THE EXTENSION OF THE X-RAY SPECTRUM TO THE ULTRAVIOLET.

By E. H. Kurth.

Synopsis.

Characteristic X-Radiation Due to Slow Electrons, 1,000 to 12 Volts.—By using the methods of modern high-vacuum technique, the difficulties experienced by previous investigators have been largely overcome. The radiation was measured in terms of the photo-electric current excited from a Pt dish. The effect was made large by utilizing a hot tungsten helix as a source of electrons, and all disturbances due to gas ions formed by the electrons were eliminated by maintaining a very high vacuum and by interposing an electrostatic field across the path of the radiation. The deflections thus obtained were large and perfectly reproducible. When the deflections *per unit* thermionic current were plotted as a function of the accelerating potential, sharp breaks appeared which each indicate the minimum energy necessary to excite the corresponding characteristic radiation. From these energy determinations the corresponding wave-lengths were computed using the quantum relation. Thus the following values have been obtained for the *convergence wave-lenghts* in Angstroms: *K-series of carbon* 42.6, *oxygen* 23.8; *L-series of carbon* 375, *oxygen* 248, *aluminum* 100, *silicon* 82.5, *titanium* 24.5, *iron* 16.3, *copper* 12.3; *M-series of aluminium* 326, *titanium* 85.3, *iron* 54.3, *copper* 41.6; *N-series of iron* 247, *copper* 116. The relation of these results to those obtained by crystal analysis and by spectrum analysis is discussed. It is suggested that the radiation from solid targets may differ from the radiation from gaseous atoms, especially for the lighter elements.

It was probably first suggested by Sir J. J. Thomson that it might be practicable to investigate by means of x-radiation produced at relatively low voltages that region of the spectrum falling between the wave-length of the longest measured x-rays and that of the shortest ultraviolet radiation studied spectroscopically. Difficulties in ruling suitable gratings and their low reflecting power have limited the exploration of this region from the ultraviolet side, while the close grating space of crystals and their strong absorption of the radiation have prevented the application of the methods of x-ray analysis. Now from the quantum relation $eV = h\nu$, it is evident that the upper frequency limit of this region corresponds to electronic impacts of approximately 1,000 volts. Investigators thus far, however, have been chiefly concerned with the question of the actual production of radiation by impacts of these slow-moving electrons against a solid anticathode, and experiments have indicated its presence for potentials down to values below 100 volts. Convincing evidence, however, of the presence of radiation in this region really characteristic of the particular anticathode material employed has not yet been secured.

A brief summary of the work done on soft x-radiation prior to 1919 was given by Dadourian in a paper published in that year.[1] Early in the following year a paper by Misses Laird and Barton appeared.[2] Still later a preliminary report relative to some work by Holweck was made before the French Academy of Sciences.[3]

The experimental arrangements used by the several observers who have endeavored to secure quantitative results have been of an essentially similar type. A hot cathode as a source of thermions and an anode, together with a device for detecting and measuring the effect of the radiation produced, are sealed into a common container which is then highly evacuated. The detecting arrangement consists of either an ionization chamber, separated from the compartment in which the radiation is excited by a very thin membrane, or simply of a metal disk connected to an electrometer, which will thus measure the photoelectric effect of the radiation falling upon the plate. It has been generally customary in any case to interpose a window of collodion or other suitable material between the source of the radiation and the arrangement employed for detecting it. The purpose of this window is to prevent the passage through to the detector of ions formed in the x-ray compartment.

This method of ensuring freedom from the effects of the ions is open to a number of objections. It is well known, for instance, that radiation of this range of wave-lengths is considerably absorbed by even the thinnest of membranes. If collodion is used for the window, furthermore, it is difficult to give the apparatus the requisite heat treatment during the exhausting process. With an apparatus in which she employed a window, Miss Laird was able to observe no radiation effects with anode potentials below 200 volts. Holweck secured no effects below 70 volts. The discrepancy between these results and those obtained by other investigators who have observed effects attributed to radiation at much lower potentials, would be best explained, perhaps, by assuming that radiation of longer wave-length was to a considerable extent absorbed

[1] A. Wehnelt and W. Treuble, Litz. Phys.-Med. Soc. Erlangen, 37, 1905.
H. Dember, Verh. Deutsch. Phys. Ges., 13, p. 601, 1911.
H. Dember, Verh. Deutsch. Phys. Ges., 15, p. 560, 1913.
R. Whiddington, Camb. Phil. Soc., 17, p. 144, 1913.
J. J. Thomson, Phil. Mag., 28, p. 620, 1914.
Elizabeth R. Laird, Ann. der Phys., 46, p. 605, 1915.
H. M. Dadourian, PHYS. REV., 14, p. 234, 1919.

[2] E. R. Laird and V. P. Barton, PHYS. REV., 15, p. 297, 1920.

[3] Holweck, Comptes Rendus, 171, p. 849, 1920.

by the window employed, and that the lowest voltage at which radiation is detected depends on its intensity.

