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The Preparation and Properties of Auroral Afterglows

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The preparation of auroral afterglows in pure nitrogen is discussed in detail. A nomenclature is introduced for the five stages which are met most frequently in the preparation of these glows. In the normal order in which they occur they are the ozone, nitric oxide, cyanogen, Lewis-Rayleigh, and finally the auroral stage. Two plates, one showing the spectrum of the discharge in pure nitrogen, which is responsible for the production of the auroral glow, and one which shows the spectra of the nitric oxide, cyanogen and auroral stages, are reproduced.

I. INTRODUCTION

During the past year a considerable number of photographs have been made of nitrogen afterglow spectra with the purpose of showing the various stages in the preparation of auroral afterglows as practiced in the writer's laboratory. The inspiration for this work comes from the complete or partial failure of other observers to produce afterglows which have the spectra corresponding to that of the aurora. A discussion of these failures will be given. Laboratory studies of the earth's upper atmosphere have aided in the identification of upper atmosphere spectra obtained from auroral and night sky observations. A notable success in this field has been the identification of many night sky radiations as members of the Vegard-Kaplan bands of nitrogen. It has been possible to produce afterglows rich in the bands of this system and comparisons have been made with the bands present in the night sky spectra.[1]

II. DESCRIPTION OF TUBE AND ITS PREPARATION

The discharge tube consists of a central Pyrex or quartz bulb (100 cc to 5 liters) with side tubes of Pyrex which contain aluminum electrodes. Other side tubes may be added to introduce purifying reagents. Graded Pyrex seals are used. A tube may be filled with commercial tank nitrogen and sealed off. Streaming nitrogen cannot be used.

Various materials may be placed in the side tubes for purification and supplying nitrogen. $KMnO_4$ and P_2O_5 are employed for cleaning up hydrogen. By heating the $KMnO_4$ with a Bunsen flame it is possible to generate pure oxygen. This oxygen reacts with hydrogen in the discharge and water is formed. The P_2O_5 absorbs the water. This simple technique is found to be effective in cleaning up hydrogen. Experience in the preparation of auroral tubes has shown that strong auroral afterglows are produced only when hydrogen has been completely eliminated.[2]

$NaNO_2$ may be used as a safe and convenient source of nitrogen. On heating $NaNO_2$ in a horizontal tube it decomposes after melting and produces nitric oxide.[3] On operation of the tube the oxygen disappears and pure nitrogen remains. Nitrogen pressures vary from 10 mm to the lowest at which glow discharges are obtainable.

The tubes are operated on a 1 kw 15,000 to 25,000-volt sign transformer. An intermittent discharge is required in the preparation and later operation of the tube. This is produced by some device for making and breaking the primary current in the transformer.

III. STAGES IN THE PREPARATION OF THE GLOW TUBE

When carbon and oxygen are present as impurities five distinct stages can usually be observed in the preparation of a glow tube. These we shall name: (1) ozone stage, (2) nitric oxide stage, (3) cyanogen stage, (4) Lewis-Rayleigh afterglow, and (5) auroral stage. The first distinct afterglow stage shows a commonly observed green afterglow. It is ascribed to chemical reaction between NO_2 and O_3. Its spectrum appears

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[1] Kaplan, Pub. Astr. Soc. Pac. **47**, 257 (1935).

[2] Kaplan, Nature **136**, 549 (1935).

[3] A horizontal tube is preferred to a vertical one since a vertical one usually cracks when the $NaNO_2$ is reheated.

to be continuous although banded structure has been reported by some observers. If a trace of carbon is present the red cyanogen bands may be superposed on the continuous background of the nitrogen oxygen glow and give the appearance of a banded structure. Ozone appears to be necessary for the glow. As the oxygen is cleaned up during the ozone stage the continuous afterglow becomes weak and finally disappears.

The nitric oxide stage next appears. The afterglow is blue in color and its spectrum is characterized by the presence of the β-bands of NO in the visible and ultraviolet and the γ-bands in the ultraviolet. This appears to be the first step in the production of the Lewis-Rayleigh afterglow which develops later.

