INTERNAL CONVERSION COEFFICIENTS OF E2 TRANSITIONS

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Abstract

An analysis of K-conversion coefficients of E2 transitions of the type $2^+ \rightarrow 0^+$, $0^+ \rightarrow 2^+$, $4^+ \rightarrow 2^+$, $6^+ \rightarrow 4^+$, and $8^+ \rightarrow 6^+$ together with their methods of determination has been carried out. The ratios of experimental to theoretical α_k values are plotted against the atomic weights and it is seen that there is no similar behaviour among these transitions.

I. Introduction

One of the most useful procedures for the classification of nuclear energy levels is the method of internal conversion. The internal conversion process constitutes one of the most effective methods of assigning angular momentum and parity quantum numbers to the low-lying nuclear states. In many cases it provides the decisive information for constructing a decay scheme. The parity change and angular momentum change of the nucleus may be deduced from the primary nuclear information obtained from a comparison of observation and accurate theoretical values of the conversion of coefficients.

The first major effort to calculate the internal conversion coefficients was made by a group of British physicists in the early thirties. These calculations were completely relativistic and based on a point nucleus and unscreened electrons. The discovery of nuclear isomerism in the forties made it clear that internal conversion coefficients for higher multipoles and almost all values of Z were needed. In view of the laborious nature of the 'exact' calculations (relativistic and full effects of the coulomb field of the point nucleus included) a number of approximate models were introduced: non-relativistic electron dynamics as one instance and, alternatively, the Born approximation as another.

Since the comparison of measured and computed coefficients was used to assign multipole orders or spin changes and parity changes to the transition,

the correctness of theoretical results could not be called into question unless this assignment could be established in an independent way.

This required a considerable development of the techniques developed for deciphering decay schemes and these techniques (together with their theoretical basis) were not available until around 1950, and later. As an example the angular correlation of gamma rays in cascade may be mentioned. The approximate conversion coefficients did not compare favourably with the British results, but this comparison could be made only with extrapolation outside the expected region of validity of the formulae.

Rose *et al.*[1] undertook to extend the results for the internal conversion coefficients for K shell to a wide range of values of Z and transition energy, using Dirac hydrogen-like wave functions. The model for this first calculation was exactly the same as in the early British work. The results showed clearly that the approximate calculations had a much more restricted range of validity than expected. In physical terms the internal conversion process is very sensitive to the small distance behaviour of the electron wave functions and, for a proper description of this, a relativistic treatment with the nuclear interaction included is mandatory.

Rose *et al.*[2] have computed the internal conversion coefficients for electric and magnetic multipole radiation for the K-shell in the relativistic case with the unscreened coulomb field acting on the electron.

After the K shell calculations were completed, it became evident that L shell calculations were just as badly needed. With the L shell results one could eliminate the necessity of measuring gamma-ray intensities and consider only K/L ratio. Actually, this ratio is now recognised as an insensitive indicator of the state parameters but with the L sub-shell coefficients it is now realized that the ratios of conversion electrons from the various sub-shells do provide a clue for these parameters which is often decisive. When the planning of the L shell calculations was initiated in 1949 it was recognized at once that screening effects, hitherto ignored, might become more important. It was also realized that, with comparatively minor added complications, the M sub-shell coefficients could also be obtained.

Even before the completion of the screened coefficients it began to appear that the assumpton of a point nucleus would not suffice for certain cases (heavy nuclei and especially magnetic dipole transitions). This fact emerged from the work of Sliv[3] and collaborators who reported an appreciable reduction of the magnetic dipole coefficients for $Z \gtrsim 60$. Subsequently Sliv[3] and his group extended their early calculations to virtually all Z values, of

interest and obtained K shell coefficients with a finite size nucleus. The model taken for the nucleus by Sliv[3] and coworkers was a uniformly charged sphere with radius $1{\cdot}20\times10^{-13}$ $A^{1/3}$ cm. The nuclear currents were taken to be on the surface of the nucleus. Only slight variations in the calculated values were observed when the nuclear radius was altered by ten per cent. or when the nuclear currents were taken to be uniformly distributed rather than confined to the nuclear surface. They therefore conclude that the internal conversion coefficients are not sensitive to the details of the distribution of charge and current within the nucleus and that the differences from the " Point Charge " values are principally the result of the removal of infinities in both the transition potentials and relativistic electron wave functions.

Green and Rose[4] included finite nuclear size into their calculations. Finally, the K and L shell coefficients are recalculated by Rose[5] with the same effects of finite size but with a very slightly different model than that used by Sliv.[3]

For a finite nucleus the two calculations lead to conversion coefficients which differ by less than five per cent. in almost all cases of physical importance. The result of either treatment is that the part of the conversion coefficient which is dependent on dynamic structure effects is but a few per cent. of the part which is independent of these effects.

Church and Weneser[6] pointed out that nuclear models which allow for shell structure effects can lead in some cases to (dynamic) structure-dependent contributions to the internal conversion coefficients which are sizable fractions or perhaps even larger multiples of the structure-independent contributions. The fact that atomic electrons can penetrate within the nuclear charge and current distributions gives rise to additional nuclear matrix elements for internal conversion which are different from the leading conversion matrix element. The leading conversion matrix element is identical with that for gamma-ray emission of the same multipole order.

The comparison of experimental and theoretical values of internal conversion coefficients is becoming more interesting with the recent developments on the theoretical side as well as the improved techniques for measuring the internal conversion coefficients.

McGowan and Stelson[7] have reported higher values for the K-conversion coefficients. The discrepancies between the experimental and theoretical values of K-conversion coefficients have also been observed by various workers.

Subba Rao[8] has collected and analysed the data on the K-conversion coefficients of pure E2 transitions from the first excited 2^+ state to the ground state of even-even nuclei. He has concluded that K-conversion coefficients may possibly depend on the deformation of the nucleus. His survey points out the reasonable agreement with theory (when the large experimental errors are considered) at low and high Z and a systematic trend to higher valnes in the deformed nuclear region of the rare earths.

Ramaswamy[9] has carried out a similar study of K-conversion coefficients of transitions of the type $0^+ \rightarrow 2^+$ with conclusions similar to those of Subba Rao. However, the error limits considered by them are still large and the observed deviations open to some question.

Thosar *et al.*,[10] comparing their recent measurements of K-conversion coefficients for some of the deformed even-even nuclei, with the values obtained by earlier workers, conclude that the discrepancy between the theoretical and experimental values can be very much reduced using improved techniques and taking into account the possible contributions due to various uncertainties. This is in contradiction to Subba Rao's conclusion that there may exist some kind of correlation between the nuclear deformation and the deviations of measured K-conversion coefficients from theory.

The discrepancies and inconsistencies discussed above stimulated us to further studies of all the E_2 K-conversion coefficients. Hence in this article we have attempted to make a survey of pure E2 K-conversion coefficients.

