reported four disintegrations of neon in accordance with (3) for which $E=3.9$ MV, $E_t=7.8$ MV. The mass of $_{10}Ne^{21}$ is 21.0093 from the right hand side of (3), and 21.0099 from the left hand side. The first of these masses is based on the value 17.0029 for $_8O^{17}$. This agreement is very good, but here again the lack of data by its influence on E_t makes it uncertain how much weight to give this agreement.

The following facts concerning neutron-stimulated disintegration of the Feather type (emission of an α-particle) seem to be well established by the information now at hand:

(1) At least in the case of nitrogen, oxygen, fluorine, and neon they are all examples of case 2 disintegrations ($E=$constant).

(2) The disintegration energies ($E\sim 3-4$ MV) do not vary greatly from element to element.

(3) A large fraction of the neutron's energy is radiated, perhaps as a γ-ray, the remainder going into excitation, mass building and kinetic energy of the temporary radioactive element. The mass of this radioactive element can be estimated from the threshold energy, which is only well determined in the case of nitrogen, for which there are now data on 60 forks.

(4) In the case of N^{15} the level in its nucleus from which α-particles escape has been identified with the resonance level for entry of the α-particles in the disintegration of boron with the emission of neutrons.

(5) Values of E show considerable spread. This is slightly in excess of that expected from experimental errors and it is suggested that it may in part be a consequence of the very short half-life expected for the radioactive intermediate nucleus.

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X-Ray Levels of Radioactive Elements with Applications to Beta and Gamma-Ray Spectra

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A table of x-ray levels of radioactive elements is presented. The levels for Tl, Pb, Bi, Th and U were computed by adding term-differences from x-ray emission spectra to some outer level obtainable from optical spectra; those for other elements were carefully interpolated. The energies of certain gamma-rays of Th B·C, Th C″·D, Ra C·C′, Ac B·C and Ac C·C″ are recomputed from the new levels and known beta-ray energies. In the case of Ellis' data, gamma-ray energies obtained from beta-rays ejected from the K-shell are brought into excellent agreement with those based on beta-rays from other shells. Energies of secondary electrons of Bi 83 and Po 84, arising in Auger processes and studied by Ellis, agree with those computed from the new levels within the limits of experimental error. This justifies the use of the new levels in computing the energies of Auger lines of other radioactive elements; those of Rd Ac·Ac X, Ac X·An, and Ms Th_2·Rd Th are discussed. The transition Pa·Ac gives gamma-rays of energy 347,400 and 359,300 electron volts, hitherto unknown. The beta-ray spectrum of this transition, so far as it is known, is now completely classified, except for one line. The beta-ray spectra of Rd Th·Th X and UX_1·UX_2 are produced by nuclear gamma-rays, not by the $K\alpha$-lines of the daughter elements. Evidence is presented for the view that the band at $Hr=2450$ gauss cm in the spectrum of UX_2·U II represents the disintegration electrons of UX_2, and that the group at 1,300,000 electron volts probably represents the secondary electrons. Attention is directed to the frequent occurrence of an energy difference of the order 84,000 to 90,000 electron volts, in gamma-ray spectra and nuclear energy diagrams.

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I. X-Ray Terms of Radioactive Elements

Gamma-ray energies are derived from those of secondary beta-rays by the equation $h\nu = E_\beta + X$, where X represents the binding energy of an x-ray level of the daughter atom, from which a secondary electron, of energy E_β, is ejected. The present situation in regard to gamma-ray energies is unsatisfactory, because different authors employ different term values, and in most cases do not state how they were derived. To classify beta-rays with certainty, and to get accurate values of gamma-ray energies, it is necessary to have a list of x-ray terms for the radioactive elements, in which the error is negligible compared to that of the best beta-ray measurements. We shall obtain x-ray terms for these elements which are believed to be more reliable than those employed in most papers on beta-ray spectra.

