ENERGY OF THE CHARACTERISTIC X-RAY EMISSION FROM MOLYBDENUM AND PALLADIUM AS A FUNCTION OF APPLIED VOLTAGE.

By Benjamin Allen Wooten.

Introduction.

SINCE the introduction of the X-ray spectrometer by W. H. and W. L. Bragg as an instrument for studying the various properties of X-radiation, much work has been done. Most of this work concerns itself with the general radiation and there is relatively little published matter on the intensity of the characteristic rays. In a recently published article[1] D. L. Webster finds that the rays of the K series of rhodium are produced only at voltages above that required by the Planck quantum hypothesis to excite general radiation of a frequency slightly greater than that of the γ line. He finds that above that potential all K lines increase in the same ratio for a given increase in potential. The rates of increase of intensity are continuously accelerated.

The following work was undertaken with a view of studying the relation between the energy of the lines of the K series of molybdenum and palladium and the voltage producing them. The spectrometer that was used was similar in general to the one used by Dr. Clayton T. Ulrey[2] in his work on the general radiation. Voltages were measured by means of an electrostatic voltmeter and energy was supplied for the X-ray tubes by a Kenotron rectifying set. During the progress of the work points concerning the probability of new lines, absorption coefficients, etc., presented themselves. They were dealt with and will be discussed.

Description of Apparatus.

Current at 125 volts and 500 cycles was taken from a motor generator set and was stepped up by a three-kilowatt oil-immersed transformer. The high voltage alternating current from the transformer was rectified by means of two General Electric Kenotrons and an oil-immersed glass-plate condenser. The energy supplied to the X-ray tube was taken from this condenser. Under normal conditions the voltage generated by the

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[1] D. L. Webster, Phys. Rev., June, 1916, pp. 599–613.

[2] C. T. Ulrey, Phys. Rev., May, 1918.

set was constant to one and one half per cent. The voltage was measured by an electrostatic voltmeter that was built in the laboratory. It consisted of a pair of fixed spheres and a pair of movable ones hung on a steel strip suspension and pivoted at the bottom on a needle. The four spheres were charged to the same potential, and the force of repulsion between the fixed and movable ones caused the instrument to show a deflection.

The voltmeter was calibrated by means of a standard spark gap. This gap consisted of 12.5 cm. balls. The relation between sparking distance and voltage was obtained from published tables. The calibration curve of the voltmeter was very regular, almost approaching a straight line at high voltages. The voltmeter kept its adjustment perfectly.

Currents to the X-ray tube were measured on a Weston direct current milliammeter in all the work except that on absorption. In that part of the work the currents were read on a Leeds and Northrup portable galvanometer properly shunted. An accident to the milliammeter made this change necessary.

The X-ray tube that was used in the work on molybdenum was one that was kindly supplied by Dr. W. D. Coolidge, of the General Electric Company. The Palladium tube was built up in the laboratory. The cathode was of the Coolidge type and it was also furnished by Dr. Coolidge. The anode consisted of a cylinder of iron with a small piece of palladium set in it. The target face was inclined at an angle of 26 degrees with the plane perpendicular to the elements of the cylinder. The tube was evacuated by means of a diffusion pump of the Langmuir type, the mercury trap of which was cooled with a mixture of carbon dioxide snow and ether. This pump was in series with a Gaede rotary pump and a piston pump. The tube was baked at 300° Centigrade while the preliminary evacuation was in progress and the target was heated to dull redness from time to time by discharges at 25 kilo-volts. It was found necessary to keep the pump in operation whenever observations were being made.

The spectrometer was peculiar only in the fact that the ionization chamber was very long. Its length was 128 cm., and complete absorption through a long range of wave-lengths was possible with its use. This chamber contained the saturated vapor of methyl iodide. Methyl iodide was used because it does not show abnormal absorption at any point throughout the range of wave-lengths investigated.[1] The chamber and electrometer were freed of water vapor by the use of phosphorous anhydride. The gold-leaf electrometer was attached directly to the end

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[1] "X-rays," G. W. C. Kaye, p. 147.

of the ionization chamber, and the image of the leaf was projected on a ground glass screen with a scale marked on it. This screen was securely fastened to the ionization chamber. The leaf was charged negatively to 400 volts by means of a small dynamotor. The X-ray tube was surrounded by a heavy lead screen and a beam was taken off at about 26 degrees from the face of the target, this beam coming as nearly as possible from the center of the focal spot. After passing through an aperture in the screen this beam was passed through an adjustable slit, the jaws of which were of lead, and then reflected by the crystal. All circuits to the tubes, voltmeter, etc., carrying high potential current returned through ground. The Coolidge cathodes were heated by current from a small storage battery.

