The Auroral Spectrum

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The first-negative bands of nitrogen, which comprise most of the nitrogen radiation in the auroral spectrum, have been excited under conditions which suggest those in the aurora very closely. Active nitrogen is produced in uncondensed discharges in concentrations sufficient to give a strong visible glow. A very strong flash is observed at the beginning of the afterglow, and this flash indicates a high concentration of active material in the exciting discharge itself. Under the best conditions for the production of the afterglow the spectrum of the exciting discharge consists almost entirely of the first-negative bands. The most important characteristic of these bands, as excited under the present conditions, is the absence of lines due to N^+. The usual excitation of the N_2^+ bands in discharges at low pressures produces these lines, whereas they are almost entirely absent in the auroral spectrum. The excitation of N_2^+ bands in the present experiments is thought to be due to the large concentration of metastable nitrogen molecules in the $A(^3\Sigma)$ state, and this experiment is presented as a proof of their presence in both the aurora and in nitrogen afterglows.

I. Introduction

RECENT discussions of the origin of the Aurora Borealis have aroused considerable interest in the problems associated with this beautiful and startling phenomenon. Of special interest is the ultraviolet light theory which was proposed by E. O. Hulburt and H. B. Maris[1] in 1929. According to that theory, the auroral displays are caused by blasts of ultraviolet light from the sun which ionize the atoms of the upper atmosphere. These ions are carried to the polar regions where they recombine and emit the auroral radiations. The earlier theories of Birkeland, Störmer and Vegard suggested that the aurora was due to charged particles from the sun which are diverted to polar regions by the earth's magnetic field, and then their energy is given to the atmosphere and converted into auroral radiation. In their paper on auroras and magnetic storms Maris and Hulburt suggested that a complete theory of auroras "will require, among other things, complete knowledge of the energy levels, metastable states and transition probabilities of the atmospheric atoms and molecules, as well as of the exact processes which give rise to the aurora light." It is the purpose of this short paper to make a contribution to that phase of the problem.

The spectrum of the aurora consists in most part of the green aurora line, due to atomic oxygen, and of the first-negative bands, due to N_2^+. Other bands have been reported in the auroral spectrum, which are members of the second-positive and the first-positive groups of N_2, but in general these radiations are very weak in comparison with the green line and the negative bands.

[1] Maris and Hulburt, Phys. Rev. **33**, 412 (1929).

The green aurora line has been studied with great success in recent years, and much has been written about it. In the present paper we will describe experiments in which the negative nitrogen bands have been studied. Because of the enormous interest shown in the green line, not much work has been done on the study of the conditions of excitation of the negative bands. We have succeeded in exciting them under conditions which suggest the actual auroral conditions so closely that it will be tempting to conclude that we have reproduced the auroral conditions.

II. Experimental Method

The experimental method used in this work was a rather unusual one. Active nitrogen was produced by passing an electrical discharge through nitrogen at pressures ranging from 5 to 10 mm, not from the condensed discharge source usually employed in active nitrogen experiments, but from an ordinary uncondensed discharge from two 1-kw, 25,000-volt Thordarssen transformers. In all other experiments of which the writer is aware active nitrogen has been produced by passing a condensed discharge through nitrogen at a pressure of about 0.5 mm or by using an electrodeless discharge at pressures around 0.01 mm. An uncondensed discharge through a tube containing nitrogen will in general not produce active nitrogen in quantities sufficient to show a visible glow. In the present experiment this was not the case. It was possible to produce a strong visible glow in nitrogen even with an uncondensed discharge.

