences were also observed between the 316- and 112-keV gamma rays. There is also a good energy match between the 258- + 57-keV cascade and the 316-keV gamma ray. This level was also observed at 2478.0 keV in the decay work of Fogelberg¹⁷ but not in the reaction studies of Bjerregaard et al.¹⁸ or Flynn et al.¹⁹ It is not beta fed but it is populated by a 1378-keV gamma transition from a level at 3856 keV (see below for the discussion of this level). Furthermore, it depopulates only to the 5^- and 7^- levels at 2162 and 2219 keV. This limits the spin to 5^- , 6, or 7^- . Absence of a transition to the 4^+ level at 2050 keV

makes the 5^- assignment unlikely; hence an assignment of 6 or 7^- is favored for this level.

2488.48 $\pm$ 0.21-keV level This new level is established by definite coincidences between the 269- and 463-keV gamma rays and the 1368-keV gamma ray. The 463- and 1368-keV gamma rays, however, are seen only in coincidence spectra, and their intensities relative to the 269-keV gamma ray are uncertain. Hence, no beta feeding for this level can be determined and no $\log ft$ can be calculated. Since this level is observed to depopulate only to the 7^- level at 2219 keV and to be populated by a transition from the high-spin level at 3856 keV, it is assumed to be a high-spin level. Thus an assignment of $J \geq 6$ is reasonable.

2525.20 $\pm$ 0.41-keV level This level is established only by coincidences between the 663-keV gamma ray and the 112-, 909-, and 1141-keV gamma rays. There is no other evidence to support its existence, and it has been indicated by a dashed line. It is only weakly beta fed and has a $\log ft$ of 6.2 ± 0.2 . The beta transition to this level is therefore allowed or first forbidden. Since this level depopulates only to the 5^- level at 2162 keV it is assumed to be a high-spin level. If the high-spin ^{126}In isomer is 6^- , the possible J values for this level are 5, 6, and 7. Since there is a transition only to the 5^- level, the assignment of 5 or 6 is favored.

2663.39 $\pm$ 0.16-keV level This level is established by definite coincidences between the 502- and the 1141-, 909-, 112-, and 1193-keV gamma rays, indicating that these transitions must form a cascade. There is also a possible coincidence between the 1193-keV gamma ray and the one at 444 keV, indicating a transition between the 2663- and 2219-keV levels. This could be the same level as that seen at 2659 keV by Bjerregaard et al. in the (t,p) reaction.¹⁸ No spin assignment was proposed for this level by Bjerregaard et al. This is only weakly fed and has a $\log ft$ of 6.0 ± 0.1 . Thus the spin is limited to 5, 6, or 7, and since it depopulates only to the 5- level, $J = 5$ or 6 is favored.

2950.70 $\pm$ 0.64 keV level This new level is established by definite coincidences between the 788-keV gamma ray and the 1141-, 909-, and 112-keV gamma rays, and observation in coincidence spectra of weak transitions at 463 and 906 keV. This level is slightly beta fed but the $\log ft$ is not less than 5.9 unless the intensity of the 463-keV transition is the maximum allowable. If the 463-keV transition has the maximum allowable intensity, then the beta transition to this level could be allowed. (It is 5.9 ± 0.1 for the maximum intensity of 3.) Hence, the spin possibilities are 5, 6, or 7, but an assignment of 5 or 6 is favored because of the transition to the 5- level, and the absence of a transition to the 7- level.

3856.18 $\pm$ 0.08-keV level This level is the only very strongly fed high spin level, receiving over half of the beta strength. It is well-established by 5 transitions which depopulate it and has been reported also by Fogelberg.¹⁷ The $\log ft$ for this level is 4.5 ± 0.1 , indicating that the beta transition is definitely allowed. If the high-spin isomer has a J^π of 6^- , then this level must be 5^- , 6^- , or 7^- . Since there is only a transition to the 7^- level and not to the 5^- level, the assignment of 7^- is favored.