The crystal used was of Montana calcite and was kindly lent to us by Professor A. J. Moses, of the Department of Mineralogy. Photographs of the back slit taken with the reflected beam showed remarkably clear and perfect lines, and it was not possible to detect any irregularities in them.

The natural leak of the electrometer when properly connected to the ionization chamber was such as to cause the leaf to move across the interval of the scale that was used in taking readings in about 625 seconds. This of course varied, but it was usually more than 600 seconds. The readings of X-ray intensity were taken in the usual way by allowing the reflected beam to pass into the chamber through an adjustable slit, and noting with a stop watch the time taken for the leaf to pass across a fixed part of the scale. The same scale interval was used in all the readings taken. The time taken for a reading varied from less than one second to 550 seconds. The projected image of the leaf on the ground glass screen was clear and sharp and readings could be repeated with an accuracy of one per cent.

Results.

The apparatus was adjusted and lined up so that a beam of X-rays from the back slit would pass over the center of the spectrometer circle. The position of the ionization chamber, when this beam was entering its slit was read on the circle and taken as its position for direct rays.

The crystal was then put in place and adjusted so that its reflecting face was as nearly as possible parallel to the beam of direct rays and over the axis of the spectrometer. The crystal was moved in steps of θ and the ionization chamber in steps of $2\,\theta$ until strong reflection was observed. The crystal was then held stationary while the chamber was moved in small steps across the reflected beam. From the readings of intensity obtained for each step and the position of the chamber at each step a curve showing a sharp peak at the position of the chamber for maximum intensity was plotted. The position of the chamber corresponding to this peak was taken as its position when the reflected beam was passing correctly through its slit.

In obtaining the values of intensity from the readings of the rate of fall of the leaf, this rate was first corrected for natural leak and then reduced to what it would have been for a current of one milli-ampere in the tube.

As the nature of the work undertaken was not such as to demand extreme accuracy in wave-length measurements, the angular readings were not corrected for depth of penetration of the beam into the crystal. The natural leak was always taken when the apparatus was in operation with the chamber well out of line. The walls of the ionization chamber were thick enough to shield out all the secondary radiation at the highest voltages that were used in this work, and no correction for it was necessary.

Voltage Intensity Curves.

After properly lining up the apparatus data was taken on intensity for different wave-lengths at constant voltages up to and including 50 KV. The readings were taken at intervals of three minutes of arc and the intensities were corrected for natural leak and reduced to values for unit current. Curves were taken for different voltages and their general shapes noted for both molybdenum and palladium. Fig. 1 is such a curve taken for palladium and it is shown as being typical of the ones obtained. These curves were taken in order to locate the more prominent lines in the *K* series and to show the general nature of the spectra of the metals.

In order to study the intensity of the characteristic radiation it was necessary to subtract the intensity of the general radiation of the same wave-length as a given line from the intensity of the line as measured by the spectrometer. With a number of the constant voltage, intensity and wave-length curves at hand, a point in the general radiation on each side of a line (α or β) was taken. These points were chosen so that a straight line through them would pass through the line at the same place that a continuation of the curve of general radiation would cut it. It was found necessary to take a great many curves in order to choose these points correctly.

