DECAY OF ^{110m}Ag

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The decay of ^{110m}Ag has been studied with a DuMond type iron-free ring-focusing beta ray spectrometer. Energies and intensities of internal conversion electrons have been measured. On the basis of these data, the K conversion coefficients of the following transitions have been obtained: 657.61, 677.5, 687.2, 706.1, 764.0, 817.8, 884.4, 937.8, 1385.2, 1475.2 and 1505.3 keV. A particular search was made for new 18 transitions reported recently by Schintlmeister *et al.*, but none was observed.

1. INTRODUCTION

The decay of ^{110m}Ag has been studied by numerous investigators.[1-15] The original decay scheme proposed by Siegbahn[1] has been modified in the subsequent investigations, in particular by Katoh *et al.*.[10] Internal conversion electrons have been well investigated[11,12] with high precision beta ray spectrometers by several investigators and the energies of the levels in ^{110}Cd populated by the decay of ^{110m}Ag have been considered to be well established.[12] Recently Schintlmeister *et al.*,[13] however, reported the existence of new 18 gamma rays with considerable intensities in the internal conversion study with an intermediate focusing beta ray spectrometer. Their result is quite different from the previous one. It must be reinvestigated whether these gamma rays actually exist or not.

The relative gamma ray intensities were studied by Antoneva *et al.*[14] and Voinova *et al.*[15], but the studies of gamma rays seem to be insufficient in comparison with the internal conversion data. Thus the internal conversion coefficients deduced from the relative electron and gamma-ray intensities are rather inaccurate, so the multipolarities of the transitions and the spins and parities of the levels are not determined uniquely. Recently, Newbolt *et al.*[12] have measured the internal conversion coefficients by the internal-external conversion method and determined the multipolarities of the 657.6, 884.4 and 937.4 keV transitions. The internal-external conversion method is very useful, since the high resolution measurement, say 0.2–0.4%, is required to resolve the complex gamma rays involved in the decay of ^{110m}Ag. In the present work, energies and intensities of internal and external conversion electrons have been studied with a DuMond type iron-free ring-focusing beta ray spectrometer. On the basis of these data the internal conversion coefficients of 11 transitions have been determined. A particular care was taken to find new gamma rays reported by Schintlmeister *et al.*

2. EXPERIMENTAL PROCEDURES

The activity ^{110m}Ag was obtained from Oak Ridge National Laboratory. For most of the internal conversion electron studies, the sources were prepared by the evaporation of nitric acid solution of $AgNO_3$ on aluminum coated Mylar film of 0.8 mg/cm^2 in thickness. Some sources were prepared by electroplating the activity onto 5 μ nickel backing.

The DuMond type iron-free ring-focusing beta-ray spectrometer[16] (instrumental const. D=28.28 cm, emission angle $\alpha=45°$) was used to study the internal conversion spectra. With a source of 1.5 mm in diameter the resolution was $\sim$0.4%. For the weak conversion lines the source of 4.5 mm in diameter was used and the resolution was $\sim$1.0%. The source thickness was not estimated. The effect of the source thickness was negligible for the conversion line studied in this work. The energies of the internal conversion lines were determined relative to the energy of the K line of the 657.61±0.15 keV transition reported by Suter *et al.*.[11]

The DuMond type beta-ray spectrometer was also used to study the external conversion spectra. The method of Hultberg[17] was applied to deduce the relative gamma ray intensities from the external conversion spectra. The gamma ray intensity is proportional to

$$I_\gamma \propto \frac{A_{ex}}{f\sigma_K}$$

where A_{ex} is the intensity of the observed K shell photo-electron line, σ_K is the K shell photo-electric cross section and f is the correction factor for K

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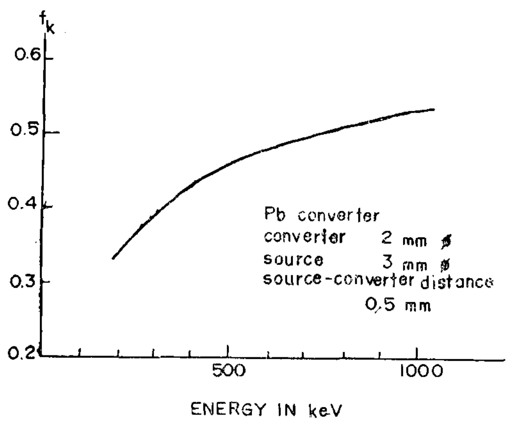

