# Disintegration Schemes of Radioactive Substances. V. $I^{130}$

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The disintegration of $I^{130}$ was studied by spectrometer and coincidence techniques. The decay proceeds by two modes of negatron emission of maximum beta-ray energy $0.61\pm0.02$ Mev and $1.03\pm0.02$ Mev, respectively. The high energy spectrum represents $60\pm10$ percent of the disintegrations and is accompanied by three gamma-rays of energies $0.537\pm0.005$ Mev, 0.667 $\pm0.008$ Mev, $0.744\pm0.010$ Mev. The low energy spectrum is accompanied by these same three gamma-rays and, in addition, by a gamma-ray of energy $0.417\pm0.005$ Mev. The coefficients of internal conversion in the $K$ shell are 0.0031, 0.0038, 0.0069, 0.012, ($\pm20$ percent) in order of decreasing gamma-ray energy. The conversion in the $L$ shell is much smaller. It is shown that the Fermi plot of the complex spectrum can be separated into straight lines which may be extrapolated to obtain the correct disintegration energies.

## INTRODUCTION

THE radioactive species of iodine of 12.6 hour half-life, obtained by bombarding tellurium with protons or deuterons, is definitely assigned to $I^{130}$ because it is produced by fast neutron bombardment of the single stable isotope of cesium, $Cs^{133}$. The only previous published results on the radiations from this species were the absorption measurements of Livingood and Seaborg[1] and the cloud-chamber observations of Tape.[2] The former gave 1.05 Mev and 0.6 Mev for the beta- and gamma-ray energies, respectively, while Tape reported 0.83 Mev and 0.59 Mev, respectively.

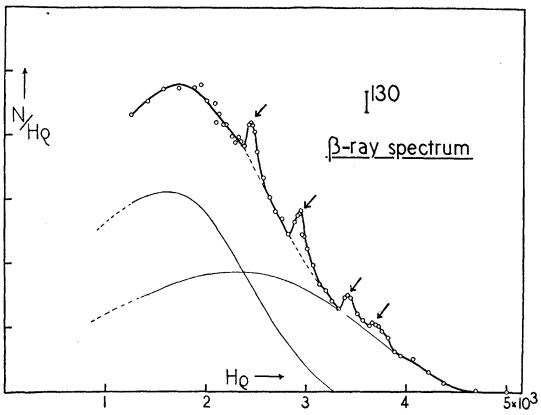


FIG. 1. The beta-ray spectrum of $I^{130}$. Arrows mark internal conversion lines.

We have studied the radiations and the disintegration scheme of $I^{130}$ by means of the methods described in the preceding papers of this series.[3] A brief report on some preliminary results was presented before the Physical Society.[4] The present paper extends, and in some details supersedes those results.

Radioactive iodine has been produced and used in this laboratory extensively, particularly for experimental and clinical studies of iodine metabolism, using both tracer and therapeutic irradiation doses.[5] The 12.6 hour species has been used largely for radiation treatment. It is important for the proper calculation of dosage to have a full knowledge of the radiations emitted. For this reason $I^{130}$ was chosen as one of the activities to be studied in this series.

When tellurium is bombarded with deuterons, at least four radioactive species of iodine are formed, with half-lives of 25 minutes, 12.6 hours, 8 days, and 13 days.[1] In the case of the bombarding energy used in the Massachusetts Institute of Technology cyclotron (about 11.5 Mev when these experiments were performed), for thick targets, and for bombardments of a few hours duration, the 25-minute activity becomes

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[1] J. J. Livingood and G. T. Seaborg, Phys. Rev. **54**, 775 (1938).

[2] G. F. Tape, Phys. Rev. **56**, 965 (1939).

[3] Phys. Rev. **60**, 470; 544 (1941); **61**, 672, 686 (1942); **62**, 3 (1942). They will be referred to by the roman numerals I to IV.

[4] J. R. Downing, M. Deutsch, and A. Roberts, Phys. Rev. **61**, 389 (1942).

