

of the Planck constant. They might have been found by Gibbs through pure reasoning concerning his paradox. The constant h enters only through the special formula for the fractional likeness amplitude between q and p ,

$$\psi(q,p) = \exp(2i\pi qp/h), \quad (8)$$

obtained from microphysical evidence. This ψ -function is periodic and thereby gives rise to de Broglie's $p = h/\lambda$,

to the Heisenberg uncertainty relation between coordinates q and momenta p , and to the duality and complementarity of the particle theory and its wave-like formalism. Also, Eq. (8) opens the path to the dynamics of those special mechanical systems whose Hamiltonian and other observables are given as functions of the q 's and p 's. Those parts of quantum theory, however, which rest on the thermodynamic continuity principle are independent of microphysical experience.

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Ionospheric Absorption by N_2 and O_2 of Certain Extreme Ultraviolet Solar Wavelengths

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Measurements are reported of the coefficients of absorption by the gases N_2 and O_2 of the emission from the H Lyman series 2-7, the resonance line 584A of He I, and twenty lines of H_2 between 980A and 850A, the atomic lines likely being strong in solar radiation. For an atmosphere of constant relative composition the absorption coefficients are related to the atmospheric heights of maximum photoionization and maximum electron concentration by equations which allow for a constant temperature gradient, the inverse square decrease of gravity, and a recombination process which may vary with height. With these laboratory measurements for N_2 and O_2 and the known calculated absorption for O, ionosphere layer heights are computed for the simple case which assumes complete O_2 dissociation above 100 km, no N_2 dissociation, and two-body recombination. Although only the first assumption is probably secure, it appears that photoionization is capable of producing layers at heights which agree with observation.

INTRODUCTION

IONIZATION of the upper atmosphere by the absorption of solar radiation is well established as the major mechanism in the production of ionosphere layers.¹ The resulting stratified concentrations of electrons, which are observed in great detail by reflection of radio waves and designated D , E , F_1 , and F_2 , occur at varying heights of about 65, 100, 200, and 300 km, respectively. To study the possible photoionization processes one must correlate information on the available solar ionizing radiation, the distribution of absorbing gases, and the absorption coefficients of the gases for these wavelengths. As available radiation there very probably is, in addition to the solar blackbody continuum, an intense line emission spectrum in the extreme ultraviolet to which the resonance spectra of H and He from the vicinity of solar flares contribute strongly.² Below 910A the excess of radiation over that from a solar blackbody at 6000°K has been estimated by Spitzer³ to be of the order of tenfold in order to establish a temperature of about 1500°K at the height

of the F_2 layer. Hunter,² Sedra,⁴ Tousey,⁵ and others have estimated this excess to be 2 or 3 orders of magnitude. The resonance line 1216A of H has not been photographed in spectra recorded during rocket flights up to 140 km,^{6,7} although from Preston's low value⁸ of its absorption coefficient in N_2 ($\alpha < 0.005 \text{ cm}^{-1}$) one would expect considerable intensity at this height. The absorption continuum of NO, expected⁹ near 1216A, may possibly account for the absence of this wavelength in ordinary spectra from rocket flights. However, the quantitative experiments of Tousey⁵ using filters and thermoluminescent phosphors have detected strong radiation in the range 795A-1050A at heights between 88 and 127 km and in the band 1050A-1340A between 80 and 90 km.

Oxygen and nitrogen are major components of the upper atmosphere, the former being almost completely photodissociated^{10,11} at heights greater than about 100 km. Emissions from aurorae and the airglow show the presence of molecular nitrogen and atomic oxygen.¹²

⁴ R. N. Sedra, *Phys. Rev.* **83**, 190 (1951).

⁵ Tousey, Watanabe, and Purcell, *Phys. Rev.* **83**, 792 (1951).

⁶ J. J. Hopfield and H. E. Clearman, *Phys. Rev.* **73**, 877 (1948).

⁷ Durand, Oberley, and Tousey, *Astrophys. J.* **109**, 1 (1949).