We have reasonably complete information on the x-ray spectra of all heavy elements which have both radioactive and stable isotopes, namely: Tl, Pb, Bi, Th and U.[1] Term and line values for other radioactive elements must be obtained by interpolation, with three exceptions. Siegbahn and Friman measured one line of the radium L-series, de Broglie determined L_{II} and L_{III} of radium, and Beuthe and von Grosse[2] measured the protactinium L-series. It has been customary to obtain x-ray terms by combining the L_{III} limit with term differences from emission spectra. Since the breadth of the L_{III} limit has introduced difficulties of measurement, and since the interpretation of absorption limits has been a matter for discussion, one of us[3] has described a more satisfactory procedure. An x-ray level of small magnitude is obtained from the optical spectra of the isolated atom,[4] and to this level one adds term differences, accurately known from x-ray line spectra, to get deeper levels. This method is satisfactory for all levels of Tl, Pb, Bi, Th and U, except the K-level, where existing measurements are less accurate than those of the more favorably situated L-series. For Tl, Pb and Bi we used the K-lines of Stephenson and Cork, and for Th and U the K absorption limits of Mack and Cork.[5]

Knowing the levels of these elements, we interpolated values for intervening ones by plotting ν/R values of terms and term differences against the atomic number Z. Small term differences were used as far as possible, to reduce plotting errors, and a semi-graphical method devised by Idei was adopted in dealing with larger ones.[6] Table I shows the results in international electron volts, computed by the formula

$$V = \frac{300Rc}{b}\frac{h}{e}\frac{d_c}{d_a}\left(\frac{\nu}{R}\right)_c = (13.545 \pm .0131)\left(\frac{\nu}{R}\right)_c . \quad (1)$$

R, c, h and e have their customary meanings; $h/e = (1.3723 \pm 0.0008)10^{-17}$ erg sec./e.s.u.; b is the ratio of the international to the absolute volt; d_c/d_a is the ratio of the conventional to the actual calcite spacing at 18°C; namely, 3029.45/3027.85; and the subscript c on (ν/R) indicates that this quantity is based on the conventional calcite spacing. The data are recorded to a greater accuracy than the *absolute* values possess so that small differences between energy levels, accurately known, may not be falsely rendered; for in many cases the corresponding ν/R values are known to 0.1 unit.

Our values for Pa agree with the L-series data of Beuthe and von Grosse within 6 electron volts. Values for the radium L_{II} and L_{III} limits are, respectively, 32 and 42 electron volts higher than those of de Broglie, whose measurements were made in the infancy of x-ray spectroscopy. The L, M, etc., levels of Tl, Pb, Bi and U agree with those in the second edition of Siegbahn's treatise within one ν/R unit. On the other hand, the values quoted by Siegbahn for Th are in error, for if they are used in conjunction with line-spectrum data, a negative value is obtained for $P_{\text{II, III}}$. We have compared our L and M levels for Tl, Pb, Bi, Th and U with absorption-edge

[1] For bibliography see Siegbahn, *Spektroskopie der Röntgenstrahlen*, 1931 edition.

[2] Siegbahn and Friman, Phys. Zeits. **17**, 61 (1916); de Broglie, Comptes rendus **168**, 854, **169**, 134 (1919); Beuthe and von Grosse, Zeits. f. Physik **61**, 170 (1930).

[3] Ruark, Phys. Rev. **45**, 827 (1934).

[4] Bacher and Goudsmit, *Atomic Energy States;* Beutler, Zeits. f. Physik **86**, 495, 710 (1933); Rasmussen, Zeits. f. Physik **87**, 607 (1934).

[5] Stephenson and Cork, Phys. Rev. **27**, 138 (1926); Mack and Cork, Phys. Rev. **30**, 741 (1927).

[6] Idei, Tohoku Science Reports **19**, 651 (1930).

TABLE I. *X-ray energy levels of radioactive elements in international electron volts.*

