

58. THE UPPER ATMOSPHERE

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(*Proc. Nat. Inst. Sci. Ind.*, 1, 217, 1935)

THE upper atmosphere is the name given to the part of our atmosphere which lies above the stratosphere, *i.e.*, above a height of about 20 km. or so in round numbers. Direct investigations of this region are difficult on account of its inaccessibility, but a number of indirect methods is available which are capable of throwing light on the subject. These methods can be grouped under the following headings:—

1. Direct exploration of the upper atmosphere, by means of pilot balloons, stratosphere ascents, etc. Such studies are being carried out in many meteorological stations, and the stratosphere flights have been carried out by Profs. Piccard and Cosyns in Belgium, by the National Geographical Society in the U.S.A., and by a Scientific Commission of the U.S.S.R.
2. Studies of the spectra of the aurora and the night sky.
3. Investigations of the ionisation of the upper atmosphere by radio methods, as sketched out by Dr. Mitra and other speakers.
4. Study of propagation of sound through the upper atmosphere.
5. Studies of the ozone content of the atmosphere and its variation with latitude, hour of the day and the season of the year.
6. Studies on the fall of meteors, fireballs and meteorites (Lindemann, Dobson and others).
7. Daily, seasonal and irregular changes in the earth's magnetism.

Though this discussion is properly on the 'Ionosphere', mature reflection has shown that we cannot shut out the discussion on the other topics, as they are all interrelated, and a complete picture of the upper atmosphere cannot be obtained unless the materials collected from all these sources are utilized in a synoptic study.

My own work is an attempt on these lines, and I would suggest that in future, discussions on this subject may be widened by including the other topics as well.

The particular phase of the problem which I have chosen to discuss is very ably summarised by Professor S. K. Mitra in the concluding part of his opening address which I was enabled to consult through his courtesy. I have therefore cut down much of the introduction, and proceed straight from the point where he left it.

The problem of ionisation of the upper atmosphere.

It is well known that the first suggestion that the upper air is ionised was made to account for the daily and seasonal variations—sometimes very irregular—of the earth's magnetism, probably by Balfour Stewart (1882). From the very beginning, there have been two rival views regarding the origin of the ionisation; according to the first, ionisation is caused by ejection of charged particles from the sun into the earth's atmosphere, and according to the second view, it is the ultraviolet light of the sun which causes ionisation of the molecules constituting the upper atmosphere. It is at present recognised that probably both agencies are at work, and the present-day efforts are directed more to a quantitative estimation of the relative rôles played by the two agencies.

1. *Ionisation by ultraviolet light.*

A. Schuster (1886) was probably the first to suggest that the ionisation of the upper air is due to ultraviolet radiation of the sun. This view was contested by Swann who maintained that the intensity of the solar rays is not sufficient for maintaining the requisite ionisation. He was followed by Chapman¹ and others who proceeded from the view that ionisation was due either to ultraviolet photons proceeding with the velocity of light or to corpuscles (electrons or neutral particles) proceeding with some finite velocity, both from the sun; and they tried to find out how the ionisation would vary with the time of the day (position of the sun in the sky), or with the season of the year.

In the meantime, the radio methods for the quantitative investigation of the ionised layers have been developed. These show that the ionisation is not uniform, but there are marked discontinuities at different heights where the electron-density changes rather suddenly and whence radio waves are very strongly reflected, as first postulated by Kennelly and Heaviside in 1902. So far four ionized regions (E_1 , E_2 , F_1 , F_2) have been found.

In addition to these layers, further claims have been made of a D-layer at a height of 55 kms. by S. K. Mitra and P. Syam, and of a G-layer by Kirby and Judson.²

It is now definitely settled that the ionisation of the E_1 , E_2 , and F_1 -layers is mainly due to the ionisation by the solar ultraviolet light. This was proved by the observation made in Canada by Henderson³ during the total solar

eclipse of 1932; the ionisation of the E -layer was found to diminish within the eclipse zone simultaneously with the beginning of the totality.

Further support is given by the observation that the variation of the ion-content with the time of the day for the E_1 , E_2 , F_1 layers follows closely the laws deduced by Chapman, Pedersen⁴ and others, who ascribe the ionisation to ultraviolet light from the sun. These points have been discussed in a recent paper by E. V. Appleton and Naismith.⁵ But there is great difficulty in accounting for the origin of the F_2 -layer ionisation on this basis as pointed out by the authors.

In this paper, I shall try to show that though the mathematical works of Chapman, Pedersen and others give the correct formula for the variation of the electron-content of the atmosphere with the time of the day and season, the physical assumptions regarding the cause of ionisation require revision in view of the recent laboratory work on the molecular and atomic spectra of oxygen and nitrogen. The chief constituents of the upper atmosphere are molecular O_2 and N_2 , and probably atomic O , and N ; hydrogen appears to be definitely excluded, and no helium has yet been found. Even if it exists, the argument will not be much changed. Ozone has been found to be confined between 20 kms. to 50 kms. and undoubtedly plays some important part in the phenomena observed in the lower layers.

Two assumptions form the basis of Chapman's calculations.

(a) That the sun radiates like a black body at a temperature of 6000°K , even for the ultraviolet region.

(b) That the solar radiation below λ 1350 (energy 9 e -volts) is capable of producing ionisation of some constituents of the upper atmosphere. This assumption has been subsequently modified. In his latest paper Chapman¹ tries to prove that ionisation is mostly due to atomic oxygen (I.P. 13.56 e -volts), and molecular oxygen (I.P. 16.1 e -volts), and that the temperature of the upper air which he takes to be 300° to 400°K , plays some part in promoting ionisation.

The original argument of Chapman was as follows:—

The total intensity of radiation from the sun, having a wavelength $< \lambda$ 1350, is 1.61×10^{-5} times the total solar energy. So the total intensity of ionising radiation received from the sun is

$$\frac{1.61 \times 10^{-5} \times 1.93 \times 4.16 \times 10^7}{60} = 22 \text{ ergs./per sec.} \dots (1)$$

The energy required for producing a pair of ions is given by

$$\frac{9}{300} \times 4.77 \times 10^{-10} = 1.4 \times 10^{-11} \text{ ergs.} \dots (2)$$

So the solar rays can produce

$$\frac{22}{1.4 \times 10^{-11}} = 1.6 \times 10^{12} \text{ ion pairs/sec.} \dots (3)$$

when they are normally incident on the atmosphere. Let us see whether this number is sufficient to maintain the observed ionisation of the earth's atmosphere. The equation of ion-equilibrium is given by

$$\frac{dn}{dt} = I - \alpha n^2, \dots (4)$$

where I is the rate of production, α is the coefficient of recombination, and n is the number of ions per cubic cm.

Now we have to find out I and α . At night we have $I=0$ and we have

$$n = n_0 / (1 + \alpha n_0 t). \dots (5)$$

The value of n , n_0 can be obtained by radio methods by studying the variation of the electron-density of a layer with the progress of the night hours.

Chapman calculates from these data that $\alpha = 10^{-9}$. Again, when at midday, the stationary conditions are reached, $I = \alpha n^2$ hence if $n = 10^3$ per c.c. $I = 10^3$. If we take the depth of the atmosphere to be 300 kms. $= 3 \times 10^7$ cms., the total number of ions to be produced per second is $3 \times 10^7 \times 10^3 = 3 \times 10^{10}$. This is much less than 1.6×10^{12} , the number which the solar rays are capable of producing.

The objection against this theory is that no constituent of the atmosphere has such a low ionisation potential as 9 volts. In Table (1), the reaction potentials of all the constituents are given.