[5] E.g., S. Hertz, A. Roberts, J. H. Means, and R. D. Evans, Am. J. Physiol. **128**, 565 (1940).

negligible about four hours after the end of the bombardment. At that time about 10 percent of the disintegrations are due to the 8-day species $I^{131}$, about one percent is due to the 13-day species $I^{126}$, and the rest to $I^{130}$. These percentages refer to the number of disintegrations. The activity ratios as observed on most instruments, except those with very thin windows tend to overestimate the amount of $I^{130}$ because of the higher beta-ray energy and the larger number of gamma-rays per disintegration. No trace[1] of the 4-day positron activity reported to be due to $I^{124}$ was found although it might be expected to be formed both by $(d, n)$ and $(d, 2n)$ reactions if the assignment is correct. It was necessary to correct all measurements for effects due to radiations from $I^{131}$, which are well understood (paper III), and, occasionally for the effects of the 13-day activity.

### A. Preparation of Sources

Tellurium was bombarded in the form of cobalt telluride by the circulating beam of the Massachusetts Institute of Technology cyclotron. Iodine was separated from the targets by distillation from a nitric acid solution. Since the sources used usually consisted of a small fraction of very strong preparations (about ten millicuries), used for therapeutic doses, and since only a total amount of about one-half milligram of iodine was used as inactive carrier in the separation, the specific activity was always very satisfactory for all purposes.

Beta-ray sources were prepared by evaporating a small drop of active NaI solution on a microscope cover slip or a flake of mica on which a drop of dilute $AgNO_3$ solution had been deposited previously.

Gamma-ray sources for the study of secondary electron spectra were obtained by sealing active NaI or AgI into suitable brass or copper capsules.

All measurements were made within 24 hours of the separation. The decay of each source was followed for several days in order to correct for the longer period activities.

### B. The Beta-Ray Spectrum

The beta-ray spectrum obtained in the short lens spectrometer, corrected for long period radiations, is shown in Fig. 1. Besides the continuous spectrum there appear four weak internal conversion lines (marked with arrows). When the $K$ binding energy of Xe is added to the energies of these lines, the following gamma-ray energies are obtained:

$0.416\pm0.005$ Mev, $0.538\pm0.007$ Mev,
$0.665\pm0.008$ Mev, $0.747\pm0.010$ Mev.

These values are in excellent agreement with

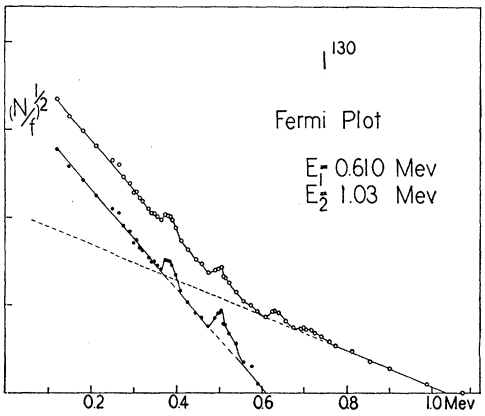


FIG. 2. Fermi plot of the beta-ray spectrum of $I^{130}$.

the values previously obtained by us from secondary electron spectra.[6]

These conversion lines will be further discussed below, but it should be pointed out here that the heights of the lines appearing in Fig. 1 do not represent the true intensities of the conversion lines, because of the correction for momentum interval, applied to the spectrum.

The shape of the continuous spectrum indicates that it is complex. Indeed, when the data are plotted as a "Fermi plot" the resulting curve (Fig. 2) clearly breaks into two straight lines, indicating two spectra of maximum energies $0.61\pm0.02$ Mev and $1.03\pm0.02$ Mev, respectively. These two spectra are indicated in Fig. 1. The areas under the two curves are very nearly equal. The low energy spectrum represents $53\pm10$ percent of all the disintegrations. The energy difference between the two end points appears to be $0.42\pm0.02$ Mev. The splitting of the Fermi plot into straight lines is not necessarily significant since it is known that at least

[6] M. Deutsch and A. Roberts, Phys. Rev. **60**, 362 (1941).

