SPECTRA OF HYDROGEN, NITROGEN AND OXYGEN IN THE EXTREME ULTRAVIOLET.

By J. J. Hopfield.

Synopsis.

Spectroscopy of Extreme Ultraviolet.—A method which has been developed of coating *films* with an emulsion suitable for work in this region is described in detail, and also an *oil-cooled discharge tube* of the internal capillary type which will stand an input of 2.25 KW and thus reduce the time of exposure and consequent fogging of the films from 10 to 100 fold. *Transparency of oxygen, nitrogen and air between 500* and *1,800* Å. was investigated. In a vacuum spectrograph with a grating of 50 cm. radius these gases were found to transmit light of from 1100 to 1225 Å. even when at a pressure of 3 cm. At around 1 mm. spectrum lines were photographed from 800 to 1,800 Å. and with oxygen at 0.001 mm., the spectrum was photographed to 430 Å. These gases, then, are not as opaque to light in this region of the spectrum as has been generally supposed.

Spectrum of discharge through hydrogen, 1,220 to 885 Å. The ultraviolet limit is the same for both continuous and disruptive discharges. Four spectrograms are reproduced and the wave-lengths are given for 90 lines below 1,059 Å., presumably due to hydrogen, as a continuous stream of pure gas was supplied. The resonance line was found superimposed in the fourth order on the H_β line; hence its wave-length is 1,215.68 ± 0.03 Å. This coincidence confirms the Bohr formula for this line, which is the first of the Lyman series.

Spectrum of Discharge through Nitrogen, 1,750 to 835 Å.—The continuous discharge gives chiefly the band spectrum of nitrogen, which is extended to 1,026 Å., the wave-lengths of 19 bands below 1,385 Å. being given. The wave-lengths of 50 new lines obtained with the disruptive discharge are also given and four spectrograms are reproduced.

Spectrum of Discharge through Oxygen, 1,863 to 507 Å.—Wave-lengths of about 100 new lines obtained with a disruptive discharge are given and six spectrograms are reproduced. *When mercury vapor was present* about 15 additional lines extending to 433 Å. were obtained.

Explanation of fluorescence observed around aluminum spark in air by Lenard in 1910, to a distance of 4 cm., may depend on the transparency of air to light of wave-length 1,000 to 1,400 Å.

Introduction.

It has long been assumed by investigators in the extreme ultraviolet, that most gases, and especially oxygen are opaque in this region. As a consequence it was believed that it was practically impossible to study the ultraviolet spectrum of oxygen under the conditions which usually exist in a vacuum grating spectrograph. About a year ago, the author, supposing oxygen to be opaque, attempted to get its spectrum by using two gases, the one hydrogen and the other oxygen. These gases were kept localized, the opaque one filling only the discharge tube, and the transparent one, hydrogen, the receiver. This was accomplished by suitably directing the two currents of gas.[1] The method was successful and suggested that after all oxygen might be transparent in the extreme ultraviolet. Following up this experiment was another in which both receiver and discharge tube were filled with oxygen, and in this case an extensive spectrum was obtained.[2] The spectrum of air also was obtained. This of course was expected in view of the transparency of nitrogen to 975 as found by Lyman,[3] and the now-established fact of the transparency of oxygen in this region.

There seems to be no especial difficulty, once the ultraviolet technique is acquired, in getting the spectrum of oxygen, and thus showing its transparency by obtaining its spectrum in the ordinary manner. In the progress of this research equipment was developed which when applied to the spectra of hydrogen and nitrogen yielded results that extended the spectra of these two gases. Other points of significance regarding these spectra were also brought out, hence these spectra as well as those obtained with oxygen will be described in this paper.

APPARATUS.

Most of the apparatus used was that ordinarily employed by investigators in this region of short wave-lengths, that is: a vacuum grating spectrograph, the necessary vacuum pumps, mercury traps, pressure gauges, generators for the gases used, driers, etc. The spectrograph, designed by E. P. Lewis and built in the department shop, consists of a sector-shaped cast brass box and holds at the smaller end, a concave grating of 50 cm. radius of curvature. This grating is of exceptionally fine quality. Within the larger end is a film-holder carried on a movable stage. This stage may be raised or lowered by rotation of a screw through a ground-glass joint, so that several exposures may be taken on the same film. This large end is also fitted with a broad flange against which the heavy glass lid is pressed. The plates were examined and measured on a Gaertner 20 cm. comparator. This comparator is the property of the Rumford Committee of the American Academy of Sciences, and was kindly loaned to the author by R. T. Birge for whose use the instrument was built. Furthermore, in order to fulfill the particular requirements of the research it became necessary to develop a special film for obtaining the photographs, and also a special discharge tube as the source of light. Since these last-mentioned articles of equip-

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[1] PHYSICAL REVIEW, **18**, 327, 1921.

[2] SCIENCE, **54**, 553, 1921.

