Disintegration Scheme of I^{131}

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The radiations of I^{131} (8-day) have been studied in a pair of lens beta-ray spectrometers placed end to end, with coincidence counting of the focused radiations from a single source. Coincidence beta-spectra are shown with end points at 608 ± 5 kev (87.2 percent), 335 ± 6 kev (9.3 percent), and 250 ± 7 kev (2.8 percent). A weak 812 ± 15 kev beta-spectrum (0.7 percent) apparently leads to the 12-day isomer of X^{131}. Relative intensities of the three main beta-components are obtained from gamma-ray measurements alone. All gamma-rays have their multipolarities assigned on the basis of measured K-conversion coefficients and K/L ratios. A consistent disintegration scheme is proposed which is an extension of that of Metzger and Deutsch. Single-particle orbital assignments are made to the lower excited states of Xe^{131} which agree with shell theory.

I. INTRODUCTION

THE present study of the disintegration of 8-day I^{131} was prompted by the lack of agreement among the many previous publications on the details of this disintegration scheme. The radiations of I^{131} are here examined by coincidence techniques in a pair of lens beta-ray spectrometers placed end to end. In this way the various subcomponents of the I^{131} beta-ray spectrum have been studied separately in coincidence with the Xe^{131} gamma-rays which respectively follow them. Given these results, we arrive at the intensities of the subcomponents of the I^{131} beta-spectrum by gamma-ray measurements alone, so that the intensities found are independent of source thickness effects and spectrum shapes. The disintegration scheme found in the present study is not difficult to reconcile with the results of all previous measurements on I^{131}. An account of the results presented in this paper was given at the annual meeting of the Royal Society of Canada, Montreal, June, 1951. Parts of the work on I^{131} have been published elsewhere.[1,2]

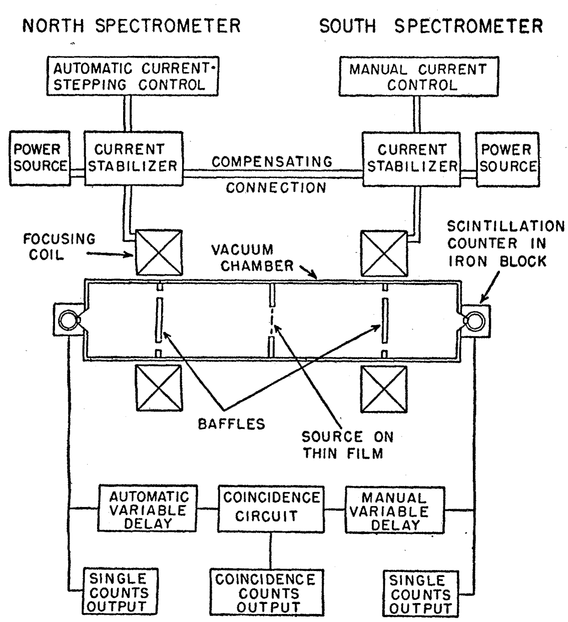

FIG. 1. Pair of end-to-end lens beta-ray spectrometers and associated equipment. This diagram illustrates the functions of the various components of the system but is not to be taken literally either mechanically or electrically. Short Lucite light pipes (not shown above) are used between the scintillating crystals and the 1P21 photomultipliers. As suggested by the diagram, the two lens spectrometers are operated at magnification ~0.7 in order to minimize the interaction effect between them.

The two published disintegration schemes of I^{131} which have found the widest acceptance are those of Metzger and Deutsch[3] and Kern, Mitchell, and Zaffarano.[4] Subsequently, Feister[5] published results lying between the two schemes. Later work by P. R. Bell, Cassidy, and Kelley[6] supports the Kern scheme, while a recent paper by Verster *et al.*[7] agrees with the Metzger-Deutsch result. In the meantime several studies[8-10] have been published on the question of the growth of the 12-day Xe^{131} isomer in low abundance from I^{131}, and this part of the I^{131} disintegration scheme will be accepted here. The accurate gamma-ray energy measurements of Lind *et al.*[11] have assisted in fixing the disintegration scheme and are useful in calibrating the spectrometers.

