exhibit a symmetric cusp at the energetic threshold for a new process. Others[23] have looked for such a cusp, but with inconclusive results. In the present experiment, data were taken in the vicinity of the threshold for the $N^{15}(p,n)O^{15}$ reaction, the threshold energy being indicated on Fig. 2 by a dashed arrow. There is no evidence in these data for a cusp. However, it is possible that the energy steps (20 kev apart) in that region were large enough so the effect was simply missed.

It is a pleasure to acknowledge the help and encouragement of Professor James A. Jacobs.

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Absolute Intensities of L X-Rays and Gamma Ray in RaD Decay*

RICHARD W. FINK
Department of Chemistry, University of Arkansas, Fayetteville, Arkansas
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The absolute intensity of L x-rays/RaD disintegration (F) has been measured to be $0.23_8 \pm 0.02$ by argon-filled proportional counter spectrometry on carrier-free RaDEF equilibrium sources, and the relative intensities were found to be $L_\alpha : L_\beta : L_\gamma :: 1.0 : 1.1 : 0.19$. The intensity of L x-rays relative to that (R) of the single, 46.5-kev, pure $M1$ gamma ray is $F/R = 5.1 \pm 0.7$. Care was taken to avoid error due to wall-effects and the counting techniques were varied and cross-checked so as to eliminate possible systematic errors. The absolute intensity of the gamma ray is $R = 0.045 \pm 0.004$ from data taken on a 3×3 inch NaI(Tl) scintillation spectrometer. Assuming the number of L-shell ionizations/RaD disintegration (I) to be 0.62, the mean L-fluorescence yield (F/I) of bismuth is 0.38 ± 0.02, which when combined with the ratio F/R, leads to an experimental value of the total L-shell conversion coefficient (I/R), which thus is 13.3 ± 2.0, the major error arising from the correction of R for the contribution due to Compton backscattering, which amounts to some 10 to 20% depending on exact conditions of geometry and collimation. The value of the L-conversion coefficient interpolated from Rose's tables is 17.85, based on a point-charge nucleus. Better agreement is obtained with a value of about 12.7 from theoretical calculations of Sliv and Listengarten, who included a correction for the finite size of the nucleus.

A new summary of mean L-fluorescence yields from nuclear excitation is presented which shows that the mean yields depend strongly upon the relative number of vacancies in the respective L subshells.

I. INTRODUCTION

PREVIOUSLY[1] we confirmed the absence of gamma rays other than the well-known 46.52-kev transition in RaD(Pb^{210}) decay. This paper presents results of measurements on (1) the absolute intensity of L x-ray quanta/disintegration, and (2) the ratio (F/R) of the intensity of L x-ray quanta/disintegration (F) to that (R) of 46.5-kev gamma quanta/disintegration in the decay of RaD. In order to establish a reliable value for the mean L-fluorescence yield ($\bar{\omega}_L$) of bismuth from excitation by L-conversion of the relatively pure $M1$ gamma-ray as discussed by Ross, Cochran, Hughes, and Feather,[2] a precision measurement of F is required which then may be combined with the number (1) of

TABLE I. Summary of measurements of F.

Value	Method	Investigator	Reference
~0.3	Abs. in Pb	Gray	b
~0.2_7	Abs. in Al	Tsien	c
$0.24_5 \pm 0.03$[a]	Collimated, low-geometry source; air ioniz. chamber	Stahel	d
0.19 ± 0.03	Thin NaI(Tl) scin. spect. Uncollimated source	Damon and Edwards	e
$0.23_8 \pm 0.02$	Argon-filled prop. counter at 2.1 atmos; carrier-free collimated sources	Present work	See Table IV

[a] Recalculated from original value of 0.250 using $e = 4.80 \times 10^{-10}$ esu and average energy of x-rays as 12.0 kev.
[b] See reference 3.
[c] See reference 4.
[d] See reference 5.
[e] See reference 6.