If carbon is present the cyanogen stage follows. This is one of the most beautiful stages of the tube. The afterglow is a fairly long lived flash which takes on the same shape as that of the discharge. The luminosity of this glow is very high. In fact, it appears to be higher than that of any other nitrogen afterglow known to the writer. The spectrum of the afterglow easily observed through a direct vision spectroscope consists almost entirely of the two well-known band systems of the CN radical, the violet and the red systems. Particularly striking is the high intensity with which the cyanogen tail bands appear in the afterglow. The intensity is to the best of the writer's knowledge the best obtainable and makes this stage a valuable one for the study of these bands.[4]

The strong yellow glow follows the cleaning up of the carbon. This is called the Lewis-Rayleigh glow because of the work of Lewis and Rayleigh on the active nitrogen.

The relation of this glow to the nitric oxide glow is shown by the fact that the introduction of oxygen into the yellow glow produces the nitric oxide glow. Undoubtedly the mechanisms of the ozone stage and that in the Lewis-Rayleigh and NO stages are different. The presence of a dark stage in some tubes between the ozone and NO stages supports this conclusion.

It should be pointed out here that the sequence of distinct stages which has been described is not closely adhered to in all tubes. The duration of any stage depends of course on the amount of the particular impurity, oxygen or carbon, which is responsible for that stage. There have been tubes in which the straw-yellow Lewis-Rayleigh glow was practically missing and the auroral glow was followed by the cyanogen stage. On the other hand, tubes have been observed in which a distinct Lewis-Rayleigh glow has been present for a long time after the tube had passed through all the other stages. It appears as if the cyanogen stage may develop before a distinct Lewis-Rayleigh stage or it may develop just before the auroral stage.

The peculiar behavior of the cyanogen stage and certain extensive observations on interaction between pure oxygen and the auroral afterglows[5] has led us to believe that there are three afterglows distinct in a sense that there are three essentially different excitation mechanisms. These glows are the afterglow which is present in the ozone stage, the straw-yellow L-R glow, and the auroral glow.

While the three afterglow tubes have been presented for the purposes of classifying the afterglows we must not forget that after the tube has reached the auroral stage the afterglow is very definitely a function of pressure, current, and even of the duration of the exciting discharge.

Several interesting phenomena observed during the preparation of the auroral tubes will be described. When a tube which has not been used for some time is again operated it shows during the first few minutes of operation a spectrum in both discharge and afterglow which corresponds to a stage to which the tube is approaching. After operation for a few minutes it reverts to its proper stage and then on further operation continues to advance through later stages. This observation is interesting in that it gives one a preview of a stage toward which the tube is advancing.

Glows differing from those in the main portion of the tube occur in the narrow portion of the

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[4] The close resemblance between the red CN bands and the first positive bands of N_2 makes it necessary to be careful in announcing results of band intensities in these glows. The strong band λ3883 of the violet system persists with good relative intensity down to remarkably small carbon concentrations and one should always be on guard and not mistake these bands for N_2^+ bands since again the violet bands resemble the N_2^+ first negative bands very closely and lie in the same spectral range.

[5] Kaplan, Trans. Am. Geoph. Union (1936).

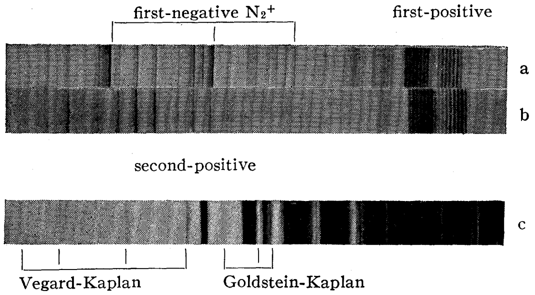

FIG. 1. *a.* Auroral discharge, visible; *b.* ordinary discharge, visible; *c.* auroral discharge, ultraviolet.

tube near the electrodes. These may be one stage in advance of the glows in the main section of the tube, that is, when the spherical section contains the auroral glow the smaller portion may be nearly dark, at least no visible light may be seen. There may be ultraviolet light as this phenomena has not been studied in quartz tubes. This observation leads us to suggest that there may be a "dark" stage later than the auroral stage.

