The Origin of Radio Fade-Outs and the Absorption Coefficient of Gases for Light of Wave-Length 1215.7A

WILLIAM M. PRESTON
Research Laboratory of Physics, Harvard University, Cambridge, Massachusetts
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It has been suggested that the ionization in the D region which causes radio fade-outs is caused by radiation of the first line of the Lyman series of hydrogen, at 1215.7A, from solar eruptions. The actual absorption coefficients for this line, previously only roughly known, have been measured with the following results: oxygen 0.28, nitrogen $\leqslant 0.005$, carbon dioxide 2.01, water vapor 390 (all values reduced to NTP). Although it can probably penetrate to sufficiently low altitudes, it appears unlikely that this line can produce ionization and hence cause fade-outs. The possibility is considered that these may be due to higher Lyman series members, or to x-rays of around 2A wave-length.

RADIO fade-outs are characterized by the weakening or disappearance of reflections of high frequency radio waves from the E and F layers of the ionosphere. The effect is transient, lasting from a few minutes to an hour or more. The immediate cause is a sudden increase in the ionization in the D region, somewhere below an altitude of 100 km, where because of the relatively higher pressure the presence of free ions results in the absorption of short radio waves. Fade-outs have been definitely correlated with eruptions or localized disturbances of the sun's chromosphere.[1,2] The coincidence in time between the initial observation of a solar disturbance and the onset of a fade-out is close, and the fade-out occurs only over the daylight half of the earth, so we may assume that the ionization is caused by ultraviolet light rather than by charged corpuscles. This radiation must be in part at least of a frequency such that it can penetrate rather deeply into the earth's atmosphere and cause ionization where it is absorbed.

Study of these solar eruptions with the spectroheliograph has shown that they are characterized by the sudden appearance of exceptionally bright flocculi, in the neighborhood of sun-spots. The emission consists solely of an intense line spectrum in which the Balmer series of hydrogen and lines of He I and Ca II have been identified.[3] The intensity of Hα in emission is of the same order of magnitude as the intensity of the blackbody continuum in near-by areas. Since the emission of Hα is necessarily followed by the emission of Lyα (the first line of the Lyman series of hydrogen, at 1215.7A), and since the intensity of blackbody emission falls off very rapidly in the ultraviolet, it may be inferred that the intensity of Lyα is enormously greater than that of the blackbody continuum in the same wave-length region. In fact, Richardson estimates[4] that the emission from a single bright eruptive area of Lyα alone is equal to about 60 percent of the total blackbody radiation from the entire solar disk, in the wave-length range from 1100A to 1300A. Now Lyα lies in a region of comparatively great transparency of air,[5] a sort of "hole" between the strong continuous absorption of O_2 (1760–1350A) and the diffuse absorption bands of both O_2 and N_2 extending from 1000A to shorter wave-lengths. Martyn and his co-workers have suggested that Lyα-radiation, because it is emitted from solar eruptions and because of its penetrating power, may be responsible for fade-out ionization.[2]

The actual value of the absorption coefficient of air at this wave-length has been only roughly estimated, because of technical difficulties in measuring very small absorption coefficients by the ordinary method of introducing gas into a spectrograph connected directly to a discharge tube source, without an intervening window. In

[1] J. H. Dellinger, Terr. Mag. **42**, 49 (1937); R. G. Giovanelli and A. J. Higgs, Terr. Mag. **44**, 181 (1939).
[2] Martyn, Munro, Higgs and Williams, Nature **140**, 603 (1937).
[3] R. S. Richardson and R. Minkowski, Astrophys. J. **89**, 347 (1939).
[4] R. S. Richardson, Astrophys. J. **90**, 368 (1939).
[5] T. L. Lyman, Phys. Rev. **48**, 149 (1935).