TABLE II. Summary of measurements of F/R.

Value	Method	Investigator	Reference
4.4 ± 0.7	Prop. counter filled with 1 atmos argon, 1 atmos krypton, or 3 atmos krypton	Wu, Boehm, and Nagle	a
$6.7_4 \pm 0.5$	Argon-filled prop. counter; press. varied to eliminate wall-effect; uncorr. for source absorption and self-excitation	Hughes	b
5 ± 1	Thin NaI(Tl) scin. spect. and argon-filled prop. counter	Damon and Edwards	c
5.1 ± 0.7	Prop. counter with 2.1 atmos argon; carrier-free sources	Present work	See Table V

[a] See reference 7.
[b] See reference 8.
[c] See reference 6.

* Supported in part by the National Science Foundation and the U. S. Atomic Energy Commission.
[1] Fink, Warren, Edwards, and Damon, Phys. Rev. **103**, 651 (1956).
[2] Ross, Cochran, Hughes, and Feather, Proc. Phys. Soc. (London) **A68**, 612 (1955).

TABLE III. Summary of measurements of R

Value	Method	Investigator	Reference
0.035	Resolution of abs. curve into L x-ray and 46.5-kev gamma ray components	Stahel	a
0.031 ± 0.01	Same as above	Bramson	b
0.04	Same as above	Gray	c
0.036	Same as above	Von Droste	d
0.038 ± 0.006	Thin NaI(Tl) scin. spect. and alpha-prop. counting	Damon and Edwards	e
$0.07\ \pm0.02$	Prop. counter measurement of F/R ratio and assuming $\bar{\omega}_L=0.475$	Wu, Boehm, and Nagle	f
0.045 ± 0.004	3×3 inch NaI(Tl) scin. spect. and alpha-prop. and alpha-scin. counting; correction for iodine K x-ray escape	Present work	

[a] See reference 5.
[b] See reference 9.
[c] See reference 3.
[d] See reference 10.
[e] See reference 6.
[f] See reference 7.

L-shell ionizations/RaD disintegration (since $\bar{\omega}_L=F/I$). This, together with the ratio F/R, gives the total L-conversion coefficient (I/R), since K-shell excitation is energetically forbidden in this case:

$$I/R=(F/R)/(F/I). \quad (1)$$

Values of F have been estimated from absorption curves by Gray[3] and Tsien,[4] and have been measured by Stahel[5] and by Damon and Edwards.[6] These results, together with the present result, are summarized in Table I. Values of F/R have been determined by Damon and Edwards,[6] Wu, Boehm, and Nagle,[7] and Hughes.[8] These values and the present results are given in Table II. The absolute intensity (R) of 46.5 kev quanta/disintegration has been determined by Gray,[3] Stahel,[5] Damon and Edwards,[6] Wu, Boehm, and Nagle,[7] Bramson,[9] and Von Droste.[10] These results are listed in Table III, along with the present value obtained by using a 3×3 inch NaI(Tl) scintillation spectrometer with corrections for iodine K x-ray escape according to the method of Axel[11] and for counting efficiency based on the curves of Bell.[12]

II. EXPERIMENTAL

Absolute L X-Ray Intensity (F) Measurements

Measurements of F and of F/R were made on an aluminum-lined, 10.0-cm diameter proportional counter[1] filled with 2.1 atmos of a 10% methane—90% argon mixture which had been purified by convection circulation for 10 days over hot calcium. The counter has a 3.2-cm diameter beryllium side window having a superficial density of 164 mg/cm². The fraction of 12-kev x-rays transmitted through the window was calculated to be 0.916 ± 0.005; and for 46.5-kev gamma rays, 0.997 ± 0.003, based on mass absorption coefficients from Allen.[13] (Air transmission for 12-kev x-rays is 0.995 ± 0.005.)