	Tl 81	Pb 82	Bi 83	Po 84	85	Rn 86	87	Ra 88	Ac 89	Th 90	Pa 91	U 92
K	85320	87780	90280	92850	95490	98180	100920	103700	106550	109510	112590	115790
L_{I}	15320	15827	16352	16902	17468	18039	18622	19213	19810	20429	21067	21711
L_{II}	14672	15167	15676	16213	16766	17322	17890	18466	19048	19651	20272	20900
L_{III}	12635	13006	13390	13787	14196	14604	15019	15432	15844	16264	16694	17128
M_{I}	3702	3843	3991	4151	4319	4485	4655	4829	4998	5173	5353	5537
M_{II}	3418	3554	3691	3843	4005	4163	4326	4492	4655	4822	4995	5172
M_{III}	2956	3064	3174	3293	3421	3545	3671	3798	3919	4041	4167	4296
M_{IV}	2487	2583	2685	2795	2914	3028	3144	3262	3373	3486	3602	3721
M_{V}	2392	2480	2576	2681	2793	2900	3010	3120	3224	3328	3436	3546
N_{I}	851	894	940	997	1062	1122	1181	1234	1280	1327	1382	1439
N_{II}	727	763	807	861	921	978	1033	1082	1124	1168	1218	1271
N_{III}	617	645	679	725	775	822	867	904	934	967	1003	1042
N_{IV}	415	438	466	507	552	593	632	664	689	715	748	783
N_{V}	393	419	442	480	524	563	601	631	654	679	708	739
N_{VI}	131	146	165	194	230	261	292	314	330	347	368	391
N_{VII}	127	140	159	190	225	256	286	308	322	338	359	382
O_{I}	142	151	160	180	199	218	237	256	274	292	311	328
O_{II}, O_{III}	83	88										
O_{II}			121	140	159	177	194	210	224	237	248	258
O_{III}			96	110	125	138	151	161	171	179	187	193
$O_{IV,V}$	20	25	28	38	49	60	68	76	84	91	97	102
P_{I}	—	—	—	—	—	—	—	—	—	—	—	—
$P_{II,III}$	6	7	8	9	10	11	12	13	14	14	16	17
Q_{I}	—	—	—	—	—	—	—	5	—	—	—	—
Possible Errors:												
K-level	80	80	80	150	150	150	150	150	150	150	150	150
Other levels	11	11	11	13	13	13	13	13	13	11	13	11

data of Sandström and of Lindberg.[7] The results are such as to support the terms and limits of error in Table I.

In conclusion, the accuracy of Table I is more than sufficient for our present purpose, the calculation of gamma-ray energies from beta-ray energies; the controlling error is in the beta-ray measurements.

2. Application of the New Terms to the Beta-Rays of Th (B+C), Ra (B+C) and Ac (B+C)

All published data on beta-ray spectra have been reviewed to determine what changes are necessary in the light of the data in Table I. In the compilation by Rutherford, Chadwick and Ellis,[8] the data on Ra B, Ra C, Th B, Th C and Th C″ are superseded by Ellis' later and more accurate work, and those on Ac (B+C) by the work of Graf and Sze.[9] For all other elements listed, no x-ray term requires a change greater than 200 electron volts.

Ellis estimates that his energy values for the beta-rays of Ra(B+C) and Th(B+C) are correct to about one part in five hundred, and that relative values may be relied on to one part in two thousand. In his paper on Th(B+C), he used x-ray levels which agree well with ours, except that the K-levels for atomic numbers 82 and 83 are both low by 280 volts. Therefore, the gamma-ray energies which he computed from beta-rays ejected from the K-level are appreciably lower than those obtained from beta-rays arising in other levels. In a later paper on Ra(B+C) and Th(C+C′), Ellis adopted values for the levels of element 83 which agree excellently with ours. For element 84 (transition Ra C·C′), there is good agreement except that Ellis' K-level is 160 volts higher than ours. Graf's data on beta-rays of Ac B·C and Ac C·C″ arising from the K-shell are also in need of slight revision. Table I yields the revised gamma-ray energies in Table II, some values from L_{I}-conversion being included for comparison.

[7] Sandström, Zeits. f. Physik **65**, 632, **66**, 784 (1930); Lindberg, Nova Acta Regiae Soc. Sci. Upsaliensis, Series IV, **7**, No. 7 (1931).

[8] Rutherford, Chadwick and Ellis, *Radiations from Radioactive Substances*, p. 359 ff.

[9] Th (B+C): Ellis, Proc. Roy. Soc. **A138**, 318 (1932);
Ra (B+C) and Th (C+C′): Ellis, Proc. Roy. Soc. **A143**, 350 (1934);
Ac (B+C): Graf, Comptes rendus **197**, 238 (1933);
Th (B+C), Ac (B+C): Sze, Ann. de Physique **19**, 59 (1933).

TABLE II. *Gamma-ray energies in electron volts,* $\times 10^{-5}$.