In the present experiments the tube was filled with nitrogen, and a small amount of oxygen was added. Then the tube was run steadily for several days during which the oxygen was gradually cleaned up. At first, the afterglow was the green continuous glow which is so readily produced by an uncondensed discharge in oxygen-nitrogen mixtures. As the oxygen was cleaned up this glow disappeared, and the afterglow due to active nitrogen appeared with increasing intensity. It is interesting to note the continuous transition between the two types of glow. The long running of the tube undoubtedly conditioned the surface of the tube in such a way as to allow it to adsorb nitrogen atoms. These adsorbed atoms react with other nitrogen atoms which collide with the wall, and the production of the visible afterglow is made possible. More will be said about this in a forthcoming paper on active nitrogen. The novelty of the present experiment is in the extremely long treatment of the tube, which finally resulted in walls which were more favorable for the production of the visible glow than those in previously reported experiments. It is difficult to account for the production of the afterglow in an uncondensed discharge in any other way. The strong afterglow in uncondensed discharges has probably been missed by others because of insufficient treatment of the discharge tubes. A condensed discharge will produce a strong afterglow in tubes in which an uncondensed discharge produces a very weak glow, hence experimenters have resorted in general to condensed discharges for the production of active nitrogen. So much, however, for the preparation of the tube. We will now discuss the actual aurora experiments.

The spectra in which we are interested were photographed in the bulb part of a discharge tube consisting of a 500 cc Pyrex bulb and a short length of 1 mm capillary tubing, and the usual large internal aluminum electrodes. The afterglow in the bulb showed a peculiar behavior which the present writer has never observed before. For a very short time after the exciting discharge was interrupted, the glow consisted of an extremely intense flash, much more intense than the afterglow which followed the flash. The writer has seen this "flash glow" hundreds of times, and there is absolutely no question of its existence. The flash was followed by the usual type of steadily decaying afterglow.

It was observed that when the afterglow in the bulb showed the short-lived flash (and this occurred only at the end of a very long treatment of the tube), the spectrum of the exciting discharge consisted of the first-positive bands of nitrogen, the negative bands of N_2^+ and the second-positive bands of N_2. The more intense the afterglow became, the more thoroughly were the second-positive bands quenched. By not running the tube steadily, but by making and breaking the current about once a second, it was possible to almost completely quench the second-positive group and to weaken the first-positive bands relative to the negative bands. Under the best conditions, the spectrum of the discharge in the bulb part of the tube consisted almost entirely of the negative bands. The plate was exposed to the light from the bulb during the entire "make," and for that reason the spectrum contained more of the second-positive group than if the exposures had been limited to the later part of the make. This could readily be seen by noticing that the second-positive bands flashed up and then died down during the first part of the make. Evidently the condition, which is responsible for the presence of the negative bands, is being produced during the first part of the discharge, and hence is not as steady as it is during the rest of the discharge time.

The spectra which are reproduced will show that some very striking changes have taken place in the nature of the electric discharge as the intensity of the afterglow increases. The spectrum of a discharge in N_2 in which no afterglow is produced consists of the first-positive and the second-positive bands. There is practically no sign of the negative bands. As a rule, the negative bands are produced with high intensity in discharges at pressures of 10^{-2} to 10^{-3} mm, and then they are accompanied by lines due to N^+. The presence of a strong afterglow changes the spectrum entirely. The spectrum of N_2^+ is now produced at a relatively high pressure and it is not associated with the strong line spectrum of N^+ which is present at low pressures. The first negative bands of the auroral spectrum are also excited without the strong excitation of the N^+ line spectrum. A comparison of the results of the present experiments with actual auroral spectra will show the remarkable resemblance between the two. The absence of the line spectrum of N^+ in the present experiment and in the auroral spectra is probably the most important point of resemblance between the two. These results are shown in Fig. 1.

When the current in the tube is diminished to about one-third of the value at which the negative bands are produced, the afterglow is of course a very weak one, the negative bands are weak, and the first-positive bands appear with definite maxima in bands arising on B_{10} and B_6. The 6323 band, corresponding to B_{10}–A_7, has been reported in auroral displays, and considerable discussion has taken place recently regarding Vegard's[2] observations of infrared bands in the aurora which are identified as transitions $B_7 \rightarrow A_6$. The B_6 maximum is quite strong in the negative glow of a discharge tube, and is often prominent in very red nitrogen discharges. The strong excitation of the B_{10} level in the same tube in which the N_2^+ bands appear is a very significant result for an understanding of the auroral spectrum.

