AN INVESTIGATION OF CONVERSION LINES IN THE β SPECTRUM OF IR^{192}

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A prism β-spectrometer with a resolution of 0.04% was used to study the conversion electron spectrum of excited Pt^{192} and Os^{192} nuclei produced in the decay of Ir^{192}. The conversion coefficient ratios K/L and $L_I:L_{II}:L_{III}$ have been determined for the transition energies of 136.3, 201.3, 205.8, 295.9, 308.5, 316.5, 468.0 and 604.5 kev. For the most intense transitions the ratios K/M, $M_I:M_{II}:M_{III}$, K/N and K/O have also been determined. All the investigated transitions were found to be E2 or E2 + M1. The amount of M1 admixture has been determined.

THE radioactive isotope Ir^{192} has been investigated by many authors.[1-3] It was established that it decays by the following double process: it goes over to Pt^{192} by emitting β electrons and then to Os^{192} by K-capture. The γ-radiation of the excited Pt^{192} and Os^{192} comes from E2 and E2 + M1 transitions.[3] Thus these isotopes are well suited for the study of internal conversion involved in the above transitions. It is of interest to investigate their conversion electron spectrum by using a high-resolution β spectrometer able to resolve the conversion electrons from the L subshells and, if possible, from the M subshells. In order to complete the picture it is desirable also to find the total conversion coefficient ratios for the K, L, M, N, and O shells.

The above investigations have been performed on a prism β spectrometer.[4,5] The resolving power of the instrument corresponds to a line half-width of 0.04% (with respect to momenta), and its transmission is 0.02%. The source was a thin film of natural iridium deposited by cathode evaporation on a strip of aluminum film subjected to a neutron bombardment. The thickness of the aluminum foil was 5 μ. The following method was used to determine the thickness of iridium film deposited. The strip of aluminum foil 1 (Fig. 1) onto which the iridium is to be evaporated is placed on a glass plate 2 and covered by a thin metal plate 3 with a slot 4 cut out of it. In addition, this metal plate has several circular holes 5 which expose the glass close to the slot. The slot determines the area of the source, and the evaporated iridium is deposited simultaneously on the aluminum foil and the glass. The iridium deposited on the aluminum is assumed to be of the same thickness as that deposited on the glass, which is measured by an interferometer.[6] Even if these thicknesses are not the same, this method makes it possible to determine the relative thicknesses fo iridium films, thus simplifying the choice of a suitable source. Several samples were prepared in this way, and from them we choose one whose iridium film thickness was 0.48 mg/cm², making it possible to obtain sufficiently intense conversion lines with a half-width almost the same as that of the apparatus. The area of the iridium film was 1.6 by 11 mm².

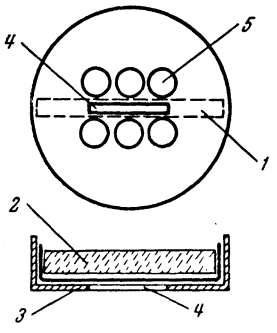

FIG. 1.

Within the limits of any given line group, a spectrum was obtained by applying a potential to the source. Since this method of measurement causes electrons of a given constant energy to pass through the spectrometer, it is unnecessary to correct for the width of an energy interval for any given group. Such a correction must be used on going from one group to another, when the magnetic system of the spectrometer is readjusted. The correction was applied according to the formula

$$n_{\text{true}} = k \frac{n_{\text{meas}}}{\varepsilon\,(1 + 1/[1 + \varepsilon/m_0c^2])},$$

where n_{true} is the number of electrons giving the true line intensity, n_{meas} is the number of counts of the recording system, k is a coefficient depending on the transmission of the instrument, and ε is the electron energy. Since ε is usually given in kev, the rest mass must be given in the same units, or $m_0c^2 = 511$ kev.

The window through which the β particles enter the counting chamber was covered by a 0.87 mg/cm^2 thick mica leaf. The electrons then passed through two aluminum foils covering neighboring counter windows, their total thickness being 1.1 mg/cm^2. Corrections for absorption in the mica were applied according to the data of Martin and Towsend.[7] The correction for adsorption in the aluminum foils was determined experimentally by comparing the number of counts of the first and second counters. Starting with energies of 300 kev these corrections produced no significant changes even in measuring the K/L ratio.