Author	Source	Level in which gamma-ray is converted K	L_I
Ellis	Th B·C	2.3794	2.3805
	"	2.9920	2.9915
	Th C″·D	2.7646	2.7669
	"	5.0976	5.1000
	"	5.8195	5.8241
	Ra C·C′	6.0662	6.0679
	"	7.6629	——
	"	9.3333	——
Graf	Ac B·C	4.0255	4.0233
	"	4.2453	4.2457
	"	8.2699	——
	Ac C·C″	3.4907	3.4875

3. Composite Photoelectric Effect in Ra(B+C), Th(B+C), Rd Ac and Ac X

Ellis[10] has shown that certain beta-ray lines having energies lying in the region 57,000 to 74,000 electron volts are common to the spectra of Ra(B+C) and Th(B+C) and that all of these arise from processes occurring in the planetary shells of atoms of atomic number 83. Thus, if a gamma-ray ejects a K-electron from an atom of Ra C(83), this atom may undergo an Auger process, in which, for example, an L_I-electron falls into the vacant place in the K-shell, and a second electron is ejected from the L-shell. The kinetic energy, T, of the latter electron will be given by

$$T=(K-L_I)-L^*, \tag{1}$$

where L^* is the energy required to remove it from an atom which already lacks an L_I electron.

Hahn and Meitner have suggested that certain lines in the beta-ray spectra of Rd Ac and Ac X arise from Auger processes, and in Black's[11] measurements for Ms Th_2 there are unclassified lines lying in the region where Auger lines may be expected. To test Hahn and Meitner's classifications, and to come to some conclusion regarding Black's lines, it is necessary to know what values to use for the energy levels of an atom which lacks two L electrons, or an L and an M electron. We shall now obtain this information empirically from Ellis' data on Auger lines of the elements 83 and 84.

Altogether, there are 10 terms arising from the configurations $2p^6$, $2s2p^5$ and $2s^22p^4$ of the doubly ionized L-shell. We could not find any computations of the positions of these terms, or of the transition probabilities for Auger processes involving them. However, as a working hypothesis, it is reasonable to assume the energies of all these final states are such, that for an atom of atomic number Z the values of L^* lie close to the L-levels of the atom of number $Z+1$. Let us call the latter levels L_I', L_{II}', L_{III}'. On this simple view, we expect beta-rays having the energies:

$$\begin{array}{lll} K-L_{III}-L_{III}', & K-L_{III}-L_{II}', & K-L_{III}-L_I', \\ K-L_{II}-L_{III}', & K-L_{II}-L_{II}', & K-L_{II}-L_I', \\ K-L_I-L_{III}', & K-L_I-L_{II}', & K-L_I-L_I'. \end{array} \tag{2}$$

As a matter of fact, Ellis found that the group consists of five lines in the case of the elements 83 and 84. He recognized that the removal of an L-electron increases the ionization energy of the others, but in his computations he did not use the above assumption concerning the energies. Instead, he compared the observed energies of Auger-process electrons with those given by the

TABLE III. *Energies of Auger beta-rays in volts.*

Transition	Atomic Number 83 Calc.	Atomic Number 83 Obs.	Atomic Number 84 Calc.	Atomic Number 84 Obs.
$K-L_{III}-L_{III}'$	63100	62960	64860	64890
$K-L_{II}-L_{III}'$	60820 }	60660	62440 }	62370
$K-L_{III}-L_{II}'$	60680 }		62300 }	
$K-L_I-L_{III}'$	60140 }	59980	61750 }	61630
$K-L_{III}-L_I'$	59990 }		61590 }	
$K-L_{II}-L_{II}'$	58390	——	59870	——
$K-L_I-L_{II}'$	57710 }	57700	59180 }	59250
$K-L_{II}-L_I'$	57700 }		59170 }	
$K-L_I-L_I'$	57030	56950	58480	58490
$K-L_{III}-M_{III}'$	73600	73470		
$K-L_I-N_I'$	72930	72850		
$K-L_{II}-M_{III}'$	71310	71080		
$K-L_I-M_{III}'$	70640	70250		
$K-L_I-M_{II}'$	70080	69850		

[10] Ellis, Proc. Roy. Soc. **A139**, 336 (1933).
[11] Hahn and Meitner, Zeits. f. Physik **34**, 795, 807 (1925); Black, Proc. Roy. Soc. **A106**, 632 (1924).

expressions $(K-L_{\rm I})-L_{\rm I}$, etc. Naturally there were systematic deviations of considerable magnitude between calculated and observed values. It is now of interest to see how the energies given in the list (2) compare with the observed energies of his lines. The upper portion of Table III shows the results.

