

The Auroral Spectrum

THE exact mode of excitation of the lines and bands in the auroral spectrum is not yet fully understood. Many attempts have been made to explain the spectrum, but none has been convincing^{1,2,3}. The purpose of the present note is to offer a simple explanation of the auroral spectrum on the lines of the theory of emission of similar lines and bands from the luminescent layer of the night sky postulated by me some time ago^{4,5}. Besides similarities, there are also differences between the two spectra; but these are to be traced mostly to the difference in the atmospheric heights at which the two phenomena originate: the height of the most frequent occurrence of aurora is between 90 and 120 km. (regions *D* and *E* of the ionosphere), and the height of the luminescent layer of the night sky is 200–400 km. (region *F* of the ionosphere). The collisional frequency of the atmospheric particles, which affects the emission of the spectra, is about two orders higher in the lower than in the higher region.

The primary cause of excitation of the auroral spectrum is bombardment by charged particles shot off from the sun. The spectrum consists of band systems of molecular nitrogen and certain lines of atomic oxygen. These are, in order of prominence: first negative bands, N_2^+ ($A' \rightarrow X'$); auroral green line $\lambda 5577 \text{ \AA}$ ($C'S \rightarrow ^1D$); first positive bands, N_2 ($B \rightarrow A$); red auroral triplet, $\lambda 6300 \text{ \AA}$ ($^1D \rightarrow ^3P$); second positive bands faintly, N_2 ($C \rightarrow B$) and Vegard-Kaplan bands very faintly, N_2 ($A \rightarrow X$). In regard to the atomic oxygen lines, it is to be noted that calculations show that oxygen gas in the upper atmosphere is photo-dissociated by absorption of solar ultra-violet radiation (Runge-Schumann continuum⁶). Above 115 km. the gas is almost completely dissociated; the dissociation extends down to 100 km. where it is estimated to be 7 per cent. Bombardment by charged particles shot off from the sun might also dissociate oxygen molecules and push the dissociation down to lower levels.

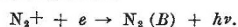
The bombardment, however, cannot be the immediate cause of excitation of all the spectra. As is well known, the red and green auroral lines are not ordinarily excited in a discharge tube or when oxygen gas is bombarded by canal rays, though other lines of O are excited. The reason for the difference between upper atmospheric spectra and the discharge tube spectra is the part which the walls of the tube play in promoting quick disappearance of the products of ionization, for example, electrons, ions and metastable particles. The electrons and ions recombine mostly on the surface (rather than in the volume), which acts as the third body absorbing the excess of energy and momentum. The metastable particles also, as they find their way to the walls, deliver up their energy by collision to the glass surface rather than by radiation. In the upper atmosphere, since there is no glass wall, the products of bombardment persist; and by reacting among themselves or with the neutral particles, they excite spectra not ordinarily obtained in discharge tubes. (In connexion with the above, I have recently put forward the hypothesis that active nitrogen is only N_2^+ ions produced by the discharge⁷. They persist in the after-glow vessel due to special conditioning of the walls, which prevents the neutralization of the electrons and ions on the surface. The conditioning is probably caused by adsorption of nitrogen, which has very little electron affinity.)

It is necessary, therefore, to distinguish between that part of the auroral spectrum which is directly excited as a result of bombardment and that which is excited as a result of the interaction of the products of the bombardment (ions and electrons) among themselves and/or with the neutral particles. To the first category belongs the first negative bands due to N_2^+ and to the second the rest of the spectrum.

First negative bands. The bombarding particles directly ionize and, at the same time, excite the N_2^+ ions produced to the A' state from which the first negative bands are emitted. That the bombardment of the upper atmosphere produces ionization is shown by ionospheric observations in high latitudes⁸. During auroral displays the ionization increases in intensity and extends down to the radio-wave absorbing region (*D*), which causes obliteration of radio echoes. Assuming an isothermal atmosphere and that the light intensity is proportional to the ionization, Vegard has calculated the intensity distribution with height due to the bombarding action of fast charged particles entering the atmosphere. The calculated distribution curve is very similar to the observed distribution curve for a large class of auroras. The first negative bands are also easily produced in the laboratory by the bombardment of nitrogen gas by cathode rays¹⁰.

First positive bands and the oxygen lines. The mode of excitation of these is the same as that which I have proposed in the night sky. Briefly, it is as follows: the oxygen atoms, on account of their high electron affinity, attach to themselves electrons and form negative ions. These react with N_2^+ ions as follows: $N_2^+ + O^- \rightarrow N_2$ (excited) + O (excited). From the excited nitrogen molecules and oxygen atoms, the first positive bands and the green and red radiations are emitted respectively. (For further details original papers should be consulted.)

Second positive bands. The above reaction cannot account for these bands on account of inadequate energy. That their mode of excitation must be different is also evident from the fact that the nitrogen molecules after emission are left in the vibration levels 0–4 of the *B*-state. The observed first positive bands, however, originate from levels 8–11 of the same state. The faint emission of the second positive bands may be explained as due to the recombination of N_2^+ ions and electrons by a radiative process:



The cross-section of N_2 for this reaction is, however, small, being only 10^{-12} cm^2 as compared with 10^{-8} cm^2 for the other process.