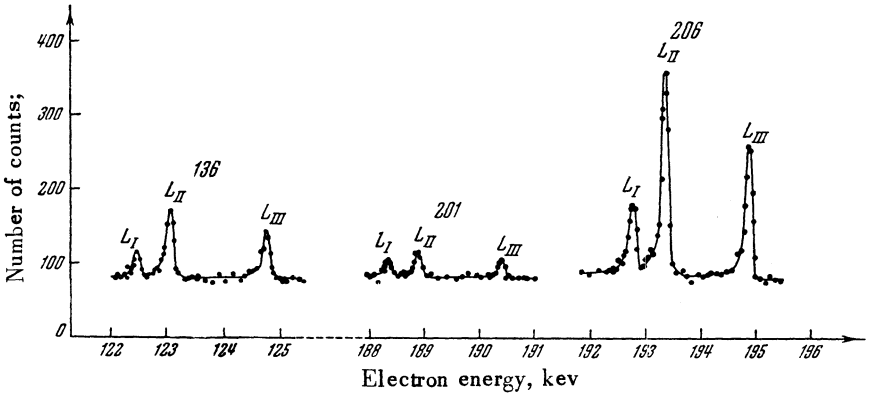

FIG. 2. Conversion lines of 136.3, 201.3, and 205.8 kev gammas on L subshells.

Conversion lines were observed for the 136.3, 295.9, 308.5, 316.5, 468.0, and 604.5 kev transitions in Pt and for the 201.3 and 205.8 kev transitions in Os. The transition energies which we give here are those of Baggerly and co-workers.[3] The measured separations between the lines of the L sublevels allowed us to verify the fact that they belong to the above transitions. Figures 2 — 5 show different sections of the β spectra (the background is subtracted). It is seen that the resolution of the instrument is sufficient to separate the conversion lines from the L subshells even for the 604.5-kev gamma quanta. For the most intense transitions, the data makes it possible to obtain the conversion coefficient ratios for the M subshells. Since the conversion lines from the M subshells were not entirely resolved, it was necessary to resolve them graphically. The conversion lines of the intense gammas on the N and O shells are clearly seen. In order to separate the overlapping lines due to conversion of 308.5 kev gammas on the L_{II} subshell and the 296 kev gammas on the N shell it was assumed that the N/L_{II} ratio for the 296 kev transitions was equal to the N/L_{II} ratio the 3.16.5 kev transitions, which was known from the experiment. Then knowing the area of the L_{II} peak for the 296 kev transition one can find the area of the N conversion

