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THE VACUUM HOT-SPARK SPECTRUM OF ZINC IN THE EXTREME ULTRA-VIOLET REGION

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BY

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THE VACUUM HOT-SPARK SPECTRUM OF ZINC IN THE EXTREME ULTRA-VIOLET REGION

By R. A. SAWYER

ABSTRACT

Hot-spark vacuum spectrograph for extreme ultra-violet.—After reviewing briefly the work of Schumann and Lyman, the author describes the apparatus by which spectra extending to less than 300 A were obtained. As source of light, a condensed spark was used which, it has been found, can be passed between electrodes a millimeter or less apart if sufficiently high potentials are applied, even in extreme vacuum. This source and a specially ruled, short focus, concave grating and the slit and the plate-holder, each provided with the necessary adjustments, were mounted inside a brass tube, a meter long by 15 cm. in diameter, which was kept evacuated by a diffusion pump. On account of the gas given off by the electrodes, a series of sparks lasting 5 seconds could be allowed only every 5 minutes or so, but 20 to 30 minutes' total exposure was sufficient as a rule. After precautions were taken to minimize the corrosion of the grating by active gases and also fogging due to stray light and gaseous discharge, highly satisfactory results were obtained.

Ultra-violet spectrum of zinc, 2200 to 316 A.—The wave-lengths of about 100 new lines probably due to zinc, 80 of which are below 1400 A, are given in Table I, accurate to about 0.5 A. See Plate X for spectrogram.

I. INTRODUCTION

This paper is the second of a series of articles upon the extreme ultra-violet spectra of hot sparks in vacuo. The first paper,[1] in the July number of the *Astrophysical Journal*, was concerned with the general outlines of the problem and with some special results in the case of the carbon spectrum. The purpose of the present article is to describe the details of the experiment and to present additional data on the extreme ultra-violet spectrum of zinc, supplementing preliminary results published earlier.[2] A third contribution, soon to appear, will present data on the spectra of other metals.

The problem of the extension of the spectrum into the extreme ultra-violet, that is, below 2000 angstroms, was first brought into prominence by the familiar work of Victor Schumann. In

[1] *Astrophysical Journal*, 52, 47, 1920.

[2] *Physical Review*, 12, 167, 1918.

the period from 1892 to 1903, using a spectrograph with optical parts wholly of fluorite and special plates of his own design, he inclosed spectrograph, plate, and source in vacuo and was able to extend the spectrum from the earlier limit to a new limit at about 1200 angstroms. The limit was imposed by the transparency of fluorite, whose principal absorption band begins at this point. The next step in the extension of the ultra-violet spectrum was made by Professor Lyman. He employed the concave grating perfected by Professor Rowland which obviated the use of both lenses and prisms and made possible a vacuum spectrograph in which there is nothing whatever in the optical path save the single reflection at the grating surface. This grating, therefore, opened the way for further extension of the spectrum, limited only by the failure of the reflecting power of the metal on which the grating was ruled, or by the lack in the source of oscillations of sufficient frequency. Availing himself of this concave grating spectrograph and using as a source a strong disruptive discharge in helium at a pressure of one or two millimeters, Professor Lyman extended the ultra-violet spectrum to 510 angstroms,[1] thus bridging more than half the gap in angstroms left by Schumann between the ultra-violet radiation of 1200 angstroms and the longest X-ray wave-lengths of about 12 angstroms.

The discharge tube as used by Lyman for gaseous or easily vaporized substances leaves little to be desired as a light source in the extreme ultra-violet. For the investigation of metallic spectra in this region, however, the lack of a suitable source of radiation has long been felt. Ultra-violet radiation is absorbed by all known gases, even at low pressures. Any successful radiator for use in the extremely short wave-lengths must be one which operates in an almost complete vacuum. Very few metallic sources are known which satisfy this requirement. The ordinary arc or spark requires prohibitive pressures. The customary procedure is to operate the arc or spark in an atmosphere of hydrogen, the most transparent gas to ultra-violet, which is separated from the evacuated spectrograph by a fluorite window. The absorption

[1] *Science*, 45, 187, 1917; also *Spectroscopy of the Ultra-Violet* (Longmans, Green & Co., 1914).

band of fluorite then limits the spectrum to wave-lengths longer than 1250 angstroms. The only metallic source heretofore described which can be used in a high vacuum is the vacuum arc. This light was used by Saunders[1] in the ultra-violet region with considerable success, although no shorter wave-lengths have been photographed by its use than λ 977.9 for calcium. This source probably lacks sufficient energy to give rise to extremely high frequencies.