The discrepancies between the observed values and the calculated values opposite them are within the combined error of the K-levels in Table I and of Ellis' measurements. As an empirical regularity, this is interesting, but the absence of a line having the energy $K-L_{\rm II}-L_{\rm II}'$ reveals the weakness of this simple correlation of lines and calculated energies. It is quite probable that the coupling in the doubly ionized L-shell is such that all the possible lines lie in the neighborhoods of the five observed lines.

The lower portion of Table III shows similar regularities for lines of element 83, of the type $(K-L)-M'$. The transitions listed are those employed by Ellis. It is possible to achieve better agreement by choosing other levels, but, since a theory of these levels is not available, discussion of such details is not profitable.

It is fair to conclude that the positions of the Auger lines $K-L-L'$ in other beta-ray spectra can be computed within about 100 volts from the transitions written opposite the observed values in Table III. Thus *the Auger lines may serve as convenient standards in determining the energies of neighboring beta-ray lines.*

We may now consider the Auger lines of Rd Ac, Ac X, and Ms Th_2. Hahn and Meitner classified four lines of Rd Ac·Ac X, and two of Ac X·An, as due to Auger processes. There are unclassified lines near by, and so we have reexamined the matter. The question of reference lines must first be considered. Ellis has given the value $Hr=1385.8$ gauss cm for the strongest line of Th B, used as a reference line by Hahn and Meitner, and has remeasured the lines of Ra(B+C) which Black employed as standards. Throughout this paper, Hr- and energy-values have been slightly changed to take advantage of Ellis' new values for the reference lines. Table IV shows the recomputed data for all lines of Rd Ac, Ac X and Ms Th_2 lying in the region of interest. The limits of the expected $K-L-L'$ and $K-L-M'$ groups are indicated, and the interpretations of Hahn and Meitner and of Black are indicated. The uncertainty in the energies may be estimated as one percent, and on this basis, we may draw the following conclusions:

TABLE IV. *Portions of the beta-ray spectra of Rd Ac, Ac X and Ms Th_2.*

Substance	Number of line	Intensity	Hr, (gauss cm)	Energy of β-ray, (e.v.)	Original interpretation	Limits of Auger groups, (e.v.)
Rd Ac	22	20	876	63600	$K-L_{\rm II}-L_{\rm I}'$,	64700–72400
	23	20	913	68700	$K-L_{\rm III}-L_{\rm I}'$	
	24	20	952	74300	——	
	25	15	983	78900	$K-L_{\rm II}-M_{\rm I}'$	
	26	40	997	81100	$h\nu-L_{\rm I}$	79500–85000
	27	20	1011	83100	$K-L_{\rm III}-M_{\rm I}'$	
	28	50	1076	93300	$h\nu-K$	
Ac X Hahn-Meitner	5	40	846	59500	$h\nu-K$	
	6	15	901	67000	$K-L_{\rm III}-L_{\rm I}'$	61500–68600
	7	10	984	79000	$K-L_{\rm III}-M_{\rm I}'$	75500–80600
	8	10	1001	81600	——	
Ms Th_2 Black	7	16	901	67000	——	68000–76500
	8	50	947	73600	$h\nu-K$	
	9	35	976	77800	——	83700–89800
	10	16	1070	92400	——	

(1) The Auger groups are not completely resolved in the spectra of Rd Ac and Ac X. The lines assigned to such processes by Hahn and Meitner may indeed be Auger lines, but the possibility still exists that beta-rays ejected by nuclear gamma-rays practically coincide with them.

(2) The following unclassified beta-rays lying near the Auger groups are produced by nuclear gamma-rays:

Rd Ac 74,300 electron volts
Ms Th_2 92,400 and possibly 77,800 electron volts.

4. The Beta and Gamma-Rays of Protactinium

In the beta-ray spectrum of protactinium, Meitner[12] measured twelve rays, noted the existence of many others too faint to measure, and showed that nine of the twelve are due to conversion of three gamma-rays in the K, L and M-shells. In Table V we give corrected energies,[13] based on the value $Hr=1385.8$ gauss cm for the strong Th B line, instead of the value 1398 employed by Meitner.

The three lines which Meitner left unclassified are 92,030, 240,800 and 252,700 electron volts. Of these, the first can be explained as due to conversion of the gamma-ray 93,500 electron

[12] Meitner, Zeits. f. Physik **50**, 15 (1928).
[13] These data supersede slightly different ones in a preliminary note, Bull. Am. Phys. Soc. **9**, No. 1, 1934.