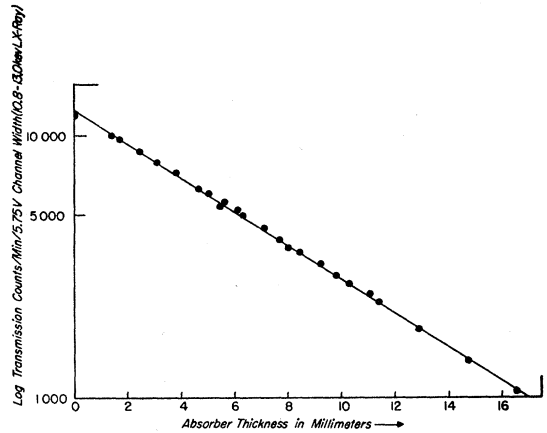

FIG. 1. Absorption of Bi L x-rays arising from RaD decay in Plexiglas as observed with the proportional counter. The channel-width on the pulse-height analyzer was set wide enough (5.75 volts) to encompass essentially all of the L peak. At first Lucite or Plexiglas of different manufacture resulted in erratic points, due to density variations, but consistency was obtained when all absorbers were made of the same stock of Plexiglas.

Five carrier-free RaDEF sources, mounted on 0.25 cm-thick flat aluminum planchets, were studied with various degrees of collimation under conditions both of "high geometry" (source-to-window distance 2.6 cm) and of "low geometry" (source-to-window distance 6.2 cm). Particulate radiation was eliminated by use of a Plexiglas absorber whose transmission for Bi L x-rays was evaluated by running an absorption curve, Fig. 1, with the channel-width set wide enough (5.75 volts) to encompass essentially all of the L peak.

The x-ray counting rate appeared to be somewhat dependent on the degree of collimation, being higher with more severe collimation, under the "high geometry" condition. This is attributed to parallax, since the geometry ($\Omega/4\pi$) was calculated from the diameter of the collimator without correction for the finite collimator-to-window distance and the divergent nature of the incident beam. However, under the "low geometry" condition, the parallax effect was negligible as shown by the fact that the intensity was independent of the degree of collimation. The collimators were of 1 cm-thick iron faced on all surfaces with aluminum to avoid fluorescent excitation of iron x-rays. To obtain the L

[3] J. A. Gray, Nature **130**, 738 (1932).
[4] S. T. Tsien, Compt. rend. **218**, 503 (1944).
[5] E. Stahel, Helv. Phys. Acta **8**, 511, 651 (1935).
[6] P. E. Damon and R. R. Edwards, Phys. Rev. **95**, 1648 (1954); Annual Progress Report, University of Arkansas, March, 1954, Appendix I (unpublished).
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[9] S. Bramson, Z. Physik **66**, 721 (1930).
[10] G. F. Von Droste, Z. Physik **84**, 17 (1933).
[11] P. Axel, U. S. Atomic Energy Commission Report BNL-271, 1953 (unpublished).
[12] P. R. Bell (privately circulated data, 1956).
[13] S. J. M. Allen, tables in *Handbook of Chemistry and Physics* (Chemical Rubber Publishing Company, Cleveland, 1952), 34th edition.

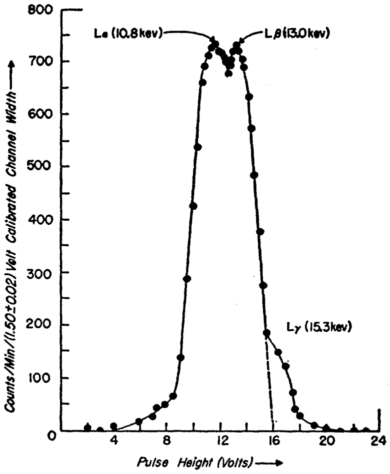

FIG. 2. Representative data on L x-rays from differential pulse-height analysis from proportional counting of carrier-free RaDEF equilibrium sources. The channel-width was calibrated before and after each run. Integral-bias counting agreed precisely with results obtained by taking the area under the three L peaks, background having been subtracted. (The background is about 30 counts/min per 1.0-volt window in the region of the L-peak.)