Now it seemed probable that if recourse were taken to the methods of modern high-vacuum technique, it might be possible practically to eliminate those ion effects which have led to the use of a window. The comparatively few ions which would then be formed could be removed by a system of electrified plates without introducing serious secondary effects. The employment of a high vacuum, furthermore, would permit the use of a tungsten filament as a cathode, which, under these conditions might be placed very close to the target without danger of serious contamination of the target surface. The high thermionic current at low voltages made possible by the increased electric intensity resulting from this close spacing of the cathode and the target would be conducive to increased radiation effects at the lower potentials. The problem of freeing the target of gas would likewise be facilitated, because the bombarding process could be effectively carried on at the moderate voltages available. In arrangements which have been used up to the present, an exceedingly small proportion of the radiation produced at the target could actually contribute to the measured effect, due to the fact that the detecting device has subtended such a relatively small portion of the active solid angle about the target. It seemed that it might be comparatively easy to render a much larger proportion of this radiation effective by suitable design of the apparatus.

Thus an attempt has been made to effect improvements over previous experimental arrangements with two aims in view: (1) the practical elimination of impeditive effects; (2) the production of a large increase in the effect to be measured. The first consideration requires the complete elimination of the possibility of gas ions reaching the detecting device, and the reduction to a minimum of the effect of all radiation not arising as a result of impacts of electrons against the atoms of the target element. With regard to the second consideration, the radiation effect has been increased to such a magnitude that the readings may be taken upon a shunted and comparatively insensitive electrometer. With this measuring arrangement one experiences an almost complete freedom from insulation troubles and from electrical disturbances coming from without the system. As a result the deflections are found to be remarkably consistent, and the resulting curves are entirely reproducible.

Apparatus.

The form of the apparatus which was used in obtaining the results given in this paper is represented diagramatically by Fig. 1. A hot cathode, *C*, consisting of a short length of helically wound, 10-mil tungsten wire was mounted in the small end of a large conical glass tube. The target, T, normally about 6 by 12 mm. in section, was arranged to be changed at will through the agency of a small ground glass joint, J, which was made tight with a little De Kotinsky cement. The long glass stem on which the target is mounted was designed to fit the side tube quite closely, and originally a short glass appendix which could be immersed in liquid air was attached at the base of the seal. This device, it was hoped, would make it improbable that any trouble might be encountered due to the leakage into the apparatus of water vapor coming off the glass near the joint. In actual operation, however, it was found that the escape of gas from this joint was negligibly small. In the body of the tube a system of seven diverging plates was arranged, between which the radiation from the target must pass before reaching the further compartment of the tube. Alternate plates of the set were connected together forming two groups, P and P', one of which was then joined to the gauze G and the other to the gauze G'. Leads from these two gauzes as well as from the third gauze, G'', were brought to the outside of the tube as indicated in the figure. These gauzes are all of exceptionally coarse mesh and they do not intercept an appreciable proportion of the radiation. The radiation detecting plate, D, is about 5 cm. in diameter and is made of platinum, as are all of the other metal parts. Appropriate guard ring devices, not shown in the drawing, were provided to take care of volume and surface leakage of electricity to the detecting disk.

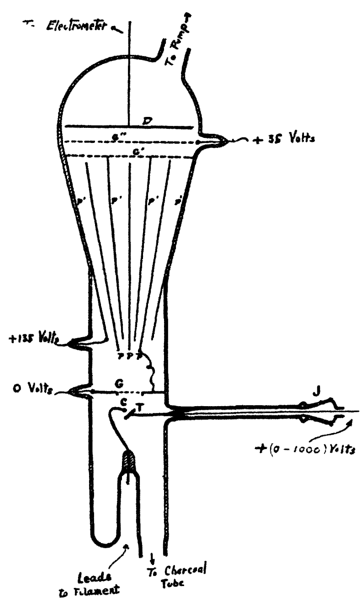

Fig. 1.

A large two-stage condensation pump backed up by an oil pump is used to evacuate the apparatus. Large bore tubing is employed for connections and two liquid air traps, one of which contained charcoal, are located between the pump and the apparatus for the purpose of freezing out mercury vapor. A reasonably sensitive McLeod gauge and a mercury cut-off are provided close to the pump for use in detecting the presence of possible leaks. An appendix containing a small quantity of charcoal is also connected directly to the apparatus. Electric heaters are arranged to bake out the apparatus, charcoal and traps at about 400° for several hours before every run. Simultaneously the connecting tube is well heated with a Bunsen flame. Finally at the conclusion of this heating process the charcoal and vapor traps are immersed in liquid air.

As long as the charcoal is being heated, a pressure of a small fraction of a bar is always indicated by the gauge. When this heating is discontinued, however, the pressure at once becomes immeasurably small. The pump is always kept in operation during the runs.

The tungsten cathode is heated by a set of high-capacity storage cells. Its resistance is approximately 0.7 ohm and it requires from 4 to 6 amperes to light it. The negative end of the cathode is joined to the gauze G and the connection is earthed. The anode voltage is provided by a small 1,500-volt direct-current generator. This potential is regulated by slide resistances and is measured on a 150-volt Weston voltmeter which is fitted with an adjustable series resistance to give suitable range to the scale. The thermionic current in this circuit is read upon a Paul Universal Testing Set. The set of plates which is joined to the gauze G' is connected to a group of dry cells which provide an adjustable source of potential up to 600 volts. The gauze G'', which receives the photo-electrons from the detecting disk, D, is raised to a potential of 35 volts furnished by a small battery. A Dolezalek electrometer with a sensitivity of about 1,700 mm. per volt is connected to the detecting disk, and the instrument is fitted with a series of India ink shunts of different resistances. Thus definite scale deflections rather than rate of deflection are observed when radiation falls upon the detecting disk.