[3] Astrophysical Journal, 43, 89, 1916.

ment may be found useful to other investigators, they are fully described in the next few paragraphs.

Films.—The plates developed by Schumann could not be used to the best advantage on account of the large curvature of the focal field employed. Hence to obtain the spectrum in many orders in sharp focus, films sensitive to the ultraviolet were made. The method of making them is as follows:

Unexposed commercial films of the desired width are soaked in a solution of sodium thiosulfate until the emulsion is just dissolved. These films are then washed for three or four hours in running tap water, rinsed in distilled water and then dried.

Individual trays for the films are prepared as follows: Pieces of thin glass are cut one centimeter narrower and one centimeter shorter than the films to be prepared. (Old photographic plates from which the gelatine had been removed were used.) These glass strips, when fitted with two glass cross-pieces each, constitute the trays. These cross-pieces or feet, in order to hold the trays level on a levelled surface, are most conveniently made by drawing off pieces of *round* glass tubing, and labelling each pair of adjacent pieces with the same number by means of a file. The glass plate is then slightly warmed and a pair of these feet is stuck to it with warm red wax, care being taken to press them in contact with the plates. The spacing of the feet may be such as to divide the glass plate into segments of about the following ratios, 1 : 2 : 1. The diameter of the tubing employed may be any convenient one; about 5 millimeter for a 4 × 15 cm. plate is found satisfactory. To avoid disturbances due to surface tension, the shoulders of these short rods should not extend as far out as the edge of the trays. Mats of filter paper are cut to the size of the trays.

The trays with their mats (as many trays as films) are then mounted on a levelled table of glass. A good piece of window glass serves very well for this purpose if the films are not too large, otherwise plate glass is recommended. The mats, now on the trays, are each wetted with distilled water, about 10 c.c. being used for each 4 x 15 cm. mat. The films of the desired size are wetted in distilled water and placed upon the mats with the former emulsion side downwards. The following operations must now be carried out in a photographic dark room in brown light. The emulsion (a note on its preparation is given in a succeeding paragraph) about 20 c.c. per 5 x 16 film, is poured from a pipette over the film. If the emulsion does not immediately cover the film, it may be spread evenly by means of the pipette stem, and a little more added to replace any emulsion lost in the operation. The emulsion is then allowed to settle for three or four hours after which time it is carefully drained off, the films stripped from the paper and hung up to dry.

For assistance in draining, a rail of small glass tubing is waxed to the left-hand edge of the glass table, and a small glass rod, "L"-shaped, is used to catch the feet of the trays in order to pull them around to this tripping rail. These feet also serve as handles while removing the films. To pin up the films for draining and drying, it is convenient to have a horn-tipped tweezers with a longitudinal groove cut on the outside of one of the tips and this channel to end in a transverse notch across both tips, so that the groove is towards the operator and the notch uppermost when the film is held by the tweezers in the right hand. Then pinning, even in the dark, is a simple matter, and there is little danger of either dropping or marring the film in the process. It is detrimental to the film to grasp it with the tweezers too soon after beginning to drain for the reason that the undrained liquid forms a surface skin over the emulsion; a slight contamination from the tweezers ruptures this skin and as a result a streak may extend the entire length of the film. To avoid this and at the same time save a minute in this preliminary draining, one may have three or four trays at the tripping rail inclined on corks, and they then will be well drained when needed. When the films are thoroughly dried, they are warped with emulsion side inward and then placed on edge in boxes for storage. The sides of these boxes should have been fitted with corrugated filter paper so as to hold the films separated and in place. In this manner a number of films may be packed into each box. These smaller boxes may be put into a larger one and thus the films, now provided with twofold cover, are well shielded from light.

The advantage of having warped films is evident when one is using them, for if by accident one is dropped onto the floor it always alights on its back; other advantages are easy storage, ready adaptability for mounting, for measurement, or for reproduction.

The method described above is readily adaptable, with only slight modification, to making plates. Evidently the process is not one of delicate technique, for if one plate or film is spilled the rest are unharmed, and even it is not spoiled for the wet mat keeps its bottom dry of emulsion.

One may use any ordinary commercial developer if diluted three- or fourfold with cold tap water. It may be used at room temperature. Fresh films are not sensitive; they become so in about a week, and then seem to increase in sensitiveness with age.

In the preparation of emulsion, the method devised by Schumann[1] was employed with a few modifications, namely; a good quality of French

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[1] Baly, "Spectroscopy," p. 375.

pastry gelatine was used instead of Nelson's number one as recommended by Schumann, and only 50 to 60 per cent. as much as used by him, and the sensitizing temperature was varied between 60 and 40° C.