Discussion of the levels fed by the low-spin isomer

Ground state As in all even-even nuclei the ^{126}Sn ground state is expected to be 0^+ . The beta feeding to this level is not known. It is reasonable to assume, however, that the ground state beta feeding is not high because of the large gamma strength observed in the low-spin decay.

1141.38 $\pm$ 0.07-keV level This level has been observed in the decay studies of Aleklett et al.¹⁶ and Fogelberg¹⁷ and in the reaction studies of Bjerregaard et al.¹⁸ and Flynn et al.¹⁹ and is known to be a 2^+ state. The 1141-keV transition has the richest coincidence spectrum and the greatest intensity. This level is strongly fed in the low-spin decay.

2111.18 $\pm$ 0.07-keV level This new level is well-established by coincidences between the 970-, 632-, and 1141-keV gamma rays, and by a crossover transition at 2111.39

± 0.22 keV. It has not been observed in any of the previous studies of ^{126}Sn . If the ground state beta feeding is less than 20%, then the $\log ft$ for this level is less than 5.9, which implies that the J^π for this level is 1^+ , 2^+ , or 3^+ . Since the crossover transition at 2111 keV populates the 0^+ ground state, a 0^+ assignment is ruled out. Also, a 3^+ assignment is less likely because of this crossover transition. Hence, an assignment of $(1,2)^+$ is favored for this level.

2194.61 $\pm$ 0.31-keV level Definite coincidences between the 1053- and 1141-keV gamma rays and possible coincidences between the 1053- and 549-keV gamma rays establish the existence of this level. It is fed slightly but its $\log ft$ is greater than 6.6, indicating the possibility of a first forbidden beta transition. It is expected to be a low-spin level because it depopulates only to the first excited 2^+ level and is not fed by any gamma transitions from high-spin levels. A $(2,3)$ assignment is most likely for this level because it depopulates to the first excited 2^+ level but not to the 4^+ level at 2050 keV or the ground state.

2209.71 $\pm$ 0.33-keV level This level is established by definite coincidences between the 1141-, 1069-, and 1755-keV gamma rays. It has been indicated by a dashed line, however, because the order of the 1069- and 1755-keV transitions could be reversed. They have been placed in the order given because the intensity of the 1069-keV transition is

greater than that of the 1755-keV transition. The $\log f_{1t}$ for this level is 8.9 or greater indicating that the transition could be first forbidden unique. Thus, this level could be 0, 1, 2, 3, or 4⁻, and an assignment of $J \leq 4$ is postulated based on the absence of a transition to 4⁺ level at 2050 keV.

2370.98 $\pm$ 0.12-keV level This level is established by definite coincidences between the 1141- and 1229-keV gamma rays and between the 1594-keV gamma ray and the 1230- and 2371-keV gamma rays. A spin greater than 2 for this level is not likely because of the transition to the 0⁺ ground state, and an assignment of 0 is ruled out for the same reason. We therefore postulate J to be 1 or 2 for this level. Flynn et al.¹⁹ observed a level at 2378 $\pm$ 5 keV in the (t,p) reaction and assigned an L value of 2 for the transfer to this level. This is probably the same as the level observed at 2371 keV in this work, therefore an assignment of 2⁺ is the favored one for this reason. (2⁺ is the natural parity state in the (t,p) reaction.)

2636.99 $\pm$ 0.21-keV level This level is established by a definite coincidence between the 1495- and 1141-keV gamma rays and the existence of the crossover transition at 2637.2 $\pm$ 0.4 keV. There is also a definite coincidence between the 1495- and 1328-keV gamma rays, leading to an established level at 3964 keV (see discussion below). Since the 2637-keV transition goes to the ground state, J = 3 is not

likely and $J = 0$ is forbidden, therefore $J = 1$ or 2 is favored for this level.

2712.60 $\pm$ 0.15-keV level Definite coincidences between the 1141-, 1252-, and 1571-keV gamma rays establish this level. These gamma rays also form a cascade depopulating an established level at 3964 keV. Flynn et al. in (t,p) work reported a level at 2720 ± 5 keV in ^{126}Sn , which is probably the same as the one observed in the present study at 2713 keV. He assigned an L value of 3 for the transfer to this level. A 3^- assignment for this level is preferred since it is a natural parity state in the (t,p) reaction.