II. Compilation of Data

Tables I to V show most of the available data on K-shell internal conversion coefficients of pure E2 transitions. Transitions of the type $2^+ \rightarrow 0^+$, $0^+ \rightarrow 2^+$, $4^+ \rightarrow 2^+$, $6^+ \rightarrow 4^+$ and $8^+ \rightarrow 6^+$ are represented in Tables I, II, III, IV and V respectively. The first and second columns in the tables represent the nucleus and the transition energy respectively. The third column gives the method used for the determination of the K-shell internal conversion coefficients. Experimental values of the coefficients are compiled in the fourth column and the corresponding references in the fifth one. Wherever an error is not assigned on the experimental value of α_K, we have assigned an error of 8% for PBS method and 10% for any other method. The weighted averages of all the observed values are given in the sixth column. The seventh column gives the theoretical values of α_K, from the references given in the eighth column. The last column shows the ratio R (α_K) of the experimental

interest and obtained K shell coefficients with a finite size nucleus. The model taken for the nucleus by Sliv[3] and coworkers was a uniformly charged sphere with radius $1{\cdot}20\times10^{-13}$ $A^{1/3}$ cm. The nuclear currents were taken to be on the surface of the nucleus. Only slight variations in the calculated values were observed when the nuclear radius was altered by ten per cent. or when the nuclear currents were taken to be uniformly distributed rather than confined to the nuclear surface. They therefore conclude that the internal conversion coefficients are not sensitive to the details of the distribution of charge and current within the nucleus and that the differences from the "Point Charge" values are principally the result of the removal of infinities in both the transition potentials and relativistic electron wave functions.

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TABLE I

K-Conversion coefficients of $2^+ \rightarrow 0^+$ *transitions*

No.	Nucleus	E_γ in Kev.	Method	α_k (Expt.)	Ref.	α_k (Adopted)	α_k (Theor.)	Ref.	R (α_k)
1	$_{26}Fe^{58}$	799	*a*	$(3\cdot0 \pm 0\cdot1) \times 10^{-4}$	1	$(3\cdot0 \pm 0\cdot1) \times 10^{-4}$	$3\cdot066\times10^{-4}$	104	$0\cdot98\pm0\cdot33$
2	$_{46}Pd^{106}$	513	*b*	$(3\cdot5 \pm 1\cdot0) \times 10^{-3}$	2	$(3\cdot5 \pm 1\cdot0) \times 10^{-3}$	$4\cdot808\times10^{-3}$	104	$0\cdot73\pm0\cdot21$
3	$_{48}Cd^{110}$	656	*b*	$(2\cdot2 \pm 0\cdot8) \times 10^{-3}$	3	$(2\cdot535\pm0\cdot113)\times10^{-3}$	$2\cdot799\times10^{-3}$	104	$0\cdot91\pm0\cdot04$
			c	$(2\cdot5 \pm 0\cdot38) \times 10^{-3}$	4				
			d	$(2\cdot5 \pm 0\cdot2) \times 10^{-3}$	4				
			e	$(2\cdot6 \pm 0\cdot2) \times 10^{-3}$	5				
4	$_{48}Cd^{112}$	610	*b*	$(3\cdot8 \pm 0\cdot7) \times 10^{-3}$	6	$(3\cdot8 \pm 0\cdot7) \times 10^{-3}$	$3\cdot388\times10^{-3}$	104	$1\cdot12\pm0\cdot21$
5	$_{52}Te^{132}$	564	*b*	$(6\cdot6 \pm 1\cdot7) \times 10^{-3}$	3	$(5\cdot125\pm0\cdot143)\times10^{-3}$	$5\cdot096\times10^{-3}$	104	$1\cdot01\pm0\cdot03$
			d	$(5\cdot2 \pm 0\cdot42) \times 10^{-3}$	7				
			f	$(4\cdot9 \pm 0\cdot4) \times 10^{-3}$	8				
			d	$(5\cdot2 \pm 0\cdot4) \times 10^{-3}$	9				
6	$_{52}Te^{124}$	603	*d*	$(3\cdot63 \pm 0\cdot4) \times 10^{-3}$	10	$(3\cdot472\pm0\cdot107)\times10^{-3}$	$4\cdot284\times10^{-3}$	104	$0\cdot81\pm0\cdot03$
			d	$(3\cdot4 \pm 0\cdot27) \times 10^{-3}$	11				
7	$_{54}Xe^{126}$	386	*d*	$(1\cdot7 \pm 0\cdot14) \times 10^{-2}$	12	$(1\cdot684\pm0\cdot024)\times10^{-2}$	$1\cdot607\times10^{-2}$	104	$1\cdot05\pm0\cdot02$
			d	$(1\cdot65 \pm 0\cdot2) \times 10^{-2}$	13				
8	$_{54}Xe^{130}$	528	*d*	$(6\cdot9 \pm 1\cdot4) \times 10^{-3}$	14	$(5\cdot58 \pm 0\cdot229)\times10^{-3}$	$6\cdot866\times10^{-3}$	104	$0\cdot81\pm0\cdot03$
			d	$(5\cdot5 \pm 0\cdot44) \times 10^{-3}$	15				
			g	$(5\cdot5 \pm 0\cdot55) \times 10^{-3}$	16				
9	$_{54}Xe^{132}$	673	*h*	$(2\cdot7 \pm 0\cdot27) \times 10^{-3}$	17	$(2\cdot749\pm0\cdot165)\times10^{-3}$	$3\cdot605\times10^{-3}$	104	$0\cdot76\pm0\cdot05$
			a	$(3\cdot3 \pm 0\cdot9) \times 10^{-3}$	18				