The films thus made proved very satisfactory in getting the spectrum of oxygen. They were less satisfactory for the spectrum of air, and failed almost completely on account of fogging when a long exposure was used in an attempt to extend the spectrum of nitrogen. It soon became evident that in order to get the spectrum of any gas that easily ionizes or forms corrosive compounds that attack the film, a short exposure, much less than an hour would be necessary. At a given pressure, the amount of fogging seems to increase rapidly with the time of exposure whatever the strength of the current might be. (It may be stated that my observations confirm those of Lyman, in that there seems to be for minimum fogging a certain nice balance between the current density, the capacity and induction in the circuit, and it may be added the heat produced in the discharge tube. With such adjustment an exposure of two hours in oxygen at 0.04 mm. pressure gave no appreciable fog on the film.) Hence a more intense source of light was needed, and a continuous input of more than 200 watts would soon destroy an ordinary tube of the internal capillary type. Thus to meet the need of this greater power capacity for producing a more intense light, an oil-cooled tube such as shown in the figure was designed and used.

Discharge Tube.—Description of the figure. *A* opens into the receiver of the vacuum grating spectrograph, *B* is an outlet to the pumps, the kerosene oil used for cooling is pumped in at *C* and leaves at *D*, *E* represents an inlet for gases if one wishes to use it. The capillary constriction is a safeguard against any of the drying chemicals being forced into the discharge tube by any sudden rush of gas. *F* is a cylindrical electrode in contact with the glass and is thus cooled by it. A quartz window is at *G*. This is used for getting the quartz-mercury-arc comparison spec trum. The tube is made of pyrex, has a total length of 23 centimeters,

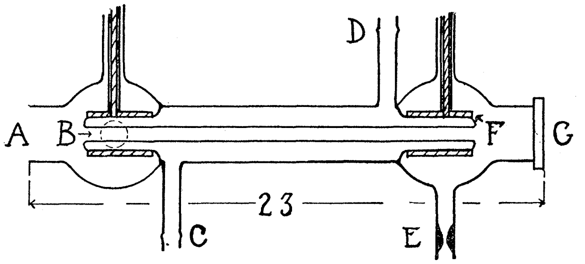

Fig. 1.

and is represented approximately to scale. This tube was found to have a power capacity of about 2.25 kw. It reduced the time of exposure from one or two hours to as many minutes and hence satisfactorily solved the problem of fogging.

METHOD.

The film is placed in the receiver. A piece of heavy plate glass with a border of especially prepared rubber grease is pressed over the opening and the oil pump started. After a half hour the pressure in the receiver is reduced to 0.04 or 0.05 mm. The receiver is then rinsed with a small quantity of the dried gas to be studied, and 4 or 5 cm. of the gas admitted and allowed to stand for an hour in order to "season" the film, for this shrinks somewhat on being exposed to the dry atmosphere of the receiver. The gas is then pumped out, and, while the spectrum is being photographed, a steady stream of gas is kept flowing through the receiver into the discharge tube, leaving via B to the pumps. Since the average exposure is but two or three minutes per spectrum, this may easily be done without using a prohibitive quantity of gas. By properly adjusting the intake and rate of pumping the pressure in the receiver may be kept at any desired steady value and at the same time a fast circulation maintained. When low working pressures are desired in the receiver, a mercury condensation pump is used, and a mercury trap cooled with liquid air keeps the mercury vapor out of the receiver. It is also necessary when working at low pressures to admit the gases through long capillary tubes.

DESCRIPTION OF PLATES.

All the photographs described below are reproduced in Plates I. and II., but necessarily many details are lost in the reproduction. It is hoped, however, that most of the essential features will be evident.

Plate I., Figures 1 and 2.—Hydrogen, direct current 320 milliamperes, 3 mm. pressure, circulation, 2 minutes' exposure. This film shows some of the series lines of hydrogen. The resonance line is shown in four orders. It is evident that a large current density brings out the series lines in the ultraviolet. This resonance line is shown self-reversed in the three higher orders, and in the fourth order the self-reversed portion coincides exactly with the sharp line H_β of the Balmer series. H_γ and H_δ also appear on the prints. This coincidence of the resonance line with H_β at once furnishes not only an accurate determination of the wave-length of the former, namely, one fourth of that of H_β, but also checks its value as derived on the Bohr theory. The first statement is strictly valid because the spectra are obtained under practically vacuum conditions, hence the wave-lengths as found by coincidence of orders need not

