# Active Nitrogen and the Auroral Spectrum

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A new afterglow of nitrogen has been photographed in the visible and the near ultraviolet. Its spectrum consists of the first-negative bands of $N_2^+$, first-positive bands of $N_2$ which originate on the vibrational levels $v'=15$, 16, 17, 18 and 19, and the second-positive group of nitrogen. The ordinary afterglow of nitrogen is also present but very weak. The spectrum of the afterglow is a very faithful reproduction of that part of the auroral spectrum which is due to nitrogen. The spectrum of the exciting discharge resembles that of the afterglow very closely. These facts are used as a basis for the hypothesis that the auroral spectrum is the superposition of a discharge spectrum and an afterglow spectrum. Attention is called to proposed extensions of the experiments.

## I. INTRODUCTION

IN an earlier paper on the auroral spectrum,[1] an electrical discharge was described in which the spectrum consisted mainly of the first-positive and first-negative bands of nitrogen rather than the first-positive and the second-positive bands which usually comprise the spectrum at the pressures at which these discharges were studied. One of the striking properties of the discharge which was described in that paper was the strong afterglow which appeared in the wide portion of the discharge, this afterglow being the first example of a nitrogen afterglow produced by an uncondensed discharge. By a nitrogen afterglow we mean one of which the spectrum consists of some of the band spectra of nitrogen. This is to distinguish the nitrogen afterglow from the well-known afterglow in nitrogen-oxygen mixtures, the spectrum of which consists of a continuous spectrum. It was pointed out in that paper that the second-positive bands are more thoroughly quenched the more intense the afterglow becomes, and at the same time the first-negative bands increase in intensity relative to both the first-positive and the second-positive bands. It was concluded therefore that the excitation of the first-negative bands was intimately connected with the production of the afterglow, and since metastable nitrogen molecules in the $A^3\Sigma$ state are involved in the production of nitrogen afterglows it was concluded that they too had something to do with the excitation of the first-negative bands in the discharge. Since the first-negative bands constitute the most intense portion of that part of the auroral spectrum which is due to nitrogen, it was concluded that in this experiment we at last had a clue as to the way in which the auroral spectrum is actually produced in the upper atmosphere. It was thought however that further experiments were needed before one could conclude that the aurora is simply an electrical discharge in a nitrogen-oxygen mixture in which metastable nitrogen molecules are present in large numbers. Some of these experiments have already been done and others are going on at the present time, and it is to report the results of some of these experiments that the present paper is being written. The particular experiments which are to be reported here are those in which the afterglow in the above-mentioned tube has been photographed.

[1] Kaplan, Phys. Rev. **42**, 807 (1932).

## II. EXPERIMENTAL METHOD

The tube in which the afterglow was photographed has been described in the paper which was referred to earlier. The afterglow was present only in the bulb part of the discharge, and it was photographed there with the aid of a rotating sector, which allowed only the light of the afterglow to reach the slit of the spectrograph. The discharge tube was made of fused quartz so that it was possible to photograph the afterglow in the ultraviolet as well as in the visible. The tube was operated in three stages, the first two of which we call the green and the blue stages. The origin of these names lies in the colors of the discharges, green-white in the first and blue-white in the second stage. Two 1-kw, 25,000-volt Thordarssen transformers were available for producing the discharge, and for most of the work the pressures were from 4 to 8 mm. In the green stage a current of about 5 amperes was allowed to go through the primary of one of the transformers; in the blue stage the current was about 10 amperes; in the third stage the current was about 15 amperes, the two transformers running in parallel.

In the experiments that are to be described here only the first two stages were employed. The change from the green-white stage to the blue-white stage with increased current is a very beautiful phenomenon. Vegard[2] has called attention to the fact that the most common colors of auroral displays are blue-white and green-white, and hence the production of discharges in nitrogen which show these colors is an important fact for the understanding of auroral displays. A complete discussion of the spectroscopy of the various stages of the discharge will be left for other papers, and only the afterglow will be discussed here. It may be mentioned however that the similarity between the colors of the discharges in nitrogen and those of auroral displays is but one of many points of resemblance which were discovered in the course of this study.