In the original set up a large electro-magnet was arranged so that a strong magnetic field could be applied perpendicularly to the plates. Under the influence of this field the normal, direct path of an ion passing between the plates would become converted into a series of loops, and the corresponding length of time that the ion would remain between the plates would be considerably increased. One might expect to remove the ions under these conditions with an electric field of very moderate strength between the plates. When the arrangement was actually tried, however, serious complications were introduced. The stray magnetic field greatly reduced the thermionic bombarding current and the photoelectric current from the disk. The tube was therefore carefully shielded from the effects of the stray lines by means of a series of soft steel frames. When this was done, and when an electric field of about 100 volts was applied to the plates, it was found that variations in the strength of the magnetic field did not affect the magnitude of the electrometer deflections. As a result of this test the magnetic field was proved unnecessary and this feature was completely eliminated after a few of the preliminary runs on the apparatus.

In fact it is easy to show by a simple calculation that it ought to be possible to remove ions, moving with the maximum velocity that one might reasonably expect under the conditions, by the application of a very moderate potential to such a system of plates. The calculation shows that a hydrogen ion, for instance, with a velocity corresponding to a fall through 1,000 volts, would be removed by a plate potential of the order of 100 volts. Secondary effects arising from the impacts of the ions against the plates in this apparatus, furthermore, are not likely to be serious if the number of impacts is not excessive. With a view, therefore, to reducing the number of ions present to a minimum particular care has been exercised to secure the very best vacuum conditions, and, as far as possible, to free the target from occluded gas.

Thus, preliminary to all runs, the target is given a thorough heat treatment, which consists in raising it to as high a temperature, by electronic bombardment from the cathode, as the particular element in use will safely withstand. A current of about 30 milliamperes at 300 volts is sufficient to bring the anode to a bright red heat. This preliminary heat treatment of the target is always carried out at a higher temperature than will be reached in the subsequent run.

Experimental Tests.

When the cathode is heated, a small deflection of the electrometer regularly takes place before the anode voltage is applied and it is in a direction corresponding to a positive charging up of the detecting disk. This deflection results from a photoelectric action upon the disk produced by intercepted light from the glowing cathode. Its magnitude depends upon the temperature of the cathode, and when this is very high, it may amount to 25 millimeters with a shunt permitting moderate electrometer sensitivity. This small deflection is, of course, constant for any particular set of readings, and its effect is completely eliminated by resetting the zero of the scale.

If now the anode voltage be gradually applied—assuming a potential of, say, 100 volts between the plates—the electrometer will remain unaffected until a potential of from 12 to 25 volts is attained depending on the material of the target. Then it will begin to deflect slowly in the same direction as before, and the magnitude of this deflection increases rapidly with further increase of the anode voltage.

If the anode voltage be now adjusted to some value which will give a fair scale deflection, an increase in the potential across the plates will not change its magnitude. If, however, the plate potential be reduced, the deflection will not change until a comparatively low critical potential difference is attained. Then a sudden increase is observed, and a further decrease in the plate potential will result in an off-scale deflection. The setting in of this effect is certain indication that positive ions formed in the radiation compartment are beginning to pass between the plates to the detecting disk. The value of this critical plate potential seems to be somewhat characteristic of the target element which is being used. With the carbon target it was found to be as high as 30 volts but with titanium it was below 12 volts. Since, during most of the actual runs, the plates have been charged to 135 volts, these experiments indicate unquestionably that the system of plates as used is perfectly effective in preventing the passage of charged bodies through to the detecting disk.

There is still, however, the question of the radiation associated with the formation of these ions to be considered. No direct tests with a view to differentiating between the true target radiation and gas radiation have yet been made. However, there are several indications that the latter effect may be safely neglected in the present investigation. First, the results secured are characteristic, in a recognizable fashion, of the different elements used as targets. There is no reason to believe that radiation from residual gas would behave in this manner. Second, the only gas presumedly present which might cause trouble in this work is oxygen. No characteristic radiation effects from this gas similar to those which were later secured when the element itself was used in an oxide as a target were ever observed. Third, the gas pressure was known to be too low to permit a sufficient number of impacts against gas atoms to give a detectable effect.

Results.

When the electrometer deflection is plotted as a function of the anode potential, curves of the type shown in Fig. 2 are obtained. In some cases marked discontinuities or "breaks" in the curvature are discernible, as in the curve for iron referred to, while in others it is practically impossible to determine with any degree of precision the position of a definite break in the curve. If, however, the deflection per unit thermionic current is plotted against the anode potential, the resulting relation is linear. Any change in the rate of increase of the effect with the voltage will now be very evident, and to determine the position of the break point with considerable precision, one has only to draw the two best straight lines through the plotted points on each side of the break, and the position of the break will be indicated by their point of intersection.

The radiation produced by impacts of electrons against a solid consists of two distinct types: general radiation and characteristic radiation. Both types are generally present and both evidently increase in intensity linearly with the voltage. A break point in the curve indicates the setting in of a new type of radiation, which is found to be characteristic of the target element. From *a priori* considerations the break may be either an upward or downward inflection, depending on whether or not the new characteristic radiation produces a larger photoelectric effect than would be produced by the additional general radiation which would be emitted if this characteristic radiation did not set in. It has been found that in general the setting in of characteristic radiation is indicated by an increase in the total emission. However, one exception has been thus far noted in these experiments. The L series of silicon is evident as an actual falling off in the total radiation. Evidently, in this case, the increase in characteristic radiation is insufficient in amount to balance the falling off in general radiation. This phenomenon has been previously noted in an investigation of the variation of total x-ray intensity with voltage in the case of silver, for radiations of the ordinary x-ray type.[1] However, while the presence of characteristic radiation is usually shown by an upward inflection in the curve, the sharpness of the break varies considerably with the different elements and among the several x-ray series of the same element. It is hoped that later, when more elements have been studied, it will be possible to establish some sort of a periodic relationship relative to the intensity of the characteristic radiation from the different elements.