Having chosen these points for the α and β line of each of the metals, data was taken in the following manner: The spectrometer was set for the wave-length of one of the chosen points, care being taken to have the setting correct. In order to make certain of this, the crystal was set on the proper reading as determined from the wave-length intensity curves and the ionization chamber moved past the reflected beam in steps as described above. The results of reflected intensity were plotted against angular displacement of the chamber and the chamber was set at the reading corresponding to the peak of this intensity curve. In all settings made in this part of the work this procedure was gone through. The voltage on the tube was increased in steps to 50 KV., and with each change of potential the current through the tube was adjusted so as to keep the energy supplied to the tube constant. Determinations were made of intensity of reflection for each value of voltage and all intensities were reduced to unit current conditions. The spectrometer was then set for the wave-length of the other point and similar readings taken for it, giving the same values to potential and current that were used before, for each step. Then the spectrometer was set for the line under consideration and values for its intensity for the voltages and currents that

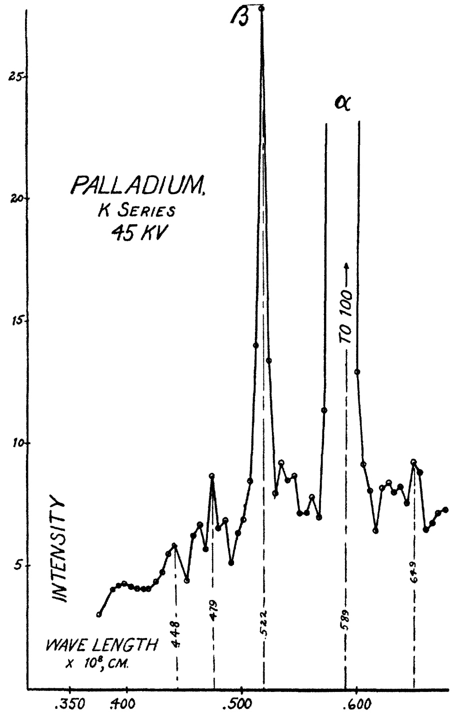

Fig. 1.

were used in the determinations on the two wave-lengths in the general radiation were obtained. This data was determined for each line that was studied.

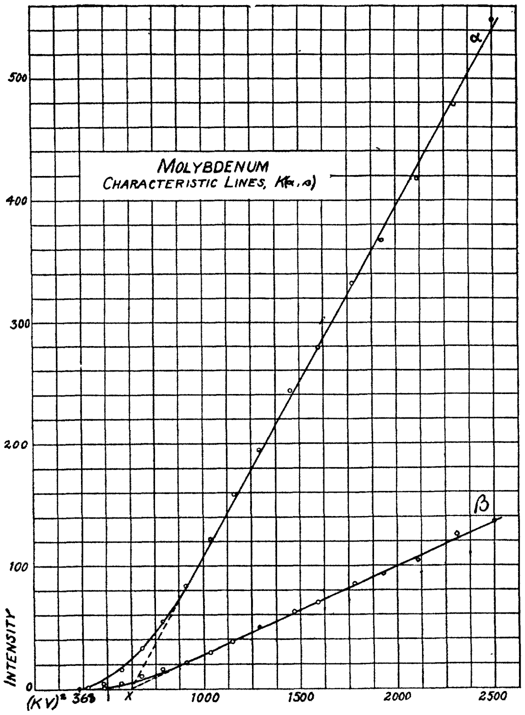

Fig. 2.

The three intensities for any potential, determined in this way give three points which determine a triangle with its acute angle very small. The distance between the vertex of this acute angle and the base line, as measured along the bisector of the angle, gives the intensity of the radiation of the line corrected for the general radiation of the same wave-length. The shape of the triangle thus formed is such as to make the length of this bisector sensibly equal to the length of either one of its sides except for low voltages.

It was found that the α and β lines for each metal appeared together at a certain minimum voltage. In the case of molybdenum this voltage was found to be 19.2 KV. and for palladium it was 24 KV. Below these potentials the wave-length curves were smooth and they intersected the wave-length axis at points corresponding to longer wave-lengths than the wave-length of the β line. It was shown by Duane and Hunt[1] that

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[1] Duane and Hunt, American Physical Society Proc., April, 1915, PHYS. REV., August, 1915.

this point of intersection of the curve with the wave-length axis represented the minimum wave-length that the potential at which the curve was taken could give by the quantum relation. This was found to be true for these curves.