TABLE V. *Beta-ray spectrum of protactinium.*

Number of line	Intensity	Origin	Hr, (gauss cm)	Energy of β-ray, e.v.	X-ray level, e.v.	Energy of γ-ray, e.v.
1	60	L_I	948	73720	19810	93530
2	40	L_{III}?	971	77220	15840	93060?
3	40	M_I	1046	88580	5000	93580
4	30	N_I	1068	92030	1280	93310
5	100	K	1581	186100	106600	292700
6	70	K	1721	215300	106600	321900
7	30	K	1839	240800	106600	347400
8	30	K	1892	252700	106600	359300
9	60	L_I	1968	269600	19810	289400
10	30	M_I	2021	281900	5000	286900
11	40	L_I	2085	296500	19810	316300
12	20	M_I	2154	312700	5000	317700

volts in the N_I shell, the intensity being of the right order of magnitude. The beta-ray 77,220 electron volts is stronger relative to the ray 73,720 electron volts than it should be if its classification is correct, and it is probable that this line is due, at least partially, to K or L_I conversion of a gamma-ray hitherto unknown.

The beta-rays 7 and 8 are due to conversion in the K-level, for if they came from any other shell, the corresponding K-conversion lines would lie in a large gap in the spectrum and would be so strong they could not have escaped notice. On this basis, we have two new gamma-rays at 347,400 and 359,300 electron volts. Beta-rays due to their conversion in the L, M, etc., shells would be weak, and inspection of a photograph published by Meitner encourages the belief that they would be too faint to measure. Thus, the measured lines are completely accounted for, with the possible exception of line 2, and the gamma-ray spectrum contains the following lines: 93,500, 289,700, 318,600, 347,400, 359,300 electron volts.

5. Beta-Ray Spectrum of Rd Th

Aided by the considerations in Section 3, we can decide between two alternative interpretations of the beta-ray spectra of Rd Th and UX_I. The beta-ray spectrum of Rd Th, measured by Meitner[14] and corrected for change of the Th B standard, is shown in Table VI, the uncertainty in energy associated with error in measuring line positions being less than one percent.

The lines 1 and 2 represent K or L_I conversion of two weak nuclear gamma-rays. The lines 3–6 are produced by two radiations of energies

TABLE VI. *Rd Th beta-ray spectrum.*

Number of line	Intensity	Origin	Hr	Energy of β-ray, e.v.	X-ray level, e.v.	Energy of γ-ray, e.v.
1	w	—	799	53390	103700, or 19210	157100, or 72600
2	w	—	820	56070	103700, or 19210	159800, or 75280
3	s	L_I	883	64580	19210	83790
4	m.s.	L_I	903	67340	19210	86550
5	m.s.	M_I	979	78410	4830	83240
6	m	M_I	1001	81690	4830	86520

83,520 and 86,530 electron volts, which lie in the neighborhood of $K\alpha_2$ and $K\alpha_1$ of the daughter element, 88, at 85,240 and 88,270 electron volts. This led Meitner to the hypothesis that these lines are produced in Auger processes, but she recognized that this interpretation leads to difficulties as follows.

She obtained a microphotometer record of a plate which contained both the lines of Rd Th and the strongest line of Th B. The number of electrons in the latter line, per 100 disintegrations, was determined by Gurney. Meitner compared the blackening due to this line with that due to the lines 3, 4, 5 and 6 of Rd Th, and assuming that the photographic effect of these beta-rays varies inversely as their energy, she found that the four lines together contain 0.072 electron per disintegration. She then assumed that the efficiency of internal conversion of the K-radiation is at the most 10 to 15 percent and concluded that in a very large percentage of the disintegrations the alpha-particles eject a K-electron from the planetary shells. This appeared very improbable to Meitner and she left the question open, but later, Rosenblum and Chamié[15] studied the alpha-particle spectrum of Rd Th and found by visual estimate that about 17 percent of the alpha-particles are emitted with an energy 88 electron kilovolts less than that of the normal group. This observation means that in 17 percent of the disintegrations the daughter nucleus is left in an excited state of 88 electron kilovolts energy, for this energy is not sufficient to ionize the K-shell of the daughter element. Accordingly, Meitner and Philipp[16] concluded that the lines 3–6 are due to nuclear gamma-rays. We shall

[14] Meitner, Zeits. f. Physik **52**, 637, 645 (1928).