II. APPARATUS

The chief apparatus was a pair of lens beta-ray spectrometers placed end to end, shown in Fig. 1. The two spectrometers are contained in the two halves of a single vacuum chamber with the source mounted at the center. Simple annular baffles and point focusing are used. Each spectrometer has its own power source and magnet current stabilizer, so that each spectrometer can focus electrons independently of the other. A given

[1] Bell, Graham, and Petch, Can. J. Phys. **30**, 35 (1952).
[2] R. L. Graham and R. E. Bell, Phys. Rev. **84**, 380 (1951).
[3] F. Metzger and M. Deutsch, Phys. Rev. **74**, 1640 (1948).
[4] Kern, Mitchell, and Zaffarano, Phys. Rev. **76**, 94 (1949).
[5] I. Feister, Phys. Rev. **78**, 179 (1950).
[6] Bell, Cassidy, and Kelley, Phys. Rev. **82**, 103 (1951).
[7] Verster, Nijgh, Van Lieshout, and Bakker, Physica **17**, 637 (1951).
[8] Brosi, DeWitt, and Zeldes, Phys. Rev. **75**, 1615 (1949).
[9] I. Bergstrom, Phys. Rev. **80**, 114 (1950).
[10] Zeldes, Brosi, and Ketelle, Phys. Rev. **81**, 643 (1951).
[11] Lind, Brown, Klein, Muller, and DuMond, Phys. Rev. **75**, 1544 (1949).

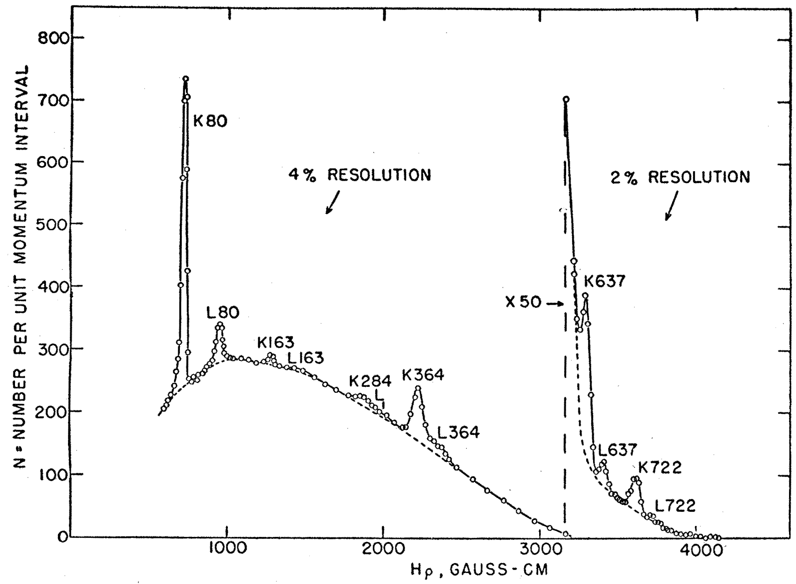

FIG. 2. Observed beta-ray spectrum of I[131]. The right-hand part of the spectrum was measured with higher resolution in the spectrometer. The standard deviations of the points are everywhere smaller than the radii of the circles.

current in one coil affects by about 0.06 of itself the value of the current required to focus electrons of a given momentum in the other coil. The compensating connection of Fig. 1 balances out this interaction effect by automatically reducing the current in either coil by 0.06 of the amount of the current in the other. There remains a small effect on the transmission of one spectrometer by the current in the other; this effect must be corrected in the observed results.

Either of the magnet current stabilizers (that of the north spectrometer in Fig. 1) may have an automatic current-stepping control replacing the more usual manual current control (south spectrometer in Fig. 1). This unit causes the magnet current to assume a series of equally spaced fixed values in turn, each value being held for a fixed time while counting proceeds. The number of fixed current values may be varied from 10 to 35. A timing switch (not shown in Fig. 1) controls the changes in current.

The detectors for the two spectrometers are stilbene-1P21 scintillation counters connected to a coincidence circuit[1,12] whose resolving time $2\tau_0$ may be varied down to 2×10^{-9} second or less, with the coincidence efficiency remaining greater than 0.9. An automatic variable delay unit[1] is connected in series with the pulses from one of the counters and may be operated by the same timing switch as that used for automatic current switching.

With chart recording of total and coincidence counting rates, the above assembly of apparatus allows us to perform automatically any combination of beta-ray spectroscopy, coincidence spectroscopy, or delayed coincidence experiments on beta-rays and conversion electrons of selected energies. The most frequent types of measurement are

(a) simple automatic beta-ray spectroscopy,

(b) delayed coincidence experiments with the spectrometers held fixed on two desired radiations, and

(c) coincidence spectroscopy in which one spectrometer is held fixed on a particular radiation while the other spectrometer is scanned in steps over some spectrum. In this case it is usual to operate the automatic variable delay unit so as to record in turn true-plus-chance and chance-alone coincidences at each value of the current in the scanned spectrometer.

Chart recording of counting rates is accomplished in the case of high counting rates by recording the output of a counting rate meter. In the case of low counting rates or in cases where the counting rate covers a very wide range, the 1's, 10's, 100's, and 1000's pulses from a scale of 1000 are recorded as pips of different signs and magnitudes on an Esterline-Angus chart.