Curves were plotted between the kilo-volts squared to the tube and the intensity obtained as above of the lines for each metal. These curves are shown in Figs. 2 and 3 for molybdenum and palladium respectively. It will be noticed that the two sets of curves, each set consisting of a curve for the α and one for the β line of a metal, are of the same general shape and character. In each set the α and β curves rise from a common point on the voltage squared axis corresponding to the square of the lowest potential that will excite the line or the series, and quickly become straight lines. The intensity of the radiation in the α and β lines for the two metals thus appears to vary as the square of the voltage applied for voltages not too near the critical voltage; and the ratio of the intensity of the α to the intensity of the β line in each case quickly becomes constant for voltage variations.

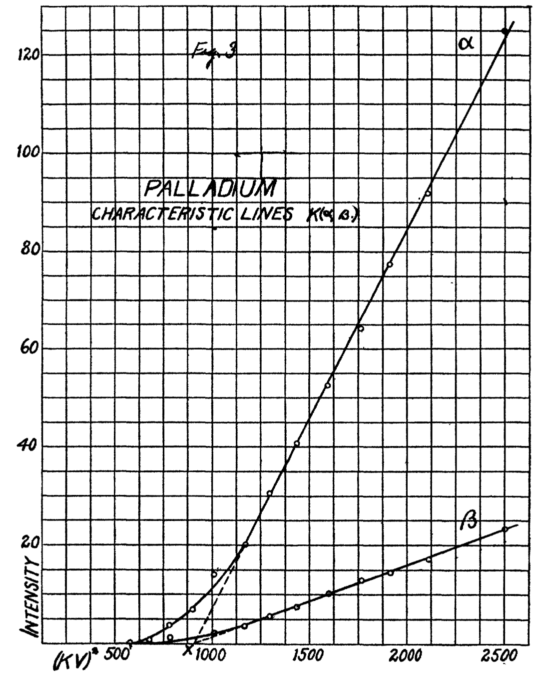

Fig. 3.

Below is a table (Table I.) of the results of various measurements taken in determining these curves, together with other data concerning them.

TABLE I.

	Molybdenum.	Palladium.
Atomic number	42	46
Wave-length of α line (cm. × 10^8)	.716	.589
Wave-length of β line (cm. × 10^8)	.641	.522
Minimum potential to produce K series, in kilo-volts	19.2	24.0
Point of intersection of straight line parts of curves with $(\text{voltage})^2$ axis, $(\text{kilo-volts})^2$	625	930
Ratio of intensity of α to β line as measured from data	3.99	5.28
Ratio of intensity of α to β line corrected for absorption in glass	5.55	6.25

ABSORPTION COEFFICIENTS.

A theoretical explanation of these voltage intensity curves has been developed by Professor Bergen Davis[1] so it was decided to correct the curves for absorption in the glass of the X-ray tubes and to compare the experimentally determined results with the curves obtained from his equation. An investigation of the absorption coefficients of the α and β lines of molybdenum and palladium in glass and in molybdenum and palladium respectively was undertaken.

The radiation was taken from a Coolidge tube with a tungsten anticathode and the wave-lengths desired were reflected from the same crystal that was used in the other part of the work. The voltage on the tube was made greater than the critical voltage of either metal for the K series and it was held constant. The collimator slit and the slit on the ionization chamber were narrowed to .2 mm. and the crystal and chamber were set at the proper angles to give the desired wave-length. An aluminum screen .3 mm. thick was placed between the crystal and the slit on the ionization chamber so that the reflected beam would pass through it. It was found necessary to use this screen in order to get consistent results. It absorbed practically all of the secondary radiation from the crystal, and thus allowed the reflected ray to pass into the ionization chamber as an homogeneous beam. This filtering out of the X-rays of long wave-length that came from the crystal was important.

The reflected beam after having passed through the aluminum filter was passed directly into the ionization chamber and its intensity determined. This value was used as the initial intensity in the computations. Then thin sheets of glass were placed in front of the slit in such a way that

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[1] Bergen Davis, PHYS. REV., June, 1918.

the reflected beam passed through them before it entered the ionization chamber. Determinations of intensity were made with the rays passing through various thicknesses of glass and the absorption coefficient calculated by the well-known exponential equation. The results obtained with different thicknesses of glass were averaged for the true absorption coefficient.

