THE TRANSPARENCY OF THE ATMOSPHERE IN THE ULTRA-VIOLET AND A POSSIBLE MEANS OF EXTENDING THE SOLAR SPECTRUM IN THE REGIONS 2200-2000 Å.

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The shortest wave-length that has been observed in the solar spectrum is 2863 Å, which was reached by Paul Götz[1] working in Switzerland. This should be considered a remarkable achievement as the intensity dies down very rapidly with decrease of wave-length beyond 2950 Å. Generally speaking, 2900 Å may be considered to be about the shortest wave-length of the solar spectrum attainable under good conditions. The reasons for this limitation of the spectrum is now well known to be the absorption exercised by ozone present in the upper atmosphere. Ozone has strong absorption between 3200 and 2200 Å with a maximum at 2550 Å. The absorption coefficients α of ozone in this region, defined by the equation $I = I_0 10^{-\alpha l}$ and as measured by Fabry and Buisson[2] and by Läuchli[3] are shown in Fig. 1. In the above equation l stands for the thickness of ozone in centimetres at N.T.P.

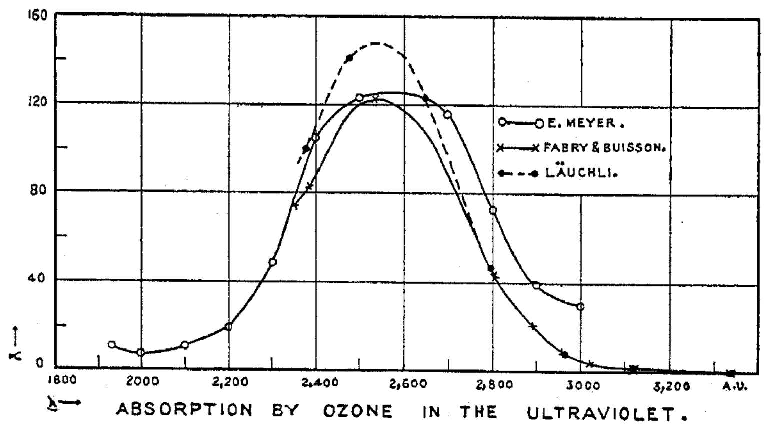

Fig. 1.

At the position of maximum absorption, a layer of ozone 1/150 cm. thick at N.T.P. would reduce the intensity of the incident radiation to one-tenth. The extensive measurements organised by Dobson[4] have shown that there is always present in the upper atmosphere an amount of ozone which, on the average, varies from 0·20 cm. (at N.T.P.) near the equator to 0·35 cm. near the poles. At 2900 Å, the absorption coefficient of ozone is 19 and even at normal incidence, a layer 0·3 cm. thick would reduce the intensity of the incident light to 2×10^{-6} of its value. The extinction due to molecular scattering of light by the thickness of the whole atmosphere at 2900 Å at sea-level is only 0·58 and hence small compared with the ozone absorption.

The effective height of the ozone layer was, till very lately, believed to be 40—50 km. but more recent measurements, with improved apparatus, by Götz, Dobson and Meetham[5] have shown that, while the mean height is about 22 km., ozone exists at all heights from the surface up to 50 km. and more. Fabry and Buisson's measurements of the absorption coefficients of ozone extend only to 2352 Å where the value of α is 74. But ultra-violet spectrum photographs[6] through increasing thicknesses of ozone show that below about 2200 Å, the absorption is very small. The only measurements of absorption coefficients in this region appear to be those of E. Meyer[7] whose values are also plotted in Fig. 1. According to Meyer, the absorption coefficients at 2200, 2100 and 2000 are 19·2, 11·5 and 7·8 respectively.

As has been realised by previous investigators, we should expect a revival of the solar spectrum on the short wave-length side of the Hartley absorption band at about 2200 Å if the sun radiates as a black body at about 6000° K and ozone is the only absorbing agent in the atmosphere. Attempts at detecting this radiation have, however, not been successful till now. For many reasons, there seems to be little doubt that the continuous spectrum of the sun outside the earth's atmosphere corresponds to that of a black body; there should therefore be some other agency responsible for preventing the solar radiation below 2200 Å from reaching the surface of the earth.

Transparency of the lower atmosphere in the Ultra-violet.

Measurements of the transparency of long horizontal columns of the order of 1 km. of the lower atmosphere have been made by Buisson, Jausseran and Rouard,[8] by Götz and Ladenburg[9] and by Götz and Leibnitz.[10] They show that in the region 3000—2600 Å there is in addition to the attenuation caused by suspended particles and molecular scattering an extra absorption which can be definitely ascribed to a small percentage of ozone, but that for wave-lengths shorter than 2600 Å, there is a further additional absorption which increases rapidly with decrease of wave-length. The measurements of both Buisson and co-workers and of Götz and Leibnitz agree as regards the wave-length at which the absorption commences and the magnitude of the absorption. The Swiss investigators give values of absorption coefficients up to 2302 Å, while the data of the French investigators extend to 1855 Å.