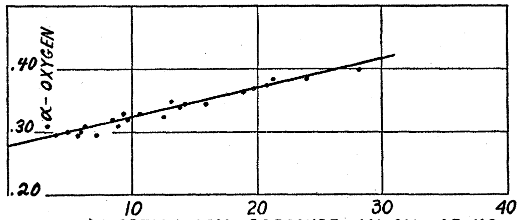

FIG. 1. The absorption coefficient α of oxygen, per centimeter path reduced to NTP, as a function of the pressure in the absorption cell.

view of a doubt expressed by Wulf and Deming[6] as to the ability of Lyα-radiation to penetrate the atmosphere much below 100 km, it appeared worth while to obtain a reasonably accurate value. It happened that an apparatus was available in this laboratory which, although built for a different purpose, was well suited for the problem.

Experimental Procedure and Results

The source was a Wood-type hydrogen discharge tube. An absorption cell 21.8 cm long was closed at each end by a lens of lithium fluoride, which is satisfactorily transparent at this wave-length if properly handled.[7] Light from the discharge was rendered parallel by the first lens, passed through the absorption cell, and was brought to a focus on the slit of a one-meter grating vacuum spectrograph by the second lens. A second slit in the focal plane of the spectrograph isolated the light of Lyα, which then passed through a lithium fluoride window into an argon-filled photoelectric cell. The latter had a sensitive element made of platinum, which is insensitive to light of wave-length longer than 2500A, an advantage in reducing the background due to stray reflected light. High sensitivity and stability were obtained by measuring the photoelectric current with a balanced d.c. amplifier[8] and a sensitive galvanometer.

The intensity of Lyα was first measured when the absorption cell was evacuated. The gas to be studied was then quickly admitted from a storage bulb, to any desired pressure up to atmospheric, and the decreased intensity noted. The approximately linear relationship between light intensity and galvanometer deflection under the operating conditions was shown by the consistency of data obtained at different intensity levels and with different potentials on the photoelectric cell. The source discharge was largely "atomic," as shown by its crimson color. In a preliminary spectrogram Lyα was far more intense than any neighboring molecular line, and the dispersion of 8.3A/mm was sufficient so that no appreciable intensity of radiation other than Lyα could enter the photo-cell, even with a comparatively broad slit opening.

Tank oxygen was freed from water vapor and CO_2 by passing it slowly through tubes containing P_2O_5 and KOH. The results obtained are shown in Fig. 1, where the absorption coefficient α is plotted as a function of the pressure of O_2 in the absorption cell. Here α is defined by the equation $I=I_0e^{-\alpha l}$, where I_0 is the intensity measured with the absorption cell evacuated, I the intensity transmitted with gas in the cell, and l the path in centimeters of gas reduced to normal pressure and temperature. In the case of oxygen, α was measured over a pressure range of from 3 to 29 cm. In Fig. 1, the points represent individual determinations. It is seen that α increases linearly with the pressure; extrapolating to zero pressure, its value is 0.28.

The exact origin of this oxygen absorption is uncertain. The wave-length λ1215.7 is probably outside the range of the continuous absorption band with maximum at 1450A, carefully studied by Ladenburg,[9] which is already very weak at 1300A. Absorption in this band results in dissociation, with accompanying "clean-up" of oxygen. This effect was never measurable, although the source also radiated some energy in the molecular spectrum over a wide wave-length range. Spectrograms taken by Price and Collins[10] show a number of absorption bands within the range 1350 to 1000A. These are weak and diffuse, and increase in width with pressure of O_2. They probably approach as a limit the first ionization potential of O_2, near 1000A, and their diffuse character may arise from predissociation. One of these bands, in the above reference, has its

[6] O. R. Wulf and L. S. Deming, Terr. Mag. **43**, 283 (1938).
[7] E. Schneider, Phys. Rev. **49**, 341 (1936).
[8] D. B. Penick, Rev. Sci. Inst. **6**, 115 (1935).
[9] R. Ladenburg and C. C. Van Voorhis, Phys. Rev. **43**, 115 (1933).
[10] W. C. Price and G. Collins, Phys. Rev. **48**, 714 (1935).

long wave-length edge at 1211.8A, at a pressure of a fraction of a millimeter. The absorption of Ly_α may be due to an extension of this band at higher pressure, or to a weaker neighbor. Pressure broadening of the lines of a molecular band may account for the increase in α with O_2 pressure.