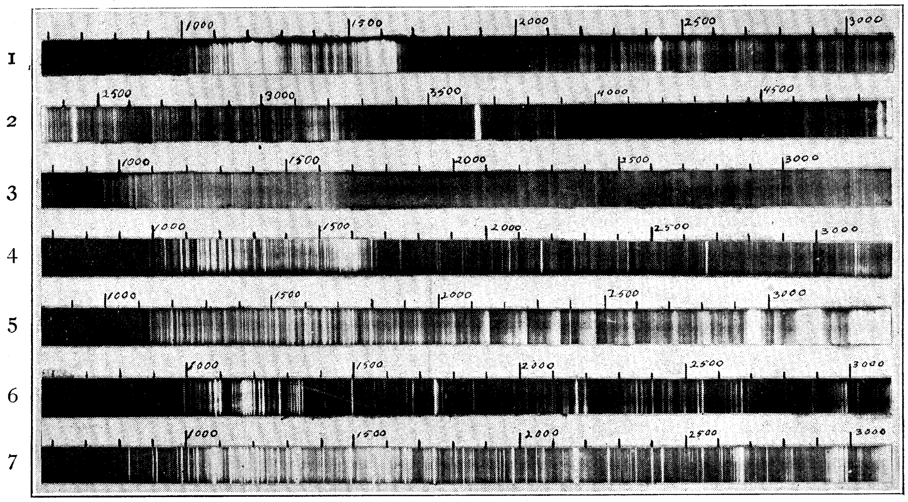

Plate I.

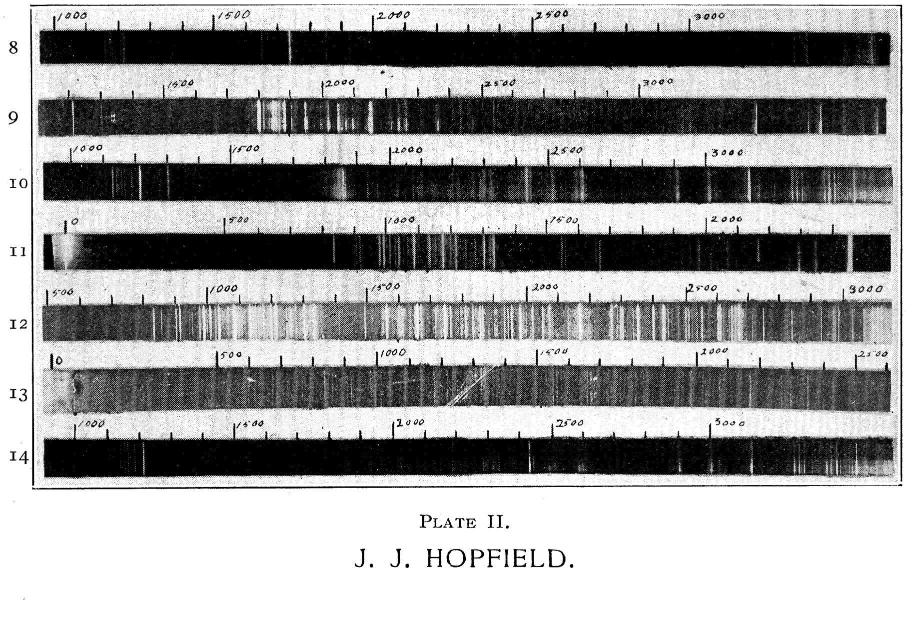

Plate II.

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be modified for the varying dispersion of the medium. The accuracy of the application of the Bohr theory to this resonance line may be seen by comparing the formula for its frequency with that giving the frequency number of H_β. The first is given by

$$\nu_1 = R\left(\frac{1}{1^2} - \frac{1}{2^2}\right)$$

and the last by

$$\nu_2 = R\left(\frac{1}{2^2} - \frac{1}{4^2}\right)$$

Hence one fourth the frequency number of the first is exactly the frequency number of the second. Thus the coincidence of the first order of the one line with the fourth order of the resonance line, as the theory would predict, has been found.

The wave-length of H_β as found by Curtis[1] and reduced to vacuum is 4862.677 Å. on the International System. Hence the wave-length of the resonance line is 1215.68Å. Owing to the unusually favorable conditions of observation, that is, a sharp line occurring in the middle of the reversed portion of a more diffuse line, it is thought that the probable error in this determination is about 0.02 or 0.03 Å. This indicates that the value attributed to this line by Lyman is too high by 0.3 Å., and that the value used by Millikan is more nearly correct. It is safe to assume, in the opinion of the author, that the best values of the other lines of the Lyman series are likewise the theoretical ones. Thus the first three that have been found by Lyman and which also occur on our plates (see Plate II., 12; Table VI.) have the following wave-lengths 1215.68, 1025.73, and 972.54 Å. These lines, which are readily obtained, may be used as standards in the ultraviolet where up to the present none have been established with an accuracy exceeding 0.1 Å.

Figure 3.—Hydrogen, direct current, 320 milliamperes, circulation, 8 minutes' exposure. This shows the extension of the secondary spectrum of hydrogen to 885.6 Å. The wave-lengths are recorded in Table I. Some of the lines recorded by Lyman[2] are also shown for the sake of comparison. (The wave-lengths in this table and subsequent ones were not measured in the expectation of great accuracy. It is hoped, however, that the individual values will be found accurate to at least 1 Å.) The continuous spectrum of hydrogen mentioned by Lewis[3] is shown on this plate in the region between 1680 and 1950 Å.