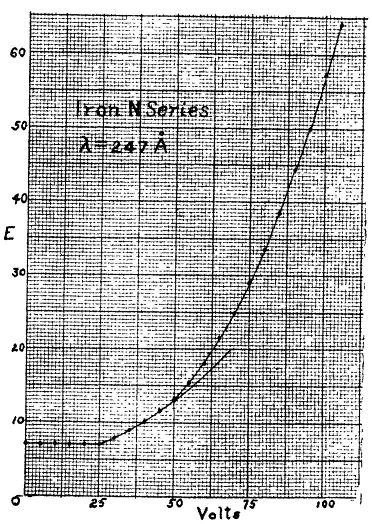

Fig. 2.

CARBON.

The radiation curves for carbon are given in Fig. 3. The upper curve shows the break corresponding to the K series of the element and the lower one indicates the L series. Both curves are the results of single runs over the respective ranges. The target in this case was cut from a piece of graphite, and during the procedure of evacuating the apparatus, it was brought to a white heat by thermionic bombardment.

[1] Brainin, PHYS. REV., 10, p. 461, 1917.

Despite this exceptionally favorable heat treatment, however, the carbon seemed to require, in order to eliminate the direct effect of positive ions, a little higher minimum voltage across the plate than any other element thus far studied. Perhaps this fact may account for the apparent slight departure which is to be noted in the case of the carbon curves from a fair linear relationship between break points. The L series break indicated for this element is of special interest because it presumedly arises as a result of electrons falling into the very outer shell of the atom. There was considerable reason to expect, in fact, that one might actually not observe a sharp break corresponding to this series for carbon in the solid form because of the proximity of the neighboring atoms. As it is, there is probably little question but that the potential energies of the electrons in the outer shell of the carbon atom vary somewhat, depending upon whether the atom is free as in a vapor or whether it is combined with other atoms as in a solid. Thus one might expect to find that the L series of the solid carbon, for instance, is somewhat different from the L series, if it might be obtained, of the vapor.

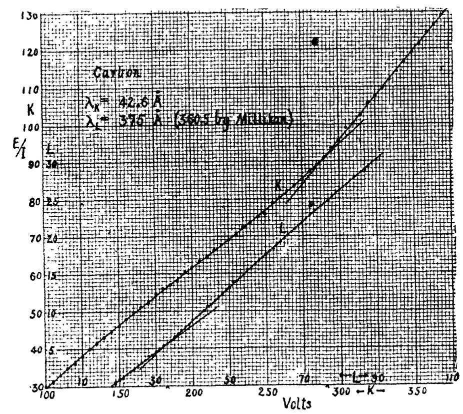

Fig. 3.

Copper.

The copper target used in these experiments was heated for a considerable time to a temperature close to its melting point. Finally, just prior to making the runs, the temperature was raised until the target melted a little at one end, and during this process, a considerable quantity of copper was distilled upon the inner surface of the glass tube. In the case of one of the preliminary runs which was made with an unusually high thermionic current, a strong break in the curve was obtained at about 500 volts. The position of this break was, however, found to depend upon the temperature of the target and it was unquestionably due to vaporization of the copper at these voltages, the new radiation arising from the copper vapor. But the actual runs, for which the curves are given, were made with the target at relatively low temperatures and in no case did this exceed that of a dull red heat.

The results for copper are given by the curves of Figs. 4, 5, and 6. A range up to 600 volts is shown in Fig. 4. This curve shows a break corresponding to the M series and the presence of a somewhat less sharply defined but intense effect beginning a little above 100 volts. This lower effect is shown to better advantage by the curve of Fig. 5, taken with larger currents. The absence of the customary sharpness in the case of this break may be accounted for by assuming that the group of lines in the spectral series which it represents may actually include two or more convergence limits. This is found to be the case in the portion of the M series already studied and presumedly it would likewise be true of a still more complicated N series. The L series break for the element is given in the curve of Fig. 6.

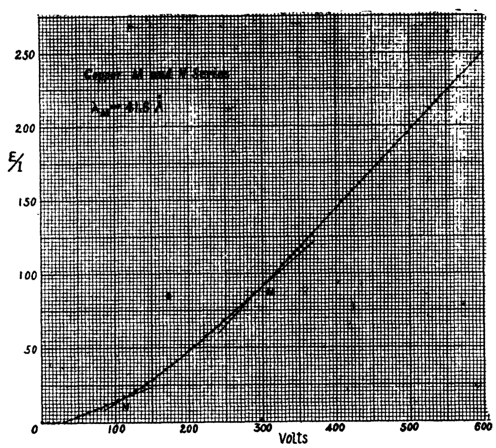

Fig. 4.