The enhancement of the first positive bands in the rare case of the so-called red auroras of type *B* (arcs and draperies, of which the lower fringe reaching abnormally low heights of 65–70 km. is tinged red) falls in the first category. The bombarding particles are slowed down by deep penetration and excite the nitrogen molecules by direct impact.

Effects of higher collisional frequency on the auroral spectrum. Faintness of *V-K* bands; greater strength of the green O-line than the integrated strength of the red lines; 'height effect', namely, comparative strengthening of the red O-radiations on passing up an auroral streamer.

These effects distinguish the auroral spectrum from the night sky spectrum. They are easily explained if the long lives of the metal stable states from which they originate and the decrease of collisional-frequency with height are taken into account. In regions of high collisional frequency, the molecules or atoms in metastable states have a greater chance of coming down to a lower state by collision with other atmospheric particles than by radiation.

Sunlit aurora. The remarkable enhancements of the negative bands of N_2^+ and of the red oxygen lines in sunlit aurora have been the subject of much comment, but no explanation has yet been given. The explanation is, however, simple if similar enhancements in the case of the night sky spectrum taken during twilight—when the rays of the rising or the setting sun touch the high atmosphere—are considered. (Compare, for example, the spectrum of the former taken by Störmer¹¹ and that of the latter by Elvey¹².) The enhancement of the negative bands is due to production of N_2^+ ions in the A' -state by absorption of $\lambda < 6613$. The enhancement of the red lines (as compared with the green line which is unaffected) is due to two factors acting in the same sense. First, the absorption coefficient of the oxygen atom for $\lambda < 6302$ for excitation to the 1D -state is much higher than that for $\lambda < 2972$ for excitation to the 3S -state; and secondly, the density of solar radiation in the first spectral region is about a hundred times greater than that in the second. (The case of enhancement in night sky spectra during twilight is fully discussed by Ghosh¹³.)

The subject-matter of the communication is being studied in fuller detail by Mr. S. N. Ghosh, my research scholar, and will shortly be published in the *Proceedings of the National Institute of Sciences of India*.

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Electronic Spectra of some Bent Triatomic Molecules

THE purpose of this communication is to summarize the results obtained by us during recent years on the absorption electronic spectra of the SO_2 , SeO_2 and TeO_2 molecules. Whereas the size and the fundamental frequencies of SO_2 are known accurately¹, no corresponding data exist for SeO_2 and TeO_2 . It has, however, been established that the selenium dioxide molecule has a similar bent structure² and, by analogy, we may infer that this is also the case for tellurium dioxide.

The electronic spectra of these three molecules were studied repeatedly³, but a detailed analysis was given only for the *b* and *c* systems of SO_2 ⁴ and for the *b* system of SeO_2 ⁵. Here, we are dealing with the *a* system of SO_2 , the *c* system of SeO_2 and with a preliminary investigation of the TeO_2 bands.

SO_2 .—The *a* system of SO_2 was observed in absorption between 2000 and 2400 Å. under widely varied experimental conditions of temperature and pressure (200°–700° K.; 0.5 mm.–100 mm. mercury pressure) and with an absorption path from 5 cm. to 100 cm. The dispersion used was either 2 Å./min. or 5 Å./min. at 2200 Å. Contrary to the statements of Price and Simpson³, we have shown that the prominent bands constitute several different progressions. They can be fitted into two separate electronic systems designated a_1 and a_2 , with the following molecular constants of the upper state:

$$\begin{aligned} a_1 \dots v_1' &= 962 \text{ cm.}^{-1}, v_2' = 379 \text{ cm.}^{-1}, v_3' = 2 \text{ cm.}^{-1}, v_0 = 42,170 \text{ cm.}^{-1} \\ a_2 \dots v_1'' &= 775 \text{ cm.}^{-1}, v_2'' = 375 \text{ cm.}^{-1}, v_0 = 44,236 \text{ cm.}^{-1} \end{aligned}$$

The bands of the a_1 system appear to be of the perpendicular type with *K* structure well defined and degraded towards the red. The analysis gives $C' = 0.9 \text{ cm.}^{-1}$ as compared with $C'' = 1.6 \text{ cm.}^{-1}$. The *J* structure is not resolved, but there are indications that the corresponding sub-bands are slightly degraded towards the red and that the convergence is slow. If so, we have a case already discussed by Metropolis⁶ and related to $\Delta a < 0$ and $\Delta r \approx 0$, with $B' \approx B''$. From Fig. 2 of the paper referred to we can conclude that *a* has decreased by about 20% while r_0 has increased a little.

There are only two allowed transitions giving perpendicular bands. One of them ($4 a_1 \rightarrow 2 b_1$) has been assigned by Mulliken⁷ to the *c* system ($\lambda_{\text{max.}} = 3700 \text{ \AA}$). Thus the a_1 system must correspond to $1 a_2 \rightarrow 4 b_2$ transition. We must point out that this attribution does not agree quantitatively with Mulliken's scheme of SO_2 levels. But according to Mulliken himself, the scheme has not much more than a qualitative meaning.

We have not succeeded in analysing the fine structure of the a_2 system. Perhaps it could be correlated with $3 b_2 \rightarrow 5 a_1$, as proposed by Mulliken, for the whole *a* system. But this new interpretation would even modify the order of the electronic terms in Mulliken's scheme