Fig. 1. Calculated f_K values plotted as a function of gamma ray energy.
Converter: Pb, Converter diameter: 2 mm ϕ, Source diameter: 3 mm ϕ, Source to converter distance: 0.5 mm.

shell photo-electric angular distribution and for finite source and converter dimensions. The f-factor was calculated for the DuMond type spectrometer. The details of the calculation are given in the following paper.[18] Fig. 1 shows the f values used in the present study. The Pb converter of 2 mm in diameter and ~3 mg/cm^2 in thickness was prepared by vacuum evaporation onto a 5 mg/cm^2 mica sheet. The converter was cemented to a 0.5 mm thick copper absorber. The source-converter distance was 0.5 mm. The source of 3 mm in diameter and about 1.5 mC in strength was used. The resolution obtained was about 0.6 %.

3. RESULTS AND DISCUSSIONS

3.1. Internal Conversion Study

All of the internal conversion lines reported in refs. 10, 11, and 12) were observed in the present work. The internal conversion electron spectrum of the 677.5 keV K, 657.6 keV L, M, and 687.2 keV K lines is shown in Fig. 2. These lines were resolved from each other by using the 657.6 keV K line shape as a standard line shape and applying the method of least squares on the very general assumption that the numbers, energies and intensities of the lines involved are unknown. Numerical computations were performed on the electronic computer at the Research Reactor Institute of Kyoto University. The detail of the method has been described elsewhere.[19] The other lines were resolved clearly at the instrumental resolution used in the present work.

Two new internal conversion lines have been observed and assigned to be the L+M line of the 446.2±0.5 keV transition and the K line of the 1558±3 keV transition. The existence of the latter transition has been reported in the Compton spectrometer study by Voinova *et al.*.[15] The K and L+M lines of the 446.2 keV transition and the K line of the 1558 keV transition are shown in Figs. 3 and 4, respectively.

Transition energies determined from the internal conversion electron study are given in Table 1. The results in the present work are in very good agree-

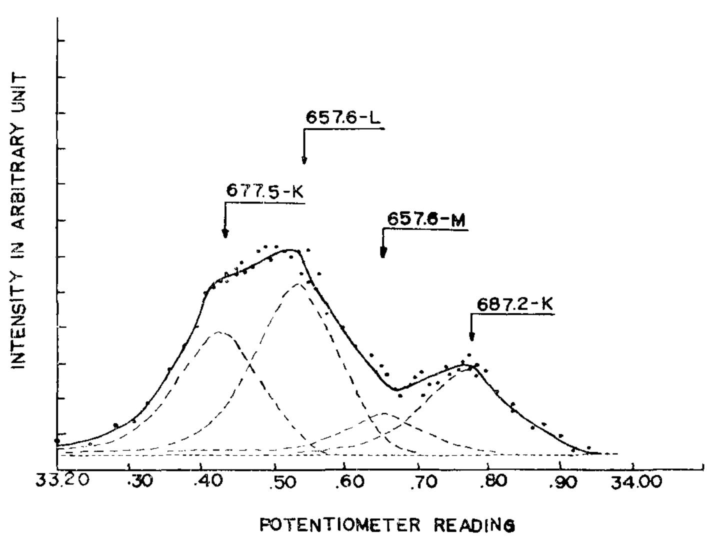

Fig. 2. Internal conversion spectrum in the 670 keV region. Dotted lines show the lines resolved by the method described in the text.