⁸ W. M. Preston, *Phys. Rev.* **57**, 887 (1940).

⁹ G. L. Weissler, conversations, June, 1951.

¹⁰ O. R. Wulf and L. S. Deming, *Terr. Magn. Atmos. Elect.* **43**, 283 (1938).

¹¹ H. E. Moses and Ta-You Wu, *Phys. Rev.* **83**, 109 (1951).

¹² A. B. Meinel, *Repts. Prog. Phys.* (The Physical Society, London) **14**, 121 (1951).

¹ D. R. Bates and H. S. W. Massey, *Proc. Roy. Soc. (London)* **A187**, 261 (1946).

² A. Hunter, *Repts. Prog. Phys.* (The Physical Society, London) **9**, 8 (1942).

³ L. Spitzer, Jr., contributor, *The Atmospheres of the Earth and Planets* (University of Chicago Press, Chicago, Illinois, 1949), Chapter 7. I am indebted to Professor Spitzer for a preliminary loan of his manuscript.

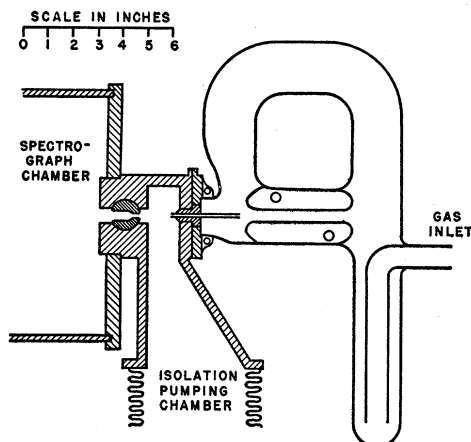


Fig. 1. Toroidal electrodeless discharge tube as mounted on vacuum spectrograph.

Also, atomic nitrogen is observed in aurorae, although the degree of nitrogen dissociation is not agreed upon.

The ionization cross section of O has been calculated by Saha and Rai¹³ and by Bates.¹⁴ Laboratory measurements of the absorption cross sections of N₂ and O₂ in the extreme ultraviolet have been made recently by Weissler¹⁵ and earlier by Schneider,¹⁶ both of whom used line emission sources. Qualitative absorption spectra in the extreme ultraviolet, which were made with a continuous source and used for wavelength studies, have been published by Takamine, Suga, and Tanaka,¹⁷ and Worley¹⁸ for N₂, by Price and Collins¹⁹ for O₂, and by Hopfield²⁰ for dry air. The absorption of the H Lyman series in O₂ has been clearly photographed by Takamine and Suga,²¹ who did not attempt cross-section measurements with their spark source.

The contribution reported here is a laboratory measurement of absorption coefficients of the gases N₂ and O₂ for the lines 2 to 7 of the H Lyman series, for the first line 584A of the corresponding resonance series of neutral He, and in addition for twenty lines of H₂. These measurements can be interpreted in terms of the height in the upper atmosphere at which the maximum rate of absorption occurs. The resulting layer of maximum absorption will be single for each wavelength, provided the atmosphere is considered to have constant relative composition and no density inversions. If ionization is at least a partial contributor in the absorption process, the layer of maximum ion production will

coincide with that of maximum absorption. The height of maximum electron density will also depend upon how the recombination and attachment processes vary with pressure and temperature.

EQUIPMENT AND PROCEDURE

Measurements were made using a normal incidence vacuum spectrograph containing a glass grating of 15,000 lines/in. and 1-m radius. The rulings have been etched with HF to improve the intensity at short wavelengths as described by Wood and Lyman.²² For high contrast, fine grain, and uniformity Eastman Process plates were used. These were sensitized by dipping in a 10 percent solution of Cenco pump oil in petroleum ether according to the technique of Schneider.¹⁶ The narrow band of fluorescence permitted emulsion calibrations using 3906A from a Hg arc. Calibration exposure times were made equal to those of the vacuum spectra to avoid reciprocity failure. A slit width of 0.04 mm produced lines sufficiently broad for accurate microphotometer tracing. The absorption coefficient is obtained from the linear slope of the semilogarithmic graph of transmitted intensity *vs* density of absorbing gas in the spectrograph.