10	$_{56}Ba^{134}$	605	*i*	$(5{\cdot}67 \pm 0{\cdot}57) \times 10^{-3}$	19	$(4{\cdot}64 \pm 0{\cdot}368) \times 10^{-3}$	$5{\cdot}146 \times 10^{-3}$	104	$0{\cdot}9 \pm 0{\cdot}07$
			a	$(5{\cdot}0 \pm 0{\cdot}2) \times 10^{-3}$	20				
			d	$(3{\cdot}5 \pm 0{\cdot}25) \times 10^{-3}$	21				
			j	$(4{\cdot}7 \pm 0{\cdot}34) \times 10^{-3}$	21				
			h	$(5{\cdot}5 \pm 0{\cdot}4) \times 10^{-3}$	22				
		1168	*h*	$(0{\cdot}9 \pm 0{\cdot}2) \times 10^{-3}$	22	$(0{\cdot}9 \pm 0{\cdot}2) \times 10^{-3}$	$1{\cdot}0 \times 10^{-3}$	105	$0{\cdot}9 \pm 0{\cdot}2$
11	$_{60}Nd^{144}$	694	*h*	$(4{\cdot}8 \pm 0{\cdot}48) \times 10^{-3}$	23	$(4{\cdot}8 \pm 0{\cdot}48) \times 10^{-3}$	$4{\cdot}385 \times 10^{-3}$	104	$1{\cdot}09 \pm 0{\cdot}11$
12	$_{62}Sm^{152}$	122	*h*	$(6{\cdot}7 \pm 0{\cdot}08) \times 10^{-1}$	24	$(6{\cdot}692 \pm 0{\cdot}098) \times 10^{-1}$	$6{\cdot}53 \times 10^{-1}$	104	$1{\cdot}02 \pm 0{\cdot}02$
			g	$(5{\cdot}8 \pm 0{\cdot}58) \times 10^{-1}$	25				
			k	$(7{\cdot}2 \pm 0{\cdot}6) \times 10^{-1}$	26				
		1087	*g*	$(1{\cdot}9 \pm 0{\cdot}3) \times 10^{-3}$	25	$(1{\cdot}9 \pm 0{\cdot}3) \times 10^{-3}$	$1{\cdot}8 \times 10^{-3}$	105	$1{\cdot}06 \pm 0{\cdot}17$
13	$_{64}Gd^{152}$	344	*a*	$(2{\cdot}85 \pm 0{\cdot}15) \times 10^{-2}$	27	$(2{\cdot}846 \pm 0{\cdot}015) \times 10^{-2}$	$3{\cdot}155 \times 10^{-2}$	104	$0{\cdot}9 \times 0{\cdot}005$
			h	$(2{\cdot}83 \pm 0{\cdot}08) \times 10^{-2}$	24				
			a	$(2{\cdot}88 \pm 0{\cdot}12) \times 10^{-2}$	28				
14	$_{64}Gd^{154}$	123	*h*	$(5{\cdot}4 \pm 1{\cdot}1) \times 10^{-1}$	29	$(6{\cdot}6 \pm 1{\cdot}2) \times 10^{-1}$	$6{\cdot}28 \times 10^{-1}$	104	$1{\cdot}05 \pm 0{\cdot}19$
			k	$(7{\cdot}8 \pm 1{\cdot}1) \times 10^{-1}$	26				
		998	*h*	$(2{\cdot}1 \pm 0{\cdot}33) \times 10^{-3}$	29	$(2{\cdot}1 \pm 0{\cdot}33) \times 10^{-3}$	$2{\cdot}346 \times 10^{-3}$	104	$0{\cdot}9 \pm 0{\cdot}14$
15	$_{64}Gd^{156}$	89	*l*	$(1{\cdot}38 \pm 0{\cdot}07)$	30	$1{\cdot}537 \pm 0{\cdot}069$	$1{\cdot}505$	104	$1{\cdot}02 \pm 0{\cdot}05$
			k	$1{\cdot}6 \pm 0{\cdot}04$	26				
			j	$1{\cdot}4 \pm 0{\cdot}14$	31				
16	$_{66}Dy^{160}$	84	*m*	$1{\cdot}65 \pm 0{\cdot}2$	32	$1{\cdot}523 \pm 0{\cdot}02$	$1{\cdot}606$	104	$0{\cdot}95 \pm 0{\cdot}02$
			j	$1{\cdot}6 \pm 0{\cdot}16$	33				
			j	$1{\cdot}5 \pm 0{\cdot}03$	34				
			n	$1{\cdot}54 \pm 0{\cdot}06$	35				
			l	$1{\cdot}52 \pm 0{\cdot}06$	36				
			k	$1{\cdot}75 \pm 0{\cdot}12$	26				
17	$_{66}Dy^{164}$	73	*o*	$2{\cdot}7 \pm 0{\cdot}5$	37	$2{\cdot}7 \pm 0{\cdot}5$	$2{\cdot}6$	105	$1{\cdot}04 \pm 0{\cdot}19$

TABLE I (*Contd.*)

No.	Nucleus	E_γ in Kev.	Method	α (Expt.)	Ref.	α (Adopted)	α (Theor.)	Ref.	R (α)
18	$_{68}Er^{164}$	91	*o*	1·9 ±0·2	37	1·643±0·154	1·253	104	1·31±0·12
			k	1·55 ±0·12	26				
19	$_{68}Er^{166}$	80·6	*m*	1·73 ±0·3	38	1·721±0·0286	1·587	104	1·08±0·02
			m	1·9 ±0·3	32				
			m	1·85 ±0·13	39				
			m	1·76 ±0·15	40				
			k	1·676±0·17	41				
			p	1·67 ±0·07	36				
			h	1·9 ±0·2	42				
			k	1·69 ±0·09	26				
20	$_{70}Yb^{170}$	84	*m*	1·5 ±0·2	32	1·351±0·102	1·311	104	1·03±0·08
			m	1·6 ±0·15	43				
			m	1·56 ±0·15	44				
			m	1·69 ±0·02	45				
			m	1·65 ±0·12	39				
			m	1·34 ±0·08	46				
			m	1·57 ±0·10	47				
			a	1·57 ±0·10 0·15	48				
			o	1·61 ±0·10	45				
			o	1·31 ±0·08	36				
			k	1·49 ±0·08	26				
21	$_{72}Hf^{176}$	88·35	*m*	1·32 ±0·11	39	1·161±0·0693	1·112	105	1·04±0·06
			m	1·25 ±0·15	49				
			o	1·10 ±0·06	36				

22	$_{72}Hf^{178}$	93	*h*	1·03 ±0·15	50	1·03 ±0·15	1·04	105	0·99±0·14
23	$_{72}Hf^{180}$	93·33	*e*	1·10 ±0·09	51	1·105±0·043	1·028	105	1·08±0·04
			m	1·3 ±0·4	52				
24	$_{74}W^{182}$	100	*e*	1·5 ±0·15	53	1·005±0·132	0·844	104	1·19±0·16
			k	0·97 ±0·04	26				
		1222	*e*	(3·0 ±0·36) × 10^{-3}	53	(3·0 ±0·36) ×10^{-3}	2·6 ×10^{-3}	105	1·15±0·14
25	$_{74}W^{186}$	123	*q*	(4·5 ±1·0) × 10^{-1}	54	(5·46 ±0·184)×10^{-1}	5·34 ×10^{-1}	104	1·02±0·03
			r	(5·63 ±0·56) × 10^{-1}	39				
			s	(5·5 ±0·3) × 10^{-1}	36				
26	$_{76}Os^{186}$	137	*o*	(3·5 ±1·0) × 10^{-1}	55	(4·08 ±0·114)×10^{-1}	3·93	104	1·04±0·03
			q	(3·7 ±0·8) × 10^{-1}	54				
			o	(3·6 ±0·36) × 10^{-1}	56				
			o	(4·5 ±0·3) × 10^{-1}	57				
			t	(3·98 ±0·28) × 10^{-1}	58				
			o	(4·2 ±0·3) × 10^{-1}	36				
27	$_{76}Os^{188}$	155	*d*	(2·9 ±0·3) × 10^{-1}	59	(2·97 ±0·265)×10^{-1}	2·98 ×10^{-1}	104	1·0 ±0·09
			m	(3·7 ±0·5) × 10^{-1}	59				
			o	(4·0 ±0·5) × 10^{-1}	57				
			o	(3·4 ±0·34) × 10^{-1}	36				
			e	(2·4 ±0·24) × 10^{-1}	60				
		633	*e*	(0·98 ±0·098)×10^{-2}	60	(0·98 ±0·098)×10^{-2}	1·564×10^{-2}	105	0·63±0·06
28	$_{76}Os^{190}$	187	*e*	(2·5 ±0·4) × 10^{-1}	61	(2·5 ±0·4) ×10^{-1}	1·96×10^{-1}	104	1·28±0·2
29	$_{76}Os^{192}$	206	*e*	(1·6 ±0·16) × 10^{-1}	62	(1·6 ±0·16) ×10^{-1}	1·44 ×10^{-1}	104	1·11±0·11
30	$_{78}Pt^{192}$	613	*e*	(1·1 ±0·11) × 10^{-2}	62	(1·155±0·05) ×10^{-2}	1·19 ×10^{-2}	105	0·97±0·04
			a	(1·2 ±0·1) × 10^{-2}	1				

TABLE I (*Contd.*)