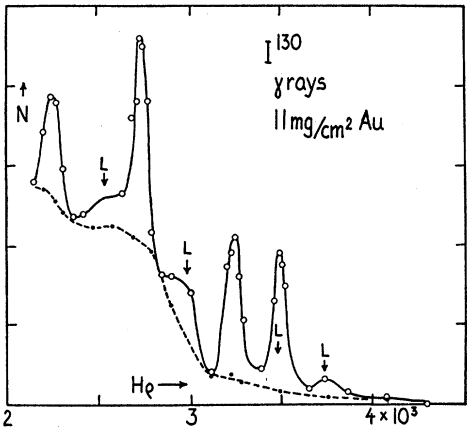


FIG. 3. Typical photoelectron spectrum due to gamma-rays of $I^{130}$. Dotted line indicates background due to recoil electrons from brass capsule.

some spectra do not show a simple Fermi distribution.[7] However, it will appear in the further discussion that in the case of $I^{130}$ this procedure is almost certainly justified. It will be noted immediately that the energy difference between the two beta-ray spectra corresponds, well within the probable error, to the energy of the 0.417-Mev gamma-ray found in the internal conversion spectrum. We shall show further on that this agreement is significant and that the gamma-ray corresponds to a transition between the two levels to which beta-ray transitions take place.

The slightly larger energy difference between the two end points of $I^{130}$ reported previously[4] was due to the fact that the earlier data were obtained with the spectrometer adjusted for lower resolution. Ordinarily this does not affect the study of continuous spectra very seriously, but in this case the presence of four unresolved internal conversion lines led to an apparent change in the slope of the Fermi plot.

### C. The Gamma-Ray Spectrum

The gamma-rays from the disintegration of $I^{130}$ were investigated by studying the energy distribution of secondary electrons produced in various radiators. The spectrometer and the general technique used are the same as in the previous papers of this series and in our preliminary report on gamma-ray energies.[6] However certain improvements in technique now permit greater resolution, and an investigation of the effects of radiator thickness allows us to estimate relative intensities of various gamma-rays with some accuracy.

Figure 3 shows a typical secondary electron spectrum obtained with a gold radiator of 11.0 mg/cm² thickness placed on top of the relatively thick brass capsule containing the active material. Only the energy range 0.35 Mev to 0.80 Mev is shown because no gamma-rays were found outside this range. Similar curves were obtained with various thicknesses of gold and lead radiators. The points marked by full circles in Fig. 3 were obtained without any radiator except the brass capsule itself. It should represent the background of Compton electrons on which the photoelectron lines are superimposed. However it was necessary to normalize the data obtained without radiator to those obtained with gold because of the different intensity of the Compton groups in the two cases.[8]

The lines shown in Fig. 3 correspond to gamma-rays of energies $0.417\pm0.008$, $0.535\pm0.010$, $0.670\pm0.013$, $0.740\pm0.015$ Mev.

The difference in energy of the two highest energy lines is very nearly equal to the difference between the $K$ and $L$ binding energies of gold so that the $L$ photoelectrons due to the 0.667-Mev gamma-ray are hidden by the $K$ photoelectrons due to the 0.744-Mev gamma-ray. This complication was avoided in another experiment by using a tin radiator. Since the results thus obtained did not reveal any different information than was obtained by the use of gold radiators, they are not presented here. In order to obtain the relative intensities of the gamma-rays, it is necessary to subtract the number of Compton recoil electrons from the data of Fig. 3 and to correct the heights of the photoelectron lines for the effect of finite radiator thickness. The procedure for this correction will be published in a separate paper dealing with spectrometer technique. In the case of the 0.744-Mev gamma-ray, the height of the line must also be corrected for the presence of the $L$ photoelectrons

[7] E. J. Konopinski and G. E. Uhlenbeck, Phys. Rev. **60**, 308 (1941).