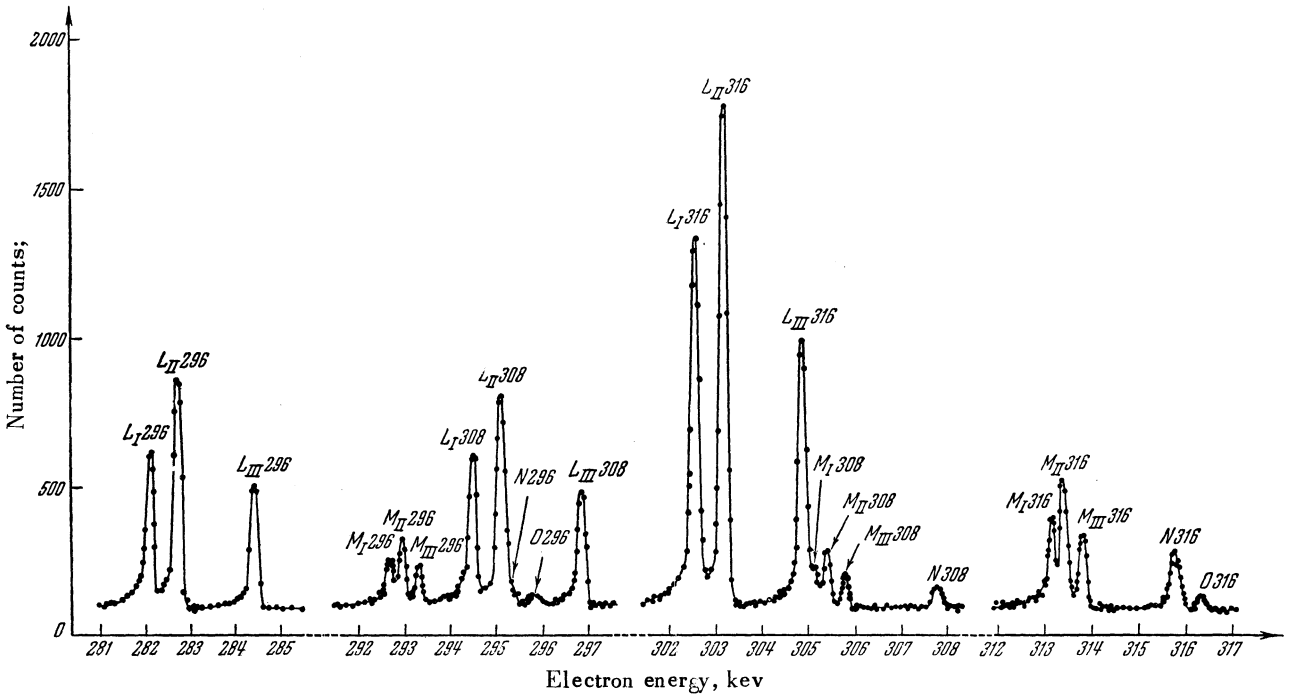

FIG. 3. Conversion lines of the 295.9, 308.5, and 316.5 kev gammas.

lines for this transition and thus separate from it the L_{II} line from the 308.5 kev transition. The separation of the electrons due to conversion of the 308.5 kev gammas on the M_I subshell from those due to conversion of the 316.5 kev gammas on the L_{III} subshell was performed graphically. In order to determine the conversion coefficient ratios, each line was measured five times, the mean value of the area ratios was obtained, and its probable error was found. The results for the K/L and $L_I:L_{II}:L_{III}$ ratios are shown, after the necessary corrections, in Table I.

TABLE I

Transition energy, kev	Experimental conversion coefficient ratio; K/L	Experimental conversion coefficient ratio; $L_I:L_{II}:L_{III}$	Theoretical conversion coefficient ratio for E2 transitions; K/L	Theoretical conversion coefficient ratio for E2 transitions; $L_I:L_{II}:L_{III}$	Type of transition	Per cent of M1 admixture Determined from; L_{II}/L_I	Per cent of M1 admixture Determined from; L_{III}/L_I	Type of transition according to Ref. 3.
136.3	—	1:(2.1±0.1):(1.7±0.1)	0.62	1:6.7:5.0	E2+M1	21%	19%	E2
201.3	1.85±0.04	1:(1.42±0.06):(0.89±0.07)	1.5	1:2.9:1.7	E2+M1	16%	13%	E2+M1
205.8	1.83±0.04	1:(2.32±0.02):(1.41±0.02)	1.5	1:2.8:1.7	E2	—	—	E2
295.9	2.35±0.04	1:(1.39±0.03):(0.74±0.02)	2.0	1:1.7:0.8	E2	—	—	E2
308.5	2.38±0.02	1:(1.18±0.02):(0.67±0.01)	2.2	1:1.5:0.7	E2+M1	5%	1%	E2
316.5	2.22±0.02	1:(1.38±0.01):(0.73±0.01)	2.3	1:1.5:0.7	E2	—	—	E2
468.0	3.0 ±0.1	1:(0.68±0.01):(0.29±0.01)	3.1	1:0.77:0.30	E2	—	—	E2
604.5	4.7 ±0.1	1:(0.33±0.01):(0.13±0.01)	4.0	1:0.50:0.19	E2+M1	14%	10%	E2+(M1)