Tank nitrogen was freed of CO_2 and water vapor in a similar manner. Its absorption coefficient for $Ly\alpha$ was measured as 0.005 at 45 cm pressure. Because of the very small value of α and the possibility of a trace of impurities, this value should be taken only as an upper limit.

In the case of dry CO_2 free air, Fig. 2, the same type of increase in α with pressure was noted as with oxygen. The extrapolated absorption coefficients were $\alpha = 0.063$ at zero pressure and $\alpha = 0.152$ at atmospheric pressure. From the experimental values of α for O_2 and N_2, the calculated value of α for air (extrapolated to the limit at zero pressure) is $0.21 \times 0.28 + 0.78 \times 0.005 = 0.063$, in agreement with the measured value. (We have here assumed that the value of α for N_2 is independent of pressure, something not proved experimentally. Even if we neglect the absorption of N_2 completely, the computed value of α for air is in fair agreement.) At atmospheric pressure, a 4.5-cm path of dry, CO_2 free air will reduce the intensity of $Ly\alpha$ by a factor $\frac{1}{2}$; at pressures below 1 cm the equivalent path (reduced to NTP) would be 11 cm.

For dry CO_2, the value measured for α was 2.01; the mean variation of five readings over a pressure range in the absorption cell of from 8 mm to 6 cm was about 1 percent.

A side tube containing distilled water was attached to the absorption cell, and cooled in a dry ice—alcohol mixture to regulate the vapor pressure. The average value of α was 390, representing three readings at vapor pressures between 0.031 and 0.018 cm. The accuracy of this value is not great, because of the rapid change of vapor pressure with temperature. Rathenau has photographed the absorption spectrum of water vapor in this region.[11] $Ly\alpha$ falls within a strong diffuse band, one of a series probably leading to H+OH (excited) and showing evidence of predissociation.

[11] G. Rathenau, Zeits. f. Physik **87**, 32 (1932).

Discussion

We may now return to the problem of the possible connection between $Ly\alpha$-radiation and radio fade-outs. To begin with, the location of the normal D region has been very uncertain. It is not known whether the ionization reaches a maximum at some altitude below the E layer, as it would if it were caused by monochromatic light with a definite absorption coefficient, or whether it is an ill-defined region extending with decreasing ion density from the E layer to lower altitudes. Also, we have no reason to assume that the fade-out ionization has the same distribution in altitude as the normal D region. However, recent measurements by Budden, Ratcliffe, and Wilkes have been made on the reflection of very long (16 kc) radio waves.[12] At angles of incidence between 30 and 60° these are normally reflected at a height of approximately 67 km, and they estimate the electron density to be about 300 electrons/cc at this altitude. Measurements made during solar disturbances associated with short wave fade-out indicated a small but definite decrease in the altitude at which these long waves were reflected. This shows definitely that the fade-out radiation must penetrate with appreciable intensity below 70 km. If we assume 9×10^{14} air molecules per cc at an altitude of 70 km,[13] the equivalent air path

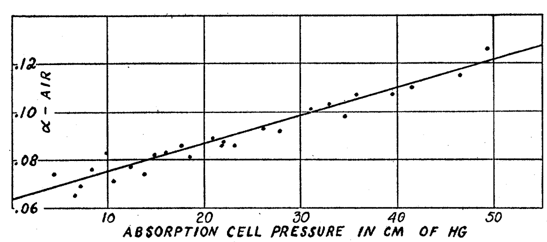

FIG. 2. The absorption coefficient α of air, per centimeter path reduced to NTP

at NTP for radiation penetrating to this level is about 20 cm.

If the absorption coefficient of air is taken as $\alpha = 0.06$ for $Ly\alpha$, and *if* we assume that the absorption above 70 km is due primarily to an equivalent path of 20 cm of *dry* air, then about

[12] Budden, Ratcliffe, and Wilkes, Proc. Roy. Soc. **171**, 188 (1939).

[13] O. R. Wulf and L. S. Deming, Terr. Mag. **41**, 299 (1936).

30 percent of the Lyα-radiation would penetrate below 70 km, and 8 percent below 65 km. The oxygen in the upper atmosphere is probably mostly in the molecular state below 80 km, and in the atomic state above 100 km.[6] Atomic oxygen in the normal state has no absorption line close to Lyα. Since the equivalent path at NTP above 80 km is only 5 cm, our estimate of the penetration of Lyα will not be greatly altered by the fact that some of the oxygen above 80 km is dissociated.