2743.16 $\pm$ 0.13-keV level No gamma transitions have been observed which populate this level. There are three gamma rays which depopulate it, and their placements are confirmed by coincidence data. Hence, this level appears to be well-established. Due to observation of gamma de-excitation to the 2^+ level at 1141 keV, we postulate $J \leq 3$ for this level.

2828.70 $\pm$ 0.16-keV level Definite coincidences between the 1687- and 1136-keV gamma rays and between the 1141- and 1687-keV gamma rays confirm the existence of this level. There are also a number of weak transitions at 517, 419, and 717 keV which connect it to other established levels. There is no beta feeding to this level but it is assumed to be a low-spin level because it is populated by a transition from

the low-spin level at 3964 keV (see below for the discussion of this level), depopulates only to levels which are low spin, and does not have transitions connecting it to any of the known high-spin levels. Hence, the spin of this level is postulated to be $J \leq 3$.

3247.27 $\pm$ 0.20-keV level No gamma transitions feed this level but there are five which depopulate it. All but one of these transitions is placed with certainty on the basis of coincidence relationships, confirming the existence of this level. The $\log f_{\beta}$ for this level is less than 8.5 for ground state beta feeding less than 90%. Since the beta feeding to the ground state is not likely to be greater than 90% because of the strong ^{126}In gamma rays, the beta transition to this level is probably allowed or first forbidden nonunique. Under these conditions the spin of the level is limited to $J = 0, 1, 2$, or 3 . Furthermore, $J = 0$ is not possible because of the ground state transition, which also makes $J = 3$ unlikely. Thus, an assignment of $(1,2)$ is favored.

3345.37 $\pm$ 0.15-keV level One of the strongest gamma rays observed in this work was the one at 3345.5 ± 0.5 keV. No gamma rays were observed in coincidence with it, thus it was assumed to proceed directly from a level at this energy to the ground state. One other strong transition depopulates this level and is in coincidence with the 1141-keV gamma ray.

This level is strongly beta fed and has a $\log ft$ indicating an allowed transition for ground state beta feedings less than 85%. This indicates a J^π of $(1,2)^+$. 3^+ is not likely because of the strong transition to the ground state, and 0^+ is ruled out for the same reason. Fogelberg also reports the existence of this level.

3887.4 $\pm$ 0.4-keV level This level is established by a coincidence between the 2745- and 1141-keV gamma rays and by a crossover transition at 3887.6 $\pm$ 0.5 keV. The $\log ft$ for this level is less than 8.5 for ground state beta feeding less than 95%. Under these conditions the J value is restricted to 0, 1, 2, and 3. 3 is less likely because of the crossover transition to the 0^+ ground state and 0 is ruled out for the same reason. The assignment is thus postulated to be $(1,2)$.

3964.7 $\pm$ 0.2-keV level This level has the most (7) gamma transitions depopulating it. Four of these transitions are in coincidence with gamma rays which depopulate lower lying levels, and one is a crossover transition to the ground state. For ground state feeding less than 70% the $\log ft$ for this level is less than 5.9. This restricts J^π to 0^+ , 1^+ , 2^+ , or 3^+ . Again 3^+ and 0^+ are unlikely due to the crossover transition to the ground state. Thus an assignment of $(1,2)^+$ is favored because of the crossover transition to the 0^+ ground state.

4240.3 $\pm$ 0.7-keV level This level is established only by the 4240.3-keV transition. No gamma rays were observed to be in coincidence with this transition. Hence, the 4240-keV gamma ray was assumed to depopulate a level at 4240.3 keV. A J assignment of (1,2) is favored for this level. 0 and 3 are unlikely because of the transition to the 0⁺ ground state. This level is indicated by a dashed line because of the small amount of support for its existence.