The absorbing gases N₂ and O₂ came from tank and electrolytic supplies, respectively. The O₂ was purified by passing over hot platinized asbestos, P₂O₅, solid CaOH, and solid CO₂ traps to remove H₂, H₂O, CO₂, and Hg, respectively. The N₂ was purified similarly except that the asbestos was not heated and liquid N₂ was used in the cold traps.

As a light source of steady and high intensity a toroidal electrodeless discharge tube was arranged as shown in Fig. 1 and excited by an inner coil at a frequency of 6 Mc/sec. The discharge was viewed end-on through a portion of the tube constricted to 1-cm diameter and water-cooled. An intermediate pumping chamber prevented the gas in the discharge from entering the optical slit of the spectrograph, and a suitable pressure differential was maintained by a capillary of 1-mm diameter and 30-mm length. The discharge was operated at pressures of 0.04 mm for purified H₂ and 0.08 mm for the mixture of 5 percent H₂ in He. The heating power developed in the discharge was estimated to be about 50 watts. The H₂ spectrum obtained was quite similar to that published by Jeppeson,²³ which likewise extended to about 850A. Prominent lines were used for absorption measurements.

Table I lists the resulting measurements of absorption coefficients. These values are the means of from three to five independent sets of observations, each usually covering four pressures of absorbing gas. The ranges of probable error indicated refer not only to internal consistency but to estimated errors in over-all calibrations. The line H Lyman α at 1215.7A was not studied because of its low absorption and the previous careful

¹³ M. N. Saha and R. N. Rai, Proc. Natl. Inst. Sci. India **1**, 227 (1938), discussed in reference 1.

¹⁴ D. R. Bates, Monthly Notices Roy. Astron. Soc. **100**, 25 (1939); **106**, 432, 509 (1946).

¹⁵ Weissler, Lee, and Mohr, J. Opt. Soc. Am. **42**, 84, 200 (1952).

¹⁶ E. G. Schneider, J. Opt. Soc. Am. **30**, 128 (1939).

¹⁷ Takamine, Suga, and Tanaka, Sci. Papers Inst. Phys. Chem. Research (Tokyo) **34**, 854 (1938).

¹⁸ R. E. Worley, Phys. Rev. **64**, 207 (1943).

¹⁹ W. C. Price and G. Collins, Phys. Rev. **48**, 715 (1935).

²⁰ J. J. Hopfield, Astrophys. J. **104**, 208 (1946).

²¹ T. Takamine and T. Suga, Sci. Papers Inst. Phys. Chem. Research (Tokyo) **29**, 213 (1936).

²² R. W. Wood and T. Lyman, Phil. Mag. **2**, 310 (1926).

²³ C. R. Jeppeson, Phys. Rev. **44**, 165 (1933).

TABLE I. Measured absorption coefficients of N₂ and O₂ and corresponding layer heights at various temperature gradients above 120 km.