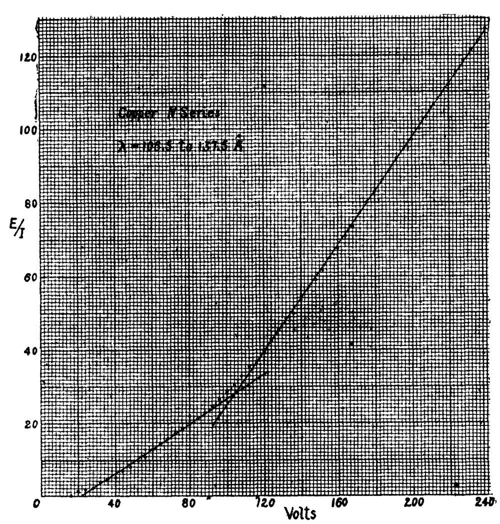

Fig. 5.

Oxygen.

When the experiments with copper were concluded, the target was removed, and the surface of the metal was carefully oxidized in a Bunsen flame. It was immediately reinserted and the apparatus re-exhausted. It was found that the oxide on the copper would safely withstand a temperature corresponding to a low red heat. The curves of Fig. 7 give the positions of the K and L series breaks obtained for this element.

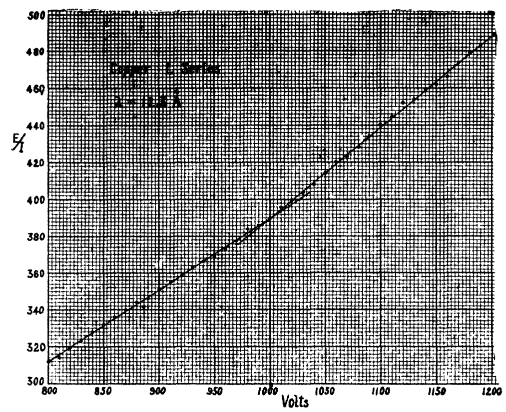

Fig. 6.

The breaks for copper could also be obtained with this target, but their positions were so far removed from the oxygen breaks as to cause no uncertainty in the interpretation of the results.

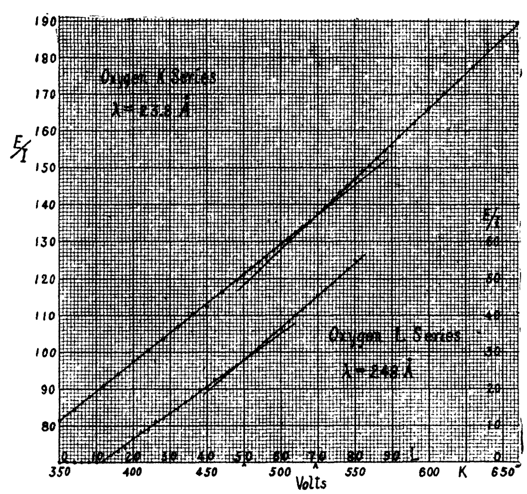

Fig. 7.

Aluminium.

Some unique difficulties were experienced in the work with this element. In the first place, the bombardment process had to be very carefully carried out because of the comparatively low melting point of 657°.

Secondly, it was found that the break points would gradually decrease in sharpness during a series of runs on successive days and, eventually, one would obtain practically a straight-line relationship over the entire region of the breaks. If the target were now removed from the apparatus, resurfaced, and again replaced, the break points would not be observed, or at best, perhaps, very weakly, upon making a run. In order to obtain the break as originally it was necessary to insert a new target. It is possible that the unusual behavior of this element is due to some peculiar action of mercury vapor upon the aluminium. Since it was not ordinarily convenient nor conside1ed desirable to keep liquid air on the traps over night or during the baking-out treatment, the target was exposed to the action of the vapor at three or four microns' pressure between the experiments. However, there were no visible indications of any effect of the mercury upon the target and if the tendency were to form an alloy, it is a little difficult to see why a temperature of red heat did not break it down.

IRON.

The L and M series breaks for iron are given in the two curves of Fig. 8. The lower break, corresponding to an N series, is shown in the

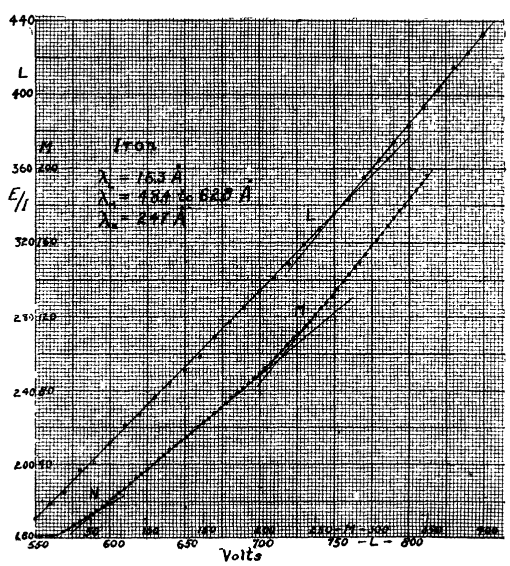

Fig. 8.

curve of Fig. 2. This break is likewise evident in the lower curve of Fig. 8. The lack of sharpness of the M series break which is to be noted is evidence that the M series at this point contains more than one convergence limit.

TITANIUM.

There is little of special interest evident as yet with regard to the radiation of this element except that the break corresponding to the L series is exceptionally strong. Both the L and M series are observed.

SILICON.

The work with silicon has not yet been completed, but the tendency, first noted with this element, for the intensity of the effect to fall off coincidently with the setting in of the characteristic radiation has been previously discussed.

INTERPRETATION.

Fig. 9 shows the Moseley curves extended to include the types of characteristic radiation discovered in the investigation described above.

