Three β-decaying isomers of ^{130}In

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The total β-decay energies of the three isomers of ^{130}In have been studied. The ground state Q_β was determined to be 10.12 ± 0.18 MeV resulting in a mass excess of -70.05 ± 0.20 MeV for ^{130}In. The relative excitation energies of the three β-decaying isomers have been determined, resulting in the first level scheme information for the $\pi^{-1}\nu^{-1}$ nucleus neighboring ^{132}Sn. Arguments on β- and γ-ray selection rules permit unique assignments of $J^\pi = 1^-$ and 5^+, respectively, for the low and medium spin isomers of ^{130}In.

The decay of ^{130}In has recently been studied[1] in some detail using γ-ray spectroscopy. This work established the major features of the decay schemes of three different β-decaying levels of ^{130}In into the excited states in the daughter nucleus, ^{130}Sn. Two of these isomers, having relatively high angular momenta, have half-lives of 0.53 s, while the half-life of the low spin isomer was reported as 0.33 s. Other experiments[2,3] have reported on the β-delayed neutron emission following the decay of ^{130}In, but surprisingly there are no reported β-spectroscopic measurements for this decay apart from the early study of Kerek *et al.*[4] who first reported on the decay of ^{130}In. These authors, having access to only very weak samples of ^{130}In, used an anthracene scintillator to obtain a β-ray spectrum end-point energy of 7.3 ± 0.4 MeV.

A more precise β-spectroscopic study of the ^{130}In decay is motivated, not only because this is the only heavy isotope of In for which a reasonably precise Q_β value is lacking, but also because it provides further information on the levels of ^{130}In. This nucleus is one of the four odd-odd nuclei surrounding ^{132}Sn, and its level properties are of importance for determinations of shell model parameters in this region.

The measurements were performed at the on-line mass separator TRISTAN[5] at the Brookhaven National Laboratory. The ^{130}In activity was produced by thermal neutron fission of approximately 2.5 g of ^{235}U situated inside the anode of a modified forced electron beam induced arc discharge (FEBIAD)-type[6] ion source. After mass separation by a 90° magnet, the radioactive beam of the $A = 130$ isobars was collected on a movable, aluminized Mylar tape. The beam collection spot was viewed by a coaxial Ge detector shielded with a β-particle absorber and by a small intrinsic Ge detector for energy spectroscopy of β particles. The latter detector was separated from the collected activity by a window of 12 μm Ti foil which degraded the electron energies by 8.2 keV. Two sets of measurements were made. The first, aimed specifically at detecting a possible β transition from the low spin isomer of ^{130}In to the ground state of ^{130}Sn, consisted of simultaneous multispectrum scaling of singles β- and γ-ray spectra. The multiscaling cycle involved a one-second collection time followed by the measurements of consecutive spectra, where each spectrum covered a period of 0.25 s. The count rate in the β detector was sufficiently low that pulse pileup was insignifcant. The data obtained clearly showed the presence of a previously unobserved high energy β transition to the ^{130}Sn ground state, and that the most energetic β particles followed the 0.3 s half-life of the low spin isomer.

The second set of measurements consisted of a conventional $\beta\gamma$-coincidence study using a data collection cycle of 1.2 s at the point of deposit, after which the beam and measurements were shut off for 0.2 s while the collected activity was transported away, to prevent a buildup of ^{130}Sn and ^{130}Te activities from the decay of In. The $\beta\gamma$-coincidence events from radiations following the decays of ^{130}Sn and ^{130}Te actually comprised the majority of the $\approx 1.1 \times 10^7$ events recorded during the experiment, but were of no consequence for the interpretation of the ^{130}In data, since ^{130}In has a much higher total β decay energy. The presence of these daughter activities was largely a consequence of their comparatively higher fission yields and the high efficiency of the FEBIAD-type ion source for these elements rather than the decay of ^{130}In.

In the data analysis, energy gates were selected for γ rays deexciting strongly populated levels as shown schematically in Fig. 1. Some examples of the γ-gated β spectra are given in Fig. 2. The β end points of these spectra, along with the resulting Q values are listed in Table I. The energy scale of the β-ray detector was calibrated up to about 2.5 MeV using standard sources and the known energies of γ transitions in ^{130}Sn. Higher energies were extrapolated from this calibration, taking into account the known nonlinearity of the ADC in the data-taking system. The main source of error in the Q_β determination was the relatively low number of counts in the gated spectra, caused by the fact that strong β transitions populate only levels which decay with high energy γ rays for which the detection efficiency is low. The results regarding total β-decay energies (Table I) were of sufficient quality to separate the excitation energies of the different β-decaying states of ^{130}In, of which the short-lived,