The residual absorptions obtained by Götz and Leibnitz on the nights of 3-9-1932 and 28-3-1933 with a column of atmosphere 1052 metres long at the height of Arosa (1900 metres above sea-level) after allowing for molecular scattering, ozone absorption and suspended matter are given in the following table :—

TABLE I.

λ	Arosa 3—9—1932	Arosa 28—3—1933
2699	0·00	0·00
2639	0·03	0·01
2603	0·07	0·08
2576	0·06	0·06
2482	0·11	0·18
2644	0·24	0·29
2446	0·20	0·25
2400	0·37	0·46
2378	0·42	0·62
2354	0·56	0·72
2339	0·56	0·76
2323	0·68	0·88
2302	0·82	0·99

Calculating from the absorptions between 3000 and 2700 Å, the amounts of ozone on the two nights were 9×10^{-4} and 36×10^{-4} cm. respectively. There seems to be some dependence of the residual absorption on the amount of ozone in the atmosphere, but the major part of it seems to be independent of the ozone. The absorption coefficients per kilometre obtained by Buisson, Jausseran and Rouard are given in Table II. α^1 refers to the observed values of the coefficients, α_2 to the values after correction for haze and molecular scattering and α to the values after correcting for ozone absorption also. For the last correction, Fabry and Buisson's values of absorption coefficients of ozone have been used up to 2482 Å and Meyer's values for wave-lengths smaller than 2313 Å. The amount of ozone has been assumed to be $2 \cdot 2 \times 10^{-3}$ cm.[11] The absorption due to dust has been taken to be 0·05 per kilometre for all wave-lengths—this value was obtained by Buisson and collaborators in the neighbourhood of 3100 Å.

TABLE II.

λ	α_1	α_2	α
2893	0·160	0·04	0·00
2805	0·225	0·09	0·00
2752	0·300	0·15	0·01
2699	0·345	0·19	0·00
2653	0·405	0·24	0·01
2536	0·516	0·32	0·04
2482	0·640	0·42	0·17
2313	1·370	1·11	1·00
2265	1·770	1·49	1·41
2195	2·350	2·03	1·99
2144	2·710	2·37	2·34
2100	4·100	3·73	3·71
2063	3·400	3·01	2·99
2026	4·350	3·93	3·91
1950	5·100	4·60	4·58
1935	17·000	16·50	16·50
1863	250·000	..	250·00
1858	370·000	..	370·00
1855	445·000	..	445·00

It is stated by Buisson, Jausseran and Rouard that the abnormal value of α_1 near λ 2063 is due to absorption by oxygen. It is obvious that with an absorption coefficient of 2·0 per kilometre, the intensity of solar radiation on reaching the surface of the earth will be reduced in the ratio 10^{-16} and this explains why attempts at detecting the solar spectrum on the short wave-length side of the ozone absorption band have been unsuccessful.

The Schumann-Runge absorption band system of O_2 commences at about 2000 Å; its convergence is at 1751 Å and is followed by a continuous spectrum which extends to 1300 Å. The absorption in the continuous region has been quantitatively investigated recently by Ladenburg, Voorhis and Boyce.[12] Their results are shown in Fig. 2. The maximum absorption occurs at 1450 Å where the decimal absorption coefficient reaches the enormous value of 207 (per cm. at N.T.P.). Between 2050 and 1870 Å, Granath[13] has made some laboratory measurements of absorption coefficients of oxygen and saturated water vapour at room temperature (temperature not specified) but his coefficients are so much larger than the attenuation coefficients determined by Buisson and co-workers that further experimental work appears to be necessary.

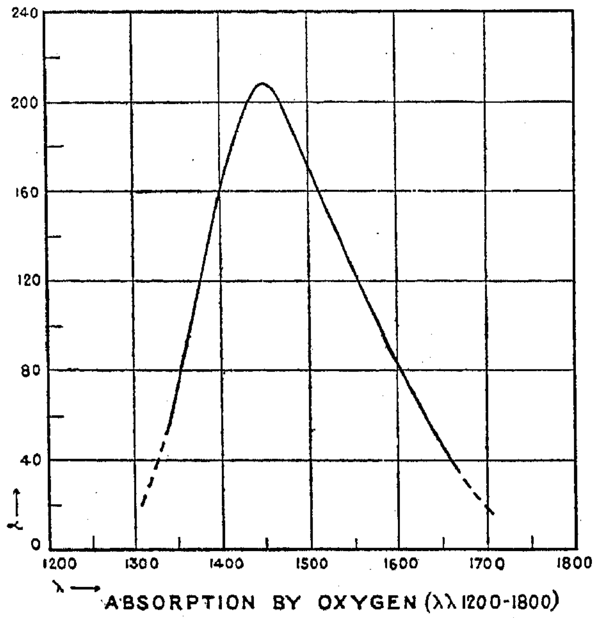

FIG. 2.