A subsidiary apparatus was a scintillation gamma-ray spectrometer consisting of a block of NaI(Tl) of dimensions 2×2 cm$\times 1$ cm thick, a 5819 photomultiplier, amplifier, and single-channel pulse-height analyzer. In addition, check measurements were made on the gamma-ray intensities emitted by an I[131] source by lead absorption experiments using scintillation and Geiger counter detection.

III. PROCEDURE AND RESULTS

A. The Beta-Spectrum

The total beta-ray spectrum of I[131], shown in Fig. 2, was recorded in the north spectrometer with the current in the south spectrometer shut off. Figure 2 is a composite of results using three different sources and two spectrometer resolution settings. The I[131] used was chemically separated from n-irradiated Te. Below $H\rho = 1000$ the source was of activity $\sim 300\ \mu$C, diameter ~ 8 mm, and average surface density $\sim 125\ \mu\text{g/cm}^2$,

[12] R. E. Bell and H. E. Petch, Phys. Rev. 76, 1409 (1949).

TABLE I. Properties of Xe^{131} gamma-transitions following the beta-disintegration of I^{131}. Intensities are given per 100 beta-disintegrations. Each measured figure is accompanied by an estimated percentage probable error in brackets. The K/L values have been calculated assuming that 0.8 of any $L+M+N$ peak is a result of L conversion.

Gamma-energy kev	I total (adopted)	I total (exp)	I_K (exp)	I_{L+M+N} (exp)	I_γ (exp)	αK (exp)	αK (theor)[b]	K/L	Multi-polarity[c]	Half-life
80	6.3 (10)	6.6 (15)	3.75 (10)	0.67 (20)	2.17 (15)	1.73 (20)	~1.6	7 (20)	$M1$	4.8×10^{-10} sec (40)[e]
163	0.70 (25)	0.70[a] (25)	0.40 (20)	...	...	...	35	...	$M4$[d]	$12d$[f]
284	6.3 (10)	5.6 (20)	0.24 (15)	0.06 (30)	5.3 (20)	0.047 (20)	0.043	5 (30)	$E2$	$<10^{-10}$ sec[g]
364	80.9 (3)	81.6 (5)	1.40 (10)	0.22 (15)	80.0 (5)	0.018 (15)	0.019	8 (15)	$E2(+M1)$	$<10^{-10}$ sec[g]
637	9.3 (15)	9.3 (15)	0.034 (20)	0.005 (30)	9.3 (15)	3.7×10^{-3} (25)	4.1×10^{-3}	9 (20)	$E2$	...
722	2.8 (25)	2.8 (25)	0.0078 (25)	0.0013 (30)	2.8 (25)	2.8×10^{-3} (30)	3.0×10^{-3}	8 (30)	$E2$	...

[a] Deduced from the beta-spectrum. Intensity observed will depend on the age of the source and on the retentivity of the source for Xe atoms. The value 0.40 given under I_K(exp) thus applies only to this particular measurement.
[b] Rose, Goertzel, Spinrad, Harr, and Strong, Phys. Rev. **83**, 74 (1951). An extrapolated value has been used for the 80-kev gamma-ray.
[c] Using the notation of reference d.
[d] M. Goldhaber and A. W. Sunyar, Phys. Rev. **83**, 906 (1951).
[e] R. L. Graham and R. E. Bell, Phys. Rev. **84**, 380 (1951).
[f] Brosi, DeWitt, and Zeldes, Phys. Rev. **75**, 1615 (1949).
[g] Bell, Graham, and Petch, Can. J. Phys. **30**, 35 (1952).

deposited as AgI on a 100 $\mu g/cm^2$ plastic film and covered with 10 $\mu g/cm^2$ of collodion. For $1000<H\rho<3200$ the source was of activity ~200 μC, diameter ~6 mm, and average surface density ~60 $\mu g/cm^2$, deposited as AgI on a 1.5 mg/cm^2 Al foil and covered with 10 $\mu g/cm^2$ of collodion. The spectrometer resolution was ~4 percent for these cases. In spite of its higher average surface density the first of the two sources aforementioned gave cleaner line shapes at low energies, possibly because of chemical attack on the Al backing in the case of the second source. Neither the sources nor the backings are thin enough to guarantee an undistorted spectrum shape. The observed shape is therefore not used to draw firm conclusions about the energies and intensities of the lower energy beta-ray components. Above $H\rho=3200$ the source was of activity ~1 mC, diameter ~4 mm, and average surface density ~1.7 mg/cm^2, deposited as AgI on a thick Al backing and covered with 10 $\mu g/cm^2$ of collodion. For this region the spectrometer resolution was set at ~2 percent. Conversion lines are seen in Fig. 2 due to the well-known gamma-rays of Xe^{131} of energies 80.1, 163, 284.1, 364.2, 637, and 722 kev.[3,9–11] The 177-kev gamma-ray found by Cork *et al.*[13] was not evident. The K-conversion peak of the 364.2-kev gamma-ray was used to calibrate the energy scale. The intensities of the conversion peaks, as determined by their relative areas in Fig. 2, are listed in the columns headed I_K and I_{L+M+N} in Table I, with their estimated probable errors. (Peaks labeled L in Fig. 2 were actually due to $L+M+N$ conversion.)