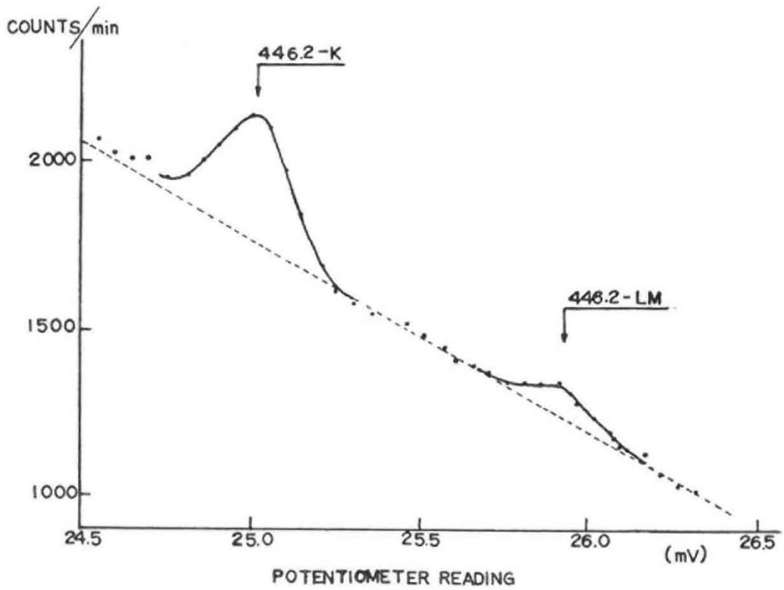

Fig. 3. The K and L+M internal conversion lines of the 446.2 keV transition.

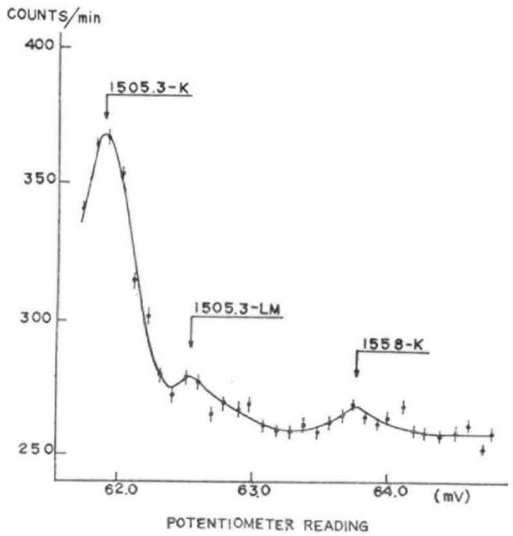

Fig. 4. The internal conversion electron spectrum of the 1505.3 keV K, L+M and 1558 keV K line.

ment with the previous data.[10-12] Relative electron intensities are given in Table II, together with the results of other investigators.[10-12] There are some discrepancies between the present results and the previous ones. In the present work a particular care was taken to evaluate the intensities as accurately as possible.[20] Each line was fitted to the standard line shape of the strong 657.61 keV K line, although most of the lines were clearly resolved from each other. This procedure largely reduced the errors in estimating the background due to the beta-continuum and the neighboring conversion lines.

As described in the introduction, Schintlmeister *et al.*[13] observed the many new conversion electron lines, some of which have considerably large intensities. The energies and intensities of these lines are shown in Table III. To check the existence of these lines, the internal conversion electron spectra in the energy ranges of 100 to 400 keV and of 1000 to 2500 keV were measured carefully with a total counting time of thirty minutes for each point. None was observed. A typical spectrum is shown in Fig. 5. The strong lines below 400 keV reported by Schintlmeister *et al.*[13] are considered not to exist. The existence of the weak lines above 1000 keV is uncertain. The upper limits of these line intensities are given in Table III.