x-ray yield from a given source, two types of counting experiments were done: (1) a differential pulse-height spectrum was plotted, Fig. 2, the yield being taken from the area under the peaks, the channel-width having been calibrated before and after each run; and (2) integral-bias counting was done for both sample and background for long counting times. The latter method, being independent of channel-width, gave precise agreement with the differential spectrum, as can be seen from Table IV, thus affording a check on the L counting rate. The correction for counting efficiency is discussed in the next section.

In measuring x-ray intensities in the presence of large beta and alpha activities, the use of carrier-free sources is essential to avoid fluorescent excitation which would contribute to the total intensity. The importance of this recently was shown[14] in a series of experiments, in connection with work on Tl^{204}, in which a series of 1-cm^3 ampoules were filled with carrier thallium nitrate solutions ranging from zero to 0.22 mg/ml in concentration; to each was added an identical amount of very high specific activity Tl^{204}. After sealing, the ampoules were studied by scintillation spectrometer and proportional counter where the ratios of K x-rays/beta-bremsstrahlung and of L x-rays/beta-bremsstrahlung, respectively, were studied *vs* the concentration of inert thallium solids in an attempt to find a "plateau" where fluorescent excitation of K and L x-rays was independent of thallium carrier. It was found that a considerable increase in the above ratios occurred with increasing concentration and that a "plateau" existed only at exceedingly low concentrations (10^{-4} molar or less).

The absolute source strength was obtained by alpha-counting on the assumption that complete equilibrium existed between RaD and its RaE and RaF daughters. The tendency for RaE to become radiocolloidal and to stick to glass surfaces on long standing even in strong nitric acid solutions is well-known, so that when a sample is made by taking an aliquot of a carrier-free stock solution of "equilibrium" RaDEF, there is no assurance that the aliquot will be in equilibrium; it may in fact be highly depleted in RaE and RaF daughters. For the present investigation, Pyrex radon needles (about two years old) were used to prepare a fresh, strongly nitric acid stock solution from which samples were made immediately. To be certain of radioactive equilibrium, measurements were repeated over a period of six months. No change was observed in the value of F.

Two independent counting techniques were employed to accomplish the alpha-counting: (1) a 2π windowless flow proportional alpha-counter (using 10% methane—

TABLE IV. Data and results of L x-ray yield per RaD disintegration (F).

Sample	Type of run[a]	Geometry ($\Omega/4\pi$)	Total L x-ray quanta/min (4π)	Total Po^{210} α's/min (4π)	F
		("Low geometry")			
A	IB (3)	8.27×10^{-3}	5.27×10^{5}	2.30×10^{6}	0.230
A	IB (2)	2.81	5.26	2.30	0.230
B	IB (3)	8.30×10^{-3}	3.36×10^{5}	1.45×10^{6}	0.232
B	IB (3)	2.83	3.22	1.45	0.222
C	IB (4)	8.01×10^{-3}	3.70×10^{5}	1.55×10^{6}	0.238
C	IB (6)	2.72	3.73	1.55	0.241
D	IB (2)	2.49×10^{-3}	2.10×10^{5}	9.10×10^{5}	0.230
D	IB (1)	8.01	2.01	9.10	0.220
		("High geometry")			
A	IB (2)	4.13×10^{-2}	5.74×10^{5}	2.30×10^{6}	0.249
A	Diff. (1)	4.13	5.63	2.30	0.245
B	IB (2)	4.14×10^{-2}	3.61×10^{5}	1.45×10^{6}	0.249
B	Diff. (1)	4.14	3.55	1.45_3	0.244
C	IB (1)	1.37×10^{-2}	4.21×10^{5}	1.63×10^{6}	0.252
C	IB (2)	3.75	4.08	1.63	0.249
C	Diff. (1)	3.75	4.02	1.63	0.247
D	Diff. (1)	1.38×10^{-2}	2.29×10^{5}	9.55×10^{5}	0.240
D	Diff. (1)	3.77	1.95	9.50	0.206
D	Diff. (1)	1.38	2.30	9.45	0.243
D	Diff. (1)	1.38	2.09	9.10	0.230
D	Diff. (1)	3.77	1.84	9.10	0.202
D	IB (1)	3.77	2.13	9.10	0.234
D	IB (2)	1.38	2.20	9.10	0.242
D	IB (1)	3.77	2.13	9.10	0.234
E	IB (1)	4.13×10^{-2}	1.99×10^{5}	8.44×10^{5}	0.236
E	Diff. (1)	4.13	1.98_4	8.44	0.235