An allowed Fermi plot of the data of Fig. 2 is shown in Fig. 3, with the conversion peaks of Fig. 2 removed for energies less than 570 kev ($H\rho<3200$). The spectrum splits naturally into four components whose apparent end points and intensities are 812±15 kev (0.7 percent), 608±5 kev (80.5 percent), 335±20 kev (9.4 percent), and 250±25 kev (9.4 percent), assuming that all components have the allowed shape. From this evidence alone it is difficult to be sure that the 250-kev component exists, and we expect that in any case its intensity here appears too high. The beta-ray components of higher energy appear to be on much safer ground. The end points given here have been verified by coincidence measurements (see below, subsection C), except for the weak 812-kev component.

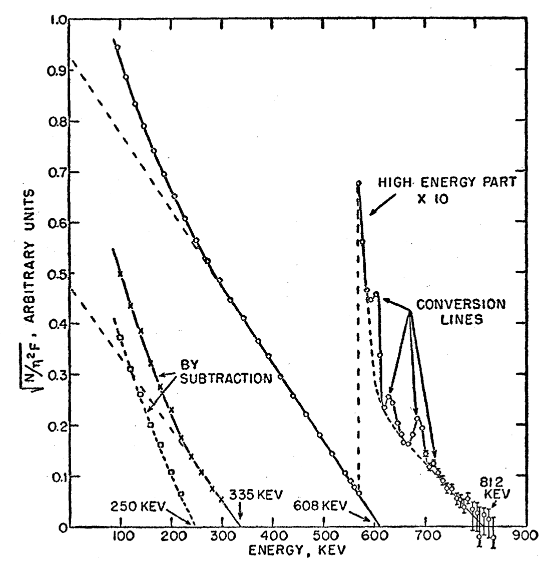

FIG. 3. Allowed Fermi plot of the beta-ray spectrum of I^{131} as observed in Fig. 2. For the part below 570 kev, the conversion lines were omitted as indicated by broken lines in Fig. 2. Where the standard deviations of the points are greater than the radii of the circles, they are indicated by vertical bars. Since the errors of the points of the subcomponents ending at 335 and 250 kev are probably chiefly systematic, no attempt has been made to indicate standard deviations for them.

[13] Cork, Rutledge, Stoddard, Branyan, and Childs, Phys. Rev. **81**, 482 (1951).

B. The Gamma-Spectrum

The secondary electron spectrum of an I^{131} source is shown in Fig. 4. Photoelectrons ejected from an 8 mg/cm² Th radiator were observed in the north spectrometer with the south spectrometer shut off. The beta-rays were stopped by 500 mg/cm² Al. The Compton electron background observed with the Th radiator removed is shown as a broken line in Fig. 4. The relative intensities of the gamma-rays 284, 364, 637, and 722 kev were measured by taking the area of each K peak in Fig. 4 and dividing it by the photoelectric cross section for that energy. The failure to resolve the $L637$ peak from the $K722$ peak is not serious here because Thulin[14] has shown for a Th radiator that the area of the $L637$ peak is almost exactly equal to that of the $K722$ peak.

Absolute quantum intensities of the gamma-rays are found as follows: It is shown later that every beta-ray except those belonging to the 812-kev spectrum is followed by exactly one of the gamma-transitions 284, 364, 637, or 722 kev. The sum of these gamma-transition intensities is therefore 99.3 percent. The sum of their quantum intensities is then equal to 99.3 percent minus the sum of all their internal conversion intensities, found in Table I. The quantum intensities found by this procedure are listed under I_γ, Table I, with estimated probable errors. The least accurate intensity is that of the 284-kev gamma-ray whose K peak in Fig. 4 is weak and awkwardly situated.