It is seen that O_2 has the lowest I.P., viz. 12.1 volts. The intensity of sunlight consisting of quanta whose energy content is larger than 12.1 e -volts is 1.5×10^{-7} times the total energy. But the whole of it is not equally effective in producing ionisation, while in Table 1 the spectrum has been assumed to extend from λ 1019 to $\lambda=0$. We shall not be far wrong if we suppose that only one-third of the amount, i.e. $\frac{1}{3} \times 10^{-7}$ is effective. Then the energy of ionising radiation falling on one sq. cm. of the earth's surface $= 11$ ergs./sec. Hence repeating Chapman's calculations, we find that the number of ions which can be produced is 0.6×10^{10} . If we take into consideration the obliquity of the rays and other factors, this has to be still further reduced. This number is less than the figure 3×10^{10} , which is required according to Chapman's calculation to maintain the ionisation of the upper atmosphere.³

There is no direct evidence so far that O_2 is ionised by the solar rays to O_2^+ , because up to this time no lines due to O_2^+ (negative bands of O_2^+) have been discovered in the night sky spectrum, though this evidence alone is not conclusive against the presence of O_2^+ ions (vide infra). But the N_2^+ bands (first negative bands of nitrogen) have been found to occur in the night sky spectrum. These bands (the o-o band is λ 3910) are very prominent in the polar light, they are rather feeble in the night sky. As the excitation potential and the electron structure of the state giving rise to these bands are very accurately known

TABLE I

Phenomenon	Active Wave-length in Å.U.	<i>e</i> -Volts	Number of quanta per cm. ² of earth per sec.	Photochemical Action.
Absorption by Ozone	2970 2300	4.136 5.40	7.2×10^{16}	Each quantum absorbed converts two O ₃ -molecules into three O ₂ -molecules.
Absorption by Oxygen	2040 1200	6.01 10.28	4×10^{14}	Each quantum absorbed produces two O ₃ -molecules.
Photo-ionisation of Oxygen (1).	1019	12.11	2.7×10^{10}	Each quantum absorbed produces O ₂ ⁺ and one electron.
Photo-ionisation of Oxygen (2)	747.8	16.5	4.2×10^8	Each quantum absorbed produces O ₂ ⁺ -excited and an electron.
Photo-ionisation of Nitrogen (1)	795.1	15.52	2.7×10^7	Each quantum absorbed produces N ₂ ⁺ -normal and one electron.
Photo-ionisation of Nitrogen (2)	660.9	18.67	10^5	Each quantum absorbed produces N ₂ ⁺ -excited and one electron.
Absorption by Oxygen	1750	7.10	7×10^{13}	Dissociation into O ³ P and O ¹ D ₂ .
Absorption by Oxygen	1324	9.32	1.65×10^{12}	Dissociation into O ³ P and O ¹ S ₀ .

they are very helpful in throwing light on the mechanism of ionisation of the upper atmosphere.

As the chart (page 223) shows, the first negative band of N₂⁺ is due to transition of the electron from a state (N ⁴S+N⁺ ³P) to the fundamental state (N ²D+N⁺ ³P).

Herzberg⁶ established that the normal state of N₂⁺ is made up of an excited N-atom (N 2*p*³ ²D) and a normal N⁺-ion (N⁺ 2*p*² ³P), and the excited state is made up of a normal N-atom (N 2*p*³ ⁴S) and a normal N⁺-ion (N⁺ 2*p*² ³P). The I.P. of N₂⁺ is 15.52 volts, and the excitation potential of N₂⁺ bands (first negative band) is 18.67 volts. It can be shown (vide Table I) that the intensity of ionising radiation energy > 15.52 *e*-volts is 5.24×10^{-10} , and for 18.67 volts, it is $< 1.5 \times 10^{-12}$, of the total solar energy. It is therefore clear, even without any calculation, that if the sun be supposed to radiate like a black body at a temperature of 6000°K, it is incapable of ionising N₂ and further exciting it to the state in which it gives N₂⁺-bands, in sufficient intensity.

Yet there is unmistakable evidence that N₂⁺ bands as observed in the night sky are due to excitation by the sun's rays, and not to electron bombardment (which is possibly the case in auroral light). For though the intensity of N₂⁺-bands in the night sky is rather feeble compared to that in the auroral light, Slipher⁷ has shown, at the Lowell

Observatory, Arizona, that the negative bands are obtained very strongly from the evening sky, when the last rays of the sun are disappearing from the upper atmosphere, or from the morning sky, when the first rays are illuminating the upper atmosphere. His exact remarks are:—

'But the negative nitrogen bands typical of auroral display spectra do not accompany this chief yellow line (green) in the sky, except when auroral displays are actually present. However, these nitrogen bands, I found, could be photographed in the morning and evening skies if brief exposure were made at the moments, when the last and first traces of sunlight touch the high atmosphere. Thus the day, as it were, begins and ends with a sort of auroral flash.'

Slipher's statement that the N₂⁺ bands do not at all occur in the quiet night sky, which is absolutely free from all auroral displays, is not quite correct. Sommer⁸ found these bands in 2 out of 30 plates of quiet night sky spectrum taken at Göttingen, and subsequently they have been found by Vegard, Du Fay,⁹ Cabannes, and Gauzit.¹⁰

The important point to infer from Slipher's observation is that the sunlight produces N₂⁺ in the excited state directly and in course of the night, the de-excitation by emission of the lines of negative band continues.

We may further explain why the N₂ molecule is directly

excited to N_2^+ . The normal N_2 molecule is composed of (N^4S+N^4S), when it is photo-ionised, the light electron of one N-atom passes to infinity leaving N^+ in the normal 3P -state. So the new ion is made up of ($N^4S+N^+^3P$). But as fig. 2 (p. 223) shows, this is the excited state of normal N_2^+ ion, which is made up of ($N^2D+N^+^3P$). This curious fact was, as mentioned already, discovered by Herzberg.

We are therefore within the horns of a dilemma. All experimental evidence shows that the sun sends out rays which are capable of ionising the constituent molecules of the upper atmosphere, at least N_2 . At the same time we find that the sun, if regarded as a black body at a temperature of $6000^\circ K.$, is incapable of emitting in sufficient intensity radiation of such short wavelength as will maintain the ionisation.

In order to solve this difficulty I wish to postulate, though with a certain amount of hesitation, that the sun emits in sufficient intensity the lines of the Lyman series of hydrogen as well as the fundamental resonance lines $1s^2$, $^1S_0-1s\ 2p\ ^1P_1$ of Helium, $\lambda\ 584$, and possibly the fundamental lines of a few more elements. In other words, if it were possible for us to take a spectrum of the sun below 2900\AA units, the Lyman series as well as the principal lines of He and other elements like Fe would appear as intensely bright emission lines on a much feebler continuous background.

2. The ultraviolet spectrum of the sun.

Let us now see how far this postulate can be justified. The sun as well as the stars are generally assumed to radiate like a black body, but there appears to be no justification either experimental or theoretical for such an assumption. The spectra of all heavenly bodies is cut off, owing to absorption by atmospheric ozone at *ca.* $\lambda\ 2900\ \text{\AA.U.}$, and measurements are usually confined to wavelengths between $\lambda\ 3000\ \text{\AA.U.}$ and $\lambda\ 5000\ \text{\AA.U.}$ Even when corrected for Fraunhofer absorption and general scattering, the curve is found to deviate strongly from what we should expect if the emission followed the black body law (vide Böttlinger, *Handbuch d. Astrophysik*, 5/1, or discussion given in *Treatise on Heat*, by Saha and Srivastava, p. 619, 2nd edition) even for this limited region. As a matter of fact, if we consider the physical composition of a star, it appears rather improbable that emission from it would be of the nature of a black body, and the radiation is likely to be more of the type which we obtain for heated metals.