[8] L. G. Elliott, M. Deutsch, and A. Roberts, Phys. Rev. **63**, 386 (1943).

due to the 0.667-Mev gamma-ray. Figure 4(A) shows the relative heights of the $K$ photoelectron lines thus corrected. The curve marked "$\tau$" shows the variation of the photoelectric cross section with energy in this region, obtained from Gray's empirical formula,[9]

$$\log \tau = \text{const.} + \log \lambda + 0.48(\log \lambda)^2.$$

It should be noted that the energy scale in Fig. 4(A) represents the energy of the photoelectrons from the $K$ shell rather than the energy of the gamma-rays.

As is easily seen in Fig. 4(A), the three high energy gamma-rays are of equal intensity (within the experimental error), but the 0.417-Mev gamma-ray is only about half as intense as the others. The value of its intensity, deduced from Fig. 4(A) is $0.3 \pm 0.1$ of the average intensity of the other three gamma-rays. The relatively large probable error is due to the fact that all of the corrections mentioned above are comparatively large for this gamma-ray.

### D. Coincidence Studies

Observations of coincidences between radiations from $I^{130}$ are complicated somewhat by the necessity for correcting all measurements for the effects due to the longer lived activities. These corrections must be determined separately for each source since the ratio of the several activities varies somewhat from target to target.

Figure 5 shows the number of beta-gamma coincidences per recorded beta-ray as a function of the amount of absorbing material between source and beta-ray counter. The data are corrected for chance and cosmic-ray coincidences, for long period radiations, for gamma-rays recorded in the beta-ray counter, and for gamma-gamma coincidences. For most of the points the corrections are fairly small. The gamma-ray counter used in these measurements was a platinum screen cathode type counter described in paper III, but the geometry used was slightly different.

Figure 5 shows that the fraction of the beta-rays which causes coincidences is independent of beta-ray energy above about 0.6 Mev. This means that all beta-rays having more than this energy are accompanied—at least on the average—by the same gamma-rays or at least by gamma-rays for which the gamma-ray counter has the same total detection efficiency. Similarly, the rise in the fractional coincidence rate as more absorber is removed shows that some of the beta-rays of less than 0.6-Mev energy are accompanied by gamma-rays of greater total detection efficiency; i.e., either by a greater number or by more energetic gamma-rays.

Coincidences between gamma-rays were measured in an experimental arrangement in which their number could be directly compared with the number of beta-gamma coincidences, as shown in Fig. 6. In this arrangement we observed $(2.93 \pm 0.15) \times 10^{-3}$ beta-gamma coincidence per recorded high energy (above 0.6 Mev) beta-ray and $(2.57 \pm 0.2) \times 10^{-3}$ gamma-gamma coincidence per recorded gamma-ray, after all corrections. The large ratio of gamma-gamma to beta-gamma fractional coincidence rate signifies—even without any knowledge of the efficiency

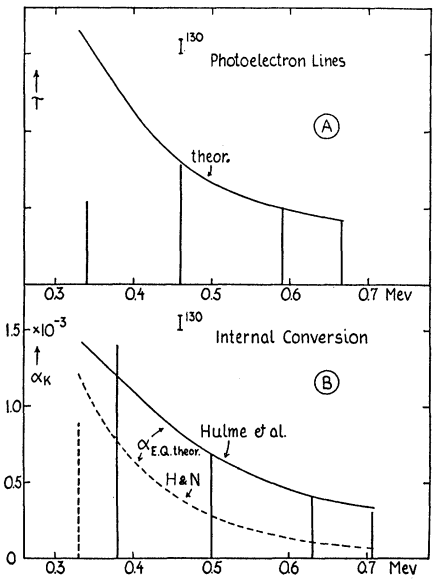


FIG. 4. (A) Relative intensity of photoelectron groups due to gamma-rays of $I^{130}$. Curve shows variation of photoelectric cross section according to Gray's formula. (B) Internal conversion coefficients for $I^{130}$ (solid) and $I^{131}$ (dotted). Curves show theoretical values for electric quadrupole transitions. Energy scale refers to electron (not gamma-ray) energies.