The multipole orders of the transitions were determined by comparing the measured conversion coefficient ratios on the L subshells and the K and L shells with the corresponding theoretical ratios for various multipole orders. The theoretical ratios of the conversion coefficients on the L subshells and the value of the total conversion coefficient on the L shell were obtain from the Rose tables[8] and the theoretical conversion coefficients for the K shell were obtained from the very detailed and accurate tables of Sliv and Band.[9] In agreement with Ref. 3 it was established that all the transitions investigated were either E2 or E2 + M1. The theoretical K/L and $L_I:L_{II}:L_{III}$ ratios for E2 transitions are shown in Table I. The theoretical $L_I:L_{II}:L_{III}$ ratio for magnetic dipole transitions hardly depend on energy, and for the transitions of interest remains practically constant at 1 : 0.088 : 0.006.

The per cent admixture p of magnetic dipole in the mixed transitions is

$$p = [\gamma_1/(\gamma_1 + \gamma_2)] \cdot 100 = [\delta_{12}^2/(1 + \delta_{12}^2)] \cdot 100,$$

where γ_1 and γ_2 are the intensities of magnetic dipole and electric quadrupole transitions, and $\delta_{12}^2 = \gamma_1/\gamma_2$ is the mixture ratio. The mixture ratio can be found if one knows the conversion coefficient ratio for any two shells or subshells for the mixed transition under consideration, as well as the conversion coefficient on these shells in the transition is purely of one kind:[10]

$$\delta_{12}^2 = \alpha_{2k}(R_0 - R_2)/\alpha_{1k}(R_1 - R_0),$$

where $R_i \equiv \alpha_{ij}/\alpha_{ik}$. Here α_{ij} and α_{ik} are the absolute conversion coefficients for γ-rays of the i-th kind on the shells or subshells j and k. They were found from the theoretical values given in the above-mentioned tables. The experimental conversion coefficient ratio is $R_0 \equiv \alpha_{0j}/\alpha_{0k}$. The values of L_{II}/L_I and L_{III}/L_I were used to find the mixture ratios. The ratio K/L is less sensitive to presence of some M1 admixture, and was therefore not used for this purpose. The percentage of M1 thus obtained is shown in the two next-to-last columns of Table 1, were it is indicated whether L_{II}/L_I or L_{III}/L_I was used to obtain the data. It should be noted that due to the small number of available theoretical conversion coefficients for the L subshells (L_{II} has been calculated for Z = 25, 55, and 85, and L_{III} for Z = 55 and 85), it is impossible to perform the necessary interpolation with sufficient accuracy. The per cent admixtures given in Table 1 may contain errors of several per cent. In particular, a per cent admixture of the order of 5 does not necessary indicate the actual presence of admixture, but may be due to error in interpolation. Therefore Table I shows admixtures whose percentage is greater than 5, and it is assumed otherwise that the transition is purely of one kind. The only exception is the 308.5 kev

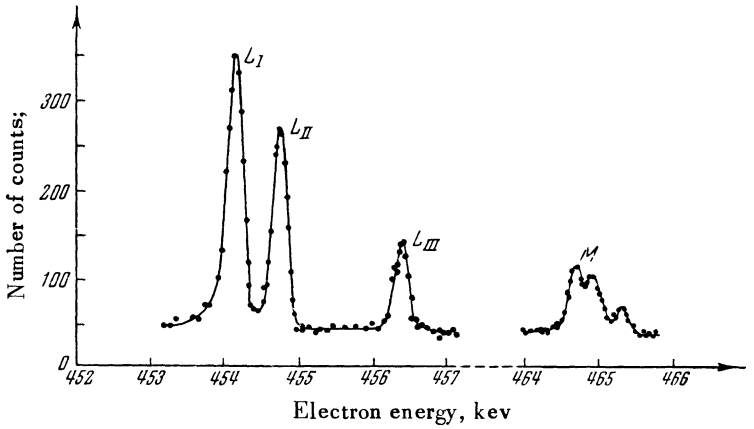

FIG. 4. Conversion lines of 468.0 kev gammas.

transition, for which the presence of M1 admixture can be deduced by comparing the experimental conversion coefficient ratio on the L subshells with this ratio for the neighboring 296 and 316.5 kev transitions. Lower amounts of admixture can be established only with the aid of more complete theoretical tables. The presence of some M1 in the 604.5 kev transition indicates that the spin and parity 3^+ should be assigned to the 920.9 kev level suggested[3] in the level scheme of Pt^{192}. The last column of the table gives the multipole orders as obtained in Ref. 3.

