Quadrupole Lines in the K-Series of Ruthenium

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The Ru $K\beta_4(K-N_{IV}N_V)$ and $K\beta_5(K-M_{IV}M_V)$ lines have been observed with a double crystal spectrometer. The wave-lengths are 559.74 and 566.68 X.U., respectively. $K\beta_5$ appears to be a doublet, the weaker component lying at the long wave-length side. The doublet separation of 0.15 X.U. is within the experimental error in accordance with the $M_{IV}-M_V$ difference. The width of the single components of $K\beta_5$ is smaller than the width of $K\alpha_1$, i.e., <11 volts. $K\beta_4$ is considerably broader, 28 volts. The intensity ratios are $K\beta_4 : K\alpha_1 = 1 : 160$, $K\beta_5 : K\alpha_1 = 1 : 400$. Also a very faint line $K\beta_6$ has been observed the intensity of which is 1 : 2000 of the intensity of $K\alpha_1$. The wave-length of $K\beta_6$ is 558 X.U. It cannot be explained by single electron transitions between known Ru levels.

INTRODUCTION

In recent years several investigators have reported the observation of very weak lines in the K-series of many elements.[1] Two of these new lines, $K\beta_4$ and $K\beta_5$, have been interpreted as quadrupole lines originating in the transitions $K-N_{IV}N_V$ and $K-M_{IV}M_V$. Mo $K\beta_4$ has been differently interpreted by Duane[2] and by DuMond and A. Hoyt.[3] Finding a rather broad line which they called the δ-band they regarded this radiation as being due to conductivity electrons falling into the K-level. Duane suggested an additional $K-O$ transition. The width of the δ-band has been estimated by DuMond and Hoyt to be about 16 volts. Carlsson[4] using the photographic method gives a half-width of 7 volts. No data have been published about the width of the $K\beta_5$ line. The only remark about the shape of this line was made by P. A. Ross[5] who found $K\beta_5$ in Pd wider than in Mo and Rh and unsymmetrical.

After the present investigation was finished Ingelstam and Ray[6] published the observation of Ru $K\beta_4$, $K\beta_5$, $K\beta_6$, $K\beta_7$ and η. It is the measurement of the natural width and intensities of some of these lines observed by a double crystal spectrometer that is reported in the present paper.

APPARATUS

The type of double crystal spectrometer which was used in this investigation has been described by Allison and Williams, the specific instrument by Allison.[7] A small part of the surface of the calcite crystals was selected which gave the best resolving power (checked by the measurement of the width of Ru $K\alpha_1$, smallest value 20″). The ionization chamber of the spectrometer was filled with methyl bromide. The electrometer was of the Compton type and operated at a sensitivity of 1000 mm/volt.

Because the lines to be observed are extremely faint, a very constant source of x-rays was required. A high power x-ray tube as described by Dershem[8] was provided with a ruthenium target and connected with a special high tension outfit. This outfit consisted in a high tension transformer, a kenotron and a condenser (0.1μf) in a half-wave rectification scheme. The primary power was produced by a 540 cycle 5 kva generator driven by an 8.5 hp. synchronous motor. The voltage was measured by an electrostatic

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[1] A. Leide, Dissert. Lund (1925) and Compt. Rend. **180**, 1202 (1925); A. Larsson, Phil. Mag. (7), **3**, 1136 (1927); S. Idei, Scient. Rep. Tokohu Imp. Univ. **19**, 641 (1930); H. Beuthe, Zeits. f. Physik **60**, 603 (1930); I. W. M. DuMond and A. Hoyt, Phys. Rev. **38**, 839 (1931); Y. Cauchois, Compt. Rend. **194**, 1479 (1932); P. A. Ross, Phys. Rev. **39**, 536 (1932); **39**, 798 (1932). W. Duane, Proc. Nat. Acad. Sci. **18**, 63 (1932); P. A. Ross and P. Kirkpatrick, Phys. Rev. **43**, 1036 (1933); E. Carlsson, Zeits. f. Physik **80**, 604 (1933); **84**, 119 (1933); E. Carlsson Ingelstam, Zeits. f. Physik **87**, 283 (1934); E. C'son Ingelstam and B. B. Ray, Zeits. f. Physik **88**, 218 (1934).

[2] W. Duane, Proc. Nat. Acad. Sci. **18**, 63 (1932).

[3] I. W. M. DuMond and A. Hoyt, Phys. Rev. **38**, 839 (1931).