Because of its very high absorption coefficient ($\alpha=390$), an equivalent path at NTP of 0.1 mm of water vapor above 70 km (for example, a concentration of about 1 part in 2000 in the region between 70 and 80 km) would reduce the intensity of Lyα to about 2 percent at 70 km. The H_2O molecule is easily split up into H+OH (excited) by electron impact, and emission of the intense OH bands near 3100 results. Neither these bands nor the Balmer lines of hydrogen have been observed in the spectrum of the aurora or the night sky,[14] so that both hydrogen and water vapor must be present, if at all, in very small concentrations above 80 km. Some authors have suggested concentrations of water vapor of the order of 1 part in 10,000 in the F region[2,15] in order to maintain a reasonable temperature equilibrium. This would not greatly reduce the penetration of Lyα unless its presence in the F region could be shown to require a somewhat greater concentration between 70 and 80 km.[16]

Next we must consider whether the absorption of Lyα can produce ionization in any of the gases present in the upper atmosphere: N_2, O_2, O, O_3, and possibly H_2O. Their ionization potentials are as follows: N_2, 15.5 volts; O_2, 12.2 volts; O, 13.55 volts; H_2O, 12.56 volts;[17] O_3 unknown. None of these, with the possible exception of O_3, can be ionized in a single process by Lyα, whose quantum energy is 10.15 electron-volts. Martyn,[2] however, supposed that Lyα might ionize atomic oxygen in a manner suggested by Chapman and Price.[14] O I has a well-known metastable level, the $^1S_0$, (4.2 volts above the ground state) which is the initial state for the transition which produces the auroral green line. If metastable oxygen atoms are present, the following process might occur:

$$O(^1S_0)+h\nu\,(\lambda=1217.6\text{A})\rightarrow O(^1P_1).$$

The $^1P_1$ lever lies 0.75 volt above the ^4S ground state of singly ionized oxygen. There would be some possibility of a second kind collision as a result of which the $^1P_1$ atom would revert to the ^4S state, with the loss of an electron. However, if it can occur at all, this three-step process must be extremely rare at altitudes as low as 70 km. First, there seems to be no likely process at this altitude which results in the formation of $^1S_0$ metastable atoms. Since at 70 km the average time between collisions is about 5×10^{-6} second, metastable atoms would in any case have a low concentration because of their short lifetime, unless produced at a high rate. Second, the necessary wave-length for excitation to the $^1P_1$ level is 1217.6A, which differs from Lyα by 1.9A. The width of a spectrum line $\Delta\lambda$, due to temperature broadening, is proportional to the wave-length. If the width of Lyα were 3.8A, so that it overlapped the oxygen line, the width of Hα should be over 5 times as great. Richardson[4] gives a width of 2A for Hα in an eruptive area, and states that there is no large Doppler shift to indicate rapid motion of the source.[18] Finally, the lifetime of the $^1P_1$ state, which is not metastable, is probably short compared with the average time of 5×10^{-6} second between collisions, so

[14] S. Chapman and W. C. Price, Reports on Progress in Physics **3**, 42 (1936).

[15] G. H. Godfrey and W. L. Price, Proc. Roy. Soc. **163**, 228 (1937) and D. F. Martyn and O. O. Pulley, Proc. Roy. Soc. **154**, 455 (1936).

[16] The temperature in the F regions is probably high enough so that atoms as light as hydrogen have a fair chance of escaping from the earth's gravitational field. This would explain the absence of much hydrogen at great heights, and would also indicate a gradual loss of H_2O by dissociation and subsequent escape of the hydrogen. To maintain any concentration of H_2O, a replenishment by upward diffusion from lower altitudes is necessary.

[17] W. C. Price, J. Chem. Phys. **4**, 147 (1936).