[9] L. H. Gray, Proc. Camb. Phil. Soc. **27**, 103 (1931). This formula is in close agreement with the theoretical results of Hulme *et al.*, Proc. Roy. Soc. **149**, 131 (1935). It was derived for lead. However the effect of the slight difference of atomic number between gold and lead should be only a small change in the value of the constant.

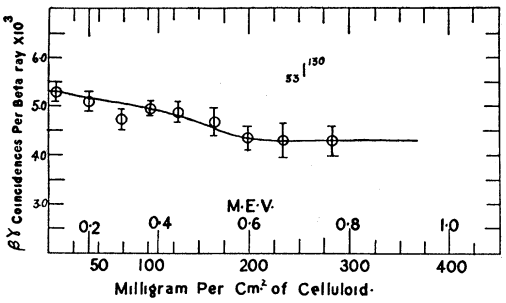


FIG. 5. Beta-gamma coincidences per recorded beta-ray as a function of beta-ray absorber.

of the gamma-ray counter—that either (a) the majority of the beta-rays is accompanied by several (more than two) gamma-rays, or (b) a large fraction of all the gamma-rays is emitted in cascade transitions *unaccompanied by beta-rays*. The latter alternative cannot be excluded a priori since $I^{130}$ could decay by orbital electron capture to $Te^{130}$ as well as by negatron emission to $Xe^{130}$, or the emission of some of the gamma-rays might be delayed.

The two possibilities may be distinguished without any assumptions concerning the disintegration scheme. The number of beta-gamma coincidences per recorded beta-ray gives the probability of detecting, in the gamma-ray counter, any of the gamma-rays accompanying an average beta-ray. On the other hand the total number of beta-rays emitted by a given source may be determined since the efficiency of our beta-ray counters is fairly well known from previous results on other substances. By multiplying this total number of beta-rays by the detection efficiency for gamma-rays found from the coincidence rate, we can predict the number of gamma-ray counts due to *the gamma-rays accompanying the beta-rays*. If the number of gamma-ray counts actually observed is greater than this predicted number, some of the gamma-rays must be emitted in processes not accompanying the beta-rays. Actually it was found that the number of gamma-rays emitted by $I^{130}$ agreed with the predicted number within the experimental uncertainty of about 10 percent.

Fortunately the fact that the efficiency of the gamma-ray counter for radiations of the energies involved is known allows an independent determination of the number of gamma-rays accompanying each beta-ray. Figure 6[10] shows the efficiency (including geometrical factors) as a function of gamma-ray energy as determined from known disintegration schemes. From this curve, each point of which should be reliable to a few percent, we obtain the following values for the efficiencies of the counter for the gamma-rays of $I^{130}$, in order of increasing gamma-ray energy:

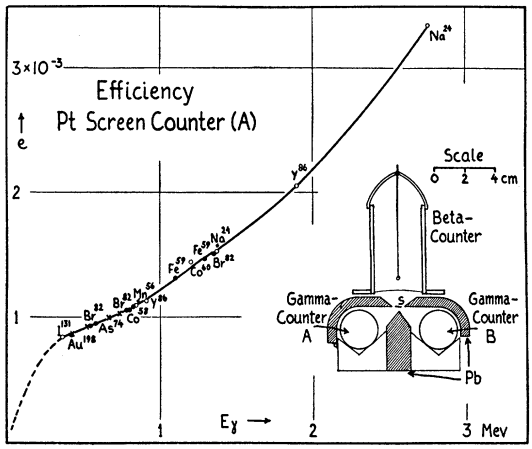


FIG. 6. Net efficiency of gamma-ray counter. Crosses show gamma-rays of $I^{130}$. For calibration points see papers I–IV, also reference 10. Dotted part of curve is doubtful. Insert: Experimental arrangement used.

$$\epsilon_1=0.90\times10^{-3},\quad \epsilon_2=0.95\times10^{-3},$$
$$\epsilon_3=1.02\times10^{-3},\quad \epsilon_4=1.06\times10^{-3}.$$

From these values we may conclude that whatever the exact disintegration scheme of $I^{130}$ may be, each high energy beta-ray is accompanied by three gamma-rays and that each gamma-ray is accompanied, on the average, by more than two and less than three other gamma-rays.[11] The fact that the efficiency varies so little in this energy range makes these conclusions particularly reliable.