No.	Nucleus	E_γ in Kev.	Method	α (Expt.)	Ref.	α (Adopted)	α (Theor.)	Ref.	R (α)
		317	*a*	$(5\cdot2 \pm 0\cdot25) \times 10^{-2}$	1	$(5\cdot282 \pm 0\cdot098) \times 10^{-2}$	$5\cdot369 \times 10^{-2}$	104	$0\cdot98 \pm 0\cdot02$
			a	$(5\cdot4 \pm 0\cdot3) \times 10^{-2}$	63				
31	$_{78}Pt^{194}$	328	*a*	$(4\cdot82 \pm 0\cdot26) \times 10^{-2}$	64	$(4\cdot482 \pm 0\cdot33) \times 10^{-2}$	$4\cdot945 \times 10^{-2}$	104	$0\cdot91 \pm 0\cdot07$
			a	$(4\cdot09 \pm 0\cdot22) \times 10^{-2}$	65				
			h	$(5\cdot6 \pm 0\cdot6) \times 10^{-2}$	66				
32	$_{78}Pt^{196}$	354	*a*	$(4\cdot15 \pm 0\cdot27) \times 10^{-2}$	64	$(3\cdot961 \pm 0\cdot117) \times 10^{-2}$	$4\cdot115 \times 10^{-2}$	104	$0\cdot96 \pm 0\cdot03$
			a	$(3\cdot95 \pm 0\cdot22) \times 10^{-2}$	48				
			a	$(3\cdot67 \pm 0\cdot24) \times 10^{-2}$	65				
			h	$(4\cdot2 \pm 0\cdot3) \times 10^{-2}$	67				
33	$_{80}Hg^{198}$	412	*d*	$(2\cdot81 \pm 0\cdot05) \times 10^{-2}$	68	$(2\cdot881 \pm 0\cdot042) \times 10^{-2}$	$3\cdot016 \times 10^{-2}$	104	$0\cdot96 \pm 0\cdot01$
			h	$(2\cdot75 \pm 0\cdot3) \times 10^{-2}$	69				
			a	$(2\cdot8 \pm 0\cdot15) \times 10^{-2}$	1				
			a	$(2\cdot84 \pm 0\cdot1) \times 10^{-2}$	64				
			a	$(2\cdot8 \pm 0\cdot15) \times 10^{-2}$	63				
			h	$(3\cdot05 \pm 0\cdot1) \times 10^{-2}$	70				
			h	$(2\cdot8 \pm 0\cdot2) \times 10^{-2}$	71				
			d	$(2\cdot85 \pm 0\cdot15) \times 10^{-2}$	72				
			a	$(2\cdot52 \pm 0\cdot13) \times 10^{-2}$	65				
			d	$(2\cdot41 \pm 0\cdot09) \times 10^{-2}$	65				
			d	$(2\cdot5 \pm 0\cdot5) \times 10^{-2}$	73				
			d	$(3\cdot0 \pm 0\cdot1) \times 10^{-2}$	74				
			d	$(3\cdot07 \pm 0\cdot4) \times 10^{-2}$	75				
			a	$(2\cdot41 \pm 0\cdot1) \times 10^{-2}$	76				
			a	$(3\cdot03 \pm 0\cdot05) \times 10^{-2}$	77				
			u	$(3\cdot635 \pm 0\cdot045) \times 10^{-2}$	78				

			u	$(2{\cdot}985\pm0{\cdot}045)\times10^{-2}$	78				
			d	$(2{\cdot}50\ \pm0{\cdot}2)\ \times10^{-2}$	79				
			d	$(3{\cdot}50\ \pm0{\cdot}28)\times10^{-2}$	80				
			d	$(3{\cdot}00\ \pm0{\cdot}24)\times10^{-2}$	81				
			d	$(3{\cdot}00\ \pm0{\cdot}24)\times10^{-2}$	82				
			a	$(2{\cdot}44\ \pm0{\cdot}08)\times10^{-2}$	83				
			d	$(2{\cdot}82\ \pm0{\cdot}10)\times10^{-2}$	84				
			a	$(2{\cdot}95\ \pm0{\cdot}05)\times10^{-2}$	85				
		1089	*b*	$(4{\cdot}0\ \pm0{\cdot}3)\ \times10^{-3}$	86	$(4{\cdot}116\pm0{\cdot}15)\times10^{-3}$	$4{\cdot}4\ \times10^{-3}$	105	$0{\cdot}94\pm0{\cdot}03$
			b	$(4{\cdot}1\ \pm0{\cdot}5)\ \times10^{-3}$	86				
			e	$(4{\cdot}6\ \pm0{\cdot}6)\ \times10^{-3}$	87				
34	$_{80}Hg^{200}$	368	*a*	$(4{\cdot}02\ \pm0{\cdot}14)\times10^{-2}$	48	$(4{\cdot}014\pm0{\cdot}009)\times10^{-2}$	$3{\cdot}926\times10^{-2}$	104	$1{\cdot}02\pm0{\cdot}002$
			v	$(3{\cdot}95\ \pm0{\cdot}8)\ \times10^{-2}$	88				
			o	$(4{\cdot}0\ \pm0{\cdot}25)\times10^{-2}$	89				
35	$_{84}Po^{212}$	729	*e*	$(0{\cdot}95\ \pm0{\cdot}11)\times10^{-2}$	90	$(0{\cdot}95\ \pm0{\cdot}11)\times10^{-2}$	$1{\cdot}067\times10^{-2}$	104	$0{\cdot}89\pm0{\cdot}10$

TABLE II

K-Conversion coefficients of $0^+ \rightarrow 2^+$ *transitions*

No.	Nucleus	E_γ in Kev.	Method	α_k (Expt.)	Ref.	α_k (Adopted)	α_k (Theor.)	Ref.	R (α_k)
1	$_{46}Pd^{106}$	624	*b*	$(2{\cdot}1\pm1{\cdot}0)\ \times10^{-3}$	2	$(2{\cdot}1\pm1{\cdot}0)\ \times10^{-3}$	$3{\cdot}456\times10^{-3}$	105	$0{\cdot}61\pm0{\cdot}29$
2	$_{48}Cd^{114}$	730	*a*	$(2{\cdot}5\pm1{\cdot}0)\ \times10^{-3}$	91	$(2{\cdot}5\pm1{\cdot}0)\ \times10^{-3}$	$2{\cdot}386\times10^{-3}$	105	$1{\cdot}05\pm0{\cdot}42$
3	$_{62}Sm^{152}$	563	*a*	$(9{\cdot}0\pm2{\cdot}0)\ \times10^{-3}$	92	$(9{\cdot}0\pm2{\cdot}0)\ \times10^{-3}$	$8{\cdot}735\times10^{-3}$	105	$1{\cdot}03\pm0{\cdot}23$
4	$_{64}Gd^{152}$	271	*a*	$(5{\cdot}0\pm2{\cdot}0)\ \times10^{-2}$	92	$(5{\cdot}0\pm2{\cdot}0)\ \times10^{-2}$	$7{\cdot}777\times10^{-2}$	105	$0{\cdot}64\pm0{\cdot}26$
5	$_{72}Hf^{178}$	1105	*h*	$(2{\cdot}6\pm0{\cdot}26)\times10^{-3}$	50	$(2{\cdot}6\pm0{\cdot}26)\times10^{-3}$	$2{\cdot}8\ \times10^{-3}$	105	$0{\cdot}93\pm0{\cdot}09$
6	$_{94}Pu^{240}$	816	*h*	$(1{\cdot}4\pm0{\cdot}5)\ \times10^{-2}$	93	$(1{\cdot}4\pm0{\cdot}5)\ \times10^{-2}$	$1{\cdot}373\times10^{-2}$	105	$1{\cdot}02\pm0{\cdot}36$