III. Discussion

The most significant characteristic of a nitrogen afterglow, for our present discussion, is the presence in it of molecules in the metastable $A(^3\Sigma)$ state. The reader will be referred to papers on active nitrogen for evidence regard-

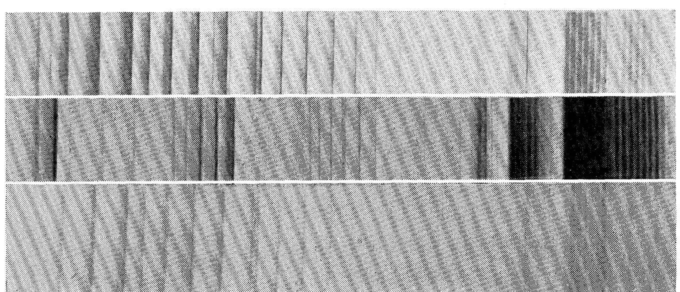


Fig. 1. Spectrum 1, normal excitation of N_2; spectrum 2, excitation in an active nitrogen producing discharge; spectrum 3, enhancement of bands which originate on B_6 and B_{10}.

ing the existence of metastable nitrogen molecules in the afterglow. In auroral displays metastable molecules will accumulate as a result of the excitation processes which are responsible for the aurora. The only mechanism for the destruction of metastable molecules in the upper atmosphere is collision with some other particle, whereas in laboratory discharges there is undoubtedly considerable destruction of metastable molecules at the walls. In a tube in which the afterglow is very strong there is a rapid production of metastable molecules, and hence a comparison between the upper atmosphere and such a tube is a reasonable one.

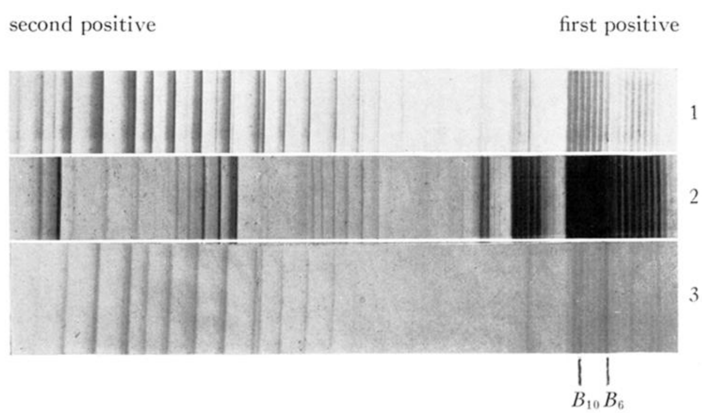
The excitation of the negative bands in these experiments can be explained in a very simple manner. It is only necessary to postulate that the light, emitted in a discharge in which there is a relatively high concentration of metastable molecules, is due to the direct excitation of these molecules by

[2] Vegard, Nature **129**, 468 (1932). Jevons, Nature **129**, 754 (1932).

electron impact in the discharge rather than to the excitation of normal nitrogen molecules. Thus, a process which in ordinary tubes is a secondary process, and hence very rare, now becomes quite frequent. The present experiment can be presented as a new proof of the existence of metastable molecules in active nitrogen. The metastable nitrogen molecules in the aurora are probably produced in the same way as in an active nitrogen tube; i.e., during the recombination of atomic nitrogen.

The unusual excitation of the levels B_{10} and B_6 in the same tube as the negative bands, but with weaker currents, gives us a very complete reproduction of the nitrogen part of the auroral spectrum. The existence of streamers and curtains in auroral displays, and their rapid motion, are indications of the unsteady nature of the phenomenon, and they may well be due to variations in an electrical current which is responsible for the excitation of the auroral display. That idea would fit in well with the present results.

This hasty account of the present experiments will be extended in the near future. The role of metastable nitrogen molecules will be discussed both for the aurora and for the light of the night sky. As a result of the present work we are tempted to conclude that the auroral display is really an electrical discharge in a nitrogen-oxygen mixture in which metastable molecules abound. There is, however, a better time for such a conclusion, namely, after more experiments have been performed.



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