There is another metallic source upon which very little work has previously been done. It has been noted by a number of observers that when electrodes a millimeter or less apart are placed in a very high vacuum and joined to the walls of a Leyden jar to which sufficiently high potentials are applied, a short brilliant spark can be made to pass between the nearest points on the electrodes. Some years ago in the Ryerson Laboratory, Professor Millikan made a somewhat extensive study of these hot sparks in vacuo and designed and built the apparatus for the present study of their spectra. It was thought that the spectra of metals might be extended far out into the ultra-violet region, possibly beyond the limits of the extreme ultra-violet spectra previously obtained. For this hot spark seemed to fill exactly the requirements for a metallic source of extremely high frequency: it operated in the highest vacuum; any conductor sufficiently refractory to withstand the sparking could be employed as a source; the high voltages applied indicated that sufficient energy would be present to excite the highest frequencies. Work on this problem was begun in 1916 but was interrupted by war activities. The data obtained up to the time of this interruption were embodied in a preliminary report[2] and gave promise of fulfilling all expectations. Additional data since secured have fully justified the earlier hopes.

II. THE APPARATUS

Several concave gratings were ruled for the experiment at the Ryerson Laboratory. All were on speculum metal and had a radius of curvature of about 833 mm. The earliest grating had

[1] *Astrophysical Journal*, 40, 377, 1914; 43, 234, 1916.

[2] *Physical Review*, 12, 167, 1918.

400 lines per millimeter. It was so damaged by the operation of causes to be spoken of later that it, like all of its successors, has had to be polished and reruled. It was reruled with 512 lines to the millimeter, giving a larger and more satisfactory dispersion. Approximately the same spacing has been used on most of the later gratings, though some have been ruled with as many as 1100 lines per mm. A compact mounting held the grating and, although occupying a cross-section hardly larger than that of the grating, permitted all necessary adjustments to be made from the rear. The spectrograph in which the grating was mounted had as its foundation a brass tube about one meter long and fifteen centimeters in diameter. This tube had flanged ends to which

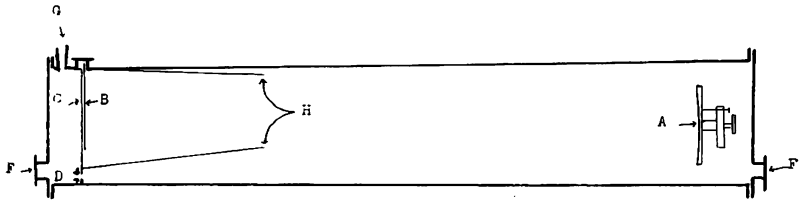

FIG. 1.—Cross-section of spectrograph

A, Grating; *B*, Plate; *C*, Diaphragm; *D*, Electrodes, represented symbolically; *E*, Slit; *F*, Windows in end plates; *G*, Connection to pump; *H*, Sleeve to keep scattered light from plates.

heavy end-plates could be screwed to make it air-tight. A plate glass window was provided in one of these end-plates and a quartz window in the other through which conditions could be observed and spark spectra taken with another spectroscope in the region of longer wave-lengths. Rubber gaskets made a seal on these ends which proved quite satisfactory.

The grating mounting was fastened at one end of this tube (see Fig. 1). About five centimeters from the other end a metal diaphragm closed the spectrograph. On the side of the diaphragm toward the grating a holder was fixed into which the photographic plate was slipped through an opening in the side of the tube. This opening, like the others, was closed by a face-plate and a rubber gasket. The photographic plate extended across about ten centimeters of the diaphragm's diameter. About two centimeters from

the end of the plate the slit was mounted in the diaphragm. The slit was adjustable in width and could be rotated in its own plane so as to make it parallel to the rulings. The lower half of the diaphragm was pierced by a two-centimeter tube to allow the main body of the spectrograph to be evacuated freely from the front end. This tube was fitted with simple light baffles at either end to render it light-tight.

The electrodes were placed just in front of the slit. They were supported by conductors which were introduced into the spectrograph through insulators, three centimeters in diameter, made air-tight by ground conical bearings smeared with rubber grease, which fitted conical openings in the wall of the spectrograph. Small electrodes of any metal could be screwed into the ends of these conductors so that different sources could be tried at will. One of the supporting conductors was free to be rotated against a ground bearing in its insulator. It was threaded at its lower end to receive a nut which bore the electrode. By rotating the conductor the nut was forced up or down and the distance between electrodes was varied. Another conical bearing was placed in the side of the spectrograph opposite the bearings for the electrodes and was ground to fit a glass joint of three centimeters' diameter, through which the tube was evacuted (see Fig. 1).