The afterglow was photographed only for the first two stages mainly because they were more interesting, and because the exposure times were so long that the study of the third stage had to be left for future work. The afterglows were comparable in intensity with the ones that have been obtained by other methods and the long exposures were necessary because of the low light gathering power of the instrument which was available for photography in the visible. In fact the initial stage of the afterglow was extremely brilliant, and in the earlier paper the writer has referred to it as a flash glow. This flash takes the same shape as the discharge, and it makes one think that the actual afterglow process has been going on in the discharge itself, and the real afterglow is simply the persistence of the afterglow which was masked by the discharge. An examination of the spectrum of the afterglow and that of the discharge will show that this is a very reasonable point of view, and in fact the very peculiar properties of the discharge can be accounted for by assuming that the discharge passes through a glowing gas rather than through ordinary nitrogen.

### III. Results

The spectrum of the afterglow when the tube was operated in the green stage is shown in Fig. 1. It was taken on an astronomical green sensitive plate made by Eastman. To anyone who is familiar with nitrogen afterglows these results will be very surprising. In the usual nitrogen afterglows selected members of the first-positive group of nitrogen comprise the entire spectrum. The strongest of these bands originate on the 10th, 11th, and 12th vibrational levels of the $B^3\Pi$ state of the molecule. Now although these bands are also present in this afterglow they are less prominent than the first-negative bands of $N_2^+$ and the first-positive bands which originate on the $v'=15$, 16, 17, 18 and 19 levels. The second-positive bands are also present but they are very weak.

In the figure the wave-lengths of only the first members of the three sequences of the first-negative bands are marked. These are the (0,0) band $\lambda$3914, the (0,1) band $\lambda$4278 and the (0,2) band $\lambda$4709. A comparison of the afterglow plate and that of the direct discharge will show several striking differences between the two. The discharge was photographed on a panchromatic plate. In the sequence which begins with the band (0,1) $\lambda$4278 it will be noticed that the relative intensities of the first band of this sequence to the next two are different in the afterglow from that in the discharge. The enhancement of the (0,1) band with respect to the (1,2) and the (2,3) bands is characteristic of the spectra of many auroral displays.

It is to be noted also that in the afterglow the first-negative bands are more intense relative to the second-positive bands than in the discharge. The three weak bands on the long wave-length side of the 3914 band in the discharge spectrum are second-positive bands. They can barely be seen on the afterglow spectrum.

[2] Vegard, Geofysiske Publikasjoner, Vol. 10, No. 4, p. 56.

The set of bands in the afterglow marked *a* are the first-positive bands (16,11), (17,12), (18,13) and (19,14). A wide slit was used and hence it is difficult to distinguish individual bands on a print. It is easy however to identify these bands on the original plates. The set marked *b* correspond to the first-positive bands (15,11), (16,12), (17,13) and (18,14). The set marked *c* correspond to the first-positive bands (12,7), (11,6), (10,5), etc.

The presence of the first positive bands of the set marked *a* demonstrates another important likeness between the spectrum of this afterglow and the auroral spectrum. First-positive bands have been reported in the aurora by Vegard,[3] who gives the wave-lengths 5001 and 5241 and the interpretations (15,10) and (16,11), respectively. The excitation of these bands in the afterglow in company with the first-negative bands should add considerable weight to the above interpretation of these bands. Other bands which arise on the levels $B_{13}$, $B_{14}$, $B_{15}$, $B_{16}$ and $B_{17}$, have been reported by Vegard in the auroral spectrum. The band 5867 is interpreted as (17,14); 5891 is interpreted as (9,5), but it could just as well be interpreted as (16,13); 5875 is called (15,12); 6058 is called (6,2), but it could be interpreted as (14,11); and 6108 is called (13,10). The present experiment is definitely an argument in favor of the interpretation that these bands originate on the higher vibrational states. In the spectral region above 5750 bands arising on low vibrational states overlap those arising on the high ones, and the interpretation is not as certain in that region as in the region *a* where no overlapping occurs. Probably in the higher wavelength region overlapping does occur, and this may explain the difficulty of obtaining very good agreement between first-positive bands and auroral bands.