TABLE III

K-Conversion coefficients of $4^+ \rightarrow 2^+$ *transitions*

No.	Nucleus	E_γ in Kev.	Method	α_k (Expt.)	Ref.	α_k (Adopted)	α_k (Theor.)	Ref.	R (α_k)
1	$_{48}Cd^{110}$	884	*e*	$(1\cdot3 \pm 0\cdot2) \times 10^{-3}$	5	$(1\cdot226 \pm 0\cdot044) \times 10^{-3}$	$1\cdot331 \times 10^{-3}$	104	$0\cdot92 \pm 0\cdot03$
			e	$(1\cdot2 \pm 0\cdot12) \times 10^{-3}$	94				
2	$_{50}Sn^{118}$	1030	*e*	$(1\cdot18 \pm 0\cdot118) \times 10^{-3}$	95	$(1\cdot18 \pm 0\cdot118) \times 10^{-3}$	$1\cdot00 \times 10^{-3}$	105	$1\cdot18 \pm 0\cdot12$
3	$_{50}Sn^{120}$	1010	*e*	$(1\cdot5 \pm 0\cdot15) \times 10^{-3}$	95	$(1\cdot5 \pm 0\cdot15) \times 10^{-3}$	$1\cdot092 \times 10^{-3}$	105	$1\cdot37 \pm 0\cdot14$
4	$_{54}Xe^{130}$	660	*g*	$(3\cdot2 \pm 0\cdot32) \times 10^{-3}$	16	$(3\cdot2 \pm 0\cdot32) \times 10^{-3}$	$3\cdot75 \times 10^{-3}$	104	$0\cdot85 \pm 0\cdot09$
5	$_{56}Ba^{134}$	800	*h*	$(2\cdot6 \pm 0\cdot3) \times 10^{-3}$	22	$(2\cdot81 \pm 0\cdot2) \times 10^{-3}$	$2\cdot67 \times 10^{-3}$	105	$1\cdot05 \pm 0\cdot08$
			i	$(3\cdot02 \pm 0\cdot3) \times 10^{-3}$	19				
		1367	*h*	$(7\cdot0 \pm 1\cdot5) \times 10^{-1}$	22	$(7\cdot0 \pm 1\cdot5) \times 10^{-1}$	$6\cdot0 \times 10^{-1}$	105	$1\cdot17 \pm 0\cdot25$
6	$_{58}Ce^{140}$	489	*b*	$(5\cdot3 \pm 2\cdot0) \times 10^{-3}$	3	$(5\cdot3 \pm 2\cdot0) \times 10^{-3}$	$10\cdot12 \times 10^{-3}$	105	$0\cdot52 \pm 0\cdot2$
7	$_{60}Nd^{144}$	615	*h*	$(6\cdot6 \pm 0\cdot66) \times 10^{-3}$	23	$(6\cdot6 \pm 0\cdot66) \times 10^{-3}$	$6\cdot896 \times 10^{-3}$	105	$0\cdot96 \pm 0\cdot10$
8	$_{62}Sm^{152}$	244	*a*	$(0\cdot91 \pm 0\cdot14) \times 10^{-1}$	27				
				$(1\cdot04 \pm 0\cdot16) \times 10^{-1}$ $0\cdot27)$	27	$0\cdot881 \pm 0\cdot05$	$0\cdot8194 \times 10^{-1}$	104	$1\cdot08 \pm 0\cdot06$
			e	$(0\cdot83 \pm 0\cdot083) \times 10^{-1}$	96				
9	$_{64}Gd^{156}$	199	*j*	$(1\cdot4 \pm 0\cdot14) \times 10^{-1}$	31	$(1\cdot4 \pm 0\cdot14) \times 10^{-1}$	$1\cdot54 \times 10^{-1}$	104	$0\cdot91 \pm 0\cdot09$
10	$_{72}Hf^{178}$	214	*e*	$(\geqslant 89) \times 10^{-1}$	50	$(0\cdot89 \pm 0\cdot089) \times 10^{-1}$	$1\cdot38 \times 10^{-1}$	104	$0\cdot65 \pm 0\cdot07$
11	$_{72}Hf^{180}$	216	*m*	$(1\cdot5 \pm 0\cdot5) \times 10^{-1}$	52	$(1\cdot5 \pm 0\cdot5) \times 10^{-1}$	$1\cdot35 \times 10^{-1}$	104	$1\cdot11 \pm 0\cdot37$
12	$_{74}W^{182}$	229	*e*	$(1\cdot6 \pm 0\cdot16) \times 10^{-1}$	53	$(1\cdot6 \pm 0\cdot16) \times 10^{-1}$	$1\cdot18 \times 10^{-1}$	104	$1\cdot36 \pm 0\cdot14$
13	$_{74}W^{184}$	253	*e*	$(8\cdot0 \pm 0\cdot8) \times 10^{-2}$	97	$(8\cdot0 \pm 0\cdot8) \times 10^{-2}$	$9\cdot053 \times 10^{-2}$	104	$0\cdot88 \pm 0\cdot09$
14	$_{76}Os^{188}$	324	*e*	$(3\cdot9 \pm 0\cdot39) \times 10^{-2}$	60	$(3\cdot9 \pm 0\cdot39) \times 10^{-2}$	$5\cdot128 \times 10^{-2}$	105	$0\cdot76 \pm 0\cdot08$
15	$_{76}Os^{190}$	361	*e*	$(4\cdot4 \pm 0\cdot9) \times 10^{-2}$	61	$(4\cdot4 \pm 0\cdot9) \times 10^{-3}$	$4\cdot101 \times 10^{-2}$	105	$1\cdot07 \pm 0\cdot22$
16	$_{78}Pt^{192}$	468	*e*	$(2\cdot2 \pm 0\cdot22) \times 10^{-2}$	62	$(2\cdot2 \pm 0\cdot22) \times 10^{-2}$	$2\cdot234 \times 10^{-2}$	105	$0\cdot99 \pm 0\cdot1$
17	$_{78}Pt^{196}$	521	*h*	$(1\cdot3 \pm 0\cdot4) \times 10^{-2}$	98	$(1\cdot3 \pm 0\cdot4) \times 10^{-2}$	$1\cdot709 \times 10^{-2}$	105	$0\cdot76 \pm 0\cdot23$
18	$_{80}Hg^{200}$	579	*e*	$(1\cdot37 \pm 0\cdot2) \times 10^{-2}$	99	$(1\cdot37 \pm 0\cdot2) \times 10^{-2}$	$1\cdot444 \times 10^{-2}$	104	$0\cdot95 \pm 0\cdot14$
19	$_{82}Pb^{204}$	375	*b*	$(4\cdot44 \pm 0\cdot29) \times 10^{-2}$	100	$(4\cdot44 \pm 0\cdot29) \times 10^{-2}$	$3\cdot939 \times 10^{-2}$	104	$1\cdot13 \pm 0\cdot07$
20	$_{90}Th^{228}$	130	*m*	$(3\cdot80 \pm 0\cdot38) \times 10^{-2}$	101	$(3\cdot8 \pm 0\cdot38) \times 10^{-2}$	$3\cdot6 \times 10^{-2}$	105	$1\cdot06 \pm 0\cdot11$