3.2. External Conversion Study and Conversion Coefficients

The external conversin electron spectrum from 550 to 1500 keV was studied. Typical external conversion spectra in the energy range of 550 to 900 keV are shown in Figs. 6–8. The Compton background were obtained without Pb converter in some cases in which the Compton background could not be replaced by a straight line. The line areas were evaluated with the method described in section 3.1. As the K external conversion line of the 744.1 keV transition coincided with the M external conversion line of the 657.6 keV transition, the intensity of the 744.1 Pb-K line could not be estimated. Relative

Table I
Transition Energies in keV

Present work	Newbolt *et al.*[12]	Suter *et al.*[11]	Katoh *et al.*[10]
116.05±0.08		116.25±0.07	115 ±4
	433.7 ±0.4 [a]	433.88±0.20[a]	432.3 ±0.6 [a]
446.2 ±0.5	446.36±0.30	446.66±0.25	446.3 ±0.5
	613.9 ±0.3 [a]	613.55±0.3 [a]	
619.7 ±0.4	620.3 ±0.3	620.1 ±0.3	618.9 ±0.6
657.61±0.15	657.61±0.35	657.61±0.15	657.7 ±0.2
677.5 ±0.3	677.36±0.25	677.26±0.25	676 ±1
687.2 ±0.4	686.31±0.35	686.8 ±0.4	688 ±1
706.1 ±0.3	706.32±0.25	706.32±0.25	707.2 ±0.2
744.1 ±0.3	743.88±0.30	743.99±0.25	745.1 ±0.4
764.0 ±0.3	763.63±0.25	763.66±0.25	764.3 ±0.2
817.78±0.35	818.07±0.30	818.00±0.25	815.3 ±0.3
884.41±0.35	884.48±0.25	884.46±0.25	884.6 ±0.2
937.77±0.35	937.45±0.25	937.3 ±0.4	937.8 ±0.3
1385.2 ±0.7	1384.9 ±0.9		1382 ±1
1475.7 ±1.5			1476 ±4
1505.3 ±1.0			1504 ±1
1558 ±3			

a) Converted in palladium from the decay of >5*y* ^{108m}Ag.

Table II
Relative electron intensities

Transition Energies (keV)	Shell	Relative Electron Intensities			
		Present work	Newbolt *et al.*[12]	Suter *et al.*[11]	Katoh *et al.*[10]
446.2	K	9.61±0.6	3.2 ±1.0	11 ±2	6.3 ±2.5
	LM	1.94±0.6			
619.7	K	4.33±0.15	3.2 ±0.6	1.8 ±0.6	5.1 ±1.1
657.61	K	100	100	100	100
	L	12.4 ±0.3	12 ±2	13 ±4	18 ±1.9
	M	4.0 ±0.2	4.0 ±1		
677.5	K	11.3 ±0.3	11 ±2	13 ±4	9.5 ±1.1
687.2	K	6.5 ±0.2	6.0 ±1.0	5.3 ±1.0	6.9 ±0.8
706.1	K	18.1 ±0.2	16 ±2	14 ±2	14 ±2
	LM	2.42±0.25	2.4 ±0.5	3 ±1	2.6 ±0.5
744.1	K	3.6 ±0.3	4.0 ±0.5	4.5 ±0.9	4.6 ±0.3
764.0	K	16.4 ±0.3	16.5 ±0.5	17 ±2	16.2 ±0.5
	LM	2.61±0.25	2.3 ±0.5	3.5 ±1.5	2.5 ±0.3
817.8	K	5.59±0.15	4.3 ±0.4	4.5 ±0.9	4.6 ±0.3
	LM	1.0 ±0.15			0.75±0.12
884.4	K	41.0 ±0.6	37.0 ±0.8	39 ±3	38.5 ±0.8
	LM	6.2 ±0.35	5.6 ±0.5	5.1 ±0.6	6.1 ±0.5
937.8	K	16.8 ±0.4	14.9 ±0.5	17 ±2	14.7 ±0.5
	LM	2.7 ±0.3	1.9 ±0.6	1.6 ±0.8	2.3 ±0.4
1385.2	K	5.3 ±0.15			5.3 ±0.3
	LM	0.88±0.20			0.88±0.5
1475.2	K	0.90±0.15			0.7 ±0.2
1505.3	K	2.64±0.15			2.1 ±0.2
	LM	0.47±0.15			0.35±0.15
1558.0	K	0.26±0.12			