Measurements were made in this way for the α and β lines of both molybdenum and palladium in glass. In addition absorption coefficients of the α and β line of molybdenum in molybdenum were determined, as were the absorption coefficients of the α and β lines of palladium in palladium.

The aluminum filter was kept in place in all this work and conditions were the same as regards voltage, current, etc., in all the determinations that were made. In one set of observations the potential across the tube was 35 KV. and in another it was held at 45 KV. The results shown in this paper were those obtained at 45 KV. The sheets of glass that were used were .022 cm. in thickness and the sheets of palladium were .0065 cm. thick. The molybdenum was .016 cm. thick and only two thicknesses were used. The absorption coefficients obtained are given in Table II.

Table II.

Line.	Wave-length Cm. $\times 10^8$.	Absorption Coeff. in Glass.	Absorption Coeff. Mo.	Absorption Coeff. Pd.
Mo. α..........	.716	14.50	210	
Mo. β..........	.641	11.65	170	
Pd. α..........	.589	7.79		138
Pd. β..........	.522	5.37		100

Wave-Length Intensity Curves.

During the early part of the work a great many curves were obtained between wave-length and intensity of radiation for molybdenum. The readings were taken for intervals of three minutes of arc on the spectrometer circle and in no case was the α line divided. The α line as obtained is wider than the β, and this widening at the base suggests that the α line consists of two lines. It has been shown by Professor Duane[1] that the α line of rhodium is a doublet consisting of an α_1 and an α_2 line. In this work no distinction is made between the α_1 and the α_2 lines and the radiation designated here as that of the α line for either metal consists of the combined intensities of the two lines of the α doublet.

In order to correct the intensities of the lines that were studied (α and

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[1] Not yet published.

β lines) for absorption in the glass of the X-ray tubes, the thickness of the glass was determined. A tube was placed under a microscope and the microscope was focused on an object on the inner surface of the glass and then on an object on the outer surface. From these readings and the index of refraction of the glass the thickness of the glass was determined. Determinations were made of the thickness of both tubes used and the results were:

Thickness of glass of molybdenum tube..............1125 cm.
Thickness of glass of palladium tube.................0706 cm.

Using these thicknesses and the absorption coefficients in Table II., the intensities within the tubes of the lines studied were found to be

Moα ....5.11 times the observed intensity.
Moβ ....3.67 " " " "
Pdα ....1.73 " " " "
Pdβ ....1.46 " " " "

The curves between intensity of radiation and voltage squared (Figs. 2 and 3) show that for the straight line parts of the curves the ratio of the intensity of the α radiation to that of the β radiation is, in the case of molybdenum, 3.99; and in the case of palladium 5.28. When the intensities of the lines are corrected for absorption in the glass these ratios are changed for molybdenum to 5.55 and for palladium to 6.25. The curves in Figs. 2 and 3 are the experimentally determined curves and they are not corrected for this absorption.

THE RATIO OF THE ENERGY IN THE α AND β RADIATION AS EMITTED FROM THE ATOM.

The corrected values give the intensities of the α and β radiation inside the tube before coming out through the glass. *A still more important matter is the ratio of the intensities of these frequencies actually emitted by by the atom.* The theory developed by Professor Bergen Davis[1] makes the calculation of this ratio possible. The equation resulting from a mathematical treatment of this theory is

$$I_a = E_a\,(hn_a)\frac{BN}{b}\left[\frac{b}{cu}\left(1 - e^{-\frac{cu}{b}(V^2 - V_0^2)}\right)\right.$$
$$\left. - 2V_0(V - V_0) + 2/3\left(\frac{cu}{b}\right)V_0\{2V^3 - V_0(V^2 - V_0^2)\}\right.$$

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[1] *Loc. cit.*

$$- \frac{V_0}{15}\left(\frac{cu}{b}\right)^2 \{8(V^5 - V^4V_0) - 4V^2V_0(V^2 - V_0^2) - 3V_0(V^2 - V_0^2)^2\}\Bigg]$$

when expanded to four terms.

V_0 = minimum voltage required to produce the characteristic radiation.
u = the absorption coefficient of a line in the metal that produces it.
c = the ratio of the path of a ray through the metal to the depth of penetration of the electron producing it.
b = a constant corresponding to a in Whiddington's law.[1] This constant is expressed for use here in terms of potential.
V = any voltage applied to the tube (Kilo-volts).
I = intensity of the line (as written above it means the intensity of the α line).
N = the number of electrons striking the target per second.
B = the number of impacts of an electron with the atomic nuclei per unit distance.