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[1] Proceedings of the Royal Society of London, A 90, 605, 1914.

[2] "Spectroscopy of the Extreme Ultra-violet," p. 112.

[3] Science, 51, 947, 1915; Physical Review, 16, 376, 1920.

TABLE I.

Hydrogen.

λ.	I.	λ.	I.	λ.	I.
885.6	1	955.3	4	1006.1	3
889.2	1	956.1	1	1006.4	4
892.5	1	957.7	2	1007.9	4
895.3	1	959.4	1	1009.6	2
903.1	1	960.5	2	1011.0	3
905.3	1	962.5	1	1012.4	4
906.7	1	963.5	3	1013.4	1
908.9	1	964.8	1	1014.6	1
911.5	2	968.9	1	1016.2	5
912.7	1	969.8	2	1017.3	4
916.9	3	970.9	4	1018.6	4
917.8	2	971.8	1	1021.3	3
919.9	4	975.4	1	1023.9	4
921.1	1	977.2	8	1025.8	8
922.4	2	978.8	8	1027.3	3
924.3	3	981.9	5	1029.4	2
927.4	2	984.4	1	1031.0	7
928.8	2	985.2	2	1034.6	7
929.5	2	989.0	3	1035.5	1
932.0	2	989.9	2	1036.9	4
935.6	5	991.1	3	1040.4	7
941.9	1	992.0	3	1044.7	4
942.6	1	993.8	1	1045.5	5
944.3	1	995.9	2	1047.1	7
946.2	3	997.1	2	1048.0	7
949.8	2	998.4	1	1049.2	4
950.6	2	999.4	1	1051.2	5
951.9	4	1001.4	4	1053.1	6
952.9	2	1002.3	4	1056.1	6
954.4	4	1004.4	3	1059.2	4

Figure 4.—Hydrogen, disruptive discharge, 0.02 mm. pressure, circulation, 20 minutes' exposure, mercury arc spectrum superimposed. No extension of the ultraviolet spectrum is observed under these conditions. The lines at λ 835, and λ 900 and many of the strong lines that appear throughout the entire spectrum are due to air.

Figure 5.—Nitrogen, direct current 324 milliamperes, 3 mm. pressure, circulation, 2 minutes' exposure. Table II. This spectrum is found to be principally a band spectrum extending to λ 1025.8, but many

TABLE II.

Nitrogen, Direct Current.

Line Spectra with D.C.		Lyman, λ.	Bands Degrading towards Red, λ.	Bands Degrading towards the Violet, λ.
λ.	I.			
1329.5	3		1054.5	1025.8
1412.4	3		1164.3	1033.3
1493.2	6	1492.8	1183.6	1046.7
1494.7	5	1494.8	1194.3	1067.0
1561.1	6		1213.9	1072.7
1657.2	6		1244.2	1086.0
1742.9	6	1742.7	1256.0	1110.4
1745.3	5	1745.3	1288.7	1152.2
			1322.7	
			1353.7	
			1384.7	

lines also occur. Lyman had previously explored the band spectrum of this gas to 1385 Å. The following evidence is offered showing that this new spectrum is probably due to nitrogen: It does not occur in either hydrogen or oxygen under the same or under any other conditions, when presumably the same impurities are present in these gases as in nitrogen. Of the line spectrum, two pairs shown in this table were found by Lyman[1] and the pair at λ 1493 was attributed to nitrogen, while the second pair at λ 1743 he states with less assurance is probably due to the same gas. The reason for this lack of certainty on his part as to the source of the above pair seems to be the possible impurities that might have been torn from the tube by the disruptive discharge used by him. That this pair is of the same origin as the first pair is indicated in the present experiment by the fact that it is produced by direct current in nitrogen, whereas the metallic lines of the electrodes which always occur when a disruptive discharge is used, never occur in this milder form of excitation. The other lines shown in Table II. are also probably due to nitrogen.

That a high-current density, such as used here, brings out line spectra not shown when smaller currents are used, is evidently due not only to the greater degree of ionization which must necessarily exist in order to carry the greater current, but also to the greater degree of molecular dissociation present at the high temperature that exists in the tube.

The near ultraviolet and visible spectrum as far as the green shown on our plates has not yet been examined for new lines.

Figure 6.—Nitrogen disruptive discharge, 1.5 mm. pressure, circulation, 2 minutes' exposure. Table III. This spectrum is of interest in that

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[1] "Spectroscopy . . .," p. 113.

it shows that the transparency of the gas at this pressure exists to about λ 800. In parallel columns in the above table of wave-lengths are shown lines obtained by Lyman[1] in helium. In fact this table and subsequent ones contain all the lines, except two faint ones, obtained by him in helium. That his lines are due to air entering his spectrograph as an impurity, despite his great care in eliminating such impurities, rather than to helium, seems quite probable.