[18] Richardson objects to the use of the word "eruption" to describe the exceptionally bright flocculi associated with fade-outs for just this reason, that in general there is no *large* radial velocity over the disturbed area. Protuberances frequently appear in the neighborhood of the bright flocculi, which consist of masses of gas moving with high velocity. At least in many cases, these appear dark in the light of $H\alpha$ against the bright background of the flocculi, and their emission of Lyα is consequently relatively small. For the excitation process under discussion, a *bright* protuberance moving *in* towards the sun with a velocity of about 500 km/sec. must be postulated; this motion would have to persist for the entire duration of the fade-out. Apparently, nothing of this sort has been observed.

that radiation rather than loss of energy in a second kind collision will be favored.[19]

Wulf and Deming have suggested the possibility that fade-outs may be caused by the ionization of ozone.[6] Although the maximum concentration of ozone in the atmosphere is known to occur near 25 km, they calculate that at 70 km there are still 6.35×10^7 molecules of O_3 per cc. Unfortunately, the ionization potential of O_3 is not known. In view of the small dissociation energy of O_3 (about 1 electron volt), it is unlikely to be much less than that of O_2 (12.2 volts, $\sim$1010A). The hypothesis of Wulf and Deming that, by some unknown multiple process, the dissociation of ozone by light of comparatively long wave-length may lead to small amounts of ionization, must await experimental elucidation.

To summarize, Lyα will penetrate to an altitude of 67 km, at which fade-out ionization has been experimentally observed, unless the water vapor concentration in the region from 70–80 km is of the order of 1 part in 2000. However, there seems to be no known process by which it is likely to cause appreciable ionization.

The question next arises, whether any of the other radiation in the far ultraviolet, inferred from the visible spectrum of solar eruptions, may be the cause of fade-outs. Probably only the higher members of the Lyman series need to be considered.[20] These are:

2	1025.73	5	937.81
3	972.55	6	930.76
4	949.74	7	926.24

The ionization potential, 13.53 volts, corresponds to 911.76A. It is worth noting that the intensity of the higher members of the Balmer series is observed to fall off *far* less rapidly in these areas of solar disturbance, than in a laboratory discharge tube.[3] The third and higher members of the series lie above the first ionization potential of oxygen (at 1010A), in a region of weak continuous absorption.[14] In the same region are the strong Hopfield absorption bands, which show some evidence of pre-ionization. Takamine and Suga investigated qualitatively the absorption of the higher Lyman series members in oxygen,[21] and found that the third, sixth, and eighth members were completely absorbed by a path of less than 0.1 mm of oxygen at NTP; these lines coincide with bands of the Hopfield series, and would certainly be absorbed in the upper atmosphere at altitudes at which O_2 first appears. The remaining members of the series, numbers 4, 5, 7, 9 and some higher, have much smaller absorption coefficients in oxygen, and might therefore penetrate below the E region. However, N_2 also has some strong absorption bands in this neighborhood, although their accurate wave-lengths do not seem to have been published.[14] Until the actual absorption coefficients of these lines in oxygen and nitrogen have been determined experimentally, it will not be possible to decide whether they can penetrate to altitudes as low as 67 km, where they might produce fade-out ionization.

It happens that the Lyman series continuum largely overlaps the ionization continuum of atomic oxygen, which commences at 910.42A. It is therefore probable that radiation in the hydrogen continuous spectrum will be absorbed by atomic oxygen at relatively great altitudes, with the production of ionization.

Even if it could be shown that part of the Lyman series radiation from solar eruptions can produce ionization at sufficiently low altitudes to be a *possible* cause of radio fade-outs, certain general considerations seem to argue against this explanation. In order to estimate the intensity and spectral distribution of the solar radiation normally incident on the earth in the far ultraviolet, it was formerly customary to assume that it followed Planck's equation for a blackbody at about 6000°K. This predicts such a small intensity for wave-lengths shorter than 1000A,

[19] Martyn apparently assumed second kind collisions between excited $^1P_1$ oxygen atoms and *electrons* as responsible for transfer to the ^4S state. Possibly he confused the probability that a free electron will collide with a gas molecule, per unit time, with the probability that any particular gas molecule (in particular, an excited atom) will collide with a free electron. The former probability is relatively large, even at 70 km; the latter (which obviously depends on the free electron density) is entirely negligible at an electron density of the order of 10^3/cc.