($E_\alpha hn_\alpha$) is proportional to the energy emitted by one atom.

It will be noticed that the constants in the equation, with the exception of $E_\alpha hn_\alpha$ and u have the same values for all the lines from a particular metal. The absorption coefficients were determined experimentally for the α and β lines of both palladium and molybdenum and their values are given in Table II. The constants E_α and E_β are the fractions of the effective impacts that result in producing the corresponding radiations.

The combined constants $E_\alpha hn_\alpha$ and $E_\beta hn_\beta$ are proportional to the energies emitted as radiation of each frequency from one atom. The ratio $E_\alpha hn_\alpha/E_\beta hn_\beta$ is the ratio of the energy of the α frequency to that of the β frequency emitted by a single atom.

The experimentally determined values of I for the α and β lines of molybdenum and palladium, after having been corrected for absorption in the glass of the tubes, were plotted. Values of I for different voltages were computed for the α and β lines of both metals and plotted to the same scale. From these computations and from the experimental results the data in Table III. were obtained.

Table III.

Metal.	**Observed** I_α/I_β.	**Inside Tube** I_α/I_β.	**Ratio of Intensities Emitted by Atom** $E_\alpha hn_\alpha/E_\beta hn_\beta$.
Mo................	3.99	5.55	5.70
Pd................	5.28	6.25	7.18

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[1] Proc. Roy. Soc., Vol. 86, 1912.

Professor Bergen Davis's equation can be written:

$$I_\alpha = (E_\alpha h n_\alpha) f_\alpha(V)$$

and therefore

$$\frac{I_\alpha}{I_\beta} = \frac{E_\alpha h n_\alpha f_\alpha(V)}{E_\beta h n_\beta f_\beta(V)}.$$

The computations made in determining the points for the curves give the ratio $f_\alpha(V)/f_\beta(V)$ so that ratio $E_\alpha h n_\alpha / E_\beta h n_\beta$ can be determined. This ratio, the ratio of the energy emitted by an atom as α radiation to that emitted as β radiation, determined in this way is contained with other data pertaining to the comparison of the curves in Table III.

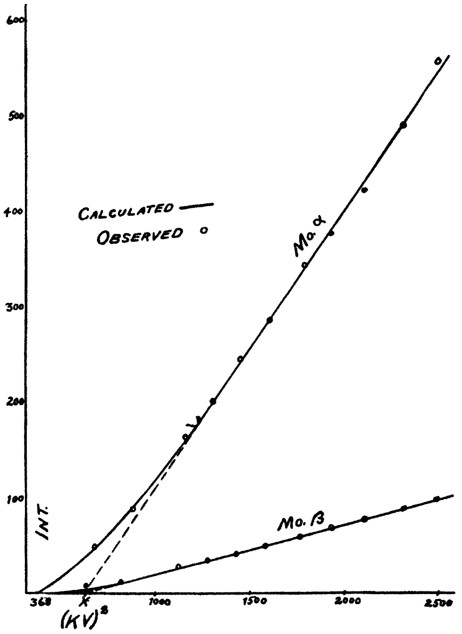

Fig. 4.

The curves given by Professor Bergen Davis's equation plotted to the same scale with the experimentally determined points corrected for absorption, are shown in Figs. 4 and 5. The very close agreement as to shape between the calculated curves and the experimental ones indicates that the assumptions underlying the theory are sound.

In these figures the calculated curves are given in full lines, and the experimentally determined points are marked with circles.

The above comparison is only true in so far as one may consider the reflecting power of the crystal the same for two frequencies not differing more than the α and β frequencies differ. If the reflecting power of a crystal does depend to a marked degree on the wave-length of the radiation it will be necessary to correct the above ratios for such variation in reflectivity when the same shall be experimentally determined.