Figure 7.—Nitrogen, disruptive discharge, 0.02 mm. pressure, circulation, 20 minutes' exposure. The lines found by Millikan[2] on the refrangible side of λ 700 and ascribed to this gas were not found, perhaps owing to the opacity of the gas, which seems even more opaque than oxygen in this region.

Plate II., Figure 8.—Nitrogen, disruptive discharge, 3.5 cm. pressure, no circulation, 2 minutes' exposure. This film was taken in order to test the transparency of nitrogen. It was fogged because of the active nitrogen formed in the discharge tube and which spread into the receiver.

TABLE III.

Nitrogen—Disruptive Discharge.

λ.	I.	Lyman, Helium, λ.	λ.	I.	Lyman, λ.
834.9	2	834.8	1328.0	1	
838.3	1		1329.7	1	
917.2	2	916.7	1331.0	2	
978.1	3	977.6	1335.3	15D	
990.8	2	990.2	1343.7	4	
992.3	4	992.0	1345.5	3	
1006.8	1		1346.6	3	
1011.0	2	1010.6	1361.0	1	
1026.4	2	1026.0	1378.1	1	
1037.7	4	1037.0	1379.3	1	1379.5 Al.
1085.5	40	1084.9	1412.3	4	
1093.8	1	1086.1	1463.6	1	
1097.9	3		1467.6	1	
1101.3	4		1493.1	8	
1135.3	4	1134.7	1494.9	7	
1144.1	2		1536.2	1	
1152.7	1		1548.2	1	
1164.8	3		1551.0	1	
1168.4	4 Doublet		1561.2	8	
			1573.3	1	

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[1] Astrophysical Journal, 43, 89, 1916.

[2] Proceedings of the National Academy of Sciences, 7, 289, 1921.

Table III.—*continued.*

λ.	I.	Lyman, Helium, λ.	λ.	I.	Lyman, λ.
1176.0	20 Complex	1175.5	1574.4	1	
1184.1	20 "	1176.3	1590.1	2	
1189.5	2		1593.2	2	
1191.3	1		1611.6	1	1611.8 Al.
1200.4	15	1199.8	1616.1	1	
1215.7	15	1216.0	1627.5	2	
1225.5	8		1629.1	2	
1229.0	6		1647.5	3	
1243.5	4		1650.0	4	
1247.8	3	1247.9	1657.2	8	
1258.9	1		1670.5	1	
1261.7	1		1675.8	6	
1270.3	2		1677.8	2	
1276.0	10				
1280.6	1		1703.5	1	
1300.6	1		1718.5	1	1718.3 Al.
1311.0	5		1740.2	5	
1319.6	5		1742.7	10	
1324.2	4		1744.9	8	
1326.9	1		1747.5	4	
			1751.3	6	

From considerations of the dimensions of the spectrograph used, and the pressure of the gas as stated above, it is evident that a layer of nitrogen 4.5 cm. thick and at atmospheric pressure is easily transparent down to 1070 Å. More will be said concerning this in a subsequent paragraph.

Figure 9.—Oxygen, direct current 320 milliamperes, circulation, 3 mm. pressure, 14 minutes' exposure. This plate shows clearly the absorption band of oxygen first observed by Schumann. In the neighborhood of λ 1300 is shown the transparent region whose less refrangible edge was located by Lyman[1] and whose more refrangible edge was found by the author at about λ 1000. The short wave-lengths shown in the plate are λ 1215.7, λ 1217.7, λ 1302.5, λ 1305.2, and λ 1306.4. The first is the resonance line of hydrogen and the others are probably oxygen lines. The last three lines might easily be mistaken for a triplet, except for the fact that their relative intensities vary with the nature of the discharge used. Thus with a disruptive discharge λ 1302.5 is strongest, while with direct current such as used here it is weakest. The last two probably

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[1] "Spectroscopy of the Extreme Ultra-violet," p. 64.

form a doublet. The bands near λ 1800 are presumably CO and O_2 bands.

Figure 10.—Oxygen, disruptive discharge, 1.5 mm. pressure, circulation, 2 minutes' exposure. Table IV. Besides the lines on the more refrangible side of the absorption band mentioned above, most of which are probably due to oxygen, this spectrum contains another item of interest, that is, a new absorption band for oxygen is shown beginning at λ 1000 and extending towards the shorter wave-lengths.

TABLE IV.

Oxygen Disruptive Discharge.