Summary of results

Conditions: Geometry	Conditions: Collimator	Mean F	Mean deviation
"high"	0.635 cm diam	0.242	0.005
"high"	2.22 cm diam	0.239	0.011
"low"	Any	0.233	0.007
Average of all runs		0.238	0.01

[a] IB = integral-bias counting; Diff. = differential spectrum. The number in parenthesis is the number of runs for the geometry stated from which the result tabulated was averaged.

[14] RamaSwamy, Robinson, and Fink (unpublished studies, 1954).

90% argon mixture) having discrimination against beta-gamma radiation was used. This counter was cross-checked with National Bureau of Standards standardized RaDEF sources; when a +1.5% correction for alpha-backscattering was added to the 2π geometry, the agreement with the National Bureau of Standards (NBS) calibration was excellent. Because of the high counting rates encountered in the five RaDEF sources under study, careful deadtime loss corrections were applied, the deadtime being evaluated with paired Po^{210} carrier-free sources having counting rates in the same range as the samples. (2) An alpha-scintillation counter, consisting of a DuMont 6292 photomultiplier faced with a very thin ZnS(Ag) screen was constructed. NBS standardized sources were used to calibrate the product of geometry and efficiency of this counter, and deadtime corrections, again evaluated with the paired Po^{210} sources, were applied. Agreement between the two counters was excellent, giving a good check on the deadtime corrections which were different for the two counters.

Data from the foregoing L x-ray and alpha-counting experiments were combined to give the values of F, as shown in Table IV, from which the mean value is

$$F=0.23_8\pm0.02 \quad L \text{ x-ray quanta/RaD disintegration.}$$

The ratio of $L_\alpha:L_\beta:L_\gamma$ x-rays, Fig. 2, averaged 1.0: 1.1:0.19, after correction for the respective transmissions and counting efficiencies. This is in good agreement with previous reports.[6-8,15-17]

Ratio of the Intensity of L X-Rays/46.5-kev Gammas (F/R)

The F/R ratio was obtained from proportional counter differential spectra by using both freshly-separated[1] and equilibrium carrier-free sources. A representative spectrum of the 46.5-kev gamma from an equilibrium source is shown in Fig. 3, where the corrections for RaE beta-bremsstrahlung and Compton backscattering are estimated as shown. With freshly-separated RaD, the amount of bremsstrahlung is