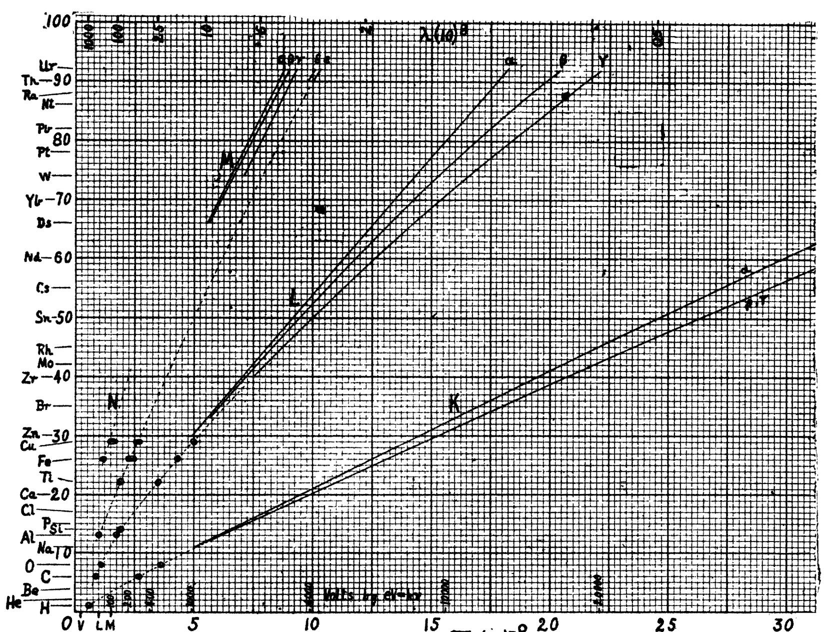

Fig. 9.

The square roots of the frequencies of the characteristic radiations are plotted against the atomic numbers of the chemical elements, showing the K, L and M series of radiations. The solid curves refer to radiations investigated by the ordinary crystal method of x-ray analysis and show how far toward the region of longer wave-lengths each type of radiation has been detected. The plotted points represent the results of the present investigation and the dotted lines through them indicate their probable relationship with the ordinary types of x-radiation.

The abscissæ marked V, L and M indicate the short wave-length limits reached by spectroscopic methods in the regions designated as the ultraviolet region, the Lyman region and the Millikan region, respectively. There remains a large gap from about 100 Å. to about 10 Å. in which no previous method of spectrosopy has been applicable and in which the first definite results are given by the present work.

In conformity with the results of Webster's work on the excitation of x-rays,[1] it is evident, by extrapolation from the x-ray curves, that the characteristic radiations in the present experiments are excited only when the bombarding electrons possess energy corresponding to the *convergence* frequencies of the series. These convergence frequencies are almost identical with the γ lines of the K and L series, but lie very slightly to the right of these lines in Fig. 9. In the K and L series the observed points fall on a reasonable extrapolation of the known lines. In the case of the M series the extrapolation is too great to be considered as anything but a suggestion, whereas the N series is purely hypothetical, since the two points ascribed to it may prove to belong to a second group in the M series. It is planned to investigate a numbei of elements of higher atomic number in order to connect these observations with the known points of the M series.

It appears that the K series continues uniformly down to hydrogen, for which the plotted value is obtained from the convergence frequency of the Lyman series. The curve is slightly concave downwards.

By applying the combination principle it is possible to predict the extension of the L α line as far as sodium, atomic number 11, and the L γ line to calcium, atomic number 20. The observed frequencies of the L radiations of copper, iron, titanium, silicon and aluminium are all larger than the values predicted by the combination principle. But the observed values of frequencies in the ordinary x-ray region are also larger than those predicted by the combination principle, and by about the same amount. Thus there is no reason for believing that the curve through the observed points is not an accurate continuation of the curve through points representing the L convergence frequencies in the ordinary x-ray region. It is planned to test some elements of atomic numbers slightly higher than that of copper in order to secure an actual overlapping of the two methods in this part of the spectrum.

The lower part of the dotted curve for the L series departs considerably from the extension of the L series curves piedicted by the combina-

[1] Webster, PHYS. REV., 7, p. 599, 1916; Webster and Clark, Nat. Acad. Proc., 3, p. 185, 1917.

tion principle, which principle suggests that the L α line should continue straight into the "Y" axis at about atomic number 7, while the L γ line should lie below it and be somewhat concave downwards. Some recent unpublished results, kindly communicated to us by Dr. Foote and Dr. Mohler, on soft x-rays from gases, fall consistently on, or to the *left* of, the extension of the L α line predicted by the combination principle. But the present results *should* lie to the right of this line because they give *convergence* frequencies, and because this line is known to be to the left of the actual values where they are known in the x-ray region. Furthermore, Millikan has observed spectroscopically the L series of carbon, and Sommerfeld points out strong reasons for believing that hydrogen possesses an L series in its Balmer series. Thus the L curves must actually curve downward toward the origin, and there is no obvious reason for believing that the L curve in Fig. 9 is not correct. It is likely that the difference between the results shown in Fig. 9, which applies throughout to radiation from solid targets, and those obtained by Foote and Mohler for gases and vapors is due to an actual modification of the characteristic frequencies in atoms of solids, arising from the influence of neighboring atoms. This modification would be expected to be less important at the higher frequencies, but would probably be very important in the case of radiation from electrons in the outer shells, or orbits. It may be that this influence accounts for the inexactness of Kossel's relations when applied to x-radiation from solid targets.