[20] The $^1S_0-{}^1P_1$ series of He I, whose high intensity is to be inferred in the same manner as that of the Lyman series, commences at 584A, a region of such strong air absorption that penetration of more than a fraction of a millimeter at NTP is impossible. Ca II, the only other spectrum identified in spectroheliograms of eruptive areas by Richardson, has no lines in the far ultraviolet; its ionization potential is 11.8 volts.

[21] T. Takamine and T. Suga, Scientific Papers, Inst. of Phys. and Chem. Research, Tokyo **29**, 213 (1936).

which alone are capable of producing ionization, that there is serious reason to doubt whether it can account for the observed ionization, particularly in the F region.[22,23] As a result it has been concluded that there is an "ultraviolet excess" intensity, far above the value calculated from Planck's formula. This is made plausible by spectroheliograms taken at total eclipse, which show predominantly a line spectrum coming from the chromosphere; most of the intensity comes from H I, He I, and He II. It has been estimated by Saha[22] that, in protuberances, the ratio of He II to He I is 10^{38} times that calculated on the assumption of purely thermal excitation at 6500°K. There is a good chance that, of all the radiation coming from the sun, in the region of wave-lengths shorter than 1000A, by far the greater part is due to the Lyman series (including their continua) of H I and He II, and the $^1S_0-{}^1P_1$ series of He I.[24] Perhaps the escape of this radiation, which of course is strongly absorbed in the sun's atmosphere, is facilitated by convective streaming in which masses of ionized hydrogen and helium from lower regions of high excitation are shot out to great heights.[23]

It is therefore quite possible that the normal ionosphere is largely produced by hydrogen and helium, rather than blackbody, radiation. It has already been stated that the higher members of the Lyman series of hydrogen can ionize O_2 in two possible ways, and the continuum can ionize atomic oxygen. The $^1S_0-{}^1P_1$ series of He I has the wave-lengths 584.4, 537.1, 522.3 etc.; the Lyman series of He II, 303.7, 256.3 etc. Both these series are capable of ionizing N_2, O_2 and O. When the actual values of the absorption coefficients are measured, it will be possible to estimate at what altitude maximum ionization will occur for each line, and the calculations will be much simpler than in the case of radiation with a continuous frequency distribution.

Whatever the source of the extra radiation in the far ultraviolet, some connection must be established between its intensity and the sun-spot cycle. The electron density in the E and F layers varies greatly with the average sun-spot number. Perhaps a considerable portion of the ionization is due to radiation from the bright flocculi normally associated with sun-spots[25] (not to be confused with the transient exceptionally intense flocculi which coincide with radio fade-outs), particularly during the maximum of the sun-spot cycle, while at sun-spot minimum a relatively larger proportion comes from the rest of the chromosphere.

We are now faced with a very definite dilemma. The study of radio fade-outs shows definitely that there is little alteration in the electron density of the E and F layers during a fade-out.[26] This can only mean that the radiation causing fade-outs is *qualitatively* different from that responsible for the normal E and F layers. Suppose we attribute fade-outs to Lyman series radiation from solar eruptive areas. These same areas also emit intensely the helium series starting at 584A. Because the E and F layers are not much disturbed during fade-outs, these two line series cannot be responsible for more than a small fraction of the *normal* E and F layer ionization. This contradicts the considerable evidence that they comprise a large, if not predominant fraction of the intensity in the far ultraviolet. Alternatively, if these series *are* responsible for a considerable part of the normal E and F ionization, they *cannot* cause radio fade-outs.

A way out would be offered if there were evidence for any other radiation from eruptive areas, of a type not normally coming from the sun with appreciable intensity. It seems scarcely possible that the spectrum of any element, other than hydrogen, helium, and ionized calcium, can occur with sufficient intensity to cause fade-outs and yet have been overlooked in studies with the spectroheliograph. Now because of the many processes by which O, O_2 and N_2 can be ionized, it is improbable that the absorption coefficient α (per unit path length, at NTP) of air, which

[22] M. N. Saha, Proc. Roy. Soc. **160**, 160 (1937). We have direct evidence, from the daylight flash spectrum of the upper atmosphere, that one ionization process is $N_2+h\nu(\lambda<661A)\rightarrow N_2^+(\text{excited})+\text{electron}$. Saha has also estimated that if only one-tenth of the measured F region electron density is attributed to this process, the intensity of ultraviolet light in this wave-length region must be of the order of 10^6 times as large as that calculated from the energy distribution of a blackbody.