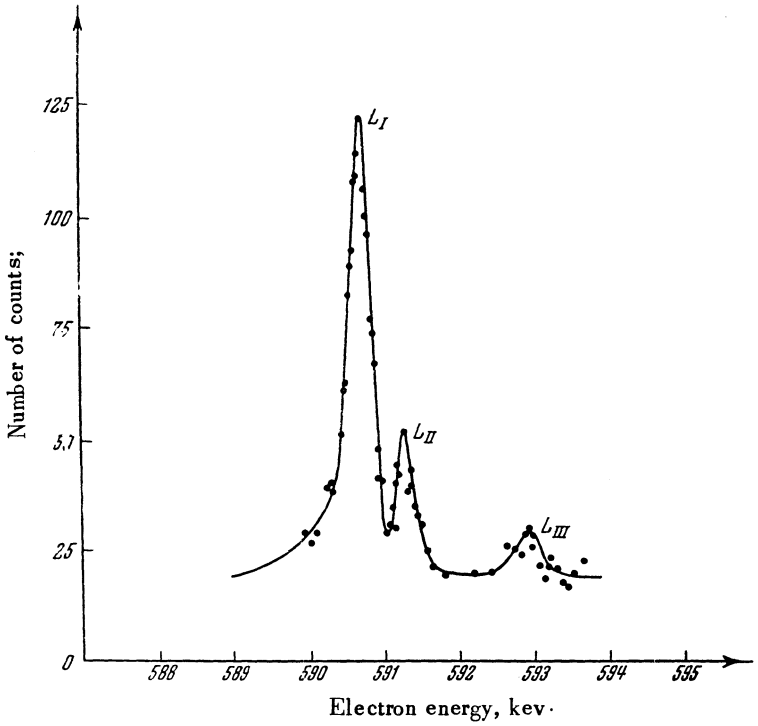

FIG. 5. Conversion lines of 604.5 kev gammas.

In Table II we present the K/M, $M_I : M_{II} : M_{III}$, K/N and K/O ratios for the most intense transitions. In no case were we able to observe conversion on the M_{IV} and M_V sublevels. We note that the $M_I : M_{II} : M_{III}$ ratios are quite close to the corresponding $L_I : L_{II} : L_{III}$ ratios. This latter situation has been noted also for M1 transitions.[11]

Measurement of the energy separation between the conversion lines denoted N and O in Fig. 3 and the corresponding M_{III} lines and their comparison with x-ray data shows that the N lines correspond to conversion on the N_I, N_{II}, and N_{III} subshells. Conversion electrons from the N_{IV} and N_V subshells, which lie between the N and O peaks, were not observed in the present work. Conversion electrons from the N_{VI} and N_{VII} subshells overlap with the electrons from the O shell, and thus form common lines indicated by the letters O in the figure.

Assuming that conversion on the N takes place primarily on the first three subshells, as is the case for conversion on the M shell, one may consider the O lines to be due mostly to electrons from the O shell. The conversion coefficient ratios K/N and K/O of Table 2 are given on this assumption.

TABLE II. Experimental conversion coefficient ratio.

Transition energy, kev	K/M	$M_I : M_{II} : M_{III}$	K/N	K/O
295.9	8.9±0.2	1 : (1.59±0.05) : (0.87±0.03)	—	(28±3)·10
308.5	9.5±0.2	1 : (1.69±0.05) : (0.87±0.04)	44±2	—
316.5	9.3±0.2	1 : (1.90±0.07) : (1.06±0.03)	38±1	255±7
468.0	10.2±0.2	—	—	—