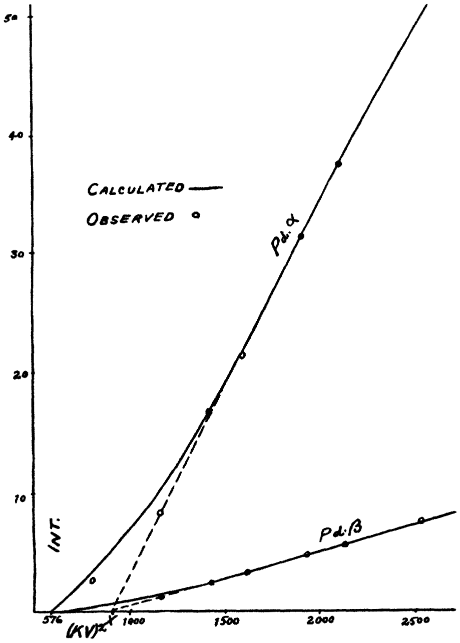

Fig. 5.

Discussion of Results.

In all the work that was done it was assumed that the crystal that was used reflected all wave-lengths with equal efficiency. W. H. Bragg[1] showed that the reflecting power of a crystal for a given wave-length varied with the angle of reflection. He varied the angle of reflection of the beam by taking the different orders of reflection. His results show that the reflecting power of a crystal varies inversely as the square of the order of reflection. This is the only experimental work that has been published as far as the writer knows, and the lack of published matter dealing experimentally with the subject of reflecting power in any single order of different wave-lengths has made the above assumption necessary.

Reference to Figs. 2 and 3 shows that the intensity of the radiation for the α and β lines of the metals used varies directly as the square of the voltage for voltages considerably higher than the critical voltage. In a

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[1] W. H. Bragg, Philosophical Magazine, 27, 1914, 881.

paper recently published by Webster and Clark[1] it was shown that the lines of the K series of rhodium vary approximately as the 3/2 power of the difference between the potential applied to the tube and the critical potential of the series. This relation was tried with the data obtained in these experiments but it was found that the curves obtained did not fit the points as well as the ones in Figs. 2 and 3 fit them.

In these curves it will be seen that the linear parts of the curves when produced back cut the voltage squared axis at the same point. In each set of curves this point is marked X. It was found on computation that the following equation is true.

$$\frac{N_{\mathrm{Pd}}^2}{N_{\mathrm{Mo}}^2} = \frac{V_{0\mathrm{Pd}}}{V_{0\mathrm{Mo}}} = \frac{\sqrt{X_{\mathrm{Pd}}}}{\sqrt{X_{\mathrm{Mo}}}},$$

where

N_{Pd} = atomic number of palladium = 46.

N_{Mo} = atomic number of molybdenum = 42.

$V_{0\mathrm{Mo}}$ = critical voltage for K series of molybdenum = 19.2 Kv.

$V_{0\mathrm{Pd}}$ = critical voltage for K series of palladium = 24.0 Kv.

X_{Mo} = point on axis where straight lines intersect = 625.

X_{Pd} = point on axis where straight lines intersect = 930.

The square root of the value in Kv. squared represented by the point X then, bears the same relation to the metal producing the characteristic radiation that the critical voltage does, *i. e.*, it is proportional to the square of its atomic number.

The method that was used in determining the absorption coefficients is the same as that of the Braggs[2] except for the aluminum filter which was placed at the crystal to absorb its secondary radiation. They find the mass absorption coefficient for the α line of palladium in palladium to be 11.4. The coefficient given in Table I., when divided by the density of palladium gives 12.1. Their work shows that absorption coefficients in a given substance vary as the 5/2 power of the wave-length of the radiation. A. W. Hull and Marion Rice[3] find that absorption coefficients when corrected for scattering vary as the cube of the wave-length, and C. D. Miller[4] finds that they vary for long wave-lengths as the 2.77 power of the wave-length. Miller uses a beam that has passed through a great thickness of absorbing material and in that way absorbs out all but the

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[1] D. L. Webster and E. Clark, Nat. Acad. of Science Proc., 3, pp. 181–185, March, 1917.

[2] W. H. and W. L. Bragg, X-rays and Crystal Structure, pp. 175–206.

[3] A. W. Hull and Marion Rice, Proc. Amer. Phys. Soc., PHYS. REV., Sept., 1916, pp. 326–328.