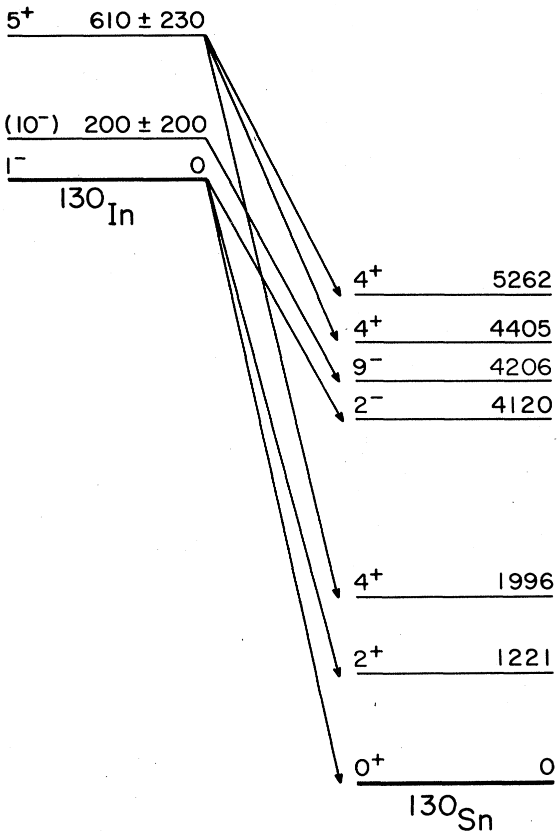

FIG. 1. A schematic representation of the β transitions observed in the present work, and used for the determination of the Q_β of ^{130}In. The J^π assignments for the levels of the $\pi^{-1}\nu^{-1}$ nucleus ^{130}In are discussed in the text. The figure is not drawn to scale.

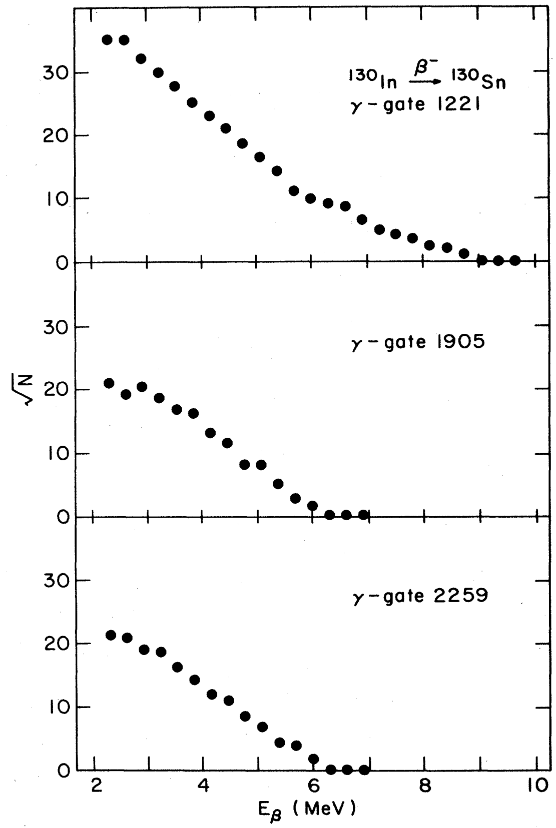

FIG. 2. Some of the β spectra recorded in coincidence with γ transitions in ^{130}Sn. Straight lines were fitted to the upper parts of the spectra for the extraction of β-ray end-point energies. The letter N refers to the number of coincident β particles in intervals with widths of about 0.3 MeV. The results of the Q_β measurements are summarized in Table I.

low-spin level was found likely to be the ground state. Adding our experimental Q_β to the mass excess[7,8] of ^{130}Sn yields the ^{130}In mass excess as -70.05 ± 0.20 MeV. In previous studies[7,9] of nuclear masses in the region near ^{132}Sn, it was pointed out that the droplet model of Myers[10] gave, for the 1975 mass predictions, the best overall agreement with experimental values near closed shells while showing the largest deviations[11] away from closed shells. For the sake of completeness we give in Table II a comparison between the present experimental value for ^{130}In with Myers' prediction, and also with four more recent nuclear mass calculations of Moller and Nix,[12] Monahan and Serduk,[13] and Uno and Yamada.[14,15] The Myers formulation is based on the liquid droplet model including shell effects while the other four have their basis in the shell model. In general, the four new mass relations show better agreement

TABLE I. Summary of Q_β results for the isomers of ^{130}In.