According to these results, the sum of the intensities of the 637- and 722-kev gamma-rays is 12.1 percent. This value was checked by absorption measurements in lead, not shown in a diagram, in which the 284- and 364-kev gamma-ray act like a single radiation, and the 637- and 722-kev gamma-rays act like another single

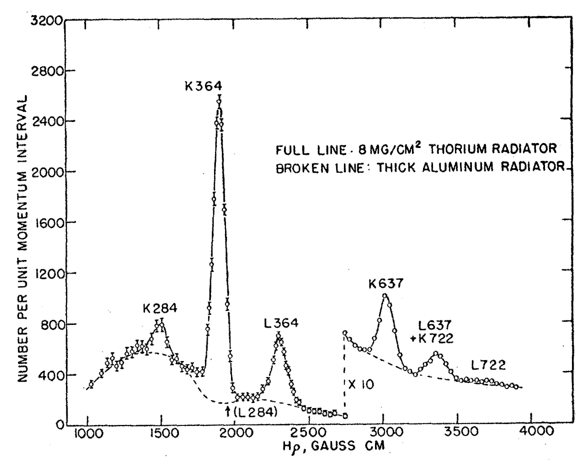

FIG. 4. Secondary electron spectrum of Xe^{131} gamma-rays from an I^{131} source using a Th radiator, 8 mg/cm². The shape of the spectrum observed with the Th radiator removed, leaving a thick Al radiator, is indicated by a broken line. Where the standard deviations of the points are greater than the radii of the circles, they are indicated by vertical bars.

[14] S. Thulin, Phys. Rev. 83, 860 (1951).

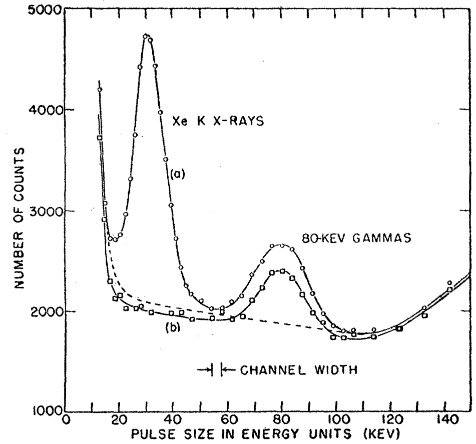

FIG. 5. Scintillation spectrum (low energy region) of the 80-kev gamma-ray and K x-rays of Xe^{131} emitted by a source of I^{131}. The detector was a NaI(Tl) crystal and 5819 photomultiplier connected to a single-channel pulse-height analyser. Curve (a) 280 mg/cm² polystyrene beta-ray absorber over source, curve (b) 410 mg/cm² additional Cu absorver over source to absorb Xe K x-rays. The shape of the background under the x-ray peak in (a) is found by comparison with (b) and shown as a broken line.

radiation. Absorption curves were measured using as detectors a brass-walled Geiger counter and the NaI scintillation counter with its bias set very low ($\sim$20-kev equivalent pulse height). The counting rates due to the two equivalent single radiations were separated in the usual way in the absorption experiments and corrected by the respective efficiencies of the two detectors for the two average energies. The relative efficiencies of the Geiger counter were taken from the curves of Bradt *et al.*,[15] and those for the scintillation counter were calculated from the total absorption of NaI. The results for the intensity of the 637+722 gamma-rays were: Geiger experiment, (10.8±1.6) percent; scintillation experiment, (11.7±1.7) percent. These results agree satisfactorily with the figure of 12.1 percent derived from the spectrometer measurement.

The quantum intensity of the 80-kev gamma-ray was measured with the NaI scintillation spectrometer. The thickness of the NaI crystal, 1.0 cm, was great enough to absorb substantially all of the 80-kev gamma-rays falling on it, and all those of lower energy. The low energy part of the scintillation spectrum of an I^{131} source enclosed in 280 mg/cm² of polystyrene to stop the beta-rays is shown in Fig. 5, curve (a). The two peaks are due to Xe K x-rays resulting from K-conversion of gamma-rays in the source and 80-kev gamma-rays. Curve (b) shows the scintillation spectrum with 410 mg/cm² Cu over the source to absorb the K x-rays. Curve (b) is included to show the shape of the background under the K x-ray peak in curve (a). When corrected for absorption in the polystyrene and for fluorescent yield,[16] taken to be 0.80 for Xe, the area of the

[15] Bradt, Gugelot, Huber, Medicus, Preiswerk, and Scherrer, Helv. Phys. Acta 19, 77 (1946).
[16] H. S. W. Massey and E. H. S. Burhop, Proc. Roy. Soc. (London) A153, 661 (1936).

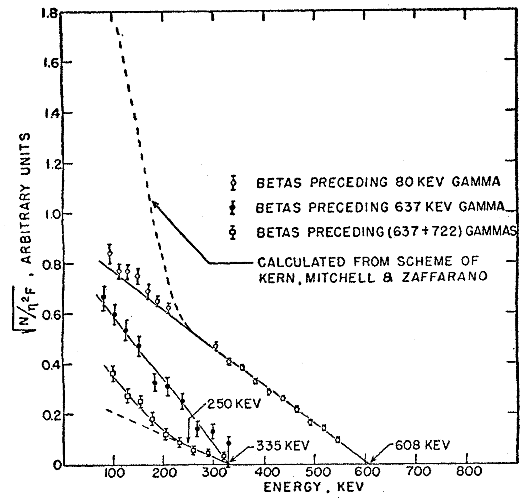

FIG. 6. Coincidence Fermi plots for I^{131}. Upper curve, spectrum of coincidences between beta-rays and 80-kev gamma-rays; the broken line shows what would be expected on the disintegration scheme of Kern *et al.*, reference 4. Middle curve, spectrum of coincidences between beta-rays and 637-kev gamma-rays. Lower curve, spectrum of coincidences between beta-rays, and an equal mixture of 637- and 722-kev gamma-rays. The standard deviations of the points are shown by vertical bars.