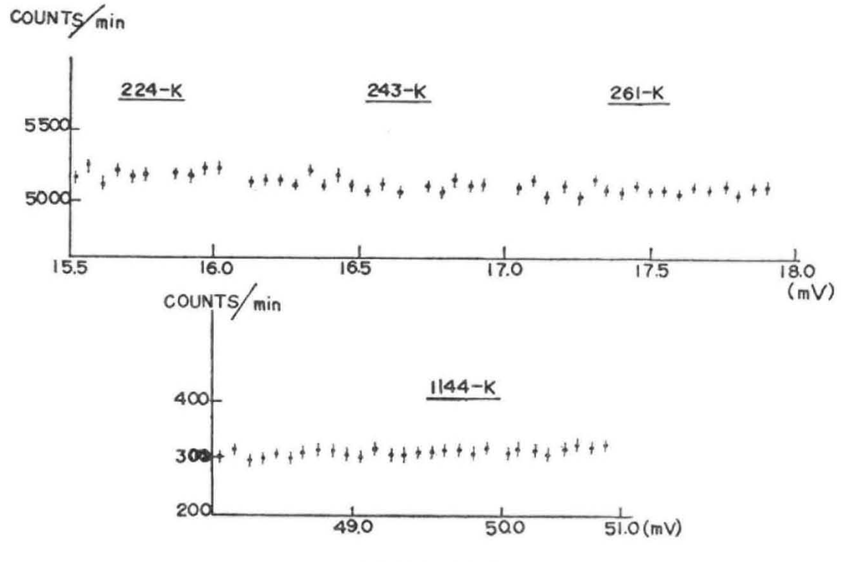

Fig. 5. The internal conversion electron spectra in the 200 keV region and in the 1100 keV region.

Table III
Upper limits of intensities of the electron lines reported by Schintlmeister *et al.*

Transition Energies	K Shell Electron Intensities	
Schintlmeister[13]	Schintlmeister[13]	Present work
121 keV	21.5	
154	37	<2.5
185	45	<2.5
206	30	<2.5
224	47	<2.6
243	35	<2.6
261	47	<2.6
330	19	<2.4
380	14.5	<2.1
(657.611)[a]	(100.0)	(100.0)
1144	0.8	<0.28
1251	0.7	<0.29
1350	1.1	<0.30
(1558)[b]	(0.4)	(0.24)
1910	0.3	<0.2
2010	0.35	<0.2
2070	0.3	<0.19
2268	0.3	<0.17
2373	0.3	
2465	0.2	

a) The intensities of other lines are relative to this line.

b) The existence of this transition was reported in ref. 15) and the K conversion line of this transition was observed in the present study.

gamma ray intensities were deduced from these spectra as described in section 2 and are shown in Table IV. The uncertainiy in $\sigma_K f$ is thought to be of the order of 5 %. The main contribution to the errors is statistical. The previous results[14,15] are also shown in the table.

The internal conversion coefficients are obtained from the relative electron and gamma ray intensities by normalizing these data with the α_K of the 657.6 keV transition. The internal conversion coefficients of the 657.6, 884.4 and 937.8 keV transitions have been directly measured with the internal-external conversion method by Newbolt *et al.*[12] and their results agree well with the corresponding theoretical E2 values.[21] This measured α_K of the 657.6 keV transition was used in the present work to deduce the conversion coefficients of the other transitions. The results are given in Table IV, together with the theoretical values by Sliv and Band.[21] The α_K's of the 884.4 and 937.8 keV transitions obtained in the present work are in good agreement with the directly measured values by Newbolt *et al.*, which are also shown in the table.

Newbolt *et al.*[12] also obtained the conversion coefficients of the other transitions by averaging the relative electron and gamma ray intensities reported by several investigators[10-12,14,15,22] and normalizing these data with the measured α_K of the 657.6 keV transition. Their results are given in Table IV. The conversion coefficients obtained in the present work are in agreement with those by Newbolt *et al.*[12] within the experimental errors.