Spectrum I in Fig. 2 shows the afterglow when the tube was operated in the blue stage. Panchromatic plates were used. Because of the necessity of using a wide slit it is difficult to distinguish individual bands, but the bands (12,8), (11,7) and (10,6), and the corresponding bands in the red sequence (12,9), (11,8) and (10,7) were very easy to identify on the original plates. In addition to these bands, which are present also in the spectrum of an ordinary nitrogen afterglow, there are bands in the region marked *a* which are comparable in intensity with the above-mentioned bands and lying in the region of the bands (6,3), (7,4), (8,5) and (9,6). These bands are more diffuse than the

[3] Vegard, reference 2, p. 38.

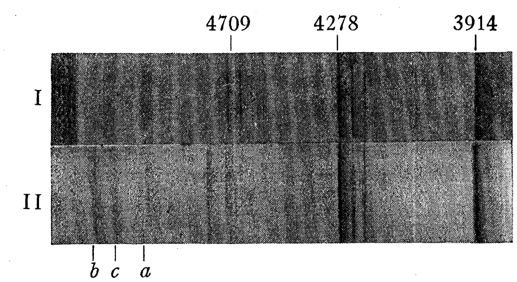


FIG. 1. I, direct discharge (Panchromatic plate); II, afterglow (green-sensitive plate).

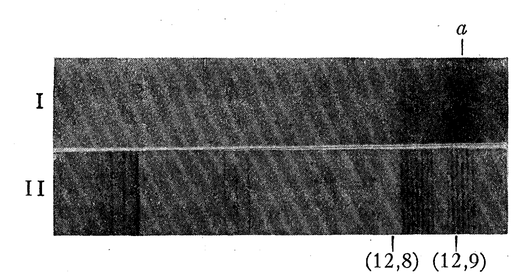


FIG. 2. I, afterglow; II, direct discharge.

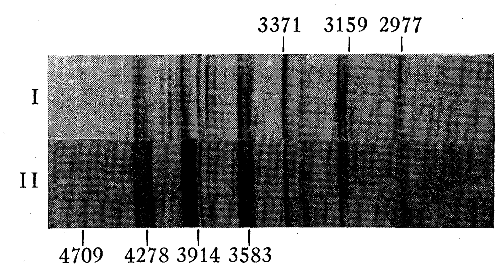


FIG. 3. I, direct discharge; II, afterglow.

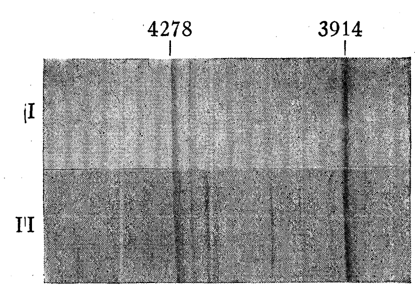


FIG. 4. I, afterglow; II, direct discharge.

bands (12,9), (11,8) and (10,7), and hence it is supposed that they are due to a superposition of the four bands mentioned above and the bands (13,11), (14,12), (15,13), and (16,14) which also fall in this region. The presence of bands arising on these high vibrational states in Fig. 1 indicates that this is a reasonable supposition. Auroral radiations have been observed in this region, and there is a very close resemblance between the spectrum of Fig. 2 and the actual auroral spectrum. Further discussion of this point will be postponed until better pictures have been obtained.

In spectrum II of Fig. 3 is shown the spectrum of the afterglow taken on a Hilger E 31 quartz spectrograph. The tube was operated in the green stage. The first members of four sequences of the first-negative group are indicated under spectrum II, and the first members of three second-positive group sequences are shown above spectrum I. The relative intensity of the first-negative to the second-positive group is larger in the afterglow than in the discharge. In fact the relative intensity in the afterglow is very much like that in auroral spectra. This is then another point of resemblance between the spectrum of the afterglow and that of the aurora.

As the tube is operated the pressure diminishes very slowly due to a clean up of the nitrogen in the tube. The afterglow corresponding to a given current through the tube changes. Only a qualitative study has been made of this effect, and it has been noticed that as the pressure goes down and the current is held constant the afterglow spectrum becomes more and more like that of the aurora. All the points of resemblance seem to be enhanced. Fig. 4 shows a spectrum of the afterglow taken at a pressure slightly lower than that at which the other three pictures were obtained. The contrast between the afterglow and the direct discharge is interesting. The first-negative bands increase in intensity relative to the first-positive bands, and the intensity distribution in the 4278 sequence is noticeably different in the afterglow from that in the discharge. This effect of the change in the spectrum of the afterglow with pressure will be studied in detail. Attention was called to it here simply because of the striking nature of this change.