K x-ray peak may be equated to the sum of all the K-conversions in the source, $\sum I_K$, already known. The area of the 80-kev peak, corrected for absorption in the polystyrene, then gives directly the quantum intensity of the 80-kev gamma-ray. The result, 2.17 percent, is given under I_γ in Table I, with its estimated probable error.

The K-conversion coefficient of any gamma-ray is the ratio I_K/I_γ and is given in Table I under α_K(exp). The theoretical predictions of Rose *et al.*[17] are given for comparison under α_K(theor) for the multipolarity indicated in the last column of Table I. The K/L ratios in Table I are derived from the experimental results with the assumption that 0.8 of any $L+M+N$ peak is caused by L conversion. The K/L ratios are all consistent with the empirical K/L curves given by Goldhaber and Sunyar[18] for the multipolarities assigned. The total intensities of the gamma-transitions are listed under I total (exp) in Table I. The half-lives of those gamma-transitions which have been measured[2] are also consistent with the assigned multipolarities.

Accurate gamma-ray energy measurements were made only for the 637- and 722-kev gamma-rays, using the accurate energy 364.2 ± 0.1 kev of the 364-kev gamma-ray as a calibration.[11] From Fig. 4, using the extrapolated upper edges of the K lines, the energy of the 637-kev gamma-ray is 637 ± 3 kev. From Fig. 2, the energy difference between 637 and 722 gamma-rays is 85.3 ± 2.0 kev, so that the 722-kev gamma-ray energy is, to the nearest kilovolt, 722 ± 4 kev. The fact that the energy difference between these two gamma-rays is significantly different from 80.1 kev is important in deciding between possible disintegration schemes.[4]

C. Coincidence Measurements

Coincidence measurements have been made in the pair of lens beta-ray spectrometers on most of the radiations from an I^{131} source, in order to establish the correlations existing between the various radiations. Previous coincidence measurements on the internal conversion peaks of the 80, 284, and 364-kev gamma-rays have shown that (1) the 364-kev gamma-ray follows nuclear beta-rays with a half-life less than 10^{-10} seconds;[2] (2) the 80-kev gamma-ray is in cascade with the 284-kev gamma-ray,[1] agreeing with Lind's conclusion[11] that this is a cascade pair of gamma-rays in parallel with the 364-kev gamma-ray; and (3) the 80-kev gamma-ray has a half-life with respect to nuclear beta-rays of $(4.8\pm2.0)\times10^{-10}$ second,[2] and is therefore emitted after the 284-kev gamma-ray.

Measurements have now been made of the beta-ray spectra which precede the 80, 637, and 722-kev gamma-rays. In the case of the 80-kev gamma-ray, the procedure was to use a source on a thin film mounted at the center of the pair of spectrometers and to hold the K-conversion peak of the 80-kev gamma-ray focused in the south spectrometer while scanning the coincidence beta-ray spectrum in the north spectrometer. The results are shown in the form of a Fermi plot in Fig. 6. The coincidence points follow the Fermi plot of the 608-kev component of the total spectrum with a slight rise at low energies, probably as a result of the effect

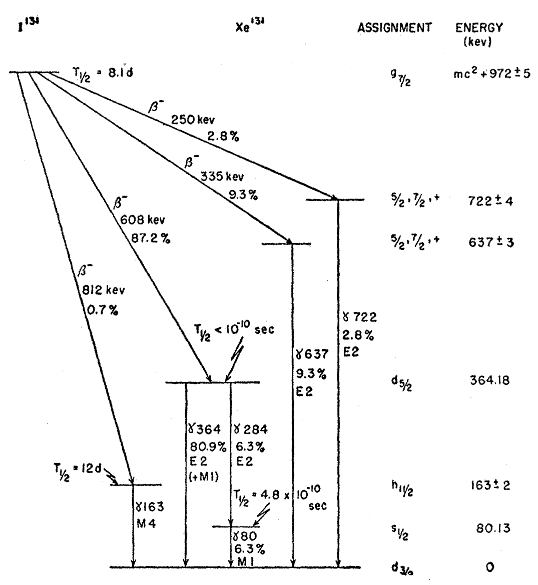

FIG. 7. Proposed disintegration scheme of I^{131}. The detailed properties of the beta-components and gamma-rays are explained in the text and listed in Tables I and II. The orbital assignments are made from experimental results and are consistent with the nuclear shell model. Most of the published observations on I^{131} can be reconciled with this scheme.