A star consists of a central core, usually called the photosphere, made up of highly condensed matter, which is enveloped by a thinner atmosphere containing atoms, molecules, and ions, the temperature in this atmosphere gradually falling outwards. Fraunhofer lines are produced as continuous light is absorbed by atoms, ions, and molecules in its passage through the outer atmosphere. It is found

that these lines are not absolutely black, but there is always some residual intensity in the lines. For example, if we take the H_α -line due to absorption by the H-atom, the residual intensity was found to be .25 of the intensity of the continuous spectrum. The present author pointed out long ago (see Mitchell, *Eclipses of the Sun*, 1st edition, 1923, p. 311) that the residual intensity is due to emission by the atoms or ions present in the atmosphere. The intensity would be nil only, if the temperature of the absorbing layers was very low.

In Wolf-Rayet stars, and nebulae, we obtain bright lines, due to commoner elements like H, He, N, He^+ , N^+ . . . superposed on a much feebler continuous background.

It appears therefore that the nature of emission from a star is a very complex phenomenon. A pioneering step for solving this problem was taken by Rosseland,¹¹ who showed that in considering the emission from a stellar atmosphere we must consider the possibility of ultraviolet light from the interior exciting the atoms to fluorescence. He showed in particular that if an L_β -quantum ($\nu/R = \frac{1}{1^2} - \frac{1}{3^2}$) coming from the photosphere is absorbed by an H-atom in the atmosphere, the excited H_β -atom may revert back to the normal stage, (1) either by the direct transition ($3 \rightarrow 1$), or (2) in two stages, viz. ($3 \rightarrow 2$) and ($2 \rightarrow 1$), but the probability of the latter process is greater than that of the former. Thus the L_β -quantum will be split up, at the upper atmosphere, into an $L_\alpha(2 \rightarrow 1)$ and an $H_\alpha(3 \rightarrow 2)$ quantum. Further, most of the ultraviolet lying beyond the Lyman limit will ionise the H-atom as they come out. But in the outer atmosphere, the free electrons will combine with the H-nucleus in different orbits, and the excited atoms so produced will, instead of emitting the *corresponding* Lyman quantum, emit quantum of Balmer or Paschen or a higher series plus an L_α -quantum. Thus, by this process ultraviolet light coming from the photosphere is dammed by H-atoms and converted into line radiation, and the net effect is that the resultant spectrum will show extraordinary strength for the first lines of the series, viz. for L_α and H_α . These considerations were utilised by Zanstra¹² for explaining nebular luminosity, and on such considerations he was able to construct a successful theory of nebular emission which has been further extended by Beals¹³ to emission from Wolf-Rayet stars.

The ideas have been further applied by Woolley¹⁴ to account for the observed central intensity of Balmer lines in the solar spectrum. He obtains in fact the result that the residual intensity of the H_α -line would amount to .40 of the intensity of the continuous spectrum. This is much larger than the figure of .25 which was deduced by Minnaert¹⁵ on the basis of his spectrophotometric measurements. Woolley did not calculate the residual intensity of the L_α or L_β -lines. This is being attempted by the present writer, but the results which have been obtained can be regarded

only as provisional. It is found that the intensity of the L_{α} radiation is much stronger than that of the continuous spectrum of a black body at a temperature of 6000°K. As these calculations are very tedious, they will be published elsewhere, but a shorter, though not satisfactory, method of arriving at the result is indicated below.

It has been shown by Minnaert¹⁵ that the H_{α} -absorption in the sun dams an amount of solar energy which is equivalent to a strip of the continuous spectrum, about 4.17Å units in breadth. We can therefore calculate the total number of H_{α} -quanta held back by absorption due to H_2 -atoms. This is given by (see note 2)

$$N_v = 8\pi^2 R^2 c \left(\frac{kT}{ch} \right)^3 \frac{x_0^3}{e^{x_0} - 1} \frac{\Delta\lambda}{\lambda}$$

Now putting the proper figures in the above formula, we have

$$N_v = 8\pi^2 R^2 \cdot 2 \cdot 10^{18} \text{ quanta.}$$

So the number dammed by unit surface of the sun

$$\frac{N_v}{4\pi R^2} = 11 \cdot 10^{18} \text{ quanta.}$$

We take the residual intensity of H_{α} to be .25. Then the number of quanta due to fluorescence = $\frac{1}{4}$ number actually dammed, the number of quanta emitted by the $H(2)$ atoms per cm^2 of the sun's surface is given by

$$n_v = 3 \cdot 10^{18} \text{ approximately.}$$

Let us now try to arrive at an estimate of the number of Lyman α -quantum which are expected to be emitted by the sun. This will be much larger than the number of H_{α} -quanta. Let us put this equal to $3x \cdot 10^{18}$, $x > 1$.

Here x can be accurately calculated, but we need not do it at the present moment. But if we take the number of Lyman α -quanta in the continuous spectrum of the sun, supposed to radiate like a black body at $T=6000^\circ\text{K}$, we obtain when we assume that $\Delta\lambda/\lambda$ for L_{α} is equivalent to $\Delta\lambda/\lambda$ for H_{α} ,

$$n_v \text{ for } L_{\alpha} = 10^{14} \text{ (approximately),}$$

i.e., the fluorescent emission of L_{α} is at least 40,000 times more intense than the continuous emission in the same region.

As remarked before, this calculation is given with a certain amount of reserve.

The other lines of the Lyman series will also be several thousand times stronger than the continuous background of sunlight.

The remarks which have been made regarding the intensity of the Lyman lines holds for all principal lines of elements lying in the ultraviolet, though calculations are more difficult in such cases as transition probabilities are not known. The only other elements which need be considered are He, O, N, He^+ and Fe and Fe^+ . As regards He, it is well known that no lines are found in the Fraunhofer spectrum, though such lines are very strong in chromospheric emission, and He^+ 4686 is found as a strong line in the middle chromosphere. Recently H. D. and H. W. Babcock¹⁶ found that the line $\lambda 10830.3$ ($2^3\text{S}-2^3\text{P}$) and the

He^+ -line $\lambda 10123.83$, $\nu = 4R \left[\frac{1}{2^2} - \frac{1}{(2+\frac{1}{2})^2} \right]$ as diffuse absorption lines on the solar disc. This discovery indicates that the HeI-resonance line ($1^1\text{S}_0 - 2^1\text{P}_1 = \lambda 584$) as well as the He^+ -line $4R \left(\frac{1}{1^2} - \frac{1}{2^2} \right)$, $\lambda 304$, would be emitted in very great intensity from the solar disc.

3. Passage of ultraviolet light through the earth's atmosphere.

If the above speculations be correct, we should get the following monochromatic rays emitted in great intensity from the sun.

It now remains to show that some of these rays cannot only maintain the necessary ionisation, but can also account for the special features of the night sky spectrum. In appendix I, we give a detailed summary of the night sky spectrum. We first discuss the ionisation of N_2 and the occurrence of band lines of N_2^+ in the night sky.

The N_2 -ionisation.