4304.2 $\pm$ 0.6-keV level This level is also established by only one transition and is also indicated by a dashed line. No gamma rays were observed to be in coincidence with the 4304.2-keV gamma ray, and it was thus assumed to proceed directly to the ground state. Again J = 0 and 3 are unlikely because of the transition to the ground state. Thus we postulate a J of 1 or 2 for this level.

CHAPTER V. DISCUSSION

 ^{126}Cd Decay

In the construction of the decay scheme of ^{126}Cd only one gamma ray was not placed, namely the one at 653 keV. Our value of 0.506 ± 0.015 sec. for the half-life of ^{126}Cd decay is considerably smaller than the range of values of 2 to 200 seconds predicted by the Gross Theory of Beta Decay.⁴⁴ This is also true for the half-lives of ^{120}Cd , ^{122}Cd , and ^{124}Cd . Our value, however, is consistent with the value of 0.53 sec. reported by Grapengiesser.⁵

Since there has been no previous decay scheme postulated for the decay of ^{126}Cd and no information on levels in ^{126}In from reaction studies, the present results can only be compared with the results of studies on other, lower mass, odd-odd In nuclei. Figure 24 shows the low-spin levels up to about 1 MeV for odd-odd ^{112}In through ^{126}In . ^{112}In and ^{114}In levels are taken from Hjorth and Allen,¹⁴ ^{116}In levels from Alexeev et al.,¹⁵ ^{118}In levels from Schwarzbach and Munzel,⁸ ^{120}In and ^{122}In levels from Scheidemann and Hagebo,⁹ ^{124}In levels from Fogelberg et al.,¹⁰ and ^{126}In levels from this study. Note that very little is known about the low-spin level structure of these nuclei, except for ^{114}In and ^{116}In , which are near stability and can be studied via various reactions, and ^{124}In which can be studied via the decay of the

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nuclei from $A = 114$ through $A = 126$

fission product ^{124}Cd .

The most striking feature of these systematics is the difference in level structure between ^{124}In and ^{126}In . One expects a smooth transition from ^{124}In to ^{126}In as only two neutrons are added. The level density at low energies for ^{124}In , however, is much higher than that for ^{126}In . The level structure of ^{126}In is much more similar to those of the lighter odd-odd In nuclei than to that of ^{124}In . If the level density does decrease significantly in going from ^{124}In to ^{126}In , then this may be due to the fact that the ^{126}In nucleus is more tightly bound, since the neutron number of 77 is only 5 away from magic $N = 82$.

It is possible that there are lower lying low-spin levels (similar to ^{124}In) below the 260-keV level in ^{126}In . Such levels, if they exist, were not populated in this experiment. The spectra from these studies have been searched thoroughly but there is no indication of gamma rays which could populate such low-lying levels. ^{126}Cd has a 0^+ ground state, therefore transitions to low-spin levels would be expected to be significant.

There is a possible way of explaining away the difference between ^{124}In and ^{126}In . This is to invert the level scheme of ^{126}In so that the higher level density occurs at lower energies. This inverted scheme is illustrated in figure 25. This possibility, however, is less likely because

Figure 25. Inverted ^{126}Cd decay scheme

the intensity balance of the 428-keV level is upset by this inversion. In other words, there is more gamma strength entering the level than leaving it, and the magnitude of the difference is more than one standard deviation. Although such an inversion is possible it is not likely.

Most of the levels in ^{126}In could be described as two-particle configurations involving the odd proton and the odd neutron. The valence neutrons in ^{126}In are assumed to be those in the $N = 50 - 82$ shell (subshells $h_{11/2}$, $d_{3/2}$, $s_{1/2}$, $g_{7/2}$, and $d_{5/2}$) and the active proton hole is assumed to be in the $P = 28 - 50$ shell (primarily subshells $g_{9/2}$ and $p_{1/2}$). Table XIV is a listing of all possible spin combinations formed by coupling a proton hole to a neutron hole. Note that there is only one 1^+ state possible from these 2-hole configurations, and there are no 0^+ states possible. Hence, the 260-, 555-, and 688-keV levels (which have been postulated to be 0^+ or 1^+) cannot all be simple 2-hole configurations. Such levels could be a proton hole coupled to either a collective vibration or a three neutron hole state.¹⁵