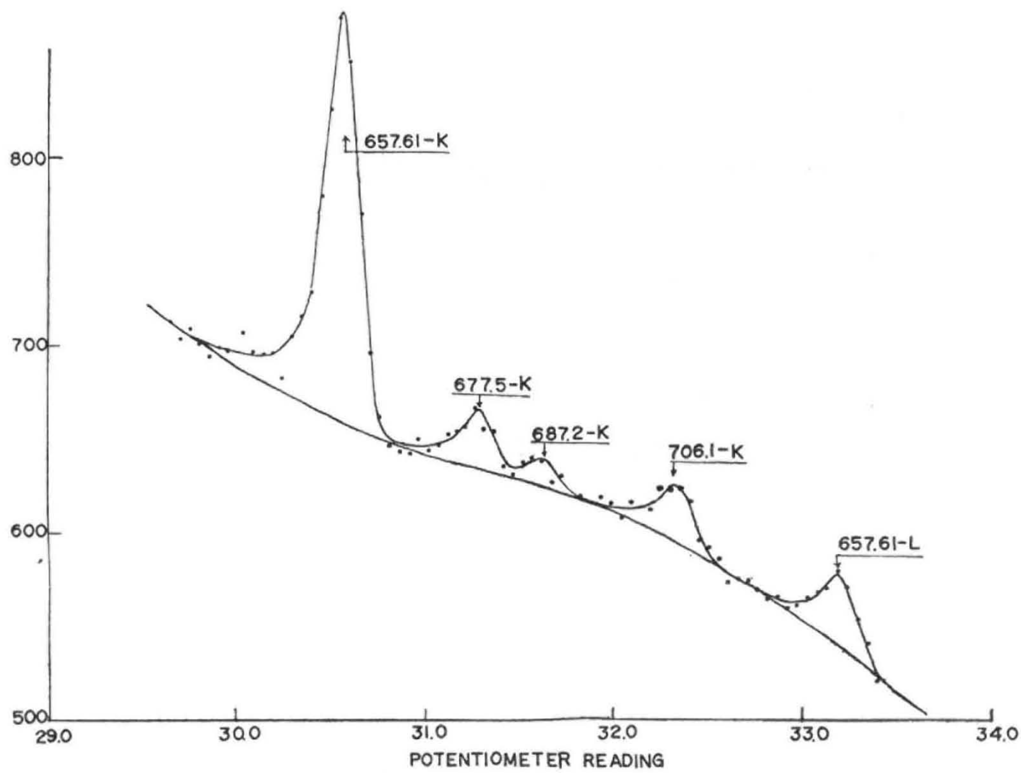

Fig. 6. External conversion electron spectrum in the energy region of 550 to 700 keV.

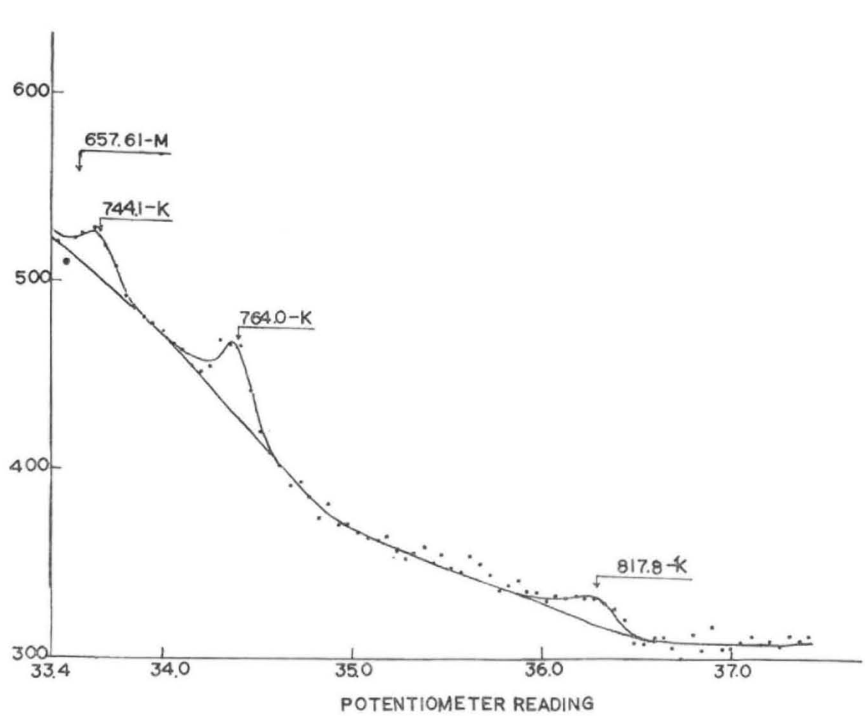

Fig. 7. External conversion electron spectrum in the energy region of 700 to 850 keV.