The N_2 -ionisation is established on sure grounds from the occurrence of the first negative bands of nitrogen. Observations by Dufay and Gauzit¹⁰ show that in the night sky we obtain lines corresponding to $\nu' = 8$. The energy of the quantum can be easily calculated. This is nearly 21.10 e-volts (*vide infra*).

Thus the energy of the quantum of He-resonance radiation $\lambda 584$, which is equivalent to 21.20 volts, is quite sufficient to knock out an electron from N_2 , and leave it

TABLE 2

Line	1215	1026	987	584	537	304	1641
Origin	L_{α} (H)	L_{β} (H)	L_{γ} (H)	$I_s^2 \ ^1\text{S}_0 - ^1\text{P}$ He	He	He^+ $4R \left(\frac{1}{1^2} - \frac{1}{2^2} \right)$	He^+ $4R \left(\frac{1}{2^2} - \frac{1}{3^2} \right)$
Energy in e-volts	10.15	12.03	12.68	21.12	22.98	40.58	7.52

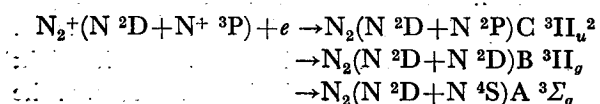
in a state when it can emit the negative bands. As pointed out before, N_2 consists of $N(^4S) + N(^4S)$. When an electron is knocked off, we get the molecule $N(^4S) + N^+(^3P)$. But as Herzberg proved, this is the excited state of N_2^+ and the normal state is obtained when the electron passes from $^4S \rightarrow ^2D$, i.e. to a state $\overline{N} \ ^2D + N^+ \ ^3P$. Such a transition seems to be paradoxical but, nevertheless, we have to admit it. A consideration of the Franck-Condon diagram for N_2 and N_2^+ shows that $\nu' = 0$ to 8 may be directly excited, as r_0 for the normal N_2 is 1.094×10^{-8} , while r_0 for the upper electronic states of N_2^+ is $1.071 \cdot 10^{-8}$ cm.

The night sky spectrum.

As described in the appendix, the night sky spectrum shows, beside the first negative bands, the following bands due to:—

- The Second Positive Group . . $B^3II_g(^2D+^2D) \leftarrow$
 $C^3II_u(^2D+^2P)$
 The First Positive Group . . $A^2\Sigma_g(^2D+^4S) \leftarrow$
 $B^3II_g(^2D+^2D)$
 Vegard-Kaplan bands . . $X \ (^4S+^4S) \leftarrow$
 $A^3\Sigma_g(^2D+^4S)$

It appears that the occurrence of all these bands can be explained if we suppose that the normal N_2^+ -molecule ion, which has got the electron structure $(N \ ^2D + N^+ \ ^3P)$, receives an electron and gets neutralized in different excited states as follows:—



It will be seen that one atom in all the initial levels of N_2 excited is in $N \ ^2D$ -state. This is because the normal state of N_2^+ has its N-atom in the $N \ ^2D$ -state. The N^+ -atom in N_2^+ is in the state $N^+ \ 2p^2 \ ^3P$ and when it receives the electron in the $2p$ -shell, the $2p^3$ -configuration gives rise to $^4S, ^2D, ^2P$ which, combined with the N in the $N \ ^2D$ -state, gives rise to the levels from which the observed bands are obtained by subsequent electron transition.

Thus the occurrence of the bands in the night sky is merely a consequence of recombination of N_2^+ produced by sunlight with free electrons during the night, and all its details are explained by the peculiar spectral properties of the N-atom and the N_2^+ -molecule. The emission of N_2^+ -band is due to de-excitation of N_2^+ excited, which is produced by sunlight to normal N_2^+ . As the recombination is going on throughout the night, we observe the bands throughout the night.

4. Atomic nitrogen in the night sky spectrum.

The occurrence of atomic nitrogen in the night sky spectrum is rendered probable by the existence of a line $\lambda 5208$, in the photographs obtained by Slipher. This has

been ascribed by Sommer¹⁷ to the forbidden transition of nitrogen $N(^4S-^2D)$. The identification is not quite on sure grounds on account of the close proximity of the line with the N_2 -band, 5228.3 (3,0).

Atomic nitrogen may arise by predissociation of the excited N_2 -levels which are responsible for the emission of the nitrogen band lines. For, according to the present hypothesis, the excited levels are due to the capture of the electron by N_2^+ in the $2p$ -level. The nuclear distance for N_2 and for each of the excited levels of N_2 are as follows:—

TABLE 3

Level	X $^1\Sigma$	A $^3\Sigma$	B 3II	C 3II	$N_2 + X \ ^2\Sigma$	$N_2 + B \ ^2\Sigma$
r_0	1.094	1.291	1.201	1.14	1.113	1.071

We may suppose, following the Franck-Condon principle, that the capture of an electron does not immediately change the nuclear distance. Hence, after recapture, the N_2 molecule will be in the vibrational state in which the nuclear distance is likely to remain unchanged. As the r_0 -values for B and A levels are very different from r_0 for N_2^+ , it is likely that the state of the neutral molecule will be in a highly excited vibrational state and it is probable that a large proportion of B and A level N_2 -molecules will *predissociate*, the first into $N \ ^2D$ and $N \ ^2D$, the second into $N \ ^4S$ and $N \ ^2D$, but exact calculation of the vibrational numbers of the states is not possible at the present moment. If $N \ ^2D$ -atoms are produced in these ways, they will revert to the 4S -state after emission of the line $\lambda 5207$.

5. The oxygen and the ozone problem.

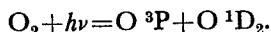
We are on less sure grounds when we consider the oxygen problem; as our knowledge of the molecular spectrum of neither O_2 nor O_2^+ is so satisfactory as that of N_2 ; in fact it may be considered extremely meagre.

One of the most curious facts of observation is that no lines due to O_2 or O_2^+ has yet been discovered with certainty either in the night sky or the aurora. Atomic oxygen is represented by the famous green line $\lambda 5577.350$, $2p^4 (^1D-^1S_0)$, and possibly also by the lines $\lambda 6300, \lambda 6363$, $2p^4 (^3P_{12}-^1D_2)$, though these last are blended with certain lines which Sommer ascribes to O_2 atmospheric bands. They may as well belong to N_2 first positive bands.

The absence of O_2 and O_2^+ lines do not indicate that the molecular O_2 is absent. As shown in the chart, all the known bands of O_2 and O_2^+ are in the ultraviolet with the single exception of the atmospheric bands. The most important are the Runge-Schumann bands starting from $\lambda 2000$ and passing to continuous absorption at $\lambda 1751$. The absorption continues up to $\lambda 1210$ Å.U.

*Note added during correction: Cabannes, *Comptes Rendus*, Vol. 200 (1935), announces that he has unmistakably obtained the red lines.

It has been shown by Herzberg that these bands denote a transition from $O_2(^3P+^3P)^3\Sigma \rightarrow O_2(^3P\ ^1D_2B)^3\Sigma_u$ and the continuous absorption at λ 1751 Å.U. correspond to the dissociation of O_2 into $O\ ^3P$ and $O\ ^1D_2$ we have



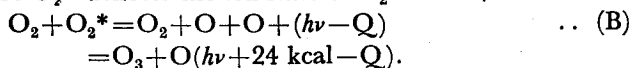
This absorption is quite heavy, and extends up to λ 1300. According to Lyman, O_2 is transparent to wavelengths between λ 1100 and λ 1217.7. In fact 3 cm. of oxygen at N.T.P. is found to transmit both λ 1100 and λ 1205.

Formation of ozone.