### E. The Disintegration Scheme

The complexity of both the beta- and gamma-

[10] For calibration points see: Phys. Rev. **62**, 558 (1942); **63**, 219, 321, 386 (1943).

[11] For complex disintegration schemes the formula for the gamma-gamma coincidence rate (papers II and III) becomes

$$N_{\gamma\gamma}/N_\gamma=\Sigma_k\,(a_k\Sigma_{i,j}\,\epsilon_i\epsilon_j)/\Sigma_k\,(a_k\Sigma_i\,\epsilon_i),$$

where the $a_k$ are the fraction of the disintegrations proceeding by the $k$th mode and the summations over $i$ and $j$ are carried out for the gamma-rays accompanying this mode. A similar formula holds for the beta-gamma coincidences, the $\epsilon_i$ being replaced by the efficiency of the beta-ray counter for the various beta-ray spectra.

ray spectra indicates that the disintegration of $I^{130}$ must follow a more complicated scheme than any yet discussed in this series. Both the Fermi plot (Fig. 2) and the coincidence data (Fig. 5) indicate clearly that the beta-decay leads to two levels in the product nucleus, differing in energy by about 0.42 Mev. There are two ways in which the four gamma-ray energies could be arranged to give a scheme consistent with this separation. If the high energy spectrum were accompanied by a 0.416 Mev and a 0.537-Mev gamma-ray in cascade and the low energy spectrum by a 0.667-Mev and a 0.744-Mev gamma-ray, an energy balance could be obtained just within the combined experimental errors of the energy determinations. On the other hand all energy measurements are in excellent agreement with the scheme shown in Fig. 7 in which the high energy spectrum is accompanied by the three gamma-rays of higher energies and the low energy spectrum by the same and in addition by a 0.416-Mev gamma-ray. The decision between the two possible schemes is readily made by considering the beta-gamma coincidence rate, as discussed in the preceding section. It was shown there that each high energy beta-ray is accompanied by *three* gamma-rays, consistent with the scheme shown in Fig. 7, but not with the alternative scheme mentioned above. In fact, the fractional coincidence rates predicted by the scheme of Fig. 7 are $N_{\beta\gamma}/N_\beta = 3.03\times10^{-3}$ and $N_{\gamma\gamma}/N_\gamma = 2.54\times10^{-3}$ compared with the experimental values of $2.93\times10^{-3}$ and $2.57\times10^{-3}$, respectively, showing excellent agreement. For the alternative scheme the predicted rates would be $1.85\times10^{-3}$ and $0.98\times10^{-3}$, respectively. Finally, the relative intensities of the gamma-rays are consistent only with the scheme of Fig. 7, since the 0.416-Mev gamma-ray is only half as intense as any one of the other three gamma-rays. We are therefore led to conclude that the scheme shown in Fig. 7 represents the main modes of disintegration of $I^{130}$. Other rare processes may, of course, have escaped detection. However, the emission of high energy gamma-rays in "cross-over" transitions between the several levels of $Xe^{130}$ cannot occur in more than about 7 percent of the disintegrations, if at all, since the spectrometer observations as well as absorption measurements over a wide range of thickness of lead absorber failed to show any sign of higher energy gamma-rays. Also the number of gamma-gamma coincidences is quite sensitive to such transitions.

An attempt was made to verify the proposed disintegration scheme directly by a modification of the method used to determine the conversion coefficient of the 0.367-Mev gamma-ray of $I^{131}$ (paper III). According to the proposed scheme conversion electrons due to the 0.417-Mev gamma-ray should coincide only with the soft beta-ray spectrum. Measurements were made of coincidences between these conversion electrons, focused in the spectrometer and beta-rays recorded in a counter placed behind the source, with and without absorber between source and counter. The results were consistent with the proposed disintegration scheme, i.e., such coincidences were not found when only high energy beta-rays were admitted to the counter. However the conversion coefficient is so low and the number of gamma-rays accompanying both the continuum and the conversion electrons is so large that the background of chance and beta-gamma coincidences is large compared with the number of conversion line-beta coincidences and the statistical counting error of the results almost completely masks the effect studied.