[15] Rosenblum and Chamié, Comptes rendus **196**, 1663 (1933).

[16] Meitner and Philipp, Zeits. f. Physik **80**, 277 (1933).

present other evidence in support of this interpretation.

(1) Other alpha-disintegrations are known in which the alpha-particles do not appreciably excite the K-radiation. Radium, for example, emits 0.35 quanta of K-radiation per 100 decomposing atoms,[17] and Bothe and Fränz[18] showed that alpha-particles entering heavy atoms from the *outside* produce less than one x-ray photon per 100 incident particles.

(2) The intensities of the lines 3 and 4 can be roughly accounted for on the assumption they are due to internal conversion of the two gamma-rays in the L_I-shell. (The contribution of the L_{II} and L_{III} shells is of no importance.) It appears that Meitner's figures for the number of electrons in these lines should be revised. We find from her microphotometer curve and from a curve of Ellis,[19] giving the relative photographic efficiency of beta-rays as a function of velocity, that lines 3 and 4 contain about 11 electrons per hundred disintegrations, whereas in 17 percent of the disintegrations the nucleus is left in an excited state. Thus the efficiency of L_1 conversion is 65 percent, which may be compared with approximate theoretical values[20] of 35 percent for quadripole radiation and 23 percent for dipole radiation. The discrepancy can easily be due to inaccuracies in Ellis' photographic efficiency curve; in Rosenblum and Chamié's estimate of the relative intensities of the alpha-ray groups; and in Fisk's values.

(3) If Meitner's lines were due to Auger processes involving an excited K-shell, we should expect Auger groups of five lines each, similar to those found by Ellis. In Fig. 1A, the predicted positions of these groups are compared with those of the observed beta-rays, and the gamma-rays and K-lines are shown. There is no agreement; Meitner's published photograph of the spectrum and her microphotometer curve show clearly that the five-line Auger groups are not present. Further, Wentzel's[21] theory gives only 2 percent for the efficiency of internal conversion of the K-radiation of heavy elements, and this agrees roughly with the intensity found for Th B·C, which is about three percent.[22] Even if the K-shell of every disintegrating Rd Th atom were ionized, the Auger groups as a whole would have an intensity several times smaller than the lines 3 and 4 alone in Meitner's spectrum.

6. Beta and Gamma-Rays of UX_1 and UX_2

Meitner[23] found only three lines in the secondary beta-ray spectrum of UX_1, and interpreted them as L, M and N conversion of the $K\alpha$-lines of the daughter element, excited by the primary electrons. Ellis and Skinner[24] questioned this interpretation on the basis that the numerical agreement is not satisfactory, and stated that the beta-rays in question are produced by conversion of a nuclear gamma-ray of energy 91,900 electron volts, but, in the treatise of Rutherford, Chadwick and Ellis,[25] Meitner's interpretation is the only one mentioned, so the matter must be reexamined. Fig 1B shows the observed beta-

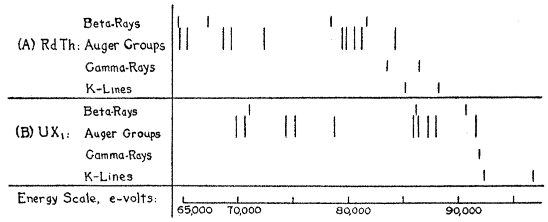

Fig. 1.

rays, the gamma-ray to which they lead, the K-lines, and the Auger groups to be expected. The following comments may be made.

(1) Meitner's published photograph of the spectrum and her energy values do not support the view that we are dealing with typical Auger groups containing five lines, like those found by Ellis.

(2) Meitner describes photographs obtained with the Rutherford (non-focussing) arrange-

[17] Stahel and Johner, J. de Physique **5**, 97 (1934).
[18] Bothe and Fränz, Zeits. f. Physik **52**, 466 (1928).
[19] Ellis, Proc. Roy. Soc. **A138**, 318 (1932).
[20] Fisk, Proc. Roy. Soc. **A143**, 674 (1934).
[21] Wentzel, Zeits. f. Physik **43**, 524 (1927).