As there seems to be little doubt that between 2600 and 2000, there is some absorbing agent in the atmosphere in addition to O_3, the question of its identification becomes one of importance. In a note to *Naturwissenschaften* in 1932, G. Herzberg[14] described a system of seven weak absorption bands between 2600 and 2420 Å which he observed in the laboratory with a column of pure oxygen 25 metres long at atmospheric pressure. The extrapolated convergence limit of the bands was near 2420 Å which corresponds to 5·09 volts, the dissociation potential of O_2 when the products of dissociation are normal O atoms. There is no doubt that there would be a weak continuous absorption beyond the convergence point, although with the length of column used by Herzberg, he could not definitely measure the amount of the absorption. Herzberg has suggested that our inability to get any trace of the solar spectrum on the short wave-length side of the ozone absorption band may be due to O_2 absorption. This seems to be the most probable explanation. Incidentally, the photoelectric action of the radiation in the neighbourhood of 2200 Å in dissociating oxygen would explain the occurrence of ozone in the lower atmosphere.

Possible means of extending the solar spectrum in the Ultra-violet.

Accepting the correctness of the atmospheric absorption coefficients determined by Buisson, Jausseran and Rouard, it is easily possible to show that by exposing a spectrograph at an attainable height in the atmosphere, there is every possibility of our being able to extend the solar spectrum on the shorter wave-length side of the ozone absorption band. In the following table are shown the values of the intensity of solar radiation at 2900, 2200, 2063 and 2000 Å at the surface, at 16 km. and at 20 km. above the surface assuming (*a*) the sun radiates as a black body at 6000° K, (*b*) the quantity of ozone in the atmosphere is 0·2 cm., (*c*) the absorption coefficients of ozone below 2300 Å given by Meyer are correct, and (*d*) the absorption coefficients of atmospheric air are those given by Buisson, Jausseran and Rouard.

TABLE III.

	2900 Å	2200 Å	2150 Å	2063 Å	2000 Å
Relative intensity of solar radiation outside the earth's atmosphere ..	48	14	12·5	9·5	7·5
Attenuation (per kilometre at N.T.P.) due to molecular scattering	0·07	0·27	0·29	0·32	0·39
Absorption coefficient per cm. of ozone at N.T.P.	20	19	15	10	8
Absorption coefficient per kilometre due to other causes probably due to oxygen	0·0	2·0	2·3	3·0	4·0
Factor of attenuation when radiation from zenith sun near equator reaches sea-level	$10^{-4\cdot6}$	10^{-22}	$10^{-23\cdot7}$	$10^{-28\cdot6}$	$10^{-36\cdot7}$
Factor of attenuation when radiation from zenith sun near equator reaches 100 mb. level nearly 16 km. above sea-level	$10^{-4\cdot1}$ $10^{-2\cdot9}$	$10^{-5\cdot6}$ $10^{-4\cdot5}$	$10^{-5\cdot1}$ $10^{-4\cdot3}$	$10^{-4\cdot6}$ $10^{-4\cdot0}$	$10^{-5\cdot1}$ $10^{-4\cdot6}$
Factor of attenuation when radiation from zenith sun near equator reaches 50 mb. level nearly 20 km. above sea-level	$10^{-4\cdot0}$ $10^{-2\cdot4}$	$10^{-4\cdot7}$ $10^{-3\cdot2}$	$10^{-4\cdot0}$ $10^{-2\cdot8}$	$10^{-3\cdot3}$ $10^{-2\cdot5}$	$10^{-3\cdot3}$ $10^{-2\cdot7}$

The upper figures in the last two rows are calculated on the assumption that all the ozone is above 20 km.; while the lower figures are calculated assuming approximately the same distribution of ozone as was found by Dobson, Götz and Meetham in Europe, *viz.*, 70% above 16 km. and 60% above 20 km.[15] It will be seen from the last three rows of Table III that owing to the absorption exercised by the atmospheric air there is no hope of detecting solar radiation at wave-lengths shorter than 2200 Å near sea-level nor even on the highest mountain tops, but that if we can expose spectrographs of the same power as we use at the surface at levels of 16 kilometres or more in the tropics it is almost certain that we shall be able to photograph the solar spectrum in that region. Even then, owing to the rapidly increasing absorption it is very doubtful if we can go further than 1950 Å. It will be seen that the estimated attenuation factors depend on the values of absorption coefficients of ozone determined by Meyer in 1903; considering the fact that his values at 2900 and 3000 Å are much larger than those of Fabry and Buisson and of Läuchli it is possible that the values at 2200 and below are also too high. Laboratory measurements of absorption coefficients of ozone in this region of the spectrum would be of great value. If, as it appears probable, the absorption coefficients are really smaller than those given by Meyer, it will be possible to detect the solar radiation in this region at a lower height than 16 km. Heights of the above order are attainable by sounding balloons and even by the new manned stratosphere balloons. It will be noticed that in making the above estimates, it has been assumed that there is no new absorbing agent in the upper atmosphere which is not present in the lower atmosphere.

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