TABLE IV

K-Conversion coefficients of $6^+ \rightarrow 4^+$ transitions

No.	Nucleus	E_r in Kev.	Method	α_k (Expt.)	Ref.	α_k (Adopted)	α_k (Theor.)	Ref.	R (α_k)
1	$_{40}Zr^{90}$	372	*e*	$\approx 6{\cdot}0) \times 10^{-3}$	102	$(6{\cdot}0 \pm 0{\cdot}6) \times 10^{-3}$	$10{\cdot}89 \times 10^{-3}$	105	$0{\cdot}55 \pm 0{\cdot}06$
2	$_{48}Cd^{110}$	937	*e* *e*	$(1{\cdot}19 \pm 0{\cdot}03) \times 10^{-3}$ $(1{\cdot}1 \pm 0{\cdot}11) \times 10^{-3}$	5 94	$(1{\cdot}184 \pm 0{\cdot}023) \times 10^{-3}$	$1{\cdot}262 \times 10^{-3}$	105	$0{\cdot}94 \pm 0{\cdot}02$
3	$_{50}Sn^{118}$	250	*e*	$(5{\cdot}1 \pm 0{\cdot}51) \times 10^{-2}$	95	$(5{\cdot}1 \pm 0{\cdot}51) \times 10^{-2}$	$7{\cdot}127 \times 10^{-2}$	105	$0{\cdot}72 \pm 0{\cdot}07$
4	$_{50}Sn^{120}$	200	*e*	$(1{\cdot}65 \pm 0{\cdot}165) \times 10^{-1}$	95	$(1{\cdot}65 \pm 0{\cdot}165) \times 10^{-1}$	$1{\cdot}352 \times 10^{-1}$	105	$1{\cdot}22 \pm 0{\cdot}12$
5	$_{54}Xe^{130}$	744	*e*	$(2{\cdot}4 \pm 0{\cdot}24) \times 10^{-3}$	16	$(2{\cdot}4 \pm 0{\cdot}24) \times 10^{-3}$	$2{\cdot}993 \times 10^{-3}$	105	$0{\cdot}80 \pm 0{\cdot}08$
6	$_{60}Nd^{144}$	474	*h*	$(1{\cdot}04 \pm 0{\cdot}104) \times 10^{-2}$	23	$(1{\cdot}04 \pm 0{\cdot}104) \times 10^{-2}$	$1{\cdot}216 \times 10^{-2}$	105	$0{\cdot}86 \pm 0{\cdot}09$
7	$_{72}Hf^{180}$	332	*m*	$(5{\cdot}5 \pm 1{\cdot}4) \times 10^{-2}$	52	$(5{\cdot}5 \pm 1{\cdot}4) \times 10^{-2}$	$4{\cdot}525 \times 10^{-2}$	105	$1{\cdot}22 \pm 0{\cdot}31$
8	$_{96}Cm^{244}$	154	*h*	$(1{\cdot}9 \pm 0{\cdot}19) \times 10^{-1}$	103	$(1{\cdot}9 \pm 0{\cdot}9) \times 10^{-1}$	$1{\cdot}60 \times 10^{-1}$	103	$1{\cdot}19 \pm 0{\cdot}12$

TABLE V

K-Conversion coefficient of $8^+ \rightarrow 6^+$ transitions

No.	Nucleus	$E\gamma$ in Kev.	Method	α_k (Expt)	Ref.	α_k (Adopted)	α_k (Theor.)	Ref.	R (α_k)
1	$_{72}Hf^{180}$	444	*m*	$(2{\cdot}6 \pm 0{\cdot}7) \times 10^{-2}$	52	$(2{\cdot}6 \pm 0{\cdot}7) \times 10^{-2}$	$2{\cdot}113 \times 10^{-2}$	105	$1{\cdot}23 \pm 0{\cdot}31$

to theoretical values. R (α_k) is plotted against the atomic weight in Figs. 1 to 4. Some of the available data on experimental α_k values are not included in the tables due to the lack of information on the experimental methods involved.

III. ANALYSIS OF DATA AND DISCUSSION

(*a*) *Spherical Region*

Deviations are pronounced for Te^{124}, Xe^{126}, Xe^{130} and Xe^{132} in Fig. 1. In the case of Te^{124} and Xe^{126} all the α_k values are determined by P B S methods only and hence we can attribute the deviations to the possible systematic experimental errors. $2'^{+}\rightarrow 0^{+}$ transition in Ba^{134} shows better agreement with theory than $2^{+}\rightarrow 0^{+}$ which is pure E2. So we may expect a correlation between the deviation of α_k and the nuclear structure among these nuclei. The nuclei beyond $A > 192$ do not lie on the R (α_k) = unity line and a general trend in α_k for $2^{+}\rightarrow 0^{+}$ transitions to be lower than theory is observed for the spherical nuclei.

In Fig. 2, out of the three points that lie in the spherical region, one point, *i.e.*, Pd^{106} deviates from the unity line.

In Fig. 3, the points lie equally well on both sides of the line R(α_k) = unity. The closed-shell nuclei Sn^{118} and Sn^{120} lie far above the unity line. Deviations are observed in most of the cases where relative intensity measurements are made for the measurement of α_k.

All the spherical nuclei deviate in Fig. 4, among which Zr^{90}, Sn^{118}, Sn^{120} are closed-shell nuclei.

All the α_k values for $6^{+}\rightarrow 4^{+}$ transitions except in the cases of Nd^{144} and Cm^{244}, are determined from relative intensity measurements and the accuracy of the experimental α_k value depends in turn on the theoretical value used for the normalization of the relative values. In general, α_k values show a tendency to be lower than theory.

Measured α_k values for $8^{+}\rightarrow 6^{+}$ transitions are not available for any nucleus in the spherical region.

Pd^{106} (in Figs. 1 and 2), Cd^{110} and Xe^{130} in Figs. 1, 3 and 4 behave similarly.

The closed-shell nuclei Sn^{118} in Fig. 3 and Sn^{120} in Figs. 3 and 4 lie well above the unity line whereas the same nucleus Sn^{118} lies below the line in Fig. 4.