λ.	I.	λ.	I.
1036.8	5	1743.1	5
1083.7	4	1745.7	4
1109.7	4	1752.3	3
1128.4	8	1760.9	8
1129.4	5	1781.4	7
1130.3	4	1787.0	7
1132.3	10	1799.7	4
1142.1	5	1821.9	3
1143.8	7	1854.7	6 Al.
1147.5	7	1862.8	8 Al.
1149.2	3		
1158.7	5		
1167.7	7		
1168.5	5		
1189.7	5		
1215.7	15		
1217.8	10		
1277.7	8		
1302.5	10		
1305.2	8		
1306.4	7		

Figure 11.—Oxygen, disruptive discharge, 0.04 mm. pressure, circulation, 2 hours' exposure. Table V. Another type of discharge tube was used in obtaining this spectrum. This film is of especial interest because it extends the spectrum of oxygen to λ 507.2.[1] It also shows that the second absorption band of oxygen gradually fades away with reduced pressure. Even the first band, that is, that in the neighborhood of λ 1500 disappears rapidly as the pressure is reduced so that spectrum

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[1] Some of these lines were found by Millikan and independently by the author by this distinctly different method.

lines begin to appear throughout its entire extent. It thus becomes evident that instead of oxygen being one of the most opaque gases in the Lyman region, it is perhaps one of the most transparent in the more

Table V.

Oxygen, Disruptive Discharge.

λ.	I.	Millikan, λ.	Lyman (Helium), λ.	λ.	I.	Lyman, λ.
507.2	1	507.8		946.1	3	
538.1	1			954.4	1	
554.2	1	554.2		962.8	2	
580.5	1			972.3	1	972.7
599.6	1	599.5	599.0	977.6	10	977.6
				980.2	3	
608.4	1			989.9	10	
610.0	1	610.1		991.5	10	
616.5	1	616.7		1000.0	3	
625.0	1	625.2		1006.4	1	
644.5	1	644.0	643.7	1010.5	11	
673.3	1			1026.0	5	
685.7	2			1028.6	2	
703.0	2	703.1	702.4	1037.0	10	
704.1	1		703.5	1040.6	1	
718.9	3	718.5	718.2	1041.8	1	
763.5	1			1066.3	5	
764.5	1			1085.2	10	
765.4	1			1110.3	2	
776.2	1			1103.7	1	
787.9	2			1114.4	1	
790.4	2			1122.9	1	
796.9	3			1128.4	5	
833.7	8		796.8	1129.6	2	
834.5	4	834.0	833.4	1130.4	2	
835.1	10		834.8	1132.5	2	
859.0	5			1134.8	10	
879.9	2			1139.0	2	
883.3	1			1142.0	2	
884.3	1			1144.1	3	
889.7	5			1147.4	4	
904.7	10		904.6	1149.2	1	
916.4				1149.8	1	
917.8	15			1151.3	1	
928.8	1			1152.6	6	
923.9	3			1153.9	2	

TABLE V.—*continued.*

λ.	I.	λ.	I.
1164.7	1	1265.1	1
1167.	2	1267.7	1
1169.0	2	1269.8	1
1175.6	20	1272.6	1
1183.0	1	1275.6	2
1184.8	3	1277.5	4
1193.7	2	1280.7	1
1194.8	1	1286.6	1
1197.4	4	1288.7	1
1200.1	10	1290.3	1
1206.8	3	1295.1	1
1209.9	1	1296.9	1
1215.7	10	1299.2	1
1218.0	5		
1222.3	1		
1225.6	1		
12 0.6	2		
1239.1	4		
1243.0	3		
1247.7	10		

refrangible part of that region and in the beginning of the Millikan region. The table also gives, in parallel columns, the values of the wave-lengths found by the author in oxygen, those found by Millikan and attributed to oxygen, and those found by Lyman in helium. This experiment strengthens Millikan's assertion that the lines he observed are oxygen lines. Of course all the lines recorded in the table are not oxygen lines. Many are common to the spectrum of nitrogen, a few to the spectrum of hydrogen, and some arise from the impurities in the receiver. Still after the elimination of all of these, it is the opinion of the author, that there remain in the region between λ 800 and λ 1400 many strong oxygen lines.

Figure 12.—Oxygen, disruptive discharge, 0.02 mm. pressure, circulation, exposure 1 hour. It is hoped that this plate will show the short wave-lengths mentioned above better than Fig. 11. The spectrum is not as pure as the one described above.

Figure 13.—Oxygen, disruptive discharge, 0.001 mm. pressure, circulation, about 30 minutes' exposure. Table VI. In this experiment the mercury condensation pump was kept running and no attempt was made to keep the vapor out of the receiver and discharge tube. Since the pressure indicated above was read on a McLeod gauge, it represents the

TABLE VI.

Occurring in Oxygen with Mercury Vapor.

λ.	I.	Millikan, λ.
433.0	V.D.	
451.1	V.D.	
526.0	1	525.7
530.2	1	
533.5	1	
558.1	1	
574.5	1	
629.8	2	629.6
635.7	V.D.	
651.	1	
660.6		
671.8	3	
691.3	1	
747.5	2	
773.0	2	
788.1	1	

partial pressure of oxygen only. At this low pressure, many new lines were observed in the ultraviolet. These new lines are indicated in Table VI. Perhaps mercury and oxygen are the principal sources. Even a cursory examination of this plate shows that the lines near λ 600 are of intensity comparable with those of longer wave-length. This would indicate that in a strong discharge in oxygen these short waves are produced strongly with the rest, but of course are absorbed before they reach the plate.