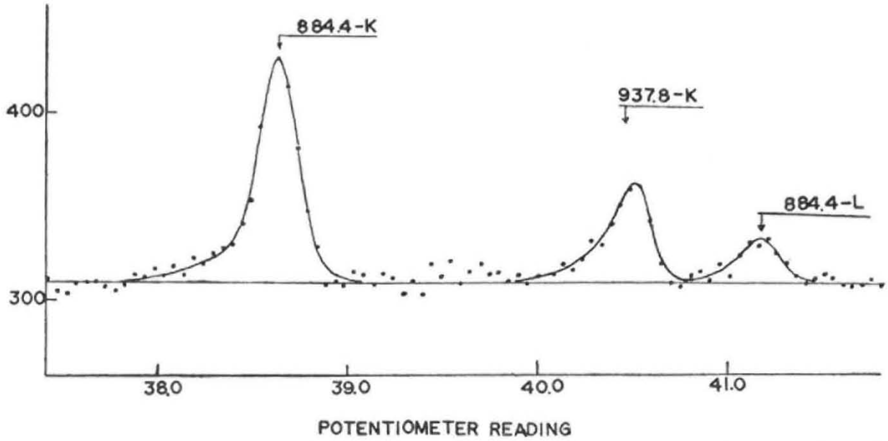

Fig. 8. External conversion electron spectrum in the energy range of 850 to 950 keV.

Table IV
Relative gamma-ray intensities and conversion coefficients

Transition energy (keV)	Gamma-ray intensities			Conversion coefficients × 10^3			
	present	Anton'eva[14] *et al.*	Voinova[15] *et al.*	Exp.	M1[21]	E2[21]	Newbolt[12] *et al.*
657.61	100	100	100	(2.64)	3.00	2.65	2.64±0.10 [a]
677.5	12.5±1.5	10 ±1		2.4 ±0.3	2.90	2.55	2.9 ±0.4 [b]
687.2	7 ±2	7 ±1		2.5 ±0.8	2.75	2.45	2.3 ±0.4 [b]
706.1	19 ±2.5	21 ±2	18±2	2.5 ±0.4	2.55	2.25	2.0 ±0.2 [b]
744.1			5±2		2.3	2.0	2.3 ±0.9 [b]
764.0	24 ±5	24 ±2	23±2	1.80±0.4	2.15	1.85	1.85±0.15 [b]
817.8	10 ±2	10 ±1	6±1	1.44±0.3	1.85	1.55	1.4 ±0.3 [b]
884.4	86 ±8	71 ±5	74±1	1.27±0.13	1.55	1.30	1.26±0.06 [a]
937.8	39 ±4	34 ±3	33±2	1.14±0.12	1.37	1.15	1.12±0.08 [a]
1385.2	25 ±5	20 ±2	24±1	0.55±0.05	0.57	0.51	0.61±0.07 [b]
1475.2	5	3.6±1.0	4±1	0.5	0.49	0.46	0.52±0.15 [b]
1505.3	15	10 ±1	13±1	0.5	0.48	0.44	0.53±0.07 [b]

a) Obtained directly with the internal-external conversion method.

b) Obtained indirectly by averaging the relative electron intensities reported in refs. 10-12, 22) and the relative gamma ray intensities in refs. 14-15) and normalizing these data with the directly obtained α_K of the 657.6 keV transition.

The experimental conversion coefficients are compared with the theoretical values[21] and it is found that all of the transitions listed in the table are M1, E2 or mixtures of both, in agreement with the previous assignments.[10),12)] It is difficult to estimate the admixtures from the conversion coefficients because of the errors, but the 817.8 and 764.0 keV transitions are likely to be E2 predominant.

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