THE ATTENUATION OF ULTRA-VIOLET LIGHT BY THE LOWER ATMOSPHERE*

By L. H. Dawson, L. P. Granath and E. O. Hulburt
Naval Research Laboratory

(Received March 27, 1929)

Abstract

Measurements were made with a quartz mercury lamp, a quartz spectrograph and a recording densitometer of the attenuation of ultra-violet light from 3000 to 2050A by the atmosphere at sea level. For wave-lengths from 5000 to 3000A the absorption was too slight to be observed at distances up to 400 meters; for wave-lengths below 2800A there was pronounced absorption above that attributable to molecular scattering. The absorption was the same day and night, was unaffected by changes in the humidity,but increased with haze. The thicknesses of clear air necessary to reduce the light to 10^{-2} were about 22, 5, 0.57 and 0.20 km for 2800, 2500,2200 and 2050A, respectively. The absorption in the lower atmosphere around 2800 to 2900A was not sufficient to account for the sharp cessation of the solar spectrum in this region. This result is in keeping with the fact that the ultra-violet limit of the solar spectrum is due to ozone in the high atmosphere. The absorption in the lower atmosphere at 2200 to 2050A, a spectrum region where ozone is relatively transparent, is great enough to prevent sunlight of these wave-lengths from penetrating to sea level.

THERE have been very few measurements of the attentuation of ultra-violet light by the lower atmosphere and no measurements at all for wave-lengths below 2600A. In the present investigation the absorption coefficients in the region 3000 to 2050A have been obtained for a clear and a hazy atmosphere. The absorption was found to increase with a decrease in wave-length and an increase in haze. Schaeffer[1] determined the atmospheric transmission on clear winter nights for the region 3300 to 2600A; his values are referred to in a later paragraph. Rayleigh[2] in connection with the investigations of atmospheric ozone by Fabry and Buisson[3] observed qualitatively that the absorption by several km of the atmosphere for wave-lengths around 2536A was greater than that given by the Rayleigh molecular scattering formula.

The present experiments were carried out on the edge of the Potomac River about five miles from the city of Washington. The source of ultra-violet light was placed at the focus of a metal mirror 24 inches in diameter, and the spectrum was photographed from a distance with a quartz spectrograph. For a specified region of the spectrum the distance was chosen so that the spectrum lines were weakened by absorption neither too much nor too little; this gave the most accurate results. A distance of 404 meters was used for the region 3000 to 2288A and in this case the source was an atmospheric pressure quartz mercury arc taking about 1.2 kw. Cadmium

* Published with the permission of the Navy Department.

[1] Schaeffer, Proc. Amer. Acad. of Arts and Sci. **57**, 365 (1922).

[2] Strutt, Proc. Roy. Soc. **A94**, 260 (1918).

[3] Fabry and Buisson, Journal de Phys. **3**, 196 (1913).

and zinc were put into the mercury to furnish some strong lines in regions of the spectrum where the mercury lines were faint. For wave-lengths 2288 to 2050A the distances were 30 to 50 meters and the source was a condensed spark between silver terminals with a current of about 15 amperes.

The method employed was one often used in ultra-violet photometry and has been described by Fabry[4] and others. It consisted in photographing the spectrum of the source at a distance, then bringing the spectrograph to within a meter of the source reflected from the mirror and impressing on the same plate with the same time of exposure a series of comparison spectra through screens which reduced the intensity of the light by known amounts. Wire gauze screens were used of transmissions 100 (i.e. no screen), 58, 32, 15 percent and sometimes of intermediate values. The transmissions of the screens were measured with a quartz monochromatic illuminator and a photoelectric cell, and tests showed the transmission of each screen was constant for wave-lengths in the visible and ultra-violet regions of the

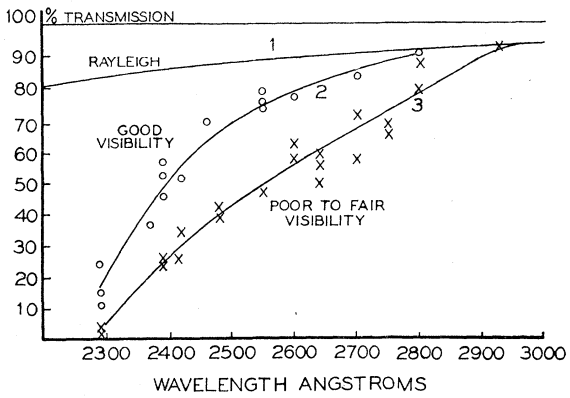

Fig. 1. Percentage of light of various wave-lengths transmitted through 404 meters of the of the atmosphere. Curve 1 calculated from Eq. (2); curve 2 and circles, values observed for a clear atmosphere, visibility greater than 15 km; curve 3 and crosses, values observed for a hazy atmosphere, visibility about 8 km.

spectrum. By means of a diaphragm the intensities of the comparison spectra were adjusted so that the strongest spectrum was stronger and the weakest weaker than the spectrum of the distance source. The width of the slit of the spectrograph was 0.1 mm and no lens was used in the front of the slit. Curves were taken with a recording densitometer of the spectra on each plate and from the measured heights of the curves the relative atmospheric transmission at each wave-length was determined. To get the absolute values of the transmission it was assumed that for wave-lengths where the absorption was too slight to be observed at the longest distance used, i.e. about 2800A for curve 2 and 2900A for curve 3, Fig. 1, the absorption was that given by the Rayleigh molecular scattering formula.

