THE LIGHT OF THE NIGHT SKY

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Abstract

The two lines at 4416A and 4168A, recently reported by Lord Rayleigh in the light of a very bright night sky, are identified as O_{II} lines. A theory is proposed which accounts for the strong excitation of the green aurora line both in the night sky and in the aurora borealis. The theory explains why no O_2+ bands are found in the aurora while N_2+ bands are very strong. Explanations are proposed for the two lines of singly-ionized oxygen and for the continuous spectrum in the night sky. Experiments performed by the writer substantiate the theory.

THE initial purpose of this note was to propose an identification for the two unknown lines recently remeasured by Lord Rayleigh in the light of an exceptionally bright night sky.[1] These lines, which Lord Rayleigh calls X_1 and X_2, have wave-lengths of 4416 ± 2A and 4168 ± 2A and it is suggested that they correspond to two lines of singly ionized oxygen having wave-lengths of 4416.97A and 4169.23A. This agreement is within the errors of measurement. In addition to these two lines the light of the night sky contains the green aurora line and a faint continuous spectrum. The green aurora line is by far the strongest line in the night sky and in most cases it is the only line which is observed.

In trying to understand the possible meaning of the existence of lines belonging to ionized oxygen in the night sky, it occurred to the writer to compare these lines with some of the lines which are observed in the spectrum of the aurora borealis. The reason for this comparison lay in the fact that the green aurora line is a constituent of both the aurora and the night sky spectra. The comparison showed that of eight lines listed by Vegard[2] in the aurora spectrum, five corresponded to lines belonging to singly-ionized oxygen and three are listed either as unidentified nitrogen lines or as singly-ionized nitrogen lines. These identifications were obtained from the Kayser "Tabelle der Hauptlinien" where they are listed both as "luftlinien" and oxygen or nitrogen lines. It is suggested therefore that the method, by which the aurora green line and the other oxygen lines are excited, is essentially the same in both the aurora and the night sky. Furthermore, oxygen molecule-ions, formed by sunlight in the case of the night sky and probably by electrical discharge in the aurora, are the essential elements for the production of the aurora green line. It will be the purpose in what follows, to justify these statements and in that way to explain a most remarkable spectroscopic feature of these two displays, namely, that the only oxygen arc line which is observed in either of the two cases is the green aurora line.

[1] Lord Rayleigh, Proc. Roy. Soc. **131,** 376 (1931).
[2] Vegard, Phil. Mag. **46,** 193, 577 (1923).

We will first point out one other feature of the aurora spectrum which will help us to understand the present problem. The aurora spectrum consists almost completely of the first negative bands of the nitrogen molecule-ion and the green aurora line. Other radiations in the aurora are in general very weak compared with these. In view of the fact that band spectra, which are emitted by ionized molecules, are characteristic of low pressure discharges, it is surprising that the second negative bands of oxygen are completely missing from the aurora spectrum. These bands fall in the red and yellow and are very easily excited in the laboratory discharges in oxygen at pressures around 10^{-2} mm. This fact immediately suggests that the failure of these bands to appear in the aurora, as well as the production of neutral and singly-ionized oxygen atoms, are due to the dissociation of O_2^+. It is proposed therefore to discuss how the dissociation of O_2^+ can result in the formation of oxygen atoms and how this will account for the light of the night sky.

The recombination of an ionized oxygen molecule and an electron can yield a highly excited oxygen molecule with sufficient energy to dissociate into one or perhaps even two oxygen atoms in the $^1S_0$ metastable state on which the green line originates. That this is a process which may well have a very high probability is shown by the following remarkable coincidence. The heat of dissociation of oxygen into two normal atoms is now known to be exactly 5.06 volts;[3,4,5] the energy of the oxygen atom in the $^1S_0$ state is 4.19 volts, so that the energy necessary to dissociate an oxygen molecule into two $^1S_0$ atoms is 13.44 volts. The ionization potential of oxygen, while not definitely known, is generally given as 13.5 volts[6] and it is seen that there is a most striking agreement between the energy required in this process and the most probable value of the available energy.