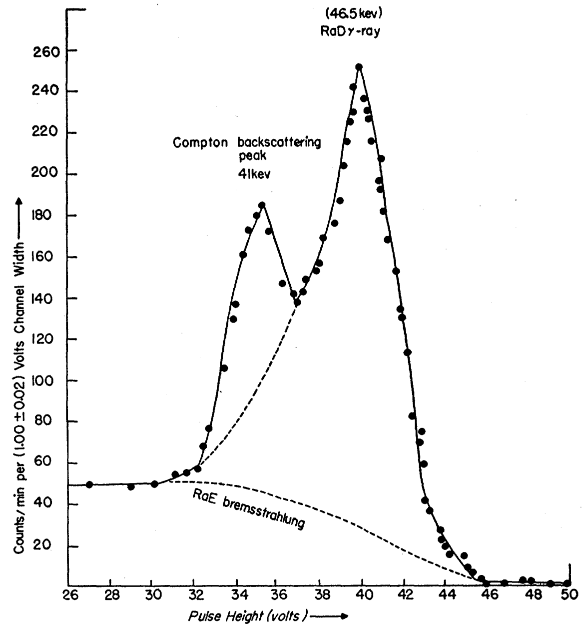

FIG. 3. A representative spectrum of gamma-rays from pulse-height analysis from proportional counting of the RaDEF equilibrium sources through various Plexiglas absorbers thick enough to stop RaE beta-particles. With freshly-separated carrier-free RaD, the RaE beta-bremsstrahlung continuum was absent. The dotted lines are the estimated corrections for Compton backscattering and RaE bremsstrahlung. The scale is much expanded over that used in Fig. 2.

negligible,[1] but the Compton backscattering remains to be estimated; depending on geometry and collimation, this correction amounts from 10 to 20% of the total area, as discussed in a previous paper,[18] and from it arises the major source of error in the measurement of F/R. The value is computed from

$$F/R=[(A_L/A_R)][(f_a)_R/(f_a)_L]\times[(E_R/E_L)][(f_w)_R/(f_w)_L], \quad (2)$$

where (A_L/A_R) is the ratio of the area under the L-peak to the corrected area under the gamma peak; $(f_a)_R$ is the transmission of 46.5-kev quanta through Plexiglas or aluminum absorber, the value of which for Plexiglas was determined to be essentially unity up to a thickness of 12.9 mm by running an absorption curve in the same manner as for Fig. 1; $E_R=0.027$, the counting efficiency of 46.5-kev quanta in 2.1 atmos argon, assuming no wall-effect, computed from absorption coefficients from Allen[13]; $(f_w)_R=0.997\pm0.003$, the transmission of 46.5-kev quanta through the 164-mg/cm² beryllium window, as discussed previously; $(f_a)_L$ is the transmission of L x-rays through the Plexiglas or aluminum absorber, the value of which for various Plexiglas absorbers was obtained from Fig. 1 (see Table V); $E_L=0.670\pm0.005$, the mean counting efficiency of 10.8–13.0 kev x-rays in 2.1 atmos argon, assuming no wall-effect, computed

TABLE V. Results of determinations of F/R using proportional counter.

Source (carrier-free)	Collimator (diameter)	Absorber (thickness)	$(f_a)_L/(f_a)_R$	F/R
Equilib. RaDEF	2.25 cm	12.9 mm Plexiglas	0.145	5.1±0.4
Equilib. RaDEF	2.25	9.2 mm Plexiglas	0.256	5.2±0.7
Equilib. RaDEF	3.2	9.2 mm Plexiglas	0.256	4.5±0.5
Freshly-purif. RaD	3.2	9.2 mm Plexiglas	0.256	5.1±0.4
Equilib. RaDEF	2.25	4.68 mm Plexiglas	0.500	5.2±0.7
Equilib. RaDEF	2.25	4.68 mm Plexiglas	0.500	5.4±0.7
Equilib. RaDEF	1.30	4.68 mm Plexiglas	0.500	5.7±1.0(?)
Equilib. RaDEF	2.25	337 mg/cm² aluminum	0.016_8	4.8±0.9
			Mean	5.1±0.7

[15] Frilley, Gokhale, and Valadares, Compt. rend. 232, 157 (1951).
[16] G. T. Ewan, thesis, 1952 (unpublished), quoted in reference 2.
[17] A. J. Cochran, quoted in reference 2.
[18] R. W. Fink and B. L. Robinson, Rev. Sci. Instr. 27, 712 (1956).

from absorption coefficients from Allen[13]; and $(f_w)_L = 0.916 \pm 0.005$, the mean transmission of L x-rays through 164 mg/cm^2 beryllium window.