Line source	Wavelength A	Absorp. coefficient in cm ⁻¹ S.T.P.					Height in km of max absorption			
		N ₂		O ₂		O	a = 9.03°K/km	7.36	5.14	0
HLy2	1025.7	8± 3		53± 20		(calc	136	137	138	138
H ₂	984.3	18 10		343 25		by	157	156	155	149
HLy3	972.6	3900 100		1350 150		Saha	400	400	346	223
HLy4	949.8	27 5		171 15		and	165	163	161	154
HLy5	937.8	100 20		113 10		Rai)	212	203	193	172
HLy6	930.8	190 30		460 20			243	228	212	181
HLy7	926.2	71 10		172 10			196	191	184	168
H ₂	923.9	103 10		296 15			213	204	194	173
H ₂	920.0	610 100		166 15			324	291	255	197
H ₂	919.1	16 3		127 15			151	150	150	147
H ₂	916.8	240 50		388 10			257	240	220	185
H ₂	916.0	22 10		120 15			159	158	157	151
H ₂	914.1	52 15		130 15			187	181	176	164
H ₂	911.3	420 100		177 20			295	268	241	192
H ₂	910.3	58 30		399 10			190	183	178	165
H ₂	909.2	67 40		356 10	120		224	213	201	176
H ₂	905.4	52 15		133 10	120		219	208	197	175
H ₂	903.8	25 10		198 10	120		207	198	190	171
H ₂	901.6	48 20		270 25	120		217	207	196	174
H ₂	894.1	32 10		229 10	120		210	201	192	172
H ₂	890.7	96 25		250 15	120		234	221	207	179
H ₂	886.1	340 50		248 20	120		291	266	239	192
H ₂	880.6	230 50		185 15	120		270	250	227	187
H ₂	868.8	331 50		154 10	120		290	265	239	191
H ₂	859.0	24 5		137 10	120		206	198	190	171
H ₂	855.6	480 100		290 60	120		315	283	251	196
HeI	584.3	480 30		440 80	310		328	293	257	198

measurements by Preston, which Tousey⁵ and others regard as the most reliable. With two exceptions the present results cannot be directly matched with those of Weissler and of Schneider, which were made using neighboring emission lines. Included in the careful measurements of Weissler¹⁵ were the lines H Lyman β (1025.7A) and He I 584.4A. The absorption coefficients of N₂ for these lines were observed by him to be 60 cm⁻¹ and 700 cm⁻¹, respectively, and for O₂ the values were 43 cm⁻¹ and 550 cm⁻¹. It is seen that the agreement is quite satisfactory in the case of O₂, while the absorption by N₂ appears to be significantly greater than the values in Table I. Weissler, using 1215.13A of He II, obtained for N₂ the value of 66 cm⁻¹.

DENSITY DISTRIBUTIONS

The data for composition, pressure, and temperature of the atmosphere to 120 km are taken from the recent compilation of the National Advisory Committee for Aeronautics.²⁴ Below 80 km the fractions by volume of the major constituents O₂ and N₂ in dry air are taken, following Wildt,²⁵ to be 0.2095 and 0.7809, respectively. The region of partial O₂ dissociation in summer daylight hours is taken to lie between 80 and 100 km, the volume fraction of atomic O increasing linearly through this region from 0 to 0.346. The volume fraction of N₂

correspondingly decreases to 0.646. Above 100 km the atmosphere will be assumed to consist of N₂ and O.

If the temperature and the acceleration of gravity are considered constant, the variation of air density ρ with height h above sea level, measured relative to the value ρ₀ at h₀, follows the well-known exponential form

$$\rho/\rho_0 = \exp(-z/H_0), \tag{1}$$

where z = h - h₀ and the scale height H₀ = RT₀/Mg, with R the gas constant, T₀ the temperature, M the mean molecular weight, and g the acceleration of gravity. The effect of the change in g with height can be included by using as the scale height the geometric mean of its values at h and h₀.

The temperature above 120 km, however, is undoubtedly not constant. With the exception of the low rotational temperatures observed by Vegard²⁶ in auroral streamers, where the excitation mechanism raises doubts,^{27,28} all evidence indicates that the temperature increases rather steadily, reaching a value between 1000 and 2000°K at 300 km. If, as suggested by Bates,²⁹ Spitzer,³ and Woolley,³⁰ this increase is described by a

²⁶ L. Vegard, contributor, *The Emission Spectra of the Night Sky and Aurorae* (The Physical Society, London, 1948), p. 82.

²⁷ N. C. Gerson, Repts. Prog. Phys. (The Physical Society, London) 14, 316 (1951).

²⁸ L. M. Branscomb, Phys. Rev. 79, 619 (1950).

²⁹ D. R. Bates, Proc. Phys. Soc. (London) B64, 805 (1951).