These simple arrangements comprised the original spectrograph. During the work some modifications and additions were made. These, however, were all found to be unnecessary and the final data were secured with the apparatus as described.

To secure the requisite high vacuum a Gaede molecular pump was used at first, supported by a Gaede rotary mercury pump, and that in turn by a small oil fore-pump. The molecular pump was later replaced by the Western Electric mercury diffusion pump, which was perfectly satisfactory. For the final work, however, a two-stage Westinghouse mercury diffusion pump supplanted both the Western Electric pump and the Gaede rotary mercury pump. A glass trap was placed between the pump system and the spectrograph and was immersed in liquid air at all times while the spectrograph was evacuated. In this way mercury vapor

was prevented from getting into the spectrograph and the pressure of any vapors that might be present was reduced. A McLeod gauge was attached between the trap and pumps. The gauge was calibrated to read pressures down to one ten-thousandth millimeter of mercury and would indicate pressures somewhat lower than this. During sparking, however, it not infrequently showed no reading whatever at its finest calibration mark. It is certain, therefore, that the pressure which existed in the apparatus during observations was always less than one one-thousandth of a millimeter—usually very much less.

The required potential was produced by a large induction coil, rated by the makers as a ten-inch coil. The primary of this coil was connected to a 60-cycle 110-volt alternating potential. For test exposures in air a large resistance was used in the primary circuit. To obtain the spark in vacuo, however, the full 110 volts were required. Four large navy Leyden jars connected in parallel were shunted across the secondary of the coil in parallel with the spark gap. An auxiliary spark gap in air was placed in series with the spark gap in vacuo and at the beginning of exposures was usually opened about one centimeter. As the exposure proceeded and the sparking potential rose, due to the fatigue effect,[1] this external gap was closed. These arrangements made possible a very brilliant condensed spark in vacuo; in fact, under favorable conditions the spark obtained was nearly as brilliant as the spark produced in air with an equal gap. The spark gap used in vacuo, of course, had to be very short—from 0.01 mm up to 2 mm.

The special plates perfected by Victor Schumann for work in this region of the spectrum were used. These plates were obtained from Adam Hilger and Company of London and proved perfectly satisfactory. They were developed by the pyro-gallic acid developer recommended by the makers. To prevent development fog and coarse grain on the plates, however, it was found necessary to dilute this developer one-half with water and to cool it on ice. Development on ice was found necessary by Lyman also, who,

[1] *Physical Review*, 12, 167, 1918.

however, used an ortol-potash developer.[1] As the plates grew older, the use of potassium bromide solution to keep down fogging was found to be vital.

The grating was adjusted so that the direct image of the slit was thrown near one end or the other of the photographic plate. The dispersion of the grating was such that the whole spectral region of wave-lengths shorter than about 2100 angstroms was then obtained on the plate at once. Since the plates were not bent, it was theoretically impossible to have the entire length of the plate in exact focus. The method followed was to obtain what appeared to be a sharp focus both on the image of the slit and on the lines around 2000 angstroms. The focusing was, of course, done in air. When this adjustment had been made, the lines obtained in vacuo between the two extremes were found to be in satisfactory focus.

The zinc spectra here described were all taken with the direct image of the slit on the end of the photographic plate farthest from the slit itself. The normal of the grating then fell on the plate in the neighborhood of the 1300-angstrom region. Since all the distances involved were known, it was easy to compute the deviation from the normal of the spectrum produced under these conditions. The details of this computation and the determination of the true wave-lengths will not be entered into here. The corrections to the wave-lengths obtained by assuming a normal spectrum are found in some cases to be as much as 1.6 angstroms and have been applied to the wave-lengths here published. These corrections were not applied to the wave-lengths published in August, 1918, because the accuracy attained in their measurement did not justify such refinements. Those wave-lengths were determined simply by obtaining the grating constant by measuring carefully the distance from the slit image to some known wave-length in the region of 2000 angstroms which could be obtained in air, and assuming a true normal spectrum.