[4] C. D. Miller, PHYS. REV., Oct., 1916, pp. 329–343.

shortest wave-length. The absorption coefficient is determined for this end beam.

The results obtained here, while uncorrected for scattering in the thin sheets of absorbing material that were used, follow the cube of the wave-length law more consistently than they do either of the others. Their agreement with this law is fairly good. The coefficients for the molybdenum α and β radiation in molybdenum are not as trustworthy as the others, because it was not possible to use more than two thicknesses of molybdenum in the screen.

On substituting the observed values of the critical voltage in Planck's equation,

$$Ve = hn$$

in the case of molybdenum, the value of n is such as to correspond to a wave-length of $.643 \times 10^{-8}$ cm. The wave-length of the β line as measured is $.641 \times 10^{-8}$ cm. The measured voltage required to excite the K series characteristic radiation is therefore almost exactly the same as that given by the Planck relation for the β line of the K series of this metal.

For palladium the calculated result, using the observed critical voltage, is a slightly shorter wave-length than that of the β line of the K series of palladium as measured. The measured wave-length of the β line is $.552 \times 10^{-8}$ cm. while the calculated wave-length for the critical voltage is $.516 \times 10^{-8}$ cm.

In a paper published by Uhler[1] it is shown that while Moseley's law does not completely represent the X-ray series over the entire range of wave-lengths, it represents the series for wave-lengths corresponding to the atomic numbers of molybdenum and palladium very closely. Placing $\tau_1 = 2$ in Bohr's equation to determine the wave-length of the α line, the value obtained is, for molybdenum $.713 \times 10^{-8}$ cm., and for palladium $.581 \times 10^{-8}$ cm. The measured wave-length for the molybdenum α radiation is $.716 \times 10^{-8}$ cm. and for palladium α radiation it is $.589 \times 10^{-8}$ cm. In each case the agreement between calculated and observed wave-length is as close as Moseley's law agrees with the observed wave-lengths according to Uhler.

SUMMARY.

The K series characteristic X-radiation of molybdenum and palladium has been studied.

It was found that in each metal the α and β radiation appeared at a certain voltage. For molybdenum this voltage was found to be 19.2 Kv. and for palladium it was 24 Kv. For molybdenum this measured

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[1] H. S. Uhler, Phys. Rev., April, 1917, pp. 325–335.

critical voltage is almost exactly that required by the Planck hypothesis to produce the β line. For palladium the measured critical voltage is that required by the same hypothesis to produce a wave-length slightly shorter than the β line.

Curves were plotted between the voltage squared and the intensities of the α and β radiation for both metals, and these curves show that the intensities of these radiations varied directly as the square of the voltage for voltages not too near the critical voltage. The ratio of the intensity of the α line to that of the β line was found to become constant as the voltage was increased, for each metal.

The straight line parts of the curves, if produced back cut the voltage squared axis in the same point, and this point was found to bear the same relation to the atomic number of the metal of the anti-cathode that the point at which the curves themselves cut the axis bears, that is, the square root of the coördinate represents a voltage proportional to the square of the atomic number of the radiator.

Absorption coefficients for wave-lengths of the α and β lines of molybdenum and palladium in glass and in molybdenum and palladium respectively were determined, and they were found to vary approximately as the cube of the wave-length of the radiation. The observed intensities of the α and β lines of each metal were corrected for absorption in the glass of the X-ray tube.

By application of the theory of Professor Bergen Davis it was possible to calculate the ratio of the intensity of the α radiation to that of the β radiation as given by a single atom.

The curves obtained by plotting the theoretical equation were found to agree excellently with the experimentally determined curves.

CONCLUSION.

In conclusion the writer wishes to thank Professor Bergen Davis, who suggested the research, for the active help and constant advice that he has furnished throughout the work. He is deeply indebted to Columbia University for the grant of the Tyndall Fellowship for the prosecution of the research.

He is also grateful to Dr. W. D. Coolidge for supplying the molybdenum tube, and to Dr. C. S. Brainin for the loan of the sheet palladium that was used.

PHŒNIX PHYSICAL LABORATORY,
COLUMBIA UNIVERSITY,
May 1, 1918.