³⁰ R. v. d. R. Woolley, Proc. Roy. Soc. (London) A189, 219 (1947).

²⁴ C. N. Warfield, Tech. Note No. 1200 (N.A.C.A., Langley Field, Virginia, 1947).

²⁵ R. Wildt, Revs. Modern Phys. 14, 152 (1942).

constant gradient of $a^\circ\text{K}/\text{km}$, the modified density distribution above height h_0 can be simply shown³¹ to be

$$\ln(\rho/\rho_0) = -(Mg_0/Ra + 1) \ln(1 + az/T_0), \quad (2)$$

which reduces to that of an isothermal atmosphere as a vanishes.

Allowance for the variation of g as well as the linear temperature gradient also leads to an exact expression. The substitution of $g = g_0 r_0^2/r^2$ and $T = T_0(1 + az)$ in the basic atmospheric equation in the form

$$-d\rho/\rho = dT/T + dz/H \quad (3)$$

gives an integrable equation. It will be convenient to use the constants

$$\beta = aH_0/T_0 \quad \text{and} \quad \gamma = r_0/(\beta r_0 - H_0). \quad (4)$$

The resulting density distribution is

$$\ln(\rho/\rho_0) = -(\gamma^2\beta + 1) \ln(1 + \beta z/H_0) + \beta\gamma^2 \ln(1 + z/r_0) + \gamma z/(r_0 + z). \quad (5)$$

When the gradient $a \gg T_0/r_0$, this equation simplifies to

$$\ln(\rho/\rho_0) = -(1/\beta + 1) \ln(1 + \beta z/H_0) + (1/\beta) \ln(1 + z/r_0) + z/\beta(r_0 + z). \quad (6)$$

HEIGHT OF MAXIMUM RATE OF ABSORPTION

If the absorption coefficient of the i th component gas is given by $\alpha_i \text{ cm}^{-1}$ for that gas at 0°C and 760-mm

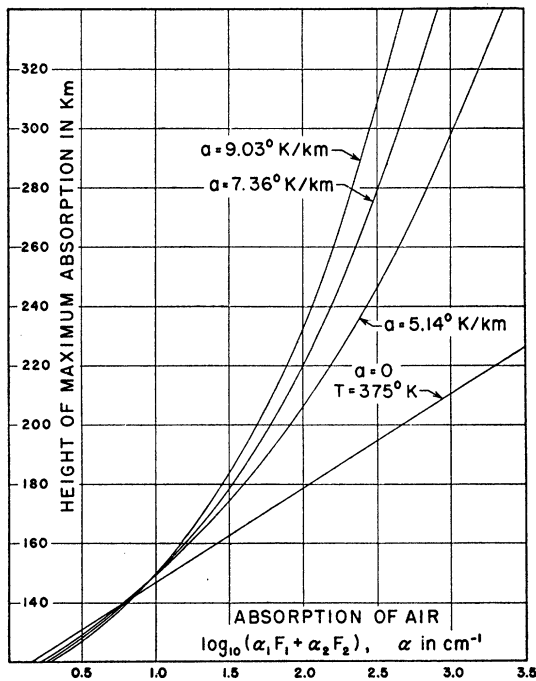


FIG. 2. Computed curves relating absorption coefficients to layer heights for inverse square gravity and various temperature gradients above 120 km.

³¹ J. A. Gledhill and M. E. Szendrei, Proc. Phys. Soc. (London) **B63**, 427 (1950).

pressure, then the total absorption coefficient of air at height h_0 is

$$A = (\rho_0/\rho_s)(\alpha_1 F_1 + \alpha_2 F_2 + \dots) 10^5 \text{ km}^{-1}, \quad (7)$$

where the composition is given by the volume fractions F_i , and ρ_s is the density at S. T. P. of air of the same composition. The change in the intensity of incident radiation J follows Beer's law and for vertical incidence is

$$dJ = JA(\rho/\rho_0)dz. \quad (8)$$

The measured absorption coefficients can be used to compute either the height of the maximum rate of absorption or the height of maximum ion concentration. The latter computation requires certain information on the processes of electron disappearance, while the former does not. It will be seen that these heights are identical under certain commonly assumed conditions of recombination.