[23] W. Grotrian, Naturwiss. **27**, 555, 569 (1939).

[24] Professor Donald Menzel, in conversation, emphasized the enormous intensity to be expected from He I, λ 584A, relative to the blackbody continuum.

[25] F. L. Mohler, Science **90**, 137 (1939).

[26] L. V. Berkner and H. W. Wells, Terr. Mag. **42**, 301 (1937) and L. V. Berkner, Phys. Rev. **55**, 536 (1939).

rises to a value of several hundred somewhat beyond 1000A,[27] will fall again to very low values until wave-lengths considerably shorter than the K-absorption limits of oxygen and nitrogen.[28] Hence unless the fade-out producing radiation lies near 1000A, it is probably of much shorter wave-length. If by some means moderately hard x-rays are liberated from eruptive areas, these will only be observed by ionization in the D region. For example, at 2.3A the linear absorption coefficient of air is $\alpha = 0.04$, and 50 percent of radiation of this wave-length would be absorbed in a path of 17 cm at NTP; it would accordingly penetrate somewhat below an altitude of 70 km. A wave-length of 2.3A corresponds to a quantum energy of 5400 electron-volts, and this therefore is a rough lower limit to the energies which would have to be involved.

Korff and Johnson[29] have already made the suggestion that the ionizing radiation which causes fade-outs may lie in the x-ray region. On the chance that it might include a highly penetrating component which could be detected at low altitudes, they measured the ionization at 20 km, by means of a Geiger counter supported by a sounding balloon, before, during, and after a fade-out. The counting rate remained constant within experimental error, from which they concluded that the fade-out producing radiations is predominantly of wave-length greater than 0.1A. From other considerations they set 1.5A as an upper wave-length limit.

Is there any independent evidence that such high energy radiation may be produced in eruptive areas of the sun and escape into space? Vegard[30] has already suggested that soft x-rays may be responsible for part of the *normal* ionosphere, and harder x-rays for fade-out ionization. He assumes that the aurora is caused by high energy electrons, and concludes that these must produce x-rays of comparable energy in the sun's chromosphere. However, most authors have not felt it necessary to evoke x-rays in order to explain the normal ionosphere, and there are grave objections to the theory that the aurora is caused by fast electrons. First, it is questionable whether charged particles of the same sign could continually leave the sun, and whether they could retain the form of a beam in shooting out to great distances, because of electrostatic forces. Moreover, there is a curious puzzle presented by the observation that intense auroral displays and magnetic storms frequently follow, after a period of about 24 hours, solar eruptions which have caused radio fade-out. If we assume that particles, expelled from the eruptive area at the same time as the fade-out producing radiation, cause these aurora, their velocities can be only of the order of 1000 km/sec. For electrons this corresponds to an energy of 3 electron-volts and negligible penetrating power.

A more recent hypothesis[31] is that the rapidly moving gas masses known as protuberances, which usually arch back into the sun, under certain conditions may be expelled into space. Escape may be favored by increased radiation pressure if a protuberance occurs in the neighborhood of an eruptive area. Such a gas mass, containing positive ions, electrons, and neutral atoms, might be electrically neutral as a whole and hence tend to remain together in space. It has been calculated that the slow positive ions would carry the electrons along with them and follow, in the earth's magnetic field, the same type of orbit as the fast electrons assumed by Vegard. Positive ions with velocities of 1000 km/sec. would have much larger energy and penetrating power than electrons of the same velocity, and they could produce aurora at altitudes in the neighborhood of the E region. Since the high energy in this second hypothesis is associated with heavy particles, there is no indication that penetrating x-rays would be produced in the chromosphere.