While the location of the 0.416-Mev gamma-ray in the disintegration scheme appears quite certain, the order of emission of the other three gamma-rays is not known, and the particular order shown in Fig. 7 is entirely arbitrary.

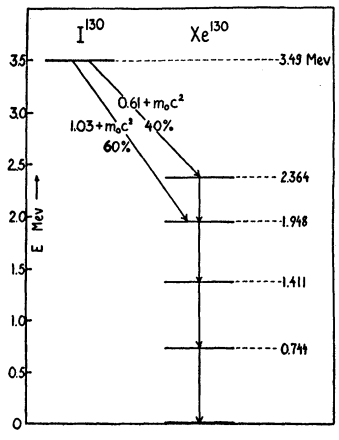


FIG. 7. Disintegration scheme of $I^{130}$. Arrangement of the first two excited states is in doubt since the order of emission of the gamma-rays involved is not known.

Although it has been shown in Section D that orbital electron capture accompanied by gamma-rays does not occur with appreciable abundance, the possibility of orbital electron capture leading directly to the ground state of $Te^{130}$ remains. A search for Te x-rays expected to accompany such a process was undertaken by means of an argon-filled counter. No x-ray activity was found to decay with the 13-hour period although very intense x-radiation was found to be emitted by an activity of longer life, probably the 13-day $I^{126}$. Since we have, as yet, no measurement of the efficiency of our counter for x-rays of this wave-length, we cannot set a definite upper limit to the possible abundance of orbital electron capture leading to the ground state of $Te^{130}$, but if it does occur at all, it is certainly considerably less frequent than negatron emission.

### F. Conversion Coefficients

Because of the difficulties pointed out in the preceding section, it was not possible to determine the coefficients of internal conversion directly by the coincidence method used for $I^{131}$ (paper III) with sufficient accuracy. Therefore we followed the usual procedure of comparing the actual number of conversion electrons in each line with the total number of beta-rays obtained by integrating the distribution shown in Fig. 1. In order to perform this integration, it is necessary to know the mean width of the transmitted momentum band. In this case this width was about three percent of the momentum. It is also assumed that the Fermi theory gives the correct shape of the spectrum at low energies. Any error in the ratio introduced by this assumption would be small. The number of electrons counted in each line should, of course, *not* be divided by the momentum as is done in the case of the continuous distribution. The data shown in Fig. 1 were so divided, and the height of the peaks appearing in that figure is not a true measure of the internal conversion.

In Fig. 4(B) the vertical lines indicate the observed conversion coefficients for the gamma-rays of $I^{130}$. The dotted line indicates the conversion coefficient for the 0.367-Mev gamma-ray of $I^{131}$ (paper III).

Besides counting errors and errors in the integration of the beta-ray spectrum, the ejection of photoelectrons from the source material might introduce an error of several percent.

The coefficients of internal conversion shown in Fig. 4(B) are $12\times10^{-3}$, $6.9\times10^{-3}$, $3.8\times10^{-3}$, $3.1\times10^{-3}$ in the order of increasing energy.

The solid curve shows the internal conversion coefficients obtained from the calculations of Hulme *et al.*[12] for electric quadrupole transitions, in which we assume $\alpha$ to vary as $Z^3$. The dotted line was computed from the non-relativistic calculations of Hebb and Nelson,[13] which are, however, probably not applicable in this case. The rather close agreement between theory and experiment should not be considered unduly significant until more accurate calculations are available for this range of $Z$. However, the fact that the conversion coefficients of all four gamma-rays fall on a smooth curve of the general shape predicted by theory suggests that all of the transitions are of the same type. Some considerations presented in the next section indicate that if this is true, they are probably all electric quadrupole transitions.

The conversion in the $L$ shell is too weak to be detected in our experiment, in agreement with all theories.