Recall that the level at 688 keV is strongly beta fed. On the basis of $\log ft$ calculations, it is expected to be 0^+ or 1^+ . If this is a simple two-hole configuration, then it is expected to be $(g_{9/2}^{-1}, g_{7/2}^{-1})$ on the basis of the simple shell model, and to more likely be 1^+ than 0^+ since no

Table XIV. Spin and parity combinations formed by coupling a proton hole to a neutron particle for valence states in odd-odd In nuclei

Configuration	Spin Possibilities
($g_{9/2}, h_{11/2}$)	$1^- - 10^-$
($g_{9/2}, s_{1/2}$)	$4^+, 5^+$
($g_{9/2}, d_{3/2}$)	$3^+ - 6^+$
($g_{9/2}, d_{5/2}$)	$2^+ - 7^+$
($g_{9/2}, g_{7/2}$)	$1^+ - 8^+$
($p_{1/2}, h_{11/2}$)	$5^+, 6^+$
($p_{1/2}, s_{1/2}$)	$0^-, 1^-$
($p_{1/2}, d_{3/2}$)	$1^-, 2^-$
($p_{1/2}, d_{5/2}$)	$2^-, 3^-$
($p_{1/2}, g_{7/2}$)	$3^-, 4^-$

simple two-hole 0^+ states are possible. Furthermore, the shell model may provide an explanation of why the transition to this level is so fast. If a $g_{7/2}$ neutron is transformed into a $g_{9/2}$ proton in the beta decay, then the transition is Gamow-Teller allowed and is expected to be very fast.

The level at 300 keV is quite uncertain and has been indicated by a dashed line. The observance of no gamma rays leaving this level is puzzling. It is possible that there

are a number of very weak transitions out of the level which are not seen. This is unlikely, however, because there are only two levels below the 308-keV level. Another possibility is that this level decays primarily by beta emission. Many of the odd-odd In nuclei have three isomers as illustrated in figure 26. Two isomers of ^{126}In (presumably the high and low spin isomers) have been reported previously and were observed in this study. It is possible that this level at 308 keV is a third isomer of intermediate spin. If it is, it is expected to be 4^+ or 5^+ on the basis of systematics. There is no sign of a third isomeric decay in these studies, but the gamma strength for this isomer is expected to be negligible compared to that of the other two because the 308-keV level is only weakly fed.

^{126}In Decay

All gamma rays which have been assigned to the decay of ^{126}In have been placed. (This may be a record.) As mentioned in the previous chapter the levels have tentatively been separated by isomer. This is possible due to the fact that the two isomeric decay schemes have only the ground state and the 1141-keV level in ^{126}Sn in common. (If there is a third isomer which contributes, then this separation may not be valid.)

(8^-) 8.5s.

Figure 26. Systematics of isomeric states in odd-odd In nuclei from $A = 110$ through $A = 126$

Our multiscale measurements indicate that the half-lives of the observed ^{126}In isomers are much closer than had previously been reported by Aleklett et al.¹⁶ In fact, our results show that the low-spin isomer has a shorter half-life than the high-spin isomer, just the reverse of the Studsvik results.¹⁶ It is possible that the phantom third isomer may be the cause of this conflict, but this is not likely because the same transitions are observed by Studsvik as by us and with similar intensities. Note that the error bars for our half-lives overlap, so it is possible that the order is reversed.

In figure 27 our results for the level structure of ^{126}Sn are compared with those of the (t,p) studies of Flynn et al.¹⁹ and the decay work from Studsvik.^{16,17} Level energies are not given in this figure except by inference from the scale at the left side of the figure. Transitions observed at Studsvik are indicated in this figure and intensities and energies for these transitions are compared with our results in Table XV. In this table the intensities of our 57- and 112-keV gamma rays include the contribution from internal conversion. (It is assumed that the Studsvik results are given with the same corrections ($\alpha(57 \text{ keV}) = 11.86$; $\alpha(112 \text{ keV}) = .129^{+2}$). Both intensities and energies agree fairly well. (No uncertainties have been reported from Studsvik.)