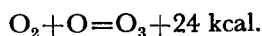
It is supposed that the Runge-Schumann absorption converts O_2 into ozone according to the process indicated below:—



where O_2^* denotes excited state of $O_2 = \overline{O\ ^3P + O\ ^1D\ B\ ^3\Sigma}$

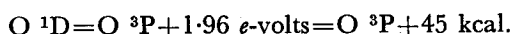


(B) indicates that O_2^* or excited oxygen collides with O_2 , and dissociates it into two atoms, and simultaneously one of these O-atoms reacts with O_2 to form O_3 . According to calorimetric relation



The reaction is exothermic, and takes place easily.

The energy set free is $h\nu + 24 \text{ kcal} - Q$, and if a wavelength of λ 2040 is used, $h\nu = 141 \text{ kcal}$. We have therefore the energy set free $141 + 24 - 117 = 48 \text{ kcal}$, and this is quite sufficient to raise the remaining O-atom to the $O\ ^1D_2$ -state, as shown below:—



This $O\ ^1D_2$ -atom reacts more readily with another O_2 -atom and forms another O_3 -molecule, and 72 kcal of heat produced. Thus, as Warburg experimentally established long ago, one quantum of light of wavelength $< \lambda$ 2040 produces two molecules of O_3 .

Let us suppose that all quanta between λ 2040 and λ 1250 are effective in producing ozone. If the sun be assumed to behave like a black body, the number of such quanta entering the earth's surface normally is given by (*vide* note 2).

$$3 \cdot 10^{17} \cdot [I_1(x_1) - I_1(x_2)],$$

where

$$I_1 = \int_x^\infty \frac{x^2}{e^x - 1} dx.$$

Now $x_1 = 11.6$, $x_2 = 19.3$, corresponding to λ 2040 and λ 1200, $I_1(x_1) = 1.46 \times 10^{-3}$, $I_2 \approx 10^{-6}$ and we have $n \approx 4.4 \cdot 10^{14}$ quanta so the number of ozone molecules formed $= 10^{15}$ per second by normally incident sunlight.

De-ozonisation.

Again it is found that all radiation from λ 2900 up to λ 2300 are absorbed by O_3 molecules, which are thereby

converted to O_2 . It can be easily shown that the number of such quanta entering the earth's atmosphere normally $= 7 \cdot 10^{15}$ and each quantum decomposes two O_3 -molecules, forming $3O_2$ -molecule. So the number of O_3 -molecules which disappear $= 14 \cdot 10^{15}$.

We thus find that ozone disappears 14 times as fast as it is formed. If this were the case, there would be no equilibrium. But we must have

$$\frac{d[O_3]}{dt} = 2n_2 - 2n_3, \quad \frac{d[O_2]}{dt} = 2n_3 - 2n_2,$$

where $[O_3]$ denotes the concentration of ozone molecules, and n_3 the number of quanta absorbed by ozone, $n_2 =$ number of quanta absorbed by oxygen, other factors like collision being neglected, and if we have equilibrium, we must have $n_3 = n_2$. This shows that between λ 2040 and λ 1200, the number of quanta in the sunlight must be as numerous as the number between λ 2900- λ 2300. Hence the sun cannot behave like a black body between λ 2040 and λ 1200. There must be strong emission lines in this region. In fact we have such lines in

$$He^+ \lambda 1640, \nu/4R = \frac{1}{2^2} - \frac{1}{3^2},$$

and probably also in L_α due to H-atom. We utilise the observation of Hopfield, that about 10 cm. of oxygen at N.T.P. is needed to completely absorb λ 1215.

Supposing that O_3 formation is due to λ 1215 and λ 1641, we can calculate the depth at which ozone formation begins. This is the height above which the superincumbent number of oxygen molecules equals the number of molecules contained in about 10 c.c. of oxygen at N.T.P. Calculation shows that this height is about 20 km. So this is the height at which L_α is completely absorbed, and ozone formation ends. This is in accordance with the observations of Götz and Meetham¹⁸ and Regener.¹⁹

Occurrence of oxygen.

Oxygen is represented by:

1. The green line due to the forbidden transition $p^4\ ^1D_2 - ^1S_0$.
2. The red lines due to the forbidden transition $p^4\ ^3P_{12} - ^1D_2$.
3. Some bands in the red which are provisionally identified by Sommer with some telluric lines.

It is thus remarkable that oxygen is represented only by atomic lines, and no lines due to the molecule are identified with certainty. Let us see what may be the cause of this remarkable difference between the occurrence of N_2 and O_2 .

For this purpose, we give an energy-level diagram of the known bands of O_2 , and O_2^+ . We at once perceive that as regards oxygen, we are in a rather very disadvantageous position, because all the stronger bands of O_2 and O_2^+ are in the ultraviolet and infra red regions where observations are either impossible or difficult. Hence the absence of

O_2 -band lines in the night sky and the auroral spectrum is no proof that the upper atmosphere contains no molecular oxygen.

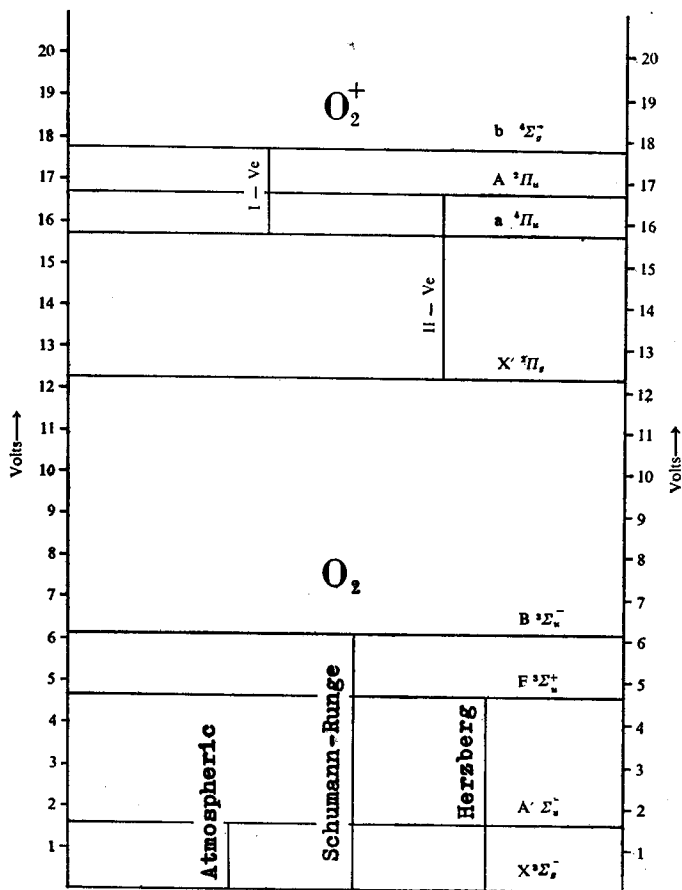


Fig. 1

In fact, as Table 2 shows, of all atmospheric components, O_2 has the lowest I.P., viz. 12.11 e -volts, and about 10^{10} electrons and O_2^+ -ions can be produced by sunlight by the ionisation of O_2 alone. Though this number is not sufficient to maintain the ionisation observed, it is clear that if the hypothesis of strong emission of L_β , L_γ -lines can be established on sure grounds, the observed ionisation can be traced to this source. This ionisation must correspond to that of the E-layer.

But the molecular energy diagram makes it almost certain that the O_2^+ -ion produced in this way is made up of $O^3P + O^4S$. When, during the night, this O_2^+ -ion combines with a free electron, normal O_2 will be produced preferably.