The percentage transmissions of wave-lengths down to 2288A through 404 meters of the atmosphere are given in curves 2 and 3, Fig. 1, for conditions of good visibility and poor to fair visibility, respectively. The

[4] Fabry, Proc. Phys. Soc. London **39**, 1 (1926).

visibility is defined as the distance beyond which a dark colored object could not be distinguished in daylight, good visibility referring to a distance greater than 15 km and poor to fair visibility to a distance about 8 km. The circles and crosses in Fig. 1 are plotted from some of the values of the various plates and indicate the experimental variations in the measurements. It is assumed that the transmission of the atmosphere is expressed by

$$I = I_0 10^{-\alpha x}, \tag{1}$$

where I_0 is the original intensity of the light, I is the intensity after passage through a distance x cm and α is the light absorption coefficient. The absorption coefficient due to molecular scattering given by Rayleigh[5] is

$$32\pi^2(\mu-1)^2/3N\lambda^4 \times 2.3, \tag{2}$$

where μ is the refractive index of the air, N the number of molecules per cm^3 and λ is the wave-length of the light in cm. The factor 2.3 is in the denominator because we have written 10 in (1) instead of the Naperian base. Curve 1, Fig. 1, is the transmission through 404 meters of air calculated from Eqs. (1) and (2). It is seen that pronounced absorption above that attributable to molecular scattering set in at about 2800A. The absorption was found to be the same for day, night, summer and winter, and for conditions of high and low water vapor content, as long as the atmosphere was clear.

The values of α calculated by Eq. (1) from the smooth curves 2 and 3, Fig. 1, are given in curves 2 and 3, Fig. 2. Curve 2′ is the extension of curve 2 to wave-length 2050A, obtained from data similar to those of Fig. 1, but taken at shorter distances; for curve 2′ the ordinates of Fig. 2 should be multiplied by 10. The values of α calculated from the molecular scattering formula (2) are shown in curve 1. In curve 4 are given the values of α calculated by Eq. (1) from the atmospheric transmission percentages observed by Schaeffer for clear winter nights at a distance of 2300 meters. He joined his curve to the Rayleigh curve at 3400Å. The measurements were made near Boston, Mass., and if it were assumed that the temperature was -10°C and that α is proportional to the density of the air and hence inversely proportional to the absolute temperature, the values of curve 4 should be reduced by about 10 percent to be compared with those of curve 2 which were for an average temperature of about 15°C. On the whole one would suppose that for wave-lengths longer than 2800A the values of curve 4 were more trustworthy than those of curve 2 and that below 2800A the reverse were true.

It is seen that the ultra-violet absorption of the atmosphere is made up of a permanent absorption due to the atmospheric gases and a variable absorption due to the particles which cause haze. From 2050 to 2100A the permanent absorption agrees with that to be expected from the oxygen in air according to the recent measurements of Granath (to be published soon). Although no measurements of the absorption coefficients are available for wave-lengths longer than 2100A, oxygen is known to possess absorption,

[5] Rayleigh, Phil. Mag. **47**, 375 (1899).

either continuous or in faint bands, in this region[6] and it seems probable that the air absorption is due mainly to the oxygen in the air.

From curve 2, Fig. 2, $\alpha = 0.9 \times 10^{-6}$ at 2800A, which shows that light of this wave-length is reduced to 10^{-2} of its original intensity by passage through 22 km of the atmosphere. Since the total vertical thickness of the atmosphere is equivalent to about 8 km at atmospheric pressure, the absorption from 2800 to 2900A by the lower atmosphere is not sufficient to account for the sharp cessation of the solar spectrum[3] at 2885A. This is in agreement with

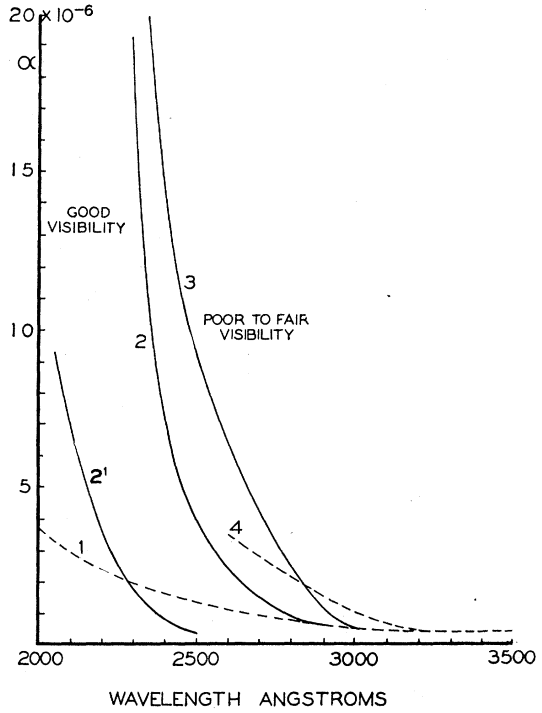

Fig. 2. Light absorption coefficient α of air. Curve 1, calculated from Eq. (2); curve 2, values observed for a clear atmosphere, visibility greater than 15 km; curve 2′, the extension of 2 to 2050A, the ordinates should be multiplied by 10 for 2′; curve 3, values observed for a hazy atmosphere, visibility about 8 km; curve 4, values observed by Schaeffer.

the fact that the ultra-violet limit of the solar spectrum is due to ozone in the high atmosphere. The ozone absorption band, however, which sets in at about 2900A extends only to about 2200A, and below this ozone is relatively transparent.[3] It has not been known why sunlight in the far ultra-violet region from 2200 to 2000A does not penetrate to the surface of the earth. The present measurements indicate that it is the lower atmosphere which stops these wave-lengths, for from the values of α of curve 2, Fig. 1, the thicknesses of clear atmosphere necessary to reduce the light to 10^{-2} of its original intensity were about 570, 350 and 200 meters for wave-lengths 2200, 2100 and 2050A, respectively.

[6] For references about the light absorption of oxygen, see Wulf, Proc. Nat. Acad. Sci. **14,** 609 (1928).