To justify the assumption of no wall-effect in the computation of the counting efficiencies, the counter was filled to 2.1 atmos; under such pressure, the wall-effect is negligible as shown experimentally by West, Dawson, and Mandleberg,[19] and, especially, by Bisi and Zappa,[20] who studied counting rate per unit pressure *vs* pressure for K x-rays of Ag (22.1 kev) and for the RaD gamma-ray. Calculations of counting efficiency based on an "average" track length (9 cm) within the sensitive volume from a collimated, "low-geometry" source agreed well with more exact results from a double-integration (a truncated cone intersecting a cylinder at right angles to their respective axes) as discussed by Bisi and Zappa.[20] The results of F/R determinations are given in Table V, from which the mean value is

$$F/R = 5.1 \pm 0.7.$$

This value of F/R from proportional counter spectrometry where the measurement is independent of geometry is considered to be better than one computed by taking the ratio of F to the absolute value of R (Table III) from scintillation spectrometry because of the larger uncertainty in the latter measurements arising from corrections for geometry, transmission, and iodine K x-ray escape. F/R values obtained by the two methods, however, agree within the experimental error.

III. DISCUSSION

Mean L-fluorescence Yield

Stanners and Ross[21] have found by the nuclear emulsion method that the ground-state beta-group occurs to the extent of $(15 \pm 5)\%$ in RaD decay. From the present work the gamma-ray intensity is 0.045 ± 0.004/disintegration, so that the number of disintegrations which are converted in passing through the 46.5-kev level is $(80.5 \pm 0.5)\%$. Since the ratio of L- to M- and higher-shell conversion lies near a mean value of 2.94 (from the work of Wu *et al.*[7] who found a value of 3.05 and of Cranberg[22] who reported a value of 2.84), the number of L-shell conversions/disintegration (I) is 0.60. The value determined by Wu *et al.*[7] is 0.64. Accepting a mean value of 0.62, the mean L-fluorescence yield of bismuth in RaD decay is

$$\bar{\omega}_L = F/I = 0.38 \pm 0.02,$$

where the error quoted reflects the uncertainty only in the value of F. This agrees rather well with the experimental determination by Küstner and Arends[23] who found a value of 0.367 for the L_{III} subshell yield of bismuth (ω_{LIII}) and a value of 0.255 for the L_{II} subshell (ω_{LII}).

Total L-shell Conversion Coefficient

When the mean L-fluorescence yield is combined with the ratio F/R (Table V) according to Eq. (1), one obtains an experimental value of the total L-shell conversion coefficient which thus is

$$\beta_1^L = I/R = 13.3 \pm 2.0,$$

in which most of the error quoted arises from uncertainty in the value of F/R. The value of the total L-conversion coefficient interpolated for a 46.5 kev, pure $M1$ transition at $Z = 83$ from the tables of Rose[24] is 17.85, based on the approximation that the nucleus may be treated as a point-charge. Better agreement with our experimental value is obtained with the results of Sliv and Listengarten[25] who included a correction of about 30% for the finite charge distribution of the nucleus. The theoretical total L-conversion coefficient is about 12.7 from their calculations. This reduction in K and L conversion coefficients at high Z, especially for $M1$ transitions, due to the finite size effect also has been verified experimentally for K and L conversion[26] and for the 40-kev, pure $M1$ transition in Tl^{208} following alpha-decay of ThC (Bi^{212}), where the total L-conversion coefficient is 15.7 from work of Weale,[27] again representing a reduction of about 25% from the point-charge approximation.†

IV. ACKNOWLEDGMENTS

The author is indebted to Dr. R. R. Edwards for suggesting a study of RaD. Thanks are due also to Mr. Roy R. Warren who carried out most of the counting experiments involved.