But a second ionisation potential of O_2 has been discovered at 16.5 e -volts. The electron-structure of the atoms composing the O_2^+ -molecule-ion produced at this potential is not yet known, but some conjectures may be advanced.

Let us consider the following energy-relationships:—

$$O_2 = O^+(^4S) + O^3P + e - 18.65 \text{ } e\text{-volts}$$

$$18.65 = \text{I.P. of } O + D_0 = 13.56 + 5.09.$$

$$O_2 = O^+(^2D) + O^3P + e - 21.95 \text{ } e\text{-volts}$$

$$20.61 = 18.65 + 3.30 (= O^+{}^2D - O^+{}^4S).$$

$$O_2 = O^+(^2P) + O^3P + e = 23.64 \text{ } e\text{-volts}$$

$$23.64 = 21.95 + 1.69 (= O^2P - O^2D).$$

$$O_2 = O^1D_2 + O^+(^4S) - 20.61 \text{ } e\text{-volts.}$$

$$O_2 = O^1D_2 + O^+(^2D) - 23.91 \text{ } ,,$$

$$O_2 = O^1S_0 + O^+(^2D) - 26.11 \text{ } ,,$$

$$O_2 = O^1S_0 + O^+(^2P) - 27.80.$$

In all these calculations, we use $O^1D_2 - O^3P = 1.96 \text{ } e\text{-volts}$, $O^1D_2 - O^1S_0 = 2.21 \text{ } e\text{-volts}$.

Of the phenomena indicated by the above figures, only the decomposition of O_2 to $O^+{}^4S$ and O^3P has been observed by Stueckelberg by the method of cathode ray bombardment.

Now the energy required to produce the state of the O_2^+ -ion composed of the atom in the states described above can be obtained if we subtract from the energy-values given above the value of Q , the energy required to dissociate the molecule-ion. Thus the first observed I.P. of 12.11 e -volts, according to Mulliken (*Phys. Rev.* 44), is due to the formation of the molecule-ion $(O^+{}^4S + O^3P)^2\Pi$. The heat of dissociation is $18.65 - 12.11 = 6.54 \text{ } e\text{-volts}$. It may be that the O_2^+ -ion produced at 16.5 e -volts is composed of $(O^+{}^2D + O^2P)$. All these energy-states have to be established by subsequent investigations.

It is clear that if there are strong violet emission lines in the solar ultraviolet spectrum of sufficient energy, O_2 may be ionised by their action to the O_2^+ -state as envisaged above. These O_2^+ -ions may, in the course of the night, capture an electron, and may be converted to different molecular states of O_2 . These may *predissociate*, forming O^1D_2 or O^1S_0 -atoms. The green and red auroral radiation may be due to emission by the excited atoms produced in this way. There appears to be no other way of getting the green line throughout the night except as an after-effect of recombination of O_2^+ (excited) with the electron. But the hypothesis leaves it unexplained why the green line is so much more intense than the other lines. For this we shall have to wait till our knowledge of the spectrum of O_2 improves.

APPENDIX I.

THE NIGHT SKY AND THE AURORAL SPECTRUM

In the foregoing pages, we have so often talked of the night sky and the auroral spectra that it is probably necessary to give some idea of the conclusions which we can deduce from their study regarding the physical state of the upper atmosphere. Both spectra are due to excitation

of the constituents of the upper atmosphere, and it is therefore but natural that they should have many features in common.

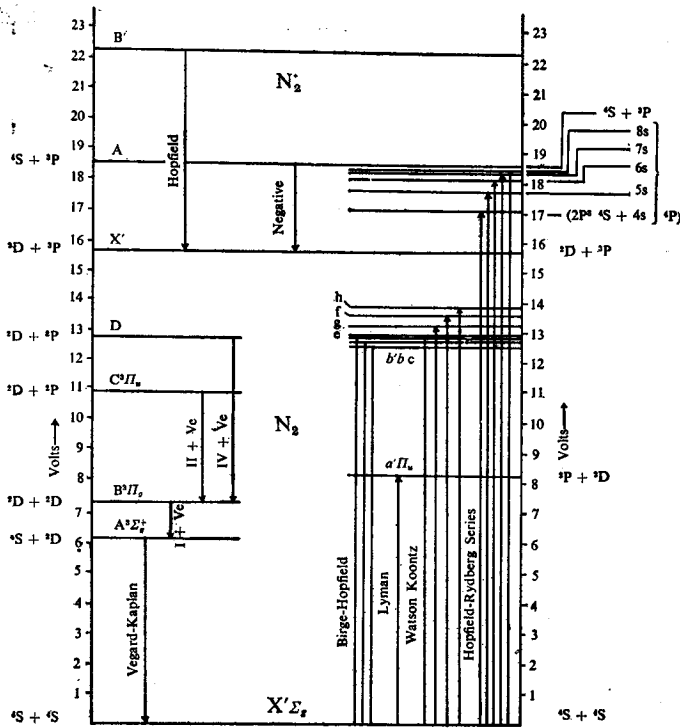


Fig. 2

The chief constituents of the atmosphere are O₂, N₂, O₃, H₂O, CO₂, A, and minute quantities of other gases. Of these CO₂ can be neglected as far as the upper atmosphere is concerned. Hydrogen and helium, which were at one time postulated to occur in comparatively greater abundance in the upper atmosphere, may also be considered as non-existent, as neither in the night sky spectrum, nor in the aurora, nor in any meteoric flash has any line due to these elements been identified.

Occurrence of nitrogen.

Nitrogen is represented by the following system of bands:

1. The first negative bands due to N₂⁺.
2. The second positive bands.
3. The first positive bands.
4. Vegard-Kaplan intercombination bands.
5. The forbidden atomic line 2p³ (4S-2D).

Deslandres' diagrams of these bands are added for the sake of further elucidation. An energy-level diagram of N₂ is also added, as otherwise, it is difficult to have a complete picture of the mechanism of excitation.

These bands are represented by the formula [Coster and Brons]

$$\nu = 25566.0 + (2396.22v' - 24.07v'^2 - 636v'^3) - (2191.02v'' - 16.196v''^2)$$

where $\nu_0 = 25566.0$ cm. is equivalent to 3.156 volts. The energy of excitation of the (0,0)-band is 18.68 volts. The

TABLE 4

First Negative Bands of N₂ (due N₂⁺).

$v' \backslash v''$	0	1	2	3	4	5	6	7	8	9	10	11
0	3914.4	4278.1	4709.3	5228.3	5864.7							
1	3582.1	3884.3	4236.5	4651.9	5148.8	5754.4						
2	3308.9	3563.9	3857.9	4199.2	4599.9	5076.5	5653.2					
3	3078.2	3298.7	3548.9	3835.4	4166.8 } 4166.4 }	4554.4 } 4553.2 }	5012.4 } 5010.8 }	5563.8 } 5560.8 }				
4		3076.4	3293.4	3558.3	3818.1	4140.7	4515.9	4958.0	5485.8			
5					3532.6		4121.3 } 4120.7 }	4485.9 } 4485.3 }	4913.2	5420.8		
6								4110.9	4466.6	4881.7	5372.3	
7										4459.3	4864.4	5340.2
8											4466.6	4864.4
9												4489
10							2987.5	3174.4	3381.5	3612.6		
11								3033.0	3222.7			

vibrational state $v'=8$, which appears to be the highest obtained in the night sky spectrum, requires 21.10 volts. These lines require the highest excitation for their production.