[17] Rose, Goertzel, Spinrad, Harr, and Strong, Phys. Rev. **83**, 79 (1951).

[18] M. Goldhaber and A. W. Sunyar, Phys. Rev. **83**, 906 (1951).

TABLE II. Properties of the separate components of the beta-ray spectrum of I^{131}. Intensities are given per 100 beta-disintegrations and are independent of the spectrum shape assumed except in the case of the weak 812-kev spectrum. Figures are included in brackets for two beta-ray spectra which were not observed but which are energetically possible according to Fig. 7.

Maximum energy, kev (adopted)	Intensity (adopted)	$\log f_0 t$	$\log[(W_0^2-1)f_0 t]$	$\log f_1 t$	Spectrum type
812±15	0.7±0.2	9.2	9.9	8.5	First forbidden, (α-shape)
608±5	87.2±3.0	6.6	...	...	l-forbidden
335±6	9.3±1.4	6.7	...	...	l-forbidden or allowed
250±7	2.8±0.7	6.9	...	...	l-forbidden or allowed
(897)	(<0.2) (Unobserved)	(>9.9)	...	...	Second or higher forbidden
(974)	(<0.2) (Unobserved)	(>10.0)	...	...	Second or higher forbidden

of source thickness. Remembering the gamma-ray coincidence results, we conclude that the 80-, 284-, and 364-kev gamma-rays follow only the 608-kev beta-spectrum.

In order to get similar results for the 637- and 722-kev gamma-rays, the I^{131} source on a thick Al backing was used in the pair of spectrometers, the open side of the source facing north. A 42 mg/cm^2 Th radiator was used on the back of the source holder, facing south. The spectrum in the south spectrometer then resembled that of Fig. 4 except that the photoelectron peaks were more intense and wider as a result of the greater thickness of the radiator. From Fig. 4 it can be seen that the south spectrometer could focus on the $K637$ peak, thus recording the 637-kev gamma-ray alone, or on the $L637+K722$ peak, thus recording 637- and 722-kev gamma-rays in about equal intensity. The north spectrometer was scanned over the coincidence spectrum in the usual way for each of these two settings of the south spectrometer. Fermi plots of the results are shown in Fig. 6. We conclude that the 637-kev gamma-ray follows a beta-ray spectrum of end point 335±15 kev and that the 722-kev gamma-ray follows a beta-ray spectrum of end point 250±20 kev. These observations verify the existence of the 335-kev and 250-kev spectra. However, the intensities of these spectra must be equated to the intensities of the 637- and 722-kev gamma-rays which are, respectively, (9.4±1.4) percent and (2.8±0.7) percent (see Table I).

IV. DISINTEGRATION SCHEME AND DISCUSSION

All the foregoing results are consistent with the disintegration scheme shown in Fig. 7. The scheme agrees in its most intense radiations with that of Metzger and Deutsch,[3] and disagrees with those of Kern, Mitchell, and Zaffarano,[4] Cork *et al.*,[13] and Owen, Moe, and Cook.[19] P. R. Bell *et al.*[6] interpreted their results as favoring a scheme similar to that of Kern *et al.*,[4] but in fact their results are nearly in agreement with this scheme.

Following Fig. 7, the roughly equal measured intensities of the 80 and 284 gamma-transitions have been averaged to give the common intensity assigned to both. This step necessitated a slight change in the intensity of the 364-kev gamma-transition. All the adopted gamma-intensities shown in Table I lie well within the probable errors of the experimental intensities.

From the end point of the 608±5 kev beta-spectrum and the energy of the 364.2-kev gamma-ray, we deduce a total disintegration energy for the I^{131} nucleus of (mc^2+972±5) kev. Since the 637±3 kev gamma-ray has been proved to follow the 335-kev beta-spectrum, we may use the total disintegration energy to obtain a smaller probable error for the energy of the 335-kev component; a similar procedure can be used for the 250-kev component. This procedure would not be allowable without the coincidence measurements of Fig. 6, and therefore cannot be applied to the 812±15 kev beta-spectrum. We thus adopt end points for the low energy beta-components of 335±6 and 250±7 kev, respectively. The adopted intensities for the 608-, 335-, and 250-kev beta-spectra are equal to those of the corresponding gamma-rays in Table I. Table II shows the adopted energies and intensities of the beta-components and their calculated $\log f_0 t$ values. Table II also includes data for two unobserved beta-components that are energetically possible in the disintegration scheme of Fig. 7, but whose intensities from Fig. 2 are less than 0.2 percent.