[1] Cork, LeBlanc, Stoddard, Child, Branjan, and Martin, Phys. Rev. 82, 258 (1951).
[2] Bashilov, Anton'eva, and Dzhelepov, Izv. Akad. Nauk SSSR, Ser. Fiz. 16, 264 (1952).
[3] Baggerly, Marmier, Boehm, and DuMond, Phys. Rev. 100, 1364 (1955).
[4] Kel'man, Kaminskii, and Romanov, Izv. Akad. Nauk SSSR, Ser. Fiz. 18, 209 (1954).
[5] Kel'man Romanov, Metskhvarishvili, and Koliunov, J. Exptl. Theoret. Phys. (U.S.S.R.) 32, 39 (1957); Soviet Phys. JETP 5, 24 (1957).
[6] S. Tolansky, Multiple-Beam Interferometry (Oxford, 1948), p. 147.
[7] L. H. Martin and A. A. Towsend, Proc. Roy Soc. (London) A170, 190 (1939).
[8] K. Siegbahn, Beta- and Gamma-Ray Spectroscopy (Amsterdam, 1955), p. 905.
[9] L. A. Sliv and I. M. Band, Таблицы коэффициентов внутренней конверсии (Tables of Internal Conversion Coefficients) (M.-L., 1956).
[10] E. L. Church and J. E. Monahan, Phys. Rev. 98, 718 (1955).

[11] Ke'lman, Romanov, and Metskhvarishvili, Dokl. Akad. Nauk SSSR 103, 577 (1955).

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THE STRIPPING PROCESS IN THE INTERACTIONS OF ACCELERATED N^{14} IONS WITH THE NUCLEI OF SOME ELEMENTS

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The formation of the radioactive isotope N^{13} was observed when Al, Ni, Cu, Ag, Cd and Sn foils were bombarded with N^{14} ions which had been accelerated to ~ 100 Mev in a cyclotron. Angular distribution measurements showed that the N^{13} was emitted in a relatively narrow angular range. The angle corresponding to maximum intensity increases with Z. When the energy of the bombarding particle exceeds the height of the Coulomb barrier the cross section for N^{13} production is only slightly dependent on the energy. The cross section is ~ 30 mb for Ni and ~ 12 mb for Al.

WHEN atomic nuclei are bombarded with nultiply-charged ions stripping reactions can occur as well as the formation of compound nuclei. Such reactions for light nuclei at not very high energies have been studied in Refs. 1 — 7. At our Institute P. M. Morozov, B. N. Makov and M. S. Ioffe have devised a special ion source which furnishes monoenergetic beams of multiply-charged ions at considerably higher energies than those used in the investigations mentioned above. This had made it possible to study stripping reactions in heavier nuclei at higher energies.

The present work is a study of reactions involving several different elements to which N^{14} loses a neutron and is transformed into radioactive N^{13}.

EXPERIMENTAL METHOD

An internal cyclotron beam was used in all experiments. The bombarding particles were quintuply-charged N^{14} ions. Their range in nickel at the radius 66 cm was 48 μ, which corresponds to 115 Mev.[5] The energy spread of the particles did not exceed 5 to 7%.

The average beam intensity at the target was a few tenths of a microampere and was measured by a current integrator. The energy of the ions was varied by moving the target along the radius. The

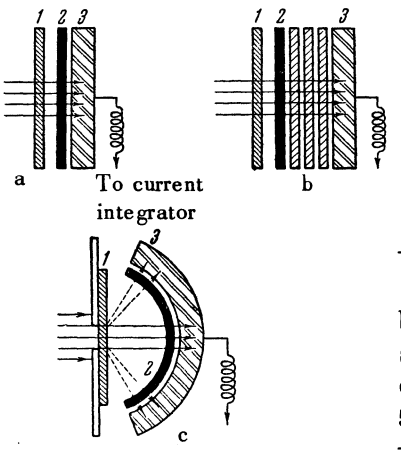

FIG. 1. Diagrams of the experiments: a — N^{13} production through bombardment of foils of different elements with nitrogen ions and the cross section measurement, b — Measurement of the angular distribution, c — Distribution of radioactivity in a stack of lead foils (there 7μ lead foils, 50μ collector). 1 — target; 2 — shield of Au or Pt foil; 3 — lead collector.