### G. Discussion

With exception of the order of emission of the higher energy gamma-rays, the disintegration scheme of $I^{130}$ (Fig. 7) may be considered well established. The relative probabilities of the two beta-ray transitions have the largest probable error of the various features—their ratio being uncertain to about 15 percent. The most interesting feature of the scheme is the fact that the highest excited state involved decays by the emission of four successive gamma-rays with no observed cross-over transition. This is the longest chain of cascade transitions observed so far, at least in induced radioactivities. Also this is the second case in which it has been shown that the extrapolation and separation of the Fermi plot leads to the correct assignment of energy levels in the product nucleus even for forbidden

[12] H. R. Hulme, N. F. Mott, F. Oppenheimer, and H. M. Taylor, Proc. Roy. Soc. **A155**, 315 (1936).
[13] M. H. Hebb and E. Nelson, Phys. Rev. **58**, 486 (1940).

spectra.[14] The first case ($Fe^{59}$), discussed in paper IV involved much lower beta-ray energies and nuclei of much lower atomic number. A third case[15] ($Mn^{56}$) will be discussed in a subsequent paper of this series.

It is customary at this point to propose angular momenta for the various states involved in the disintegration. While this is only of doubtful value it may be worth while to show that it is possible to make assignments which are consistent with the few known selection rules, even in this relatively complicated disintegration.

The ground state of $Xe^{130}$ probably has no angular momentum since this nucleus consists of an even number of protons and an even number of neutrons. If we admit that the only selection rules governing gamma-ray emission concern angular momenta and parity, then we find that the minimum possible angular momentum values are 1, 1, 2, 3, for the successive excited states. With this arrangement all of the gamma-rays would be electric dipole radiation, and no electric dipole cross-overs would be allowed. However, electric quadrupole and magnetic dipole radiations could cause cross-overs, and it is thought that these types of radiation are about equally probable as dipole radiation. It is possible to construct a scheme in which the angular momenta are 1, 2, 3, 4, and the parity assignments such that the radiations would be alternately electric dipole and electric quadrupole or magnetic dipole radiations. In this scheme the lowest multipole orders that can cause cross-over transitions are magnetic quadrupole or electric octupole radiations. Such a scheme would, however, probably show a different behavior of the conversion coefficients than is actually observed. If we specify that all of the transitions should be of the same type (electric quadrupole and/or magnetic dipole) and that no cross-overs involving lower multipole orders than electric $2^4$ pole or magnetic octupole should be allowed, the lowest possible angular momentum quantum numbers are 2, 3, 5, 6, and all states have the same parity. These values of the angular momenta appear rather high. Otherwise it is probably the scheme least open to objections since it predicts a multipole order for cross-over transitions which would have to be greater by *two* than that of the transitions actually taking place.

From the general trend of decay constants in this region of the periodic table one may conclude that both of the beta-ray transitions may be first forbidden. The ratio of the two transition probabilities is such that both may be equally forbidden or the higher energy spectrum may be forbidden by one more order. The lowest possible angular momentum of the decaying state of $I^{130}$ is 3, for the first of the quantum number schemes proposed above, or 6, for the scheme considered most satisfactory in the above discussion. It is not to be taken for granted that the decaying state is the ground state of $I^{130}$, particularly because of the probably high angular momentum.

Guggenheimer[16] has pointed out that there seem to be some whole number relationships between the gamma-ray energies of some radioactive substances. Although sufficient data are not yet available to decide whether these relations are significant or fortuitous, it may be pointed out that the multiples $4\times106=424$, $5\times106=530$, $7\times106=742$ correspond, within the experimental errors, to three of the four gamma-rays of $I^{130}$.

## Acknowledgments

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This research was supported in part by a grant from the John and Mary R. Markle foundation.

[14] The so-called "K-U plot" still occasionally applied to cloud-chamber data has no physical significance as has been shown by all careful studies in recent years.

[15] L. G. Elliott and M. Deutsch, Phys. Rev. **63**, 321 (1943).

[16] K. M. Guggenheimer, Proc. Roy. Soc. **A181**, 169 (1942).