None of the many possible gamma-transitions between the levels of Fig. 7 were observed other than those already mentioned. The upper limits to be placed on the occurrence of the unobserved gamma-rays vary with the gamma-ray energy, but in any case none of the unobserved gamma-rays can have intensities large enough to upset seriously the intensities adopted for the radiations actually found. These results are consistent with the spins and parities assigned to the states of Xe^{131} (see the following).

Single-particle orbital assignments have been made for most of the levels in Fig. 7 as follows: The ground state of I^{131} is assigned $g_{7/2}$ by analogy with the measured spin and magnetic moment[20] of I^{129}. The ground state of Xe^{131} is $d_{3/2}$ by its measured spin and magnetic moment.[20] The only orbitals which will fit the gamma-ray multipolarity assignments of Table I and explain

[19] Owen, Moe, and Cook, Phys. Rev. **74**, 1879 (1948).

[20] J. E. Mack, Revs. Modern Phys. **22**, 64 (1950).

the beta-ray results of Table II are $d_{3/2}$, $s_{1/2}$, and $d_{5/2}$ for the 0-, 80-, and 364-kev states, respectively. These assignments are consistent with the shell model.[21] The $s_{1/2}$ assignment for the 80-kev state agrees with the observation by Schiff[22] that the angular correlation of the 80- and 284-kev gamma-rays is 0 ± 3 percent. The assignment of $h_{11/2}$ to the 163-kev state follows Goldhaber and Sunyar.[18]

The foregoing orbital assignments make the 812-kev spectrum a first-forbidden, α-type spectrum ($\Delta j=2$, yes), consistent with the observed value of

$$\log[(W_0^2-1)f_0t]=9.9 \quad \text{or} \quad \log f_1t=8.5.^{23}$$

The abundance of this spectrum has been calculated on the assumption of an allowed shape, and if its spectrum is in fact of the α-shape, the abundance should be lowered somewhat from the value 0.7 percent shown in Table II. Since most of the 812-kev spectrum is obscured by more intense spectra of lower energy (Fig. 2), there does not appear to be any experimental way to settle the question of its shape, and the abundance has been left as originally computed.

The 608-kev beta-spectrum becomes an l-forbidden transition[24,25] ($\Delta j=1$, $\Delta l=2$, no) consistent with its $\log f_0t$ value of 6.6.[26] This spectrum seems to have the allowed shape as expected.

Considering the evidence of the 250-kev and 335-kev beta-spectra (Table II) and the multipolarities of the 637 and 722 gamma-rays[27] (Table I), each of the 637- and 722-kev excited states of Xe^{131} may be either $5/2+$ or $7/2+$. Both beta-components have $\log f_0t$ values suitable for l-forbidden spectra[26] which would suggest $5/2+$ for both states. In view of the fact that $\log f_0t$ values for allowed transitions in medium-weight nuclei seem to be separated from those for l-forbidden transitions by less than one unit, on the average,[26] one cannot say that these spectra are not allowed. In that case the value $7/2+$ is permissible for either state. It does not seem justifiable to try to make single-particle orbital assignments to these states, but $g_{7/2}$ for one of them is consistent with the shell model.

While this paper was in manuscript, Ketelle, Zeldes, Brosi, and Dandl[28] published coincidence spectra of I^{131} observed with a single magnetic beta-spectrometer and a NaI(Tl) scintillation gamma-spectrometer. Their results are in agreement with those presented in Fig. 6.

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[21] M. G. Mayer, Phys. Rev. **78**, 16 (1950); L. W. Nordheim, Phys. Rev. **75**, 1894 (1949); Hill, Scharff-Goldhaber, and McKeown, Phys. Rev. **84**, 382 (1951); also reference 7.

[22] D. Schiff, Bull. Am. Phys. Soc. **26**, No. 6, 31 (1951).

[23] F. B. Shull and E. Feenberg, Phys. Rev. **75**, 1768 (1949); J. P. Davidson, Phys. Rev. **82**, 48 (1951).

[24] E. Feenberg and K. C. Hammack, Phys. Rev. **75**, 1877 (1949).

[25] R. Bouchez, Compt. rend. **231**, 139 (1950).

[26] Mayer, Moskowski, and Nordheim, Revs. Modern Phys. **23**, 315 (1951).

[27] Verster *et al.* (reference 7) found on the basis of their measured internal conversion coefficient that the 637-kev gamma-ray was electric dipole radiation; however, their value of the conversion coefficient is ~50 percent low because they put the quantum intensity of the 637-kev gamma-ray ~50 percent too high and, in addition, it is inaccurate because their $K637$ internal conversion peak is not cleanly resolved from its background of beta-particles. Their data are not inconsistent with the conclusions of this paper

[28] Ketelle, Zeldes, Brosi, and Dandl, Phys. Rev. **84**, 585 (1951).