The M α curve can be predicted by Kossel's relation down as far as calcium. It shows a strong curvature downward, occurring at about cobalt, atomic number 27, and by analogy, leading us to expect a similar downward inflection near the foot of the L curves. There are no data whereby the convergence frequencies of the M series can be predicted in the region in which we are interested. The observed characteristic radiations, ascribed to the M series, are of considerably higher frequencies than the predicted M α radiation, the frequency difference being about the same as that found in the L series.

The lowest voltage at which detectable radiation was produced is 12.5 volts, in the case of oxygen. This corresponds to a wave-length of 990 Å. In most of the other cases the radiation was first detected at about 20 volts. The relatively large importance of velocity distribution corrections and of slight zero shifts on the accuracy in this region of low voltages probably renders these results of little interest, except in that they prove the production of radiation by impacts at these small voltages. It is hoped that a subsequent re-design of the apparatus may enable better accuracy to be secured in this region of weak effects.

The following table gives the averaged results obtained thus far in this investigation.

TABLE I.

Convergence Wave-lengths.

Atomic Number.	Element.	K Series.	L Series.	M Series.	N Series
6.......	Carbon	42.6 Å.	375 Å.	——	——
8.......	Oxygen	23.8	248	——	——
	Aluminium	——	100	326 Å.	——
	Silicon	——	82.5	——	——
	Titanium	——	24.5	85.3	——
	Iron	——	16.3	54.3	247 Å.
	Copper	——	12.3	41.6	116

There is overlapping of these results with those obtained by Professor Millikan[1] in the extreme ultraviolet. He has definitely placed the convergence wave-length of the L series of carbon at 360.5 Å. He finds a strong iron line at 271.6 Å., aluminium lines at 136.5 Å. and 144.0 Å. and an oxygen line at 231 Å. These are, presumably, the M α iron line, the L α aluminium lines and the L α oxygen line. He does not, however, find an aluminium line near or slightly longer than 326 Å. Remembering that our values refer to convergence wave-lengths, the agreement seems to be good. It must be remembered that the accuracy of the present method is relatively poor at the longest wave-lengths, owing to the weakness of the radiation and the uncertainties introduced by the distribution of velocities of the bombarding electrons. This correction, which could not amount to more than two or three volts, was entirely neglected since the potential drop across the filament was about sufficient to balance the average kinetic energy of emission of the electrons. At the higher voltages used, this correction would be entirely negligible, but it may have introduced small errors at the lowest voltages.

It is proposed to continue this investigation with other metals. A comparison of complete data given by this method with those being obtained for radiation from gases by Foote and Mohler should prove extremely interesting and might lead to some explanation of the condition of electrons in atoms of solids and of the failure of Kossel's relation when applied to characteristic radiation from solids.

I take this occasion to express my indebtedness to Professor Karl T. Compton for his inspiring interest in this work and for the kindly help which he has given all through the experiments.

PALMER PHYSICAL LABORATORY,
PRINCETON UNIVERSITY.

[1] Astrophys. Jour., 52, p. 47, 1920, and private correspondence.

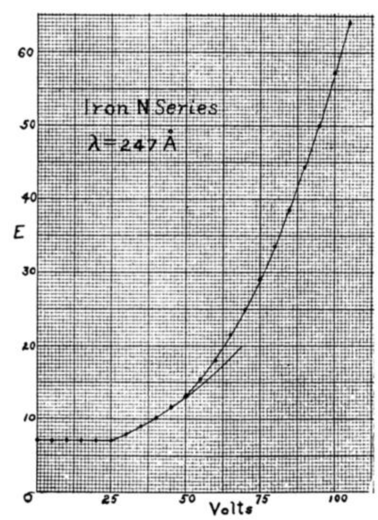

Fig. 2.

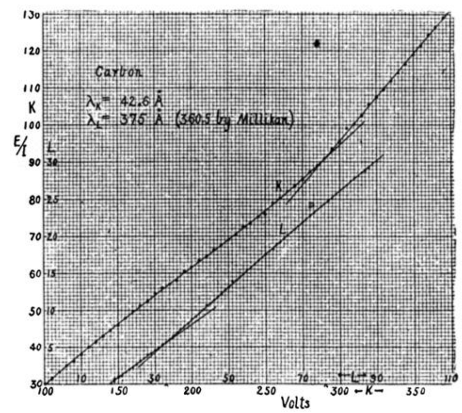

Fig. 3.

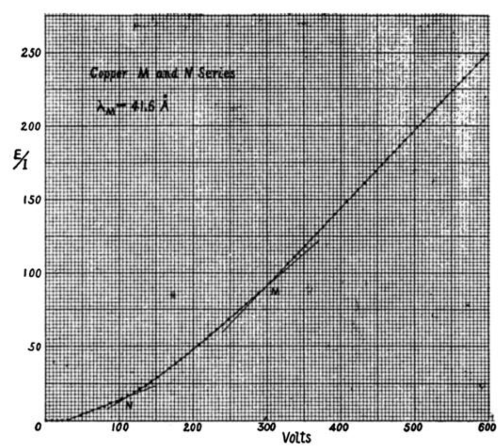
Copper M and N Series
λM = 41.6 Å
E/I
250
200
150
100
50
0
100
200
300
400
500
600
Volts
M
N

Fig. 4.