Isomer J^π	Gating γ ray	Level Energy (keV)	E_β^{max} (keV)	Q_β (keV)	Weighted mean Q_β (keV)
1^-		0	$10\,030 \pm 300$[a]	$10\,030 \pm 300$	
	1221	1221	8840 ± 250	$10\,060 \pm 250$	$10\,120 \pm 180$
	1905	4120	6060 ± 180	$10\,180 \pm 180$	
5^+	774	1996	8750 ± 240	$10\,750 \pm 240$	
	2377	4405	6240 ± 180	$10\,650 \pm 180$	
	3184	4405	6330 ± 300	$10\,740 \pm 300$	$10\,730 \pm 150$
	4042	5263	5540 ± 210	$10\,800 \pm 210$	
(10^-)	2259	4206	6120 ± 90	$10\,320 \pm 90$	$10\,320 \pm 90$

[a]This value was obtained from the singles β-ray measurements.

TABLE II. Experimental and theoretical values for the Q_β and mass excess of ^{130}In.

Quantity	This experiment (MeV)	Theory (MeV) Ref. 10	Ref. 12	Ref. 13	Ref. 14	Ref. 15
Q_β	10.12 ± 0.18	9.19	10.08	9.45	10.41	9.6
Mass excess	-70.05 ± 0.20	-71.14	-70.69	-70.81	-67.69	-70.53

than the Myers formulation. The Uno and Yamada equation with constant shell[14] and linear shell[13] corrections present the mass excess values with associated errors, that is, -67.69 ± 1.21 and -70.53 ± 1.74, respectively, for ^{130}In. In fact, the value calculated from Ref. 15 shows no better agreement than the Myers value. A comparison with a single experimental mass determination is, however, of very limited value for testing the validity of the given mass calculations.

The β-decaying levels of ^{130}In have been incorporated in Fig. 1, giving the first glimpse of the level scheme of a $\pi^{-1}\nu^{-1}$ nucleus neighboring the double shell closure at ^{132}Sn. The low spin isomer of ^{130}In has been uniquely determined to have $J=1$ in the present work, through the observation of β transitions to the ground state and the first excited 2^+ level of ^{130}Sn. Also, the additional data from the decay scheme work of Ref. 1 show the parity to be negative. The present $J=1$ assignment for the ^{130}In ground state also implies unique J^π values of 2^- and 4^-, respectively, for the 4120 and 2215 keV levels in the level scheme of ^{130}Sn given in Ref. 1.

The nature of the ^{130}In isomers was briefly discussed by Kerek *et al.*[4] These authors made a simple calculation of the relative positions of the levels in the expected low-lying $\pi^{-1}\nu^{-1}$ shell model multiplets, and concluded that the 1^- and 10^- levels should have the lowest energies in the $(\pi g_{9/2}^{-1},\nu h_{11/2}^{-1})$ multiplet, which is now confirmed by the present data and the work of Ref. 1. The nature of the $(4^+,5^+)$ isomer assigned by Ref. 1 is, however, not obvious from a calculation of the type given in Ref. 16, which predicts the 3^+ and 6^+ levels of the $(\pi g_{9/2}^{-1},\nu d_{3/2}^{-1})$ multiplet as the lowest-lying positive-parity states. From the present data we now know that this isomer has an excitation energy of about 0.6 MeV and is in a position to make a unique assignment of $J=5^+$. Values of J larger than this are excluded as a consequence of the observed strong β feeding of the 4^+ level of ^{130}Sn (see Table I and Ref. 1). An assignment of $J=4$ would make decay with a 0.6 MeV $E3$ transition to the 1^- level possible. This $E3$ transition would essentially have the character $d_{3/2}^{-1}\rightarrow h_{11/2}^{-1}$. The corresponding transition in ^{128}Sn between the $(h_{11/2},d_{3/2})_{7^-}$ and the 4^+ level which is mainly $(h_{11/2})^2$ is known[16] to have a transition probability of about 0.13 single particle units; therefore, the half-life of a 4^+ isomer at 0.6 MeV in ^{130}In would be of the order of a ms or less. This is inconsistent with experimental observation.

It is therefore likely that the relatively weak splitting of the (π^{-1},ν^{-1}) multiplets, induced by the residual interaction between the proton and neutron holes outside the ^{132}Sn core, is overcome by level-level interaction with the higher lying 5^+ level of the $(\pi g_{9/2}^{-1},\nu s_{1/2}^{-1})$ doublet, making the 5^+ state of the $(\pi g_{9/2}^{-1},\nu d_{3/2}^{-1})$ configuration the lowest lying in this latter multiplet.

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