We can advance another argument to show that the above explanation is probably the correct one. The oxygen molecule is very unstable in its higher energy states. This is shown by the fact that the highest electronic level which has been observed spectroscopically in O_2 lies at 6.1 volts. Thus between 6.1 volts and the ionization potential there are no observed levels of oxygen and in view of the number of energy levels which have been obtained for other diatomic molecules one can certainly take this as an indication that any attempts to excite energy levels higher than the 6.1 volt level, results in a dissociation of the molecule into one or more excited atoms. There is now considerable experimental evidence to show that the failure of a molecule to emit bands in certain energy regions can often be traced either to a predissociation of the excited molecule or to a direct dissociation by electron impact. We thus have another convincing argument for the notion that recombining O_2^+ yields metastable oxygen atoms and the green aurora line.

Direct evidence for the occurrence of the above discussed process has been found by the writer in some current experiments on the aurora spectrum.

[3] R. Frerichs, Phys. Rev. **36,** 398 (1930).
[4] R. T. Berge, Trans. Faraday Soc. **25,** 1929.
[5] F. Paschen, Zeits. f. Physik **65,** 1 (1930).
[6] Franck u. Jordan, Anregung von Quantensprüngen, p. 273.

These experiments are to be reported in detail elsewhere and it will be sufficient to say that it was possible, after the strong O_2^+ bands in the visible were produced, to make them disappear, to be replaced by a strong incandescence of small bits of oxide, indicating the presence of atomic oxygen. Furthermore, collisions of the second kind were observed between $^1S_0$ oxygen atoms and metastable nitrogen molecules, a process similar to the one that takes place in active nitrogen between metastable nitrogen atoms and metastable nitrogen molecules. This process was particularly striking in air at pressures ranging between 10^{-2} mm and 10^{-3} mm. There the oxygen bands failed to appear and the incandescence was quite intense. The nitrogen bands practically duplicated the nitrogen bands of the aurora spectrum so that in effect, this was a reproduction of the aurora spectrum. More will be said about this elsewhere.

We will now discuss a process by which the two lines of singly-ionized oxygen arise in the very bright night sky. A collision between a highly excited oxygen molecule (one which is about to dissociate) and a molecule ion, can result in a dissociation of the molecule ion into an atomic ion and a neutral atom. It is reasonable to assume that this process will be less probable than the recombination and dissociation process mentioned above. Hence only in the brightest night skies are the lines X_1 and X_2 observed. Furthermore, the lines of singly-ionized oxygen are very weak in the aurora.

The night sky which was described by Lord Rayleigh was so bright that the continuous spectrum made it difficult to see the green line. The same explanation that accounts for the green line will also account for a visible continuous spectrum. Thus the energy necessary to dissociate a molecule into an oxygen atom in the $^1S_0$ state and one in the ^1D metastable level is found to be 11.21 volts. The difference between this and the ionization potential will account for a continuous spectrum around 5400A.

It is possible to explain in a similar fashion the failure of nitrogen to play a role in the spectrum of the night sky. Let us assume that nitrogen molecule ions are produced in the upper atmosphere. The recombination of a molecule ion and an electron would produce an excited molecule in some one of the many electronic states which abound in nitrogen. There are at least six levels in nitrogen which are quite stable and either they do not radiate or they emit bands in the ultraviolet. It is quite possible therefore to describe methods by which the decay of nitrogen molecule ions could occur without the radiation of visible lines or bands. Dissociation is highly improbable, as is shown by the difficulty of producing nitrogen atoms in discharge tubes and also by the fact that the N_2^+ bands do appear in the aurora whereas O_2^+ bands do not. If dissociation did occur however, and metastable atoms were produced, their radiation would not be observed because the transition $^2P-^2D$, which is the analogue of the green aurora line, lies at about 1μ in the infrared. This fact and the fact that so many stable energy levels exist for N_2, take care of both possibilities, i.e. dissociation or the formation of stable molecules. It seems reasonable to expect the absence from the night sky of nitrogen radiation unless we assign part of the continuous spectrum to nitrogen molecule ions.

At the present stage of this work we don't propose to discuss the production of O_2^+. Whether ozone plays a very significant role in that process is now open to question because the oxygen molecule ions may well be formed by ultraviolet light in the night sky and by electrical discharge in the aurora. Further work will probably shed some light on this question.