There are three criteria which indicate that the tube is nearly or definitely in the auroral stage. The first is the violet and blue first negative bands of N_2^+. As the tube is almost through the cyanogen or L-R stages, depending on the sequence, these bands set in and as the tube progresses toward the auroral stage their intensity relative to the second-positive bands in the blue and violet increases so that finally the spectrum appears to be almost a pure ion spectrum in the blue and violet. The remarkable thing about the appearance of these bands at pressures as high as 10–20 mm is that they are emitted by the nitrogen molecule ion.

The second sign that the tube is on its way to a real auroral stage is the increasing relative intensity of the green sequence of the first-positive system of N_2. When one observes the first-positive bands through a direct-vision spectroscope there are four distinct sequences observable, red, yellow-orange, yellow-green and green. The green sequence consists of bands which arise on $v'=16-20$ and at the present time experiments are in progress in an attempt to obtain good plates of this characteristic enhancement of the green sequence.

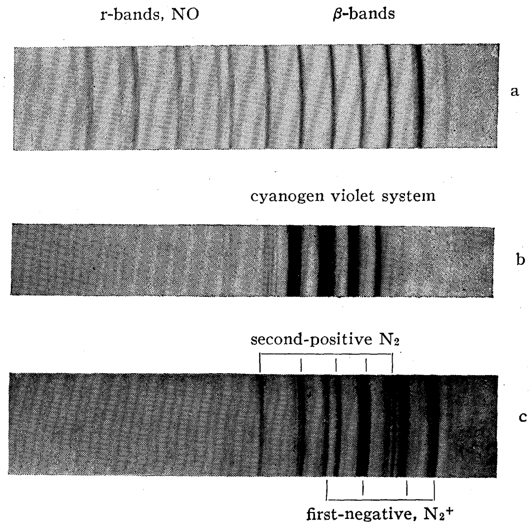

FIG. 2. *a.* Afterglow, nitric oxide stage; *b.* afterglow, cyanogen stage; *c.* afterglow, auroral stage.

Probably the most important criterion of the auroral stage is the presence of the Vegard-Kaplan bands, $A^3\Sigma \rightarrow X'\Sigma$. These bands also increase in intensity relative to the neighboring second-positive system as the tube progresses toward the auroral stage. In a sense they are the most interesting of the three criteria because it was in an auroral tube that they were first observed in gaseous nitrogen in the laboratory.

Finally, in closing, we wish to present two photographs. On Fig. 1 are spectra which illustrate a few typical discharge spectra which are obtained during the preparation of the tubes. On Fig. 2 is a sequence of afterglow spectra from the nitric oxide stage through to a very good auroral stage.

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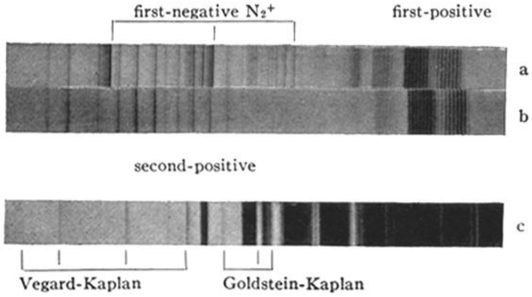
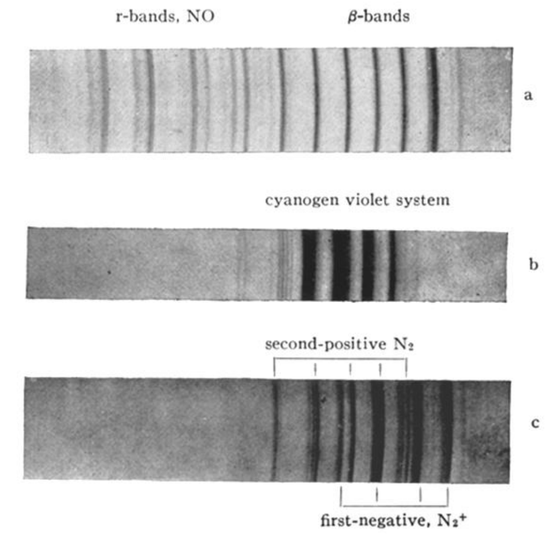


FIG. 1. *a*. Auroral discharge, visible; *b*. ordinary discharge, visible; *c*. auroral discharge, ultraviolet.



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