[22] To obtain this figure, we added the measured photographic intensities of the Auger lines of Th B·C, and divided by the sum of the measured intensities of beta-rays ejected from the K-shell by nuclear gamma-rays. The quotient thus obtained is a rough measure of the ratio of the number of Auger processes to the number of atoms in which the K-shell is ionized. The failure to observe Auger lines in the Pa spectrum is easily explained by the smallness of the internal conversion coefficient for K-radiation.
[23] Meitner, Zeits. f. Physik **17**, 54 (1923).
[24] Ellis and Skinner, Proc. Roy. Soc. **A105**, 185 (1924).
[25] Reference 8, p. 360.

ment. The secondary beta-ray lines appear with considerable strength on plates which show the neighboring band of primary electrons, with its center of gravity at *Hr* 1163 gauss cm. These lines, however, should be very weak if they are due to Auger processes. We know from experiments of Soddy and Russell[26] that the ratio of gamma-ray and beta-ray activities is about 18 times smaller for UX_1+UX_2 than for Ra(B+C), the measurements being made in such a way as to include all the soft rays possible. (The "gamma-ray activity" includes any x-rays which are emitted.) Kovarik[27] found that about two gamma-ray quanta are emitted by a source of Ra(B+C), for each disintegrating atom of Ra B. Roughly then, the efficiency of gamma-ray emission by UX_1 is less than 2/18 ray per disintegration; that is, if all its "gamma-rays" were really *K*-series x-rays, there would be about 0.1 quantum of *K*-radiation per disintegration, and since the efficiency of internal conversion of this radiation is about three percent (Section 5), there would be only 0.003 Auger-type beta-rays per disintegration.

(3) The following independent evidence strengthens that in the above paragraphs. Meitner's interpretation required that the primary electrons should copiously ionize the *K*-shell, but Bramson,[28] working with Meitner, found later that the primary electrons of Ra E excite only 0.01 quantum of *K*-radiation per disintegration. The much slower primaries of UX_1 should be less efficient in this respect, and so it appears there could not be more than 3×10^{-4} Auger-type electrons per disintegration.

These facts show clearly that the *beta-ray lines of UX_1 are produced by internal conversion of a nuclear gamma-ray of energy about 91,900 electron volts.*

It is worth noting that an energy difference of about this magnitude appears rather frequently in connection with nuclear spectra. One of us (A.E.R.) has made a series of diagrams showing all known nuclear energy levels and gamma-rays of the heavy radioactive elements, and the energy difference 84 to 90 ekv is often encountered. This may be mere coincidence, or it may be that this energy difference will be found to possess a universal significance in the theory of nuclear energy levels, like that played by the spin-relativity doublet in the theory of x-ray spectra.

The beta and gamma-rays of UX_2 remain to be considered. It has been shown[29] that within the limits set by experimental difficulties, UX_2 is responsible for the hard beta and gamma-rays of UX_1+UX_2 in equilibrium. Von Baeyer, Hahn and Meitner[30] found the following beta-ray spectrum: Band, maximum at $Hr=2450$ gauss cm, or about 350 ekv. Band or group at $Hr=5800$ gauss cm, or about 1300 ekv. Sargent[31] presented indirect evidence, based on ionization measurements, that the energy distribution curve of the primaries has its maximum at $Hr=3600$ gauss cm, or slightly less than 700,000 electron volts, but did not discuss the discrepancy between this value and that for the above-mentioned bands. The lack of agreement is partially explained by the fact that the photographic efficiency of beta-rays falls off with increasing velocity. Using Ellis' curve of relative photographic efficiency and Sargent's energy distribution, it appears that the maximum photographic effect should lie at $Hr=3100$ gauss cm. Considering the difficulties involved, it is practically certain that Meitner's band at $Hr=2450$ gauss cm represents the disintegration electrons of UX_2. If so, the group at 1300 ekv probably represents the secondary beta-rays.

This investigation is auxiliary to an experimental study of gamma-ray spectra, part of the facilities for which have been provided by the National Research Council. We wish to thank the Council for this aid.

[26] Soddy and Russell, Phil. Mag. **18**, 620 (1909).
[27] Kovarik, Phys. Rev. **23**, 559 (1924).
[28] Bramson, Zeits. f. Physik **66**, 721 (1930).

[29] Fajans and Göhring, Phys. Zeits. **14**, 877 (1913); Hahn and Meitner, Zeits. f. Physik **17**, 157 (1923).
[30] Von Baeyer, Hahn and Meitner, Phys. Zeits. **14**, 873 (1913).
[31] Sargent, Proc. Camb. Phil. Soc. **28**, 538 (1932).