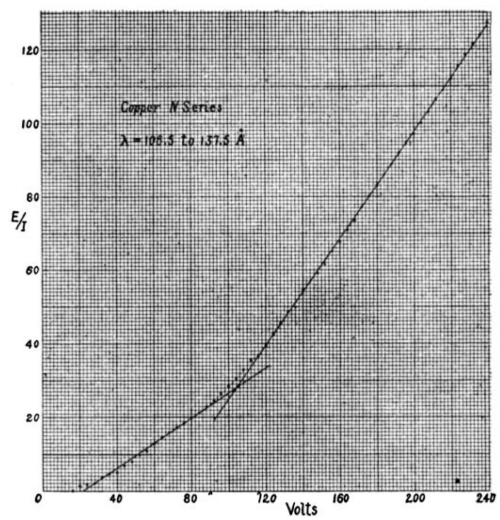
Copper N Series
λ = 106.5 to 137.5 Å
E/I
120
100
80
60
40
20
0
40
80
120
160
200
240
Volts

Fig. 5.

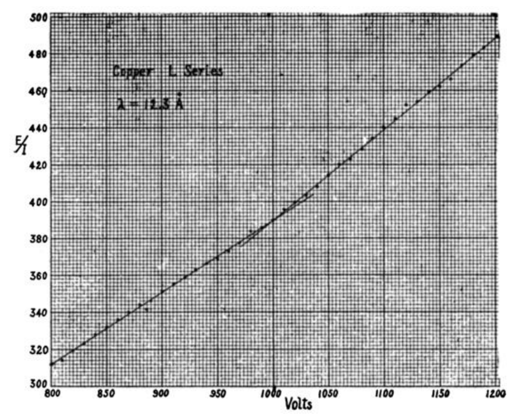
Copper L Series
λ = 12.3 Å
E/I
500
480
460
440
420
400
380
360
340
320
300
800
850
900
950
1000
1050
1100
1150
1200
Volts

Fig. 6.

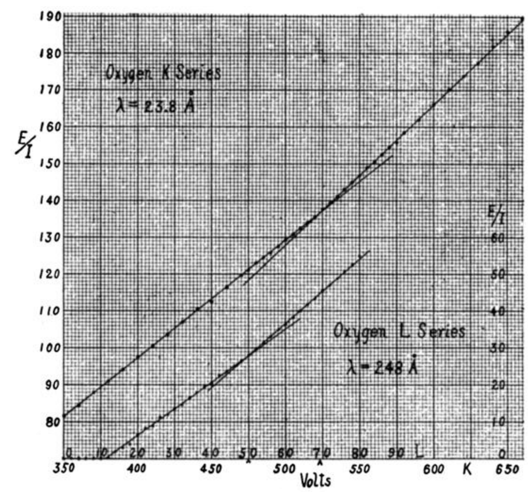

Fig. 7.

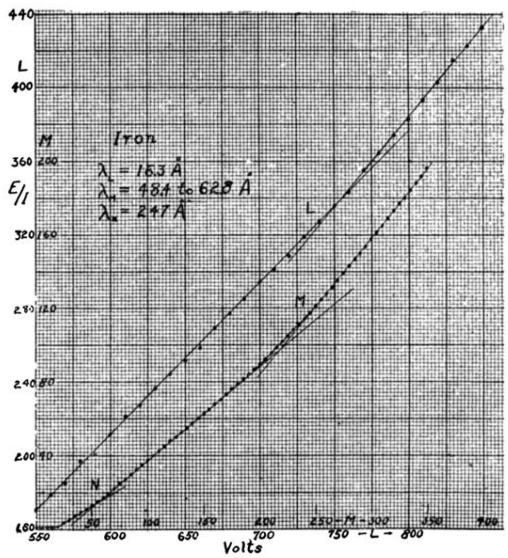

Fig. 8.

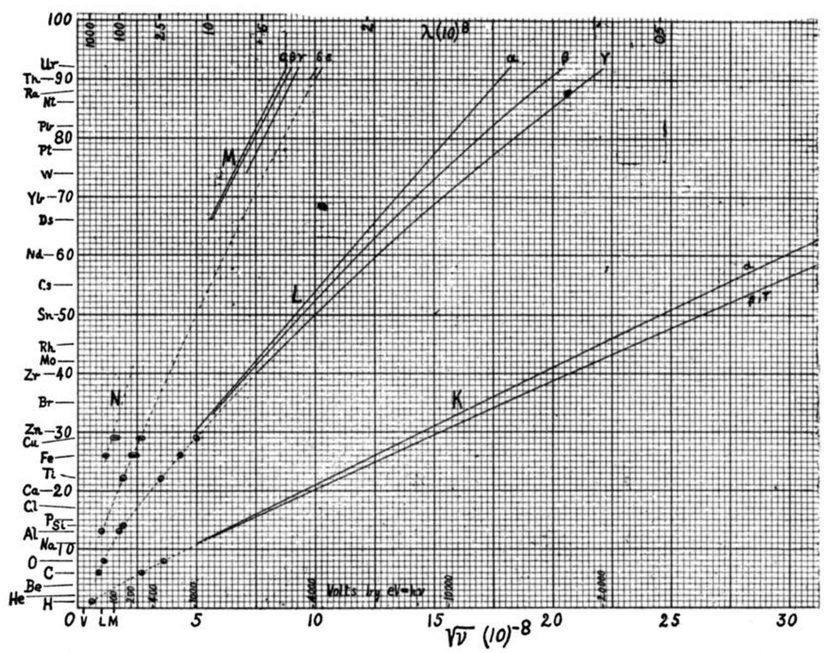

Fig. 9.