[4] E. Carlsson, Zeits. f. Physik **80**, 604 (1933).

[5] P. A. Ross, Phys. Rev. **39**, 536 (1932).

[6] E. C'son Ingelstam and B. B. Ray, Zeits. f. Physik **88**, 218 (1934).

[7] Allison and Williams, J. O. S. A. and R. S. I. **18**, 473 (1929); S. K. Allison, Phys. Rev. **41**, 1 (1932).

[8] E. Dershem, Phys. Rev. (1934). In print.

high tension voltmeter. The filament current was smoothed by a stabilizer. By these means both current and high tension could be kept constant within a small fraction of a percent. The final readings were taken at 42.5 kv and 10 m.a.

Results

Fig. 1 represents a rocking curve which shows Ru $K\beta_2$ with $K\beta_4$ at its short wave-length side. The solid points are measurements, the dotted

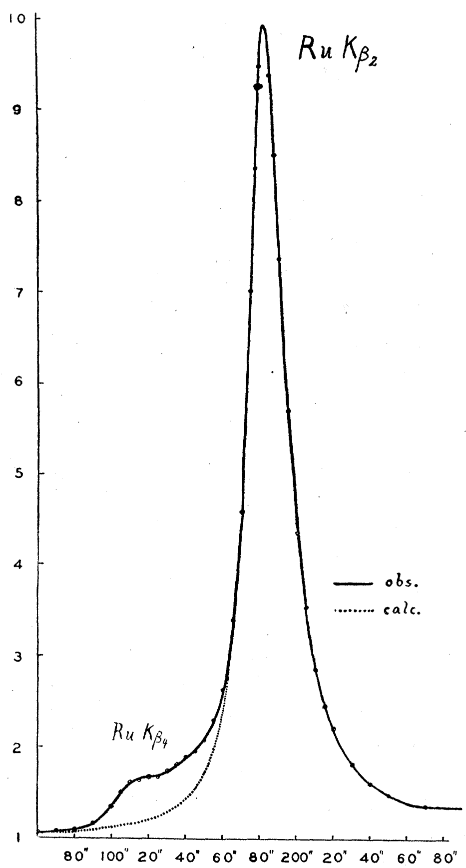

Fig. 1. Ru $K\beta_4$ and $K\beta_2$.

curve was computed by A. Hoyt's[9] equation $y=a/[1+(x/w)^2]$, where y is the ordinate corresponding to a distance x along the abscissa from the center of the line; a is the peak ordinate, w the half-width at half-maximum. This equation fits very well the observed shape of x-ray lines in this wave-length region.

[9] A. Hoyt, Phys. Rev. **40**, 477 (1932).

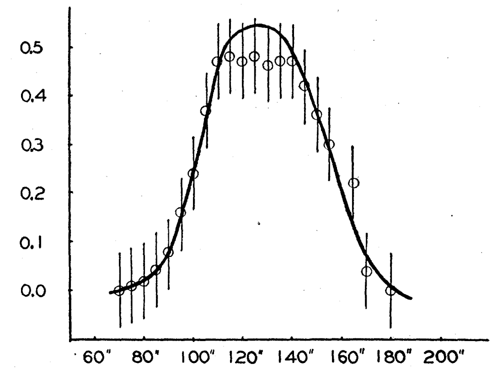

Fig. 2. Ru $K\beta_4$. The vertical lines represent the limits of error.

Plotting the difference between the two curves against Bragg's angle one obtains $K\beta_4$ isolated, Fig. 2. Five rocking curves of this line gave full widths at half-maximum of 56, 51, 36, 56, 47 seconds with an average value of 49.2 seconds or 0.71 X.U. or 28±8 volts. This is almost twice the width which has been found for Mo $K\beta_4$ by DuMond and Hoyt.[3]

The wave-length of $K\beta_4$ was measured in reference to $K\beta_1$ and $K\beta_2$. The values are given in Table I.

Table I. *Wave-lengths and ν/R values of ruthenium K lines.*

	λ_W	$\lambda_{\text{Ing. and Ray}}$	ν/R_W	$\nu/R_{\text{I. and R.}}$	$\nu/R_{\text{calc.}}$
$K\beta_4$	559.74 X.U.	559.53 X.U.	1628.0	1628.63	1628.9
$K\beta_5$	566.68	566.55	1608.04	1608.45	1608.45
$K\beta_5$	566.83	—	1607.73	—	1608.14
$K\beta_6$	558	558			

The intensity of Ru $K\beta_4$ (area of curves) is 1/9 of the intensity of $K\beta_2$. From Williams[10] measurements of the relative intensities of the Ru K-lines one finds the ratio $K\beta_4 : K\alpha_1=1/160$.