For those earlier results an accuracy of only one or two angstroms was claimed. The error of the present results cannot be greater than one-half an angstrom. This increased accuracy is due partly to the better photographs, making possible much more

[1] Lyman, *Spectroscopy of the Extreme Ultra-Violet*, pp. 130–31.

exact measurements, partly to the corrections mentioned above, and partly to the fact indicated in the preceding paper, that it was possible in the case of the carbon spectrum to check the theoretical corrections by means of short wave-length lines which appeared on the plates in the second and third order also. As a matter of fact, the corrections used should make possible an accuracy of at least two-tenths of an angstrom, and such an accuracy was obtained on the spectra of other metals, details of which will be published later; but the zinc lines, as will be noted from the photographs, are rather broad and diffuse, having a width often of three or four angstroms, and it was thought, therefore, that possibly the center of these lines was not determined more nearly than one-half an angstrom.

III. MANIPULATION AND PRELIMINARY INVESTIGATION

The process of photographing the spectrum of the spark in vacuo presented some interesting features. After the plate and electrodes had been placed in position and the spectrograph closed to the air, about an hour was required for the pumps to produce the requisite vacuum. Before any sparking was attempted, pumping was usually continued for about an hour longer to remove, as far as possible, surface layers of gas. Further preliminary pumping produced little, if any, effect. Continuous pumping during exposures was necessary to remove gases thrown off by the electrodes and insulation because of the heat of the discharge.

On throwing on the potential after two hours' pumping, a little greenish glow was observed around the electrodes. There was no general glow, however, and most of the discharge passed between the electrodes in the form of a brilliant spark, bluish white in color in the case of zinc. This discharge would so heat the electrodes, conductors, and insulation that a considerable quantity of gas would be thrown out. After the passage of three or four series of sparks, of perhaps one second in duration, the pressure in the spectrograph would be so raised by the evolved gases that the discharge would tend to become wholly gaseous. This was not allowed to happen, for the pumps would remove the gases in a few minutes and the process could then be repeated. After a number of such series

of sparks the evolved gases would be much reduced and the hot sparks became much stronger. Five or ten brilliant series of sparks of one second's duration could then be obtained at intervals of about five minutes. These intervals were necessary to allow the pumps to remove the gases which were always thrown off to some extent by the electrodes. The number of such spark series required to complete an exposure depended on the brilliancy of individual series of sparks; generally from 150 to 250 were required. As the duration of an individual series of sparks was approximately a second, it will be seen that the total period of actual exposure was not more than 15 or 20 minutes in length. Perhaps this fact, more clearly than any other, will indicate the brilliancy of the sparks obtained by this method.

The hot spark obtained with zinc electrodes was bluish white in color and very much resembled the ordinary spark in air. After a few poor sparks at the beginning of an exposure, the sparks attained a maximum of brilliancy which gradually fell away as the fatigue effect, previously mentioned, became operative. This effect became more and more pronounced and made the sparks more and more difficult to produce. The electrodes spattered badly and their tips began to present a rough and fused appearance. This fatiguing had been previously studied at great length by R. A. Millikan and has been briefly reported upon.[1] It actually in some instances imposed a limit on the length of exposure, so difficult did it become to get anything across the gap, even when this was reduced to a tenth of a millimeter.

The early photographs taken as described were found to be badly fogged. Part of the fogging was thought to be due to the general glow in the tube produced by the discharge in the quantities of gases driven out by the first sparks. A shutter, therefore, was placed in the tube just back of the diaphragm. This shutter was operated from outside the spectrograph by a powerful magnet. Investigation showed that no amount of glow in the front end of the tube affected the plate when this shutter was closed. It did not stop the fogging during exposure, however, and further investigation was made of the cause. On the supposition that it might be due to

[1] *Physical Review*, 15, 239, 1920.

scattered light reflected from the sides of the tube and the grating, the blackening of the interior of the tube was made more perfect and various systems of diaphragms and shields were tried. The shielding device which was finally used was a tin sleeve 25 cm long, fastened to the diaphragm. This sleeve not only completely shielded the plate from light from the sides of the tube but, after the opening at the far end was adjusted, permitted light from the ruled part of the grating only to fall on the plate. When this sleeve was used, fogging was greatly reduced. A little always remained and the plates at the best have never been wholly clear, though whether the residuum is a light fog or one due to chemical processes in the development is not certain. Indeed, it is very difficult to distinguish between these two effects.