Figure 14.—Oxygen, disruptive discharge, 1 cm. pressure, circulation, 15 minutes' exposure. This plate shows how transparent oxygen is in this region of transmission below its absorption band. Another plate was taken more recently at 2.5 cm. pressure, and 15 minutes' exposure. This latter shows practically the same lines as the above plate and with only slightly diminished intensity. Hence oxygen in layers of minimum thickness of 3.3 cm. has a narrow region of transmission, which includes the wave-lengths 1100 and 1217.7 Å. It has already been shown that nitrogen is equally transparent in this region in layers 4.5 cm. thick. Hence air has a remarkable transparency in this region of short wave-lengths, for if one uses as the basis of reckoning, the proportion of oxygen and nitrogen in the air, it is seen that the absorption equivalent of the above-mentioned thicknesses of oxygen and nitrogen when mixed in air is a layer 4.2 cm. thick. This fact recalls an observation of Lenard[1]

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[1] Sitz. Heidelberg Akad. d. Wiss. Abhand., p. 31, 1910.

who detected a fluorescence about an aluminum spark in air that extended to a distance of 4 or 5 cm. from the source. The above-mentioned facts of the short waves of lengths 1100–1218 Å. being able to penetrate that thickness of air would explain the fluorescence. They probably are not the same rays that penetrated both quartz and fluorite as stated by him.

It gives the author great pleasure to acknowledge his indebtedness to his teacher Professor E. P. Lewis, by whose suggestion this research originated, and to express his thanks to his friend Professor R. T. Birge, for his many kind suggestions.

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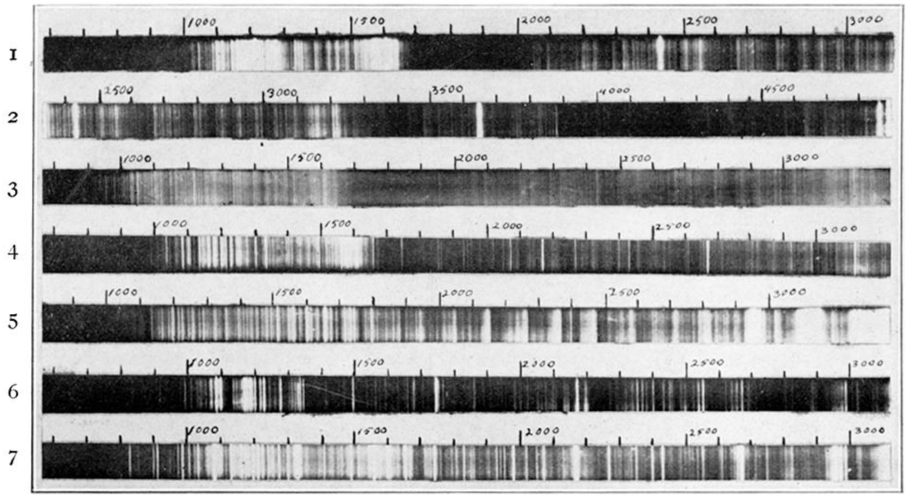

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Plate I.

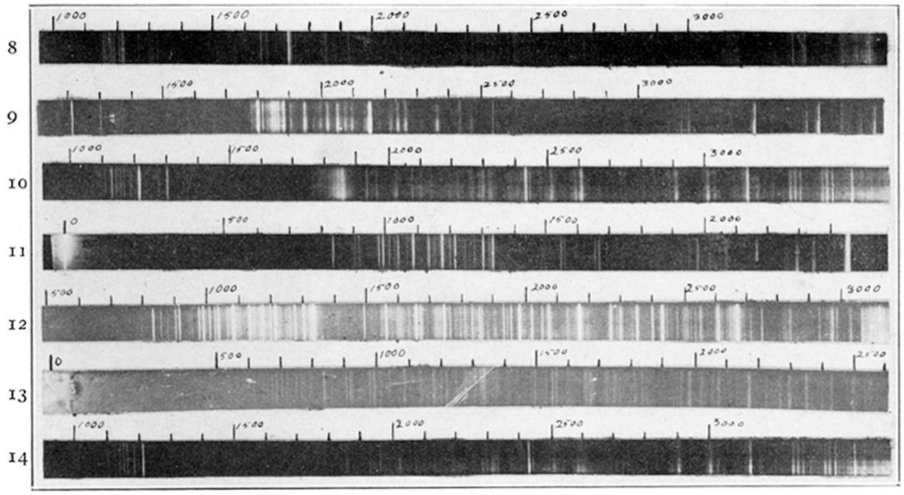
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PLATE II.