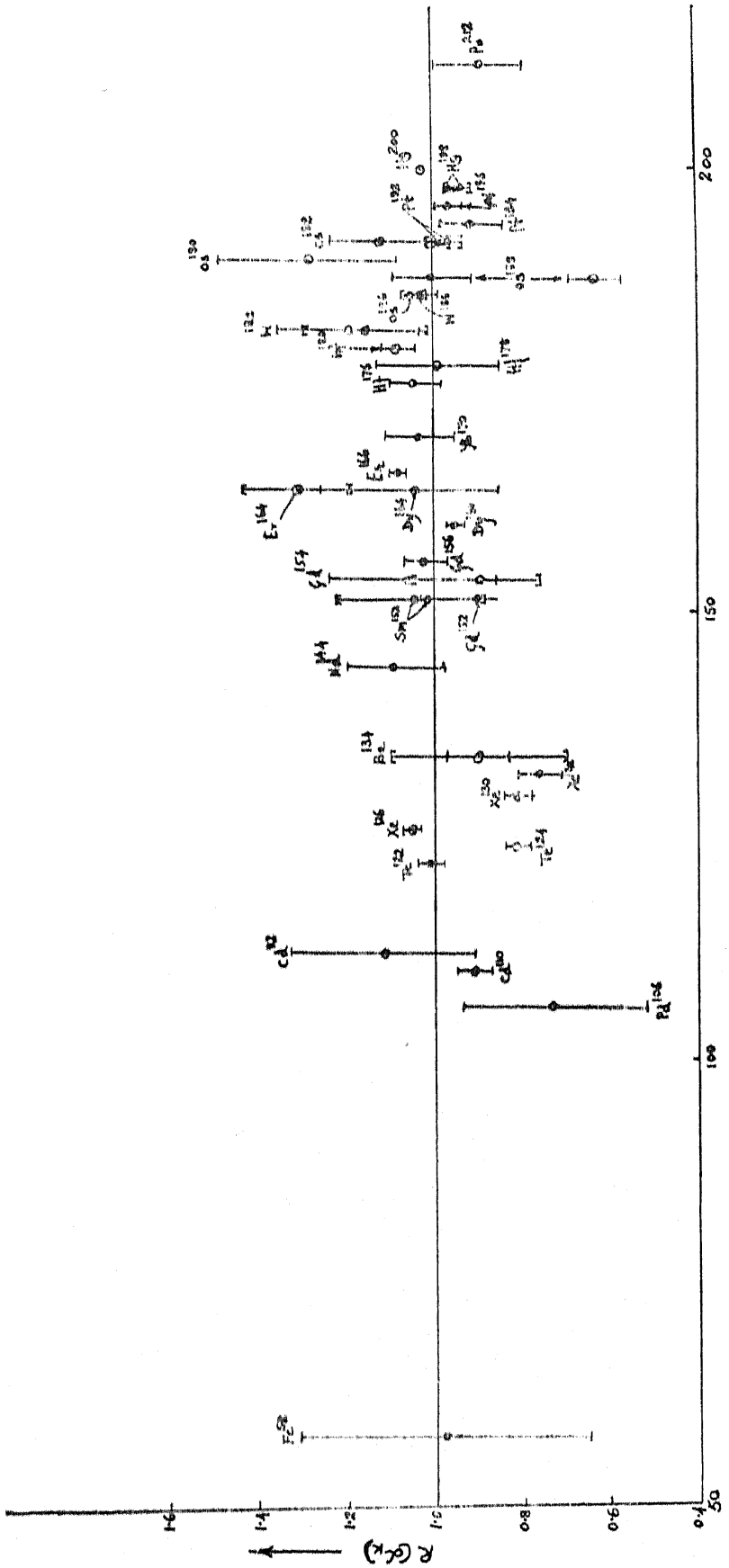

FIG. 1. Variation of R (α_K) with atomic weight for $2^+ \rightarrow 0^+$ and $2^+ \rightarrow 0^+$ transitions.

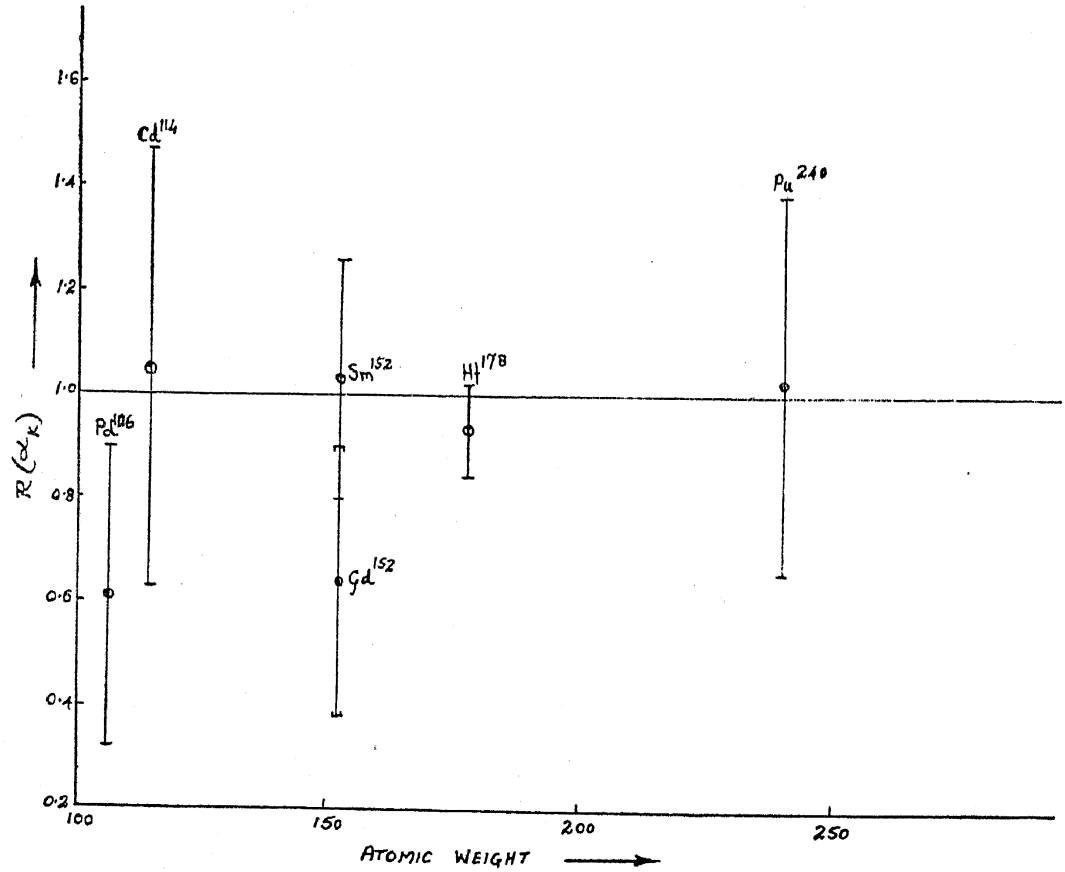

FIG. 2. Variation of R (α_k) with atomic weight for $0^+ \rightarrow 2^+$ transitions.

Since Nd^{144} agrees with theory in Figs. 1 and 3 and as it lies below the unity line in Fig. 4, the $6^+ \rightarrow 4^+$ transition may not be pure E2 and there may be an admixture of M3 transition. Hg^{200} is an interesting case because there is a good agreement for the $4^+ \rightarrow 2^+$ transition in Fig. 3 but the point lies slightly above the line for $2^+ \rightarrow 0^+$ transition in Fig. 1 which is a pure E2 transition.

(b) Deformed Region

An analysis of Fig. 1 clearly indicates that the large deviations observed by earlier workers are very much reduced in the deformed region. Nuclei other than Gd^{152}, Dy^{160}, Er^{164}, Er^{166}, Hf^{180}, W^{182}, Os^{186}, and Os^{190} lie on the line R (α_k) = unity. As we have taken the weighted averages of all the available data on α_k so as to reduce the possibility of a constant error entering the experimental values no particular comment can be made on the above deviation. In the case of Os^{188}, a large deviation is observed for the $2'^+ \rightarrow 0_+$ transition (633 Kev.) and hence there is the possibility of 633 Kev. transition being not pure E2.