A more serious difficulty was met in eliminating the cause of a corrosion which was noticed on the grating. This corrosion was sufficient to cause marked discoloration of a new grating in a single exposure and to diminish its power so that a few exposures rendered it useless. This situation made it impossible to get the best results from a grating, even for a single exposure, and considerable time was spent in seeking the cause. From the fact that much of the discoloration could be removed by wiping the grating with a bit of absorbent cotton moistened with a mixture of alcohol and ether, it was thought that the corrosion might be largely physical, caused by spattered particles shot off from the spark. To test this possibility a pair of condenser plates were mounted just behind the slit with faces parallel to the light beam. This condenser was charged during sparking to 1000 volts per millimeter by a large storage battery. Very little material was caught on the plates, however, and the corrosion still persisted. To see, then, if the effect was purely chemical, small mirrors of polished copper were placed in the spectrograph entirely out of the path of the light beam. These mirrors became more heavily corroded than the speculum metal gratings. Indeed, sufficient corrosion accumulated for chemical analysis, which showed that the corrosion was a sulphide, produced, apparently, by the free sulphur and sulphur compounds present in the hard rubber insulation and rubber gaskets. The hard rubber insulation of the electrode-bearing

conductors was replaced by redmanol or synthetic amber, produced by the Redmanol Chemical Products Company of Chicago, and the gasket rubber was replaced by sulphur-free antimony-cured gasket rubber kindly supplied by Dr. Grafton, of the Manhattan Rubber Company of New Jersey.

These changes made a great improvement. Not only was the corrosion markedly reduced and the life of the grating lengthened in consequence, but very much less gas was thrown off during sparking, longer series of sparks became possible, and a better vacuum was maintained. A result of the better vacuum was the reduction of the fogging caused by glow in the tube, and much clearer photographs were obtained. There still remained a slow corrosion of the grating due probably to very active gases, possibly higher nitrites given off by the electrodes themselves, since these are known to be produced in great quantities by arcs and sparks in air. Frequent renewals of the grating, therefore, were still necessary, but conditions were much better than those which had existed earlier, and the extreme ultra-violet spectra which had long been hoped for were now obtained.

IV. RESULTS

A typical zinc spectrum obtained under the conditions described is shown in Plate X, *a* and *b*. A plate exactly as obtained is shown at *a*, while *b* shows it magnified laterally, much as stellar spectra are magnified. The lines on the original plate are necessarily short because of the short spark-gap. The slight fogging described renders the background somewhat cloudy. The lines, however, are definite enough to be easily measured by a comparator. They were measured by a Gaertner comparator and the wave-lengths determined as stated above. Table I gives the wave-lengths obtained with their relative intensities. A few other observers have worked on the ultra-violet spectrum of zinc, obtaining in some cases lines of as short wave-length as λ 1450. Such of their lines as seem to coincide with the results of this work are included in the tables. Handke's and Wolff's wave-lengths are taken from Lyman's *Spectroscopy of the Ultra-Violet*, page 123.

TABLE I

ULTRA-VIOLET SPECTRUM OF ZINC

Wave-Length*	Intensity	Character†	Handke Spark	Wolff Arc	McLennan, Ainslie, and Fuller Arc in Vacuo	Saunders' Vacuum Arc
316.4	0					
319.7	0					
322.8	0					
336.0	0					
340.1	0					
342.9	0					
424.9	0					
427.8	1					
430.5	1					
433.3	0					
435.7	0					
437.5	0					
441.5	0					
443.8	1					
446.4	0					
449.4	1					
452.0	1					
455.8	0					
458.5	0	Carbon?				
467.3	2	Double				
472.8	2	Double				
477.7	1					
480.7	0					
502.2	0	Double				
507.6	0	Double				
573.9	1	Carbon				
641.5	0	Carbon				
677.9	5	Double				
703.7	1	Carbon?				
714.0	0					
755.4	0					
767.4	1					
779.6	0					
788.8	0					
802.8	0					
812.5	1					
825.0	1					
833.5	3	Carbon				
844.7	0					
851.5	1					
860.9	1					
871.7	0					
881.4	0					
887.5	0					
898.2	1					
903.6	2	Carbon				
912.0	0					
921.3	0					
927.1	0					

* Wave-lengths reduced to vacuum.
† "Carbon" indicates line probably due to carbon.