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[27] J. W. Weale, Proc. Phys. Soc. (London) **A68**, 35 (1955).
† *Note added in proof.*—The source used by Hughes (reference 8) for his measurement of $F/R = 6.7 \pm 0.5$ (Table II) consisted of 80 millicuries of RaD (anodically deposited as peroxide on a platinum foil 0.010 in. thick and covered with 6.3 mg/cm^2 of aluminum foil). The superficial density of this source was 4 mg/cm^2 (private communication from J. Hughes, January, 1957). In such a source containing lead carrier in the presence of an extremely high level of activity, it is clear that appreciable fluorescent x-ray excitation occurs which leads to an excessively high value of F/R.

V. APPENDIX. SUMMARY OF DATA ON MEAN L-FLUORESCENCE YIELDS

Since the last summary of mean L-fluorescence yields,[28] many additional measurements have been reported. These results are plotted in Fig. 4, together with the values obtained by Lay[29] (solid points) for x-ray excitation. The break at $Z \sim 73$ is interpreted to mean that above this point Coster-Krönig transitions of the type $L_I - L_{III}M_{IV,V}$ contribute,[30] thus shifting L_I vacancies to the L_{III} shell for which the partial fluorescence yield is greater. As pointed out by Burde and Cohen,[31] Coster-Krönig transitions of the type $L_I - L_{II}N$ and $L_{II} - L_{III}N$ occur to only a very small extent since the transition probability depends strongly on the momentum of the emitted electron. Below $Z \sim 73$, however, the $L_I - L_{III}M_{IV,V}$ and $L_{II} - L_{III}M_{IV,V}$ transitions are forbidden energetically as are the $L_I - L_{II}N_{I-IV}$ transitions, so that L_I vacancies once formed essentially are frozen in place and decay without further complication; thus, below $Z \sim 73$, mean L-fluorescence yields resulting from nuclear excitation, in which L_I vacancies predominate, lie lower than yields resulting from x-ray excitation, in which the three L subshells share more equally the vacancies produced.

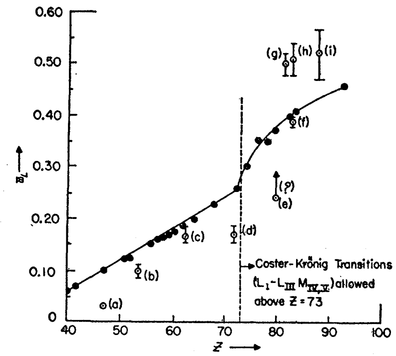

FIG. 4. Mean L-fluorescence yields *vs* Z. The solid points are the results of Lay (reference 29) from x-ray excitation. Open points all are derived from nuclear excitation and represent the following work: (a) Ag^{109}, from E.C. in Cd^{109}, Bertolini, Bisi, Lazzarini, and Zappa, Nuovo cimento **9**, 539 (1954). (b) Xe^{131}, from E.C. in Cs^{131}, R. W. Fink and B. L. Robinson, Phys. Rev. **98**, 1293 (1955). (c) Eu^{153}, from decay of Gd^{153}, Bisi, Germagnoli, and Zappa, Nuclear Phys. **1**, 593 (1956); Nuovo cimento **4**, 764 (1956). (d) Hf^{179}, from E.C. in Ta^{179}, Bisi, Zappa, and Zimmer, Nuovo cimento **4**, 307 (1956). (e) Hg^{204}, from E.C. in Tl^{204}, H. Jaffe, University of California Radiation Laboratory Report UCRL-2537, 1954 (unpublished). (f) Bi^{210}, from decay of Pb^{210} (RaD), present result. (g) Tl^{208}, from alpha decay of Bi^{212}(ThC), J. Burde and S. G. Cohen, Phys. Rev. **104**, 1085 (1956). (h) Bi^{212}, from decay of Pb^{212}(ThB), J. Burde and S. G. Cohen, Phys. Rev. **104**, 1085 (1956). (i) Ra^{220}, from alpha decay of Th^{230}(Io), Booth, Madansky, and Rasetti, Phys. Rev. **102**, 800 (1956).

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