The lines obtained in the night sky are underlined. The ultraviolet lines were obtained by Dufay and Gauzit.

Difference of behaviour in the night sky and the aurora.

These bands are very intense in the aurora, but are rather faint in the night sky. In fact, in the former, 3914 (0,0), 4278 (1,0) sometimes exceed even the green line in intensity. But in the latter, they are very feeble, and $\lambda 4278$ is not sometimes observed even after long exposure. The bands $\Delta n=0$ are the strongest.

The second positive group is due to the transition ($^2D^2P$) $C^3II-(^2D^2D) B^3II$ and is represented by the formula

$$\nu = 29670.6 + (2020.0v' - 26.40v'^2 + 1.158v'^3) - (1719.64v'' - 14.47v''^2).$$

These lines were first found by Sommer in the night sky and by Vegard in the aurora. These bands are very bright in the night sky, but faint in the aurora. The line 3555 (8,9) is found to be very intense in the night sky; the reason being unknown. (Table 5).

The lines obtained in the night sky are underlined. The lines (12, 8), (13, 9) are the bands which are observed to predissociate in the laboratory, giving rise to two

2D -atoms. These bands are not observed owing to ozone absorption. But presumably owing to predissociation a considerable proportion of N 2D -atoms will be produced in the daytime in this way.

The first positive group is due to the transition ($^2D^3D$) $B^3II-(^2D^4S) A^3\Sigma$ and is represented by the formula

$$\nu = 9518.6 + (1718.40v' - 14.437v'^2) - (1446.46v'' - 13.929v''^2).$$

The bands observed in the night sky are underlined. They were observed by Vegard (*Norw. Geophys. Pub.* 9, No. 4, 1932) in the aurora, in which they are much fainter than the second positive group, but in the night sky they are very intense.

The Vegard-Kaplan bands are due to the intercombination between singlet and triplet systems and to the transition ($^4S.^2D$) $A^3\Sigma-(^4S.^4S) X^1\Sigma$. They are represented by the formula:—

$$\nu = 49774.4 + (1446.46v' - 13.93v'^2) - (2345.16v'' - 14.445v''^2).$$

After emission of these bands, the N_2 -molecule reverts to the normal state. We get only one part of the Vegard-Kaplan bands in the night sky, as the other part is in the far ultraviolet.

It is only recently that the Vegard-Kaplan bands have been discovered in the night sky (see Cabannes and Dufay,

TABLE 5

The Second Positive Group of Nitrogen.

$n' \backslash n''$	0	1	2	3	4	5	6	7	8	9
0	<u>3371</u>	<u>3577</u>	<u>3805</u>	<u>4059</u>	4344	4666				
1	<u>3159</u>	<u>3339</u>	<u>3536</u>	<u>3755</u>	<u>3998</u>	<u>4269</u>	<u>4574</u>	4917		
2	2977	<u>3136</u>	<u>3309</u>	3500	<u>3710</u>	<u>3942</u>	<u>4201</u>	4490	4814	
3	2820	2962	<u>3116</u>	<u>3285</u>	<u>3469</u>	<u>3671</u>	<u>3894</u>	<u>4141</u>	4416	4723
4		2814	2953	<u>3104</u>	<u>3267</u>	<u>3446</u>	<u>3642</u>	3857	<u>4094</u>	4356
5					<u>3102</u>	3263	3437	<u>3628</u>	3837	<u>4059?</u>
6						<u>3115</u>	3274	3446	<u>3634</u>	3840
7								3309	<u>3482</u>	<u>3670(?)</u>
8								<u>3217</u>	3380	3555
9								3171		3502

TABLE 6
The First Positive Group of Nitrogen

$n' \backslash n''$	0	1	2	3	4	5	6	7	8	9
0	10491									
1	<u>8911.57</u>									
2	7753.05	<u>8722.28</u>	9927							
3		<u>7626.13</u>	8541.73	9657						
4		<u>6788</u>	<u>7504.0</u>	8369.02	9409					
5		<u>6127</u>	<u>6704</u>	<u>7386.5</u>	8204.62	9180				
6			<u>6076</u>	<u>6624</u>	<u>7273.0</u>	<u>8047.26</u>				
7				6014	<u>6545</u>	7164.6	<u>7896.28</u>			
8					5959	<u>6469</u>				
9						<u>5906</u>	<u>6394</u>			
10						5442	<u>5855</u>	<u>6323</u>		
11							5407	5804	6252	
12								5375	<u>5755</u>	<u>6185</u>
13										

Comptes Rendus, vol. 200, p. 1504; 1935). The most intense lines are (2,15), (3,15), (2,14), (4,15), i.e. $\Delta n=12,11$. In fact the bands (2,14), and (4,15) appear to be identical with λ 4435, 4220Å, which were observed by Lord Rayleigh to occur strongly in the spectrum of the night sky (*Proc. Roy. Soc.*, vol. 131, p. 376; 1931). The reason that lines having $\Delta n=10,11$ appear strongly is to be sought in the Franck-Condon principle, for r_0 for the initial A $^3\Sigma=1.291 \times 10^{-8}$ cm., for the final X $^1\Sigma=1.094 \times 10^{-8}$ cm. As these are very different, transition from A $^3\Sigma$ can take place to that vibrational state of X $^1\Sigma$ where its vibration quantum number is very large.

NOTE 2

Number of Quanta in the Solar Spectrum whose energy-value exceeds a certain limit.

Let the sun be considered as a black body at a temperature T , and having a radius R . The energy radiated

per second by the sun within the frequency interval $d\nu$ is given by:—

$$\pi R^2.c.\rho_\nu.d\nu, \quad \dots (1)$$

where ρ_ν =energy density of black body radiation and is given by Planck's Law

$$\rho_\nu = \frac{8\pi h}{c^3} \frac{\nu^3}{e^{h\nu/kT} - 1}. \quad \dots (2)$$

The number of quanta emitted is obtained by dividing (1) by $h\nu$. We thus obtain:

$$dN_\nu = \frac{8\pi^2}{c^2} R^2.c. \frac{\nu^2}{e^{h\nu/kT} - 1}. d\nu. \quad \dots (3)$$

Let us now put $h\nu/kT=x$. We have then

$$dN_\nu = 8\pi^2 R^2.c. \left(\frac{kT}{hc}\right)^3 \frac{x^2}{e^x - 1}. dx. \quad \dots (3')$$

TABLE 7
The Vegard-Kaplan Bands

ν	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
0				2332.8	2461.6	2608.8	2760.6	2935.7			3600 3608	3886 3889 (1)	4216 4220 (1)	4601 4603	5055 5062 (2)						
1					2377.5	2509.8	2655.5		2997	3197.5	3424 2426 (2)	3681 3685	3976 3979 (1)	4316 4317 (1)	4714 4719 (1)	5185 5185 (0)					
2						2424.2	2560.9	2710.1				3500 3501 (1)	3765 3769	4069 4073 (3)	4421 4425 (5)	4833 4838 (4)	5321 5324 (0)				
3													3580 3582 (1)	3853 3855 (3)	4167 4171 (5)	4581 4586 (3)	4957 4962 (0)				
4														3663 3669 (?)	3945 3950 (3)	4270 4270 (4)	4647 4650 (1)	5068 5083 (2)			
5																4042 4056 (2)	4378 4382 (?)	4768 4768 (1)			
6																	4144 4144 (2)	4491 4493 (1)			
7																	3937 3936 (2)	4294 4252	4610 4616 (2)		
8																				4361 4361 (1)	

If now we wish to find out the number of quanta whose energy exceed a certain limit ($h\nu_0$) we have to evaluate the integral

$$I_1 = \int_{x_0}^{\infty} \frac{x^2}{e^x - 1} dx, \quad \dots (4)$$

where $x_0 = h\nu_0/kT$.