In obtaining the height of maximum ion concentration, one may write the standard equation for the rate of production of ion density n to include a general recombination process

$$dn/dt = (JA\rho/\rho_0) - \alpha' f\phi, \quad (9)$$

where $f = f(\rho)$, $\phi = \phi(n)$, and α' is the recombination coefficient. For the case of recombination in two-body collisions, as is commonly assumed for the F layers, $f = 1$ and $\phi = n^2$. The conditions for equilibrium and for maximum ion density, respectively, are

$$dn/dt = 0, \quad dn/dz = 0 = d\phi/dz. \quad (10)$$

Equation (9) may then be equated to zero at equilibrium and used, together with Eq. (8), to eliminate J and dJ from the differential form of Eq. (9). Since ϕ is by Eq. (10) an extreme at the height of maximum ion density, one then obtains at this height the relation

$$(\rho df/d\rho - f)d\rho/dz = A\rho^2 f/\rho_0. \quad (11)$$

If it is known or assumed how ρ and f vary with z and if A is obtained from laboratory absorption measurements, one can graphically find the height at which Eq. (11) is satisfied, which is the height of maximum ion density.

On the other hand, to find the height where the rate of absorption is a maximum, dJ/dz must be maximized. Applying the necessary condition $d^2J/dz^2 = 0$ to Eq. (8), one obtains at the height of this maximum

$$-d\rho/dz = A\rho^2/\rho_0, \quad (12)$$

which is identical with Eq. (11) if f is constant. This assumption of simple two-body recombination will be made in the presentation here of measured absorption coefficients, and the height of maximum ion density will therefore be identical with the height of maximum rate of absorption.

For the case of isothermal $T = T_0$ and constant $g = g_0$

this layer height \bar{z} is simply

$$\bar{z} = H_0 \ln AH_0, \quad (13)$$

and at this height the intensity is reduced from its original value by the fraction

$$J(\bar{z})/J(\infty) = e^{-1}. \quad (14)$$

The assumption of a constant temperature gradient and constant g can directly be shown³¹ to produce the following modifications of Eqs. (13) and (14):

$$\ln(1 + \beta\bar{z}/H_0) = \beta \ln[AH_0/(1 + \beta)], \quad (15)$$

$$J(\bar{z})/J(\infty) = e^{-1-\beta}. \quad (16)$$

Nicolet³² has given an equivalent expression for electron layer height assuming recombination by collisions of an arbitrary number of bodies and an effective recombination coefficient which has an arbitrary power dependence on density.

The concept of associating the layer of maximum absorption with a certain optical depth in the atmosphere, as indicated in Eqs. (14) and (16), becomes artificial when one allows g to vary with the inverse square law, for as Mitra³³ implies, the total mass above any height is given by a nonconvergent integral. But the treatment in Eq. (12) is still applicable, since the density function is given in Eq. (5). The equation for \bar{z} becomes, in logarithmic form,

$$\ln A = \ln \left[\frac{\beta(\beta\gamma^2 + 1)}{H_0} - \frac{\gamma}{r_0} \left(1 + \frac{\beta\bar{z}}{H_0} \right) \left(\frac{r_0}{r_0 + \bar{z}} \right) \left(\frac{r_0}{r_0 + \bar{z}} + \beta\gamma \right) \right] + \beta\gamma^2 \ln \left(1 + \frac{\beta\bar{z}}{H_0} \right) - \beta\gamma^2 \ln \left(1 + \frac{\bar{z}}{r_0} \right) - \frac{\gamma\bar{z}}{r_0 + \bar{z}}. \quad (17)$$