Fig. 3 represents the rocking curves of $K\beta_5$. This line appears not only to be unsymmetrical but also to consist of two components, the weaker one lying at the long wave-length side. The separation of the components amounts to about 10 seconds or 0.15 X.U. whereas the term difference $M_{IV}-M_V$ leads to 0.12 X.U. The resolving power being 9300 the agreement is as good as one can expect. The wave-lengths of the lines are given in Table I. The relative in-

[10] J. H. Williams, Phys. Rev. **44**, 146 (1933).

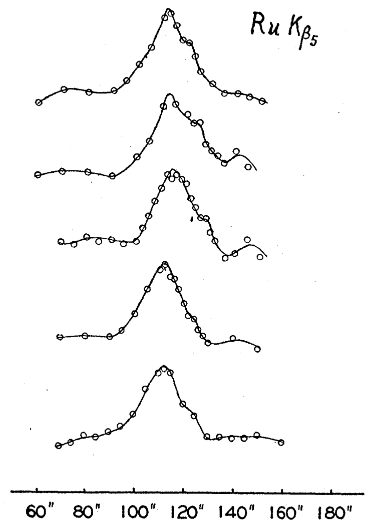

FIG. 3. Ru $K\beta_5$.

tensities of the components can be calculated from the statistical weights of M_V and M_{IV}. The j-values being 5/2 and 3/2, respectively, the intensity ratio is expected to be 3/2, which is consistent with the observation. The intensity of both lines together is 1/400 of $K\alpha_1$'s intensity. Supposing the relative intensities are 3 : 2 one gets for the single lines the ratios 1/670 and 1/1000 of $K\alpha_1$.

The width of both $K\beta_5$ components together is 19 seconds or 0.28 X.U. or 11 ($\pm$1.4) volts. The widths of $K\beta_2$ and $K\alpha_1$ are 24 seconds, 0.35 X.U., 14 volts and 20.5 seconds, 0.30 X.U., 11 volts. Consequently the single components of $K\beta_5$ must be narrower than $K\alpha_1$ i.e., 11 volts. They are the sharpest lines found so far in the ruthenium K-series. It might be mentioned that one gets very nearly the observed curve of $K\beta_5$ if one assumes the intensity as being 3/2, the wave-length difference 0.12 X.U. and the width 14 seconds or 8 volts for each component.

A very faint line was found about midway between $K\beta_5$ and $K\beta_1$ at 558 X.U. This line, $K\beta_6$, has also been found by Ingelstam and Ray.[11] Its intensity amounts to 1/5–1/4 of the $K\beta_5$ doublet or 1/2000 of $K\alpha_1$.

Discussion

The interpretation of $K\beta_4$ and $K\beta_5$ as being quadrupole transitions $K-N_{IV}N_V$ and $K-M_{IV}M_V$, respectively, is very well proved by the agreement between the observed and the calculated frequencies. Furthermore the doublet structure which has been found in the case of $K\beta_5$ corresponds quantitatively to the level diagram. The small width of the $K\beta_5$ lines can be explained classically by the small damping of quadrupole radiation. In the quantum theory it means that the lifetime of the state is a long one.

Now the question rises why $K\beta_4$ is so broad. Relative measurements of the width of lines in the L-series of Mo, Pd, Ag by Jönsson[12] have shown that $L\beta_2$ ($L_{III}-N_V$) is much broader than $L\alpha_1$ ($L_{III}-M_V$). Thus the large width is a general property of lines with the N_V level as final state in these elements. This might be due to the fact that in the elements Y (39) to Rh (45) the electron population of the $N_{IV,\,V}$ level is incomplete. Also an influence of the potential field of the crystal might be exerted upon the outer x-ray levels of these elements (de Kronig[13]).

No single electron transition can account for $K\beta_6$.

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[11] E. C'son Ingelstam and B. B. Ray, Zeits. f. Physik **88**, 218 (1934).
[12] A. Jönsson, Zeits. f. Physik **46**, 383 (1928).
[13] L. de Kronig, Zeits. f. Physik **70**, 317 (1931).