Now $\omega = 4.65 \times 10^{-3}$ in radians, and if we take $T = 6000^\circ\text{K}$, we obtain after putting the values of k, c, h ,

$$N_\nu = 3.10^{17} \cdot I_1 \text{ (approximately)} \quad \dots (5')$$

Number of Quanta emitted within the wavelength λ_1, λ_2 .

Let $x_1 = h\nu_1/kT, x_2 = h\nu_2/kT$, where $\nu_1 = c/\lambda_1, \nu_2 = c/\lambda_2$. We have then

$$N_{\nu_1-\nu_2} = 3.10^{17} \cdot (I_1 - I_2).$$

When $\lambda_1 - \lambda_2$ is small, it can be easily shown that $N_{\nu_1-\nu_2}$ is given approximately by:—

$$N_{\nu_1-\nu_2} = 3 \times 10^{17} \cdot \frac{x_0^3}{e^{x_0} - 1} \cdot \frac{\Delta\lambda}{\lambda_0},$$

where λ_0 is the mean wavelength, $\frac{\lambda_1 + \lambda_2}{2}$.

Tables of $\log I$, and $\log I_2/6.494$ (vide infra) have been prepared by Zanstra in connection with problems of

nebular luminosity and are given in Table 8. With the aid of these tables, we can carry out the numerical calculations for all values of x_0 .

Number of Quanta entering the earth's atmosphere.

The number of quanta given by (5') is distributed over a surface $4\pi d^2$, where d = distance of the earth from the sun. Hence the number n , whose energy exceed $h\nu$ entering unit surface of the earth's surface is given by

$$\begin{aligned} n\nu &= 2\pi \left(\frac{R}{d}\right)^2 \cdot c \cdot \left(\frac{kT}{ch}\right)^3 \cdot I_1 \\ &= 2\pi\omega^2 \cdot c \cdot \left(\frac{kT}{ch}\right)^3 \cdot I_1. \end{aligned} \quad \dots (5)$$

NOTE 3

Energy of the Solar Radiation below a certain wavelength.

Let us denote by $E_\nu d\nu$ the radiation between the frequencies ν and $\nu + d\nu$. We have

$$E_\nu d\nu = \frac{8\pi^3 R^2}{c^3} \frac{\nu^3}{e^{h\nu/kT} - 1} d\nu..$$

TABLE 8

Wave-length in Ångstroms	e-volts	$x = h\nu/kT$. $T = 6000^\circ\text{K}$.	$\log I$ $I_1 = \int_x^{\infty} \frac{x^2}{e^x - 1} dx$	$\log (I_2/6.494)$. $I_2 = \int_x^{\infty} \frac{x^3}{e^x - 1} dx$	Wave-length in Ångstroms	e-volts	$x = h\nu/kT$. $T = 6000^\circ\text{K}$.	$\log I$ $I_1 = \int_x^{\infty} \frac{x^2}{e^x - 1} dx$	$\log (I_2/6.494)$. $I_2 = \int_x^{\infty} \frac{x^3}{e^x - 1} dx$
23868.4	.517	1	0.3118	1.9843	1705	7.238	14	4.2740	4.6423
11934.2	1.034	2	0.1517	1.9130	1491	8.272	16	5.5137	5.9348
7956.1	1.551	3	1.9360	1.7837	1326	9.306	18	6.7414	5.2099
5967.1	2.068	4	1.6812	1.6053	1193	10.340	20	7.9595	6.4710
4773.6	2.585	5	1.3979	1.3896	1084.9	11.374	22	7.1698	7.7204
3977	3.102	6	1.0938	1.1457	994.6	12.408	24	8.3735	8.9599
3410	3.619	7	2.7731	2.8782	918.0	13.442	26	9.5716	8.1914
2977	4.136	8	2.4409	2.5936	852.4	14.476	28	10.7650	9.4159
2652	4.653	9	2.0955	2.2923	795.6	15.510	30	11.9544	10.6338
2386	5.170	10	3.7435	3.9795	745.8	16.544	32	11.1400	11.8472
2170	5.687	11	3.3838	3.6569	702.0	17.578	34	12.3225	11.0547
1989	6.204	12	3.01887	3.3258	663.1	18.612	36	13.5021	12.2584

Putting $h\nu/kT=x$, the required quantity is given by

$$\int_{\nu_0}^{\infty} E_{\nu} d\nu = 8\pi^2 R^2 \cdot \frac{k^4}{h^3 c^2} \cdot T^4 \cdot \int_{x_0}^{\infty} \frac{x^3 dx}{e^x - 1},$$

where $x_0 = h\nu_0/kT$; ν_0 is a certain minimum frequency. The total energy E_0 radiated by the sun is obtained by putting $x_0=0$. In this case, the integral $=\pi^4/15=6.494$. Let us denote by I_2 the integral

$$I_2 = \int_{x_0}^{\infty} \frac{x^3 dx}{e^x - 1}.$$

We have then

$$\frac{E}{E_0} = \frac{I_2}{6.494}.$$

The values of I_2 have been calculated and tabulated by Zanstra, and are shown in Table 8.

I have to thank my pupils Messrs. G. R. Toshniwal, L. S. Mathur and N. K. Saha for help in preparing the paper, particularly with respect to the mathematical calculation and preparation of Tables. The Deslandre-diagrams and the charts of N_2 and O_2 -levels are taken from a forthcoming paper by L. S. Mathur and P. K. Sengupta in the *Proceedings of the U.P. Academy of Sciences*.

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59. SPECTRA OF COMETS

(*Sci. & Cult.*, 1, 476, 1936)

In a recent discussion on the ionosphere held under the auspices of the National Institute of Sciences, India, the writer of this note expressed the view that the ionization of the upper atmosphere and the spectrum of the night sky can be best explained if we suppose that the sun does not radiate like a black body in the ultraviolet, but sends out strong ultraviolet emission lines which can be identified with the resonance and other strong ultraviolet lines of He, He⁺, H, O... etc. Two lines of argument were cited in favour of this view; (1) that Slipher has established that the spectrum of the morning or evening flash gives strongly the band-spectrum of N⁺₂, even on days perfectly free from Aurora; (2) that the equilibrium of ozone formation requires that the number of quanta emitted between 3000 Å° and 2200 Å° must be as great as that between 2000 Å° and 1300 Å°.

Recently further corroboration of this view has been obtained in the spectra of comets. It is well known that

when comets are very far from the sun, they appear like a faint star (called the *nucleus*) which becomes enveloped in a kind of mist (*coma*) as the comet approaches the sun. With further approach to the sun, the comet develops a tail *i.e.* a long appendage which is held to consist of molecules repelled from the nucleus by the action of pressure of sunlight. With these characteristic changes in the appearance of the comet, it is observed that the spectrum also changes, the nucleus at a distance shows a continuous spectrum crossed with Fraunhofer lines showing that the comet consists of meteorites and the continuous spectrum is due to reflection of sunlight from these. When the comet approaches closer, the meteorites get heated and evolve gas. The spectrum of the coma shows emission bands due to CN, C₂ (Swanbands) CH (doubtful). Zanstra thinks that these emission bands are due to absorption of sunlight by the vapour in the coma and subsequent re-emission just as in his well-known theory of nebular luminosity. The