INTERPRETATION OF RESULTS

Equation (17) gives the dependence of the layer height \bar{z} upon A . Since the constants β , γ , H_0 , and r_0 are known or estimated properties of the atmosphere and A is evaluated from absorption coefficients, the equation may be graphically solved for \bar{z} . Using at $H_0 = 120$ km the values $r_0 = 6490$ km, $T_0 = 375^\circ\text{K}$, $M = 23.94$, and $g_0 = 9.65 \times 10^{-3}$ km/sec² according to the N.A.C.A. tables, one computes a scale height $H_0 = 13.49$ km. With these values Eq. (17) is solved graphically in Fig. 2, where the right side is plotted horizontally as a function of the ordinate \bar{z} for four suggested values of temperature gradient. These values of a in $^\circ\text{K}/\text{km}$ are 9.03 ($T = 2000^\circ\text{K}$ at 300 km); 7.36 (Spitzer, 1700°K at 300 km); 5.14 (Woolley, 1300°K at 300 km); and 0 (isothermal). If g were taken to be a

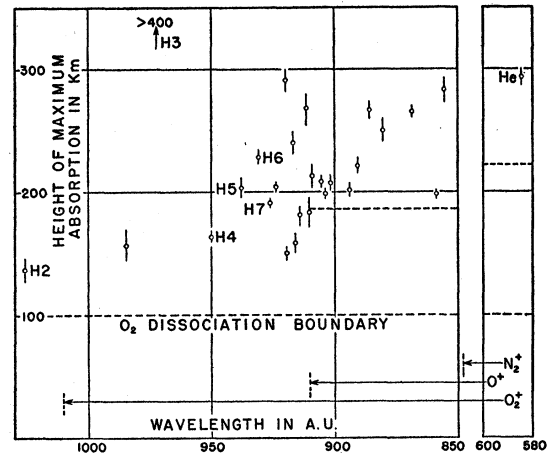


FIG. 3. Layer heights for various wavelengths, assuming $a = 7.36^\circ\text{K}/\text{km}$. Lines of H Lyman series are numbered points. Continuous absorption by O sets the lower limit shown by upper dashed line.

constant g_0 , then the curve for $a = 9.03$ would be lower by 10 km at 300 km. The measured absorption coefficients of N_2 and O_2 are listed by wavelength in Table I. Also, the corresponding coefficients of the continuous absorption by O as computed by Saha and Rai¹³ are given. This absorption continuum is somewhat uniform between about 500A and the ionization limit at 910A because of the overlapping of the continua of excited atoms. The values $\alpha = 120$ cm⁻¹ above 856A and $\alpha = 310$ cm⁻¹ at 584A have been used.

Assuming that N_2 and O are the sole components above 120 km, one computes $\ln A$ and from the graph of Fig. 2 finds the height of maximum rate of absorption. These heights are plotted by wavelength in Fig. 3 for the assumed value of $a = 7.36^\circ\text{K}/\text{km}$. This value of a is seen to give a maximum at 293 km for the presumably strong 584A radiation from He I, which could concurrently ionize both N_2 ($\lambda < 796$) and O ($\lambda < 910$). This height would agree with that of the F_2 ionosphere layer. It is seen that for this same temperature gradient no wavelength between 910A and about 500A can penetrate the continuous absorption by O at a layer height of about 190 km, regardless of N_2 transparency.

For all wavelengths measured the maximum rate of absorption occurs well above 120 km, and hence, absorption by O_2 , which exists only below 100 km, need not be considered. But other wavelengths may escape the line absorption in the range $1010 > \lambda > 910$ and ionize O_2 . Since the air density is relatively high in the dissociation region, any wavelength appreciably absorbed by O_2 would be very rapidly attenuated, and the height of maximum rate of absorption would lie close to the upper boundary of the region. This height would agree with that of the E layer. For example, if O_2 alone were the absorber, radiation for which $\alpha = 120$ cm⁻¹ would be reduced by $1/e$ in the first 2 km below 100 km, and only 5 km would similarly be needed if

³² M. Nicolet, *J. Atmos. Terr. Phys.* 1, 141 (1951).