Figure 27. Comparison of ^{126}Sn levels with those from previous studies

Table XV. Comparison of ^{126}Sn gamma transition energies and intensities with previous results

Energy (keV)		Intensity	
This Work	Studsvik	This Work	Studsvik
57.36 $\pm$ 0.16	57.3	58 $\pm$ 10	50
111.79 $\pm$ 0.07	111.7	102 $\pm$ 12	90
258.5 $\pm$ 0.2	259	10 $\pm$ 3	11
316.03 $\pm$ 0.16	316.6	12 $\pm$ 2	12
908.71 $\pm$ 0.08	908.5	100 $\pm$ 4	100
1378.35 $\pm$ 0.13	1378.3	23 $\pm$ 3	19
1636.89 $\pm$ 0.11	1637.4	23 $\pm$ 2	23

Except for the first few excited levels, the states observed in the $^{126}\text{Sn}(t,p)$ reaction by Flynn et al.¹⁹ are different from ours. This is not surprising, however, due to the different mechanisms involved in population of the levels. Only the (t,p) levels up to 4 MeV have been listed. Approximately twice as many levels above 4 MeV were observed in the (t,p) experiments, but our study was not sensitive to these levels due to the reduced beta strength at low beta endpoint energies. Some of the L transfer results from the (t,p) work have been useful in establishing J^π assignments for some of the levels postulated in this work.

There have been few theoretical investigations of the level structure of ^{126}Sn . Many more calculations have been done on the lighter even-even Sn nuclei, ^{110}Sn through ^{124}Sn .³⁴ Protons in these calculations are assumed to be inert since their number is 50, which is magic and indicates shell closure. The level structure is assumed to be dominated by 2 and 4 neutron quasiparticle components, although two collective states (the first 2^+ and first 3^-) are known to exist in all even-even Sn nuclei. (Collective states can be described as many qp states.)

Figure 28 shows the systematics of the even-even Sn levels from ^{112}Sn through ^{128}Sn for which spins and parities have been well-established. (The data for this figure have been taken from Nuclear Data Sheets.²⁴⁻³²) Note that in these nuclei the first excited state lies at about 1 MeV which is the odd-even mass difference, and that this energy is fairly constant over the entire range of nuclei. There is a large increase in level density above about 2 MeV (not shown in figure 28), which is approximately the pairing energy for these nuclei. This increase in density occurs because there is enough energy to break pairs above this energy and 2qp and 4qp states begin to appear.

Following is a discussion of the ^{126}Sn levels for which the structure is fairly well-established. Other levels are not as well-understood, except to say that they are mostly

Figure 28. Systematics of even-even Sn levels from A = 112 through A = 128

2qp states below about 4 MeV. Above this energy other configurations begin to complicate matters.⁴⁵

Ground state The 0^+ ground states in even-even Sn nuclei are described as members of a pairing vibrational band.⁴⁶ Pairing vibrations are described as fluctuations in the Fermi surface or neutron quasi-particle occupation numbers. Enhanced 2-particle transfer cross sections have been advanced as experimental evidence for this band structure. (There are strong two-particle transfers between even-even Sn ground states.) Low-lying excited 0^+ states have been observed in other even-even Sn nuclei but not in ^{126}Sn . These are also postulated to be pairing vibrational states.

First excited 2^+ and 3^- states As indicated previously the first excited 2^+ states in even-even Sn nuclei are known to be partially collective in nature. They have enhanced inelastic scattering cross sections, and the $B(E2)$ values for the 2^+ to 0^+ transitions are considerably larger than the single particle estimate. Similarly, the first excited 3^- states are known to be octupole oscillations, again having enhanced inelastic scattering cross sections and enhanced $B(E3)$ values.⁴⁷ 3^- states have been observed in most of the even-even Sn nuclei (see figure 28) and it is assumed that the state observed at 2720 keV in ^{126}Sn by Flynn et al. is the 3^- octupole state. The L transfer to this state is 3 and its position is consistent with the

systematics of the 3^- collective states in the other even-even Sn nuclei. Presumably the level at 2712-keV observed in the present work is the same 3^- state. If this is the one phonon octupole state, then the low beta feeding to this level might be assumed to result from a mismatch of single particle and collective wave functions. A similar effect has been observed in the decay of ^{136}I to levels in the $N = 82$ closed shell nucleus ^{136}Xe .⁴⁸