## IV. Discussion

This new and interesting afterglow of nitrogen seems to demand the conclusion that an auroral display is a series of electrical discharges and afterglows. The great similarity between the spectra of Fig. 1 indicates that a condition may exist in which the spectrum of the discharge is the same as that of the afterglow. Now a nitrogen afterglow means that metastable molecules in the $A^3\Sigma$ state are present, and the spectrum II of Fig. 1 shows the radiation that is emitted when these molecules interact with other nitrogen molecules. The difference between the two spectra is due to the fact that in the discharge there are not only afterglow processes going on but also "discharge" processes. By the latter we mean excitation of molecules by electron impact in the discharge. The spectrum I is really the superposition of a discharge and an afterglow spectrum. If one tried to imagine the appearance of spectrum I as the number of metastable molecules in the discharge increased, one would certainly expect it to approach that of the afterglow in spectrum II or something very much like it. One is inevitably driven to the conclusion that the peculiar spectrum of the aurora is due to the large number of metastable molecules which are present in the upper atmosphere during auroral displays. The production and survival of these molecules in the upper atmosphere is easily accounted for. There are no walls with which they can collide and be destroyed, and transitions to the ground state are forbidden by selection rules. These are so rare in fact that not a trace of radiations arising on this level have ever been observed. In the present experiments the afterglow was produced by small currents. This eliminates the rapid destruction of metastable molecules in the discharge and allows the accumulation of more metastable molecules than in the afterglows that are produced by condensed discharges. It is hoped that a further study of the problem will allow a quantitative formulation of it. It is also hoped that some light will be shed on the allied problem of the origin and nature of the light of the night sky, since it is believed that metastable molecules play a part in that phenomenon also.

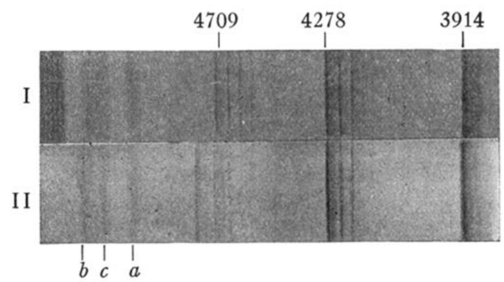


FIG. 1. I, direct discharge (Panchromatic plate); II, afterglow (green-sensitive plate).

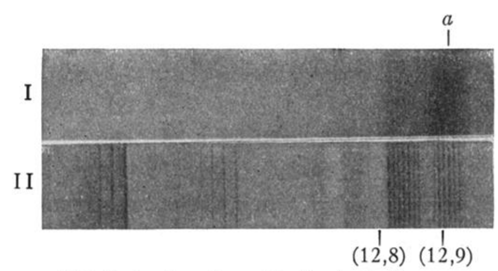


FIG. 2. I, afterglow; II, direct discharge.

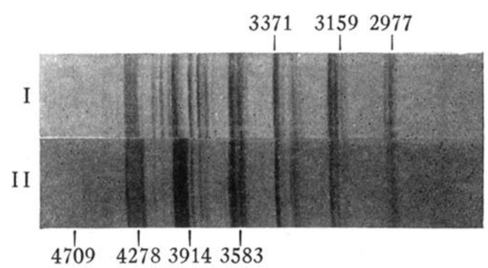

FIG. 3. I, direct discharge; II, afterglow.

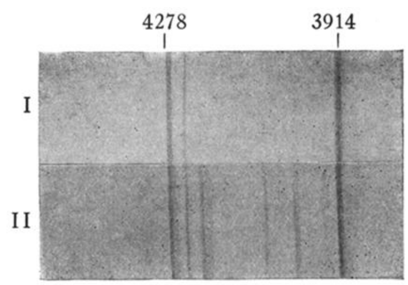


FIG. 4. I, afterglow; II, direct discharge.