³³ S. K. Mitra, *The Upper Atmosphere* (Royal Asiatic Society of Bengal, Calcutta, India, 1947), Chapter 1.

$\alpha = 17 \text{ cm}^{-1}$. The strong line absorption by N_2 of those members of the H Lyman series used in the measurements seems to eliminate their role in E layer formation, but the necessary radiation could possibly come from the wings of these lines broadened in solar emission, from series members higher than the seventh, or from the solar blackbody continuum.³⁴ The observations of Tousey⁵ and of Friedman³⁵ indicate that there may also be soft x-rays of irregular intensity.

Bates³⁶ has recently argued on the basis of computed and observed intensities of the first negative nitrogen bands in twilight enhancement that N_2^+ forms but a small portion of the F layer ions and also that the F_2 layer is derived from the F_1 through a variation with altitude of the O^+ recombination coefficient. His results raise doubt as to the importance of N_2 as an absorber even of wavelengths above its ionization limit and would indicate either or both of the following conclusions: the radiation around 584Å is weak, and nitrogen in the F region is largely atomic. Herzberg³⁷ has suggested that a known predissociation of N_2 may be appreciable at these heights. The continuous absorption by N, for whose spectral head Bates has computed $\alpha = 1620 \text{ cm}^{-1}$, should ideally be included in the analysis of atmospheric absorption. But as yet the degree of dissociation is not known; and hence the role of N, which may still be small, is here conveniently ignored. If the dissociation and the air density were known functions of height, then the dependence of A on z would be known. Equation (11) would be modified only by the additional term $f\alpha'\rho(dA/dz)/A$ on the right and could again be solved graphically for \bar{z} .

SUMMARY

Absorption coefficients of N_2 and O_2 are given for the H Lyman series to the seventh member, the principal line of the resonance series of He I, and twenty wavelengths of H_2 , the atomic lines being chosen be-

³⁴ R. v. d. R. Woolley and C. W. Allen, Monthly Notices Roy. Astron. Soc. **108**, 292 (1948).

³⁵ Friedman, Lichtman, and Byram, J. Opt. Soc. Am. **41**, 292 (1951).

³⁶ D. R. Bates, Proc. Roy. Soc. (London) **A196**, 562 (1949).

³⁷ G. Herzberg, Nature **161**, 283 (1948).

cause of their probably strong contribution in solar emission. The relation of these data to ionosphere production is discussed, using an analysis for the height of maximum rate of absorption which takes into account a linear increase in atmospheric temperature with height above 120 km and the inverse square decrease of gravity. If the temperature is assumed to increase to 1700°K at 300 km, the combined absorption by N_2 and O of the principal line of He I would have a maximum at 293 km, the height of the F_2 layer. The wavelengths studied between 1010Å and 910Å could not penetrate N_2 to the extent necessary to ionize O_2 at the E layer; the source of this ionization may be broadened wings of these lines in solar emission, further lines in the H Lyman series, continuous solar radiation, or soft x-rays. Other intense solar emission than the lines studied may well contribute to the formation of other layers, in particular the F_1 layer at the height of the maximum rate of O^+ production. The location of the absorption coefficients on a height scale strongly suggests that the upper atmosphere is not isothermal. The foregoing analysis has discussed the heights of maximum production rate of ions; these are also the heights of maximum concentration of electrons in the simple case where the two-body recombination coefficient is constant and the atmosphere has constant relative composition. Under less simple conditions of electron removal these heights will, in general, fail to coincide, and this situation may exist in the upper atmosphere. In fact Bates has suggested that the F_1 and F_2 layers may be formed by the same ions and radiation and rendered separate by a marked change in recombination coefficient with height. A correct computation of electron layer height must await further knowledge of the dominant mechanism of electron removal and the variation of recombination and attachment coefficients with height.

The laboratory measurements reported here were carried out at the Lyman Laboratory of Harvard University. The writer is very grateful to Professor O. Oldenberg for his friendship, for the suggestion of this research, and for the stimulating supervision of its experiments.