In discussing the first 2^+ collective state it is interesting to compare the level structure of ^{126}Sn with the predictions of the vibrational model. According to this model, the first excited 2^+ state is the 1 phonon quadrupole vibrational state. There should be a two phonon $(0,2,4)^+$ triplet at twice the energy of this first 2^+ state, a three phonon multiplet at triple this energy, and so on. The first excited 4^+ state is at 2050 keV. The ratio $E(4^+)/E(2^+)$ is 1.79 which is less than the value of 2 predicted by the vibrational model. This implies that the 4^+ level is 2qp as well as collective in nature. There are many other states at about twice the energy of the first 2^+ state but these are now usually described as 2 quasi-particle states instead of vibrational states.

5- and 7- levels In neighboring odd-mass Sn isotopes states with spins $1/2^+$, $3/2^+$, and $11/2^-$ are the ground states or low-lying excited states. These can be interpreted as the

shell-model states $s_{1/2}$, $d_{3/2}$, $h_{11/2}$, respectively. The lower neutron orbits $g_{7/2}$ and $d_{5/2}$ are filled. Within this limited model space, a 7^- state can only be formed by coupling a $d_{3/2}$ neutron to an $h_{11/2}$ neutron. A 5^- state can be formed from a coupling of the $h_{11/2}$ to an $s_{1/2}$ or a $d_{3/2}$ neutron. Krien et al. calculated the g-factors of the 5^- and 7^- states in ^{116}Sn through ^{120}Sn and concluded that the 7^- levels in these isotopes are indeed $(h_{11/2}^n, d_{3/2})$ whereas the 5^- levels are predominantly $(h_{11/2}^n, s_{1/2})$ with some admixture of $(h_{11/2}^n, d_{3/2})$.⁴⁹ (n is 1 for ^{116}Sn , 3 for ^{118}Sn , etc.) Presumably the 7^- state in ^{126}In is $(h_{11/2}^{11}, d_{3/2})$ and the 5^- state is mostly $(h_{11/2}^{11}, s_{1/2})$. Flynn et al. assigned the configuration $(h_{11/2}, d_{3/2})$ to the 7^- state in ^{126}Sn and a wave function dominated by $(h_{11/2}, s_{1/2})$ and $(h_{11/2}, d_{3/2})$ components to the 5^- state, which is consistent with Krien et al.

CHAPTER VI. SUGGESTIONS FOR FURTHER STUDY

Although much has been learned in the study of ^{126}Cd and ^{126}In presented here, further study of these isotopes would be useful. Ground state beta feeding has not been measured in either of the low-spin decays, but must be measured in order to calculate the $\log ft$ values accurately. Furthermore, this would probably make it possible to distinguish between the two possible values for the J^π of the low-spin In isomer.

Measurement of the multipolarities of the 62.9- and 102.8-keV transitions in ^{126}In should also be made. This might help to further support the version of the level scheme proposed in this work.

A much longer multiscale run is necessary to determine the half-lives of the ^{126}In isomers more accurately. In particular it would be good to reduce the error so that the errors for the half-lives of the two isomers do not overlap. This experiment would also make it possible to definitively assign the gamma rays to one isomer or the other on the basis of half-lives. Furthermore, it might prove that there are three and not two isomers of ^{126}In .

Finally, it would be interesting to measure electronically the half-life for the 7^- level which is expected to be in the microsecond range. Once this was done the g-factor for the level could be determined using the method of perturbed angular correlation. The g-factor is of great

interest in determining the shell model purity of the 7-
state's wave function and the possible effects of core polar-
ization.

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