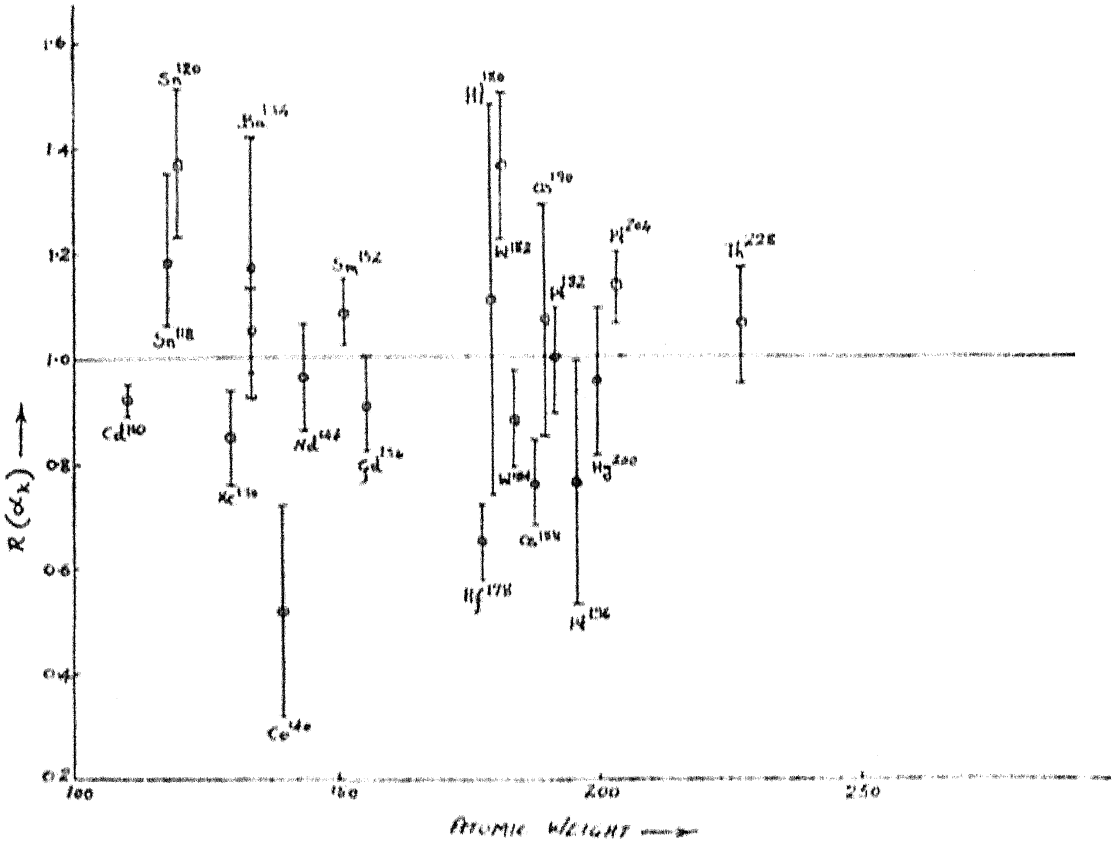

FIG. 3. Variation of R (α_K) with atomic weight for $4^+ \rightarrow 2^+$ transitions.

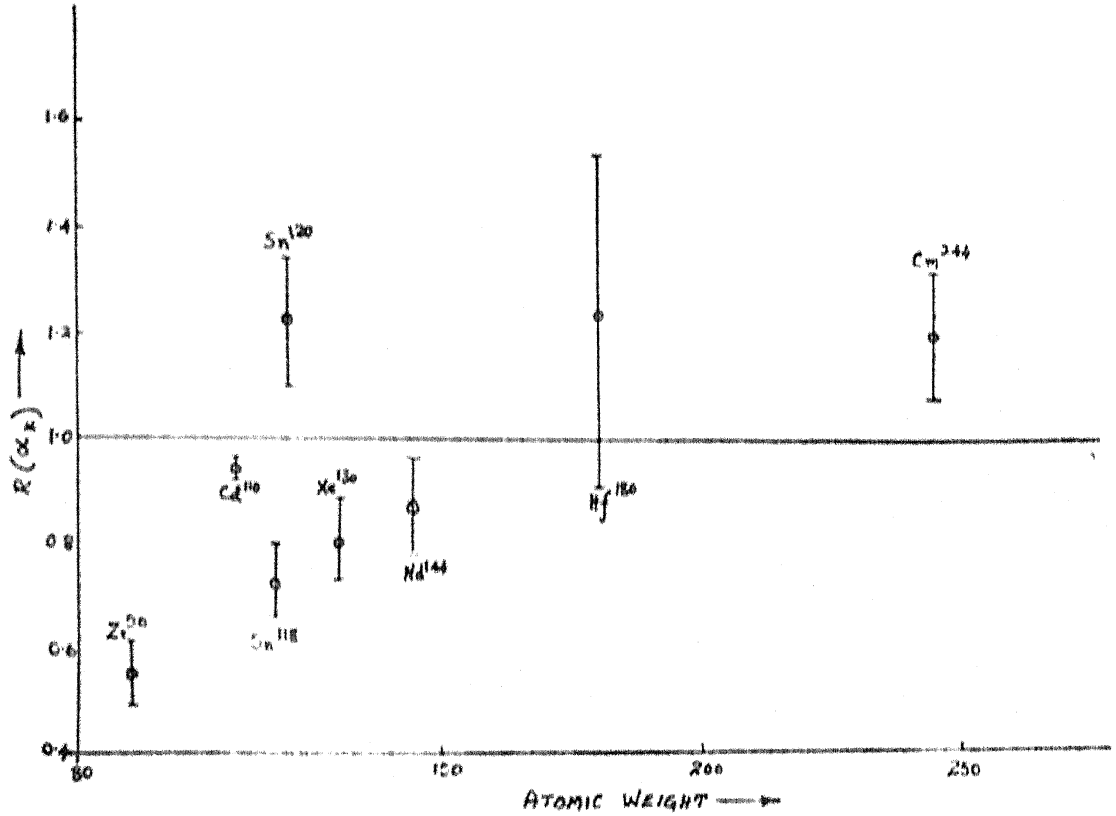

FIG. 4. Variation of R (α_K) with atomic weight for $6^+ \rightarrow 4^+$ transitions.

values obtained by gamma scintillation spectra method are usually higher than those obtained by other methods. Coincidence methods yield good results almost in all the cases. In general, the values obtained by IEC method are in good agreement with one another. It will be of interest if α_k values for pure E2 transitions of all types are remeasured using the improved techniques.

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FOOTNOTE TO TABLES I TO V

a = Internal-External Conversion.
b = Intensity measurements of e^- and γ (whether relative or absolute is not specific).
c = Coincidence spectrometry.

d = Peak-to-beta ray spectrum.
e = Relative intensity measurements of e^- and γ.
f = Beta-ray spectroscopy.
g = Gamma-ray intensity measurements.
h = Coincidence methods (type of the coincidence is not specific).
i = Magnetic spectrometer measurements.
j = Absolute intensity measurements of e^- and γ.
k = Lifetime measurements.
l = γ-γ coincidence.
m = r-Scintillation spectra.
n = Sum-coincidence technique.
o = β-γ coincidence.
p = β-γ coincidence and singles spectrum.
q = Double lens spectrometer and coincidence methods.
r = Coulomb excitation.
s = X-ray-γ coincidence.
t = electron-electron coincidence.
u = electron-β coincidence.
v = electron-γ coincidence.

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