TABLE I—*Continued*

Wave-Length*	Intensity	Character†	Handke Spark	Wolff Arc	McLennan, Ainslie, and Fuller Arc in Vacuo	Saunders' Vacuum Arc
935.5	0	Double				
945.7	1	Carbon?				
950.2	1					
957.7	1					
965.2	1					
976.9	3	Carbon				
989.9	3					
1001.2	3					
1009.3	3	Carbon				
1017.6	3					
1023.2	2					
1029.8	2					
1036.1	3	Carbon				
1043.4	2					
1048.8	3					
1066.3	2	Triple Carbon				
1080.5	1					
1085.1	1					
1094.2	1					
1102.2	1					
1109.5	1					
1117.0	1					
1135.6	1	Double				
1145.5	1					
1155.9	1					
1165.9	1					
1176.6	1	Carbon				
1186.6	1					
1194.6	0	Carbon?				
1201.5	1					
1215.9	1	Hydrogen				
1223.1	1					
1228.6	1					
1252.5	0					
1264.0	0					
1273.1	0					
1282.9	0					
1293.3	0					
1306.1	0					
1320.1	0					
1330.5	0					
1342.8	0					
1376.7	0					
1451.1	0			1450.8	1451.1	
1456.8	0			1457.6	1457.5	
1464.3	0					
1473.5	0			1474.7		
1478.5	0					
1485.6	0			1486.2	1486.2	
1499.5	0					
1505.8	0					
1515.9	0					

TABLE I—*Continued*

Wave-Length*	Intensity	Character †	Handke Spark	Wolff Arc	McLennan, Ainslie, and Fuller Arc in Vacuo	Saunders' Vacuum Arc
1552.2	1					
1561.1	1	Carbon				
1581.4	2					
1598.1	2					
1601.4	2					
1619.6	2					
1622.8	2					
1629.3	3					
1639.1	2					
1644.7	2		1647.0			
1651.5	2		1653.2	1649.9		
1672.7	3		1673.6			1673.1
1688.5	2		1689.0			1689.0
1695.4	1		1695.9			
1706.3	2		1707.0			1706.9
1749.4	3		1750.4			1749.6
1753.4	1		1754.1			
1761.7	0					
1767.5	2		1768.0			1767.8
1811.0	1		1811.2			
1833.3	1		1834.0			1833.8
1838.8	2		1839.8			1839.2
1856.3	1					
1864.4	2		1864.6			
1919.6	1		1919.5			1919.0
1930.0	1		1931.2			
1953.5	1		1953.1			
1982.2	1		1982.7			1982.2
2025.7	20					
2062.8	20					
2101.0	5					
2139.2	3					

Saunders' complete results are in the *Astrophysical Journal* (**40,** 377, 1914), while McLennan, Ainslie, and Fuller's work is published in the *Proceedings of the Royal Society of Canada* (**95,** 316, 1919). Wave-lengths 2026.1, 2100.6, and 2139.2 were taken as standards. The values are those of Kayser's *Handbuch der Spectroscopie*, **6,** 1033, reduced to vacuum.

The lines here given coincide well with those published in August, 1918, with the exception of the region 1250–1450 angstroms. On the later plates, several of the lines in this region, and a few other lines, as well, while undoubtedly present, were too weak for measurement on the comparator. The earlier measurements were made with a steel rule and the naked eye and much fainter lines were, therefore, included.

PLATE X

The zinc used for electrodes was chemically pure and it is believed that most of the lines are true zinc lines. A few lines, however, are thought to be due to carbon, as indicated in the table, and λ 1215.9 is assigned to hydrogen. These are the lines as described in the preceding paper which appear on all the plates except those taken with chemically pure silver, which has only the hydrogen line and possibly one more.

The spectrum of zinc, then, is extended to 316.4 angstroms. There can be little uncertainty about the reality of practically all the lines, since most of them have been obtained with different gratings. The position of the group of lines of shortest wave-length is marked in Plate X, *b* and it is hoped they can be seen. The group around 430 angstroms will certainly be apparent. It is interesting to note that the spectrum seems to cease rather abruptly at 316.4 angstroms, for the same grating shows that the iron spectrum extends still farther down.

Clearly the two most important factors in the solution of this problem were a very high vacuum, without which no sparks could be obtained, and a satisfactory grating. For work in the extreme ultra-violet the character of the grating is of the highest importance. Since work is done in the first order spectrum only, the largest part of the light must be thrown into this order. The extreme shortness of wave-length in comparison with grating space necessitates a high uniformity of ruling. Since the appearance of the visible spectrum seems to give little, if any, indication of the value of the grating for the ultra-violet, the earlier gratings were good largely by chance. Great improvement has been effected in the later gratings by the methods described in Professor Millikan's paper which preceded this, though the corrosion of the grating still necessitates frequent renewals.

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