To summarize our argument: It is very unlikely that Lyα-radiation can produce fade-out ionization. Further experimental work will show whether higher Lyman series members might be responsible, insofar as their penetrating and ionizing power go. But there are strong reasons

[27] E. G. Schneider, forthcoming publication.

[28] The K-absorption limit of N, for example, lies at 31.56A. At a somewhat longer wave-length, 44.5A, $\alpha = 5.0$; at the shorter wave-length 17.67A, $\alpha = 9.1$. (A. H. Compton and S. K. Allison, *X-rays in Theory and Experiment* (Van Nostrand, 1935).)

[29] T. H. Johnson and S. A. Korff, Terr. Mag. **44**, 23 (1939).

[30] L. Vegard, Naturwiss. **26**, 639 (1938).

[31] As a general reference for this and the preceding paragraph, see reference 23.

for supposing that the normal E and F layers are produced to a considerable extent by atomic rather than by blackbody radiation, and this must be attributed largely to hydrogen and helium. If this is so, the absence of any large disturbance of the E and F regions during fade-outs indicates independently that hydrogen or helium radiation *cannot* be responsible for fade-outs. It is then difficult to see to what type of radiation we can attribute fade-outs, unless we consider the possibility of x-rays. However, no independent evidence for the production of x-rays in eruptive areas of the sun seems to be suggested by our present incomplete theories of conditions in the chromosphere and of delayed disturbances in the earth's upper atmosphere following solar eruptions.

I particularly wish to express my appreciation to Professor Otto Oldenberg for many helpful discussions of the subject of this article.

Note: Just before the submission of this article for publication an article appeared by S. E. Williams (Nature **145** 68 (1940)). Williams investigated the absorption of Lyα in oxygen, and found a coefficient approximately 50 times larger than that reported in the present paper. Lacking details of his experimental method, no explanation can be suggested for this huge difference. Nearly any impurity in his absorbing gas, particularly H_2O or CO_2, would result in too large a value for the absorption coefficient.

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The Arc Spectrum of Silver*

A. G. SHENSTONE
Palmer Physical Laboratory, Princeton University, Princeton, New Jersey

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AMONG all the simpler arc spectra, that of silver has been for years the best example of a badly analyzed spectrum. This is the result of inadequate observation of the spectrum by the many workers who have measured it. The reason for the incompleteness of the observations now appears to be the fact that instruments of too great dispersion were used for the detection of very diffuse lines. Such lines are numerous in silver and attain widths as great as 500 wave numbers.

New observations have been carried out in Princeton with various forms of arc. A preliminary report has been published.[1] The form of arc, which was found by R. Haskins in his senior thesis problem to be the most suitable for observations in the visible and infra-red, was as follows. The electrodes consisted of silver buttons about 5 mm in diameter screwed firmly to water-cooling tubes. The arc was run at 6 to 8 amperes in air or oxygen with the anode down, the cathode being focused on the slit of the spectrograph. Under these conditions the cathode disintegrates by sputtering and the anode increases in weight. The unusual procedure of observing arc lines at the cathode is effective in this case, I believe, because of the high excitation of most of the new lines. It has the added advantage of eliminating the band lines which occur rather strongly at the anode. In the infra-red some exposures were taken with a 20-ampere graphite arc and in the Schumann region small graphite arcs in pure nitrogen were used.[2] This type of arc was necessitated by the fact that silver arcs will hardly run at all in pure nitrogen. The arc observations were made on the following instruments. λ10,000–5000 Steinheil three-prism glass spectrograph; λ5000–2100, Hilger El quartz spectrograph; λ2100–1250, a 30,000 line 2-meter vacuum spectrograph.

In addition the spectra from a hollow cathode argon-filled tube were observed with the 30,000 line 21-ft. grating. The tube was run with the silver in the cathode molten, and very good pictures were obtained in less than an hour.

* When this paper was in preparation there appeared a letter in Phys. Rev. **57**, 243 (1940) from Ebbe Rasmussen in which some of the new levels of AgI, notably $s^2\,{}^2D$, were given.

[1] A. G. Shenstone, Phys. Rev. **56**, 209 (1939).

[2] A. G. Shenstone, Trans. Roy. Soc. **237**, 453 (1938).