

think this is the reason why  $H_{\alpha}$  intensity shows rather flat occurrence frequency distribution?

**Nakamura, J.:**  $H_{\alpha}$  luminosity spreads out to wider region, but its nocturnal variation shows rather rapid change. It is because of the statistical operation through many nights that almost no local time dependence can be seen in Fig. 2.

JOURNAL OF THE PHYSICAL SOCIETY OF JAPAN Vol. 17, SUPPLEMENT A-I, 1962  
INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part I

### 1-4-9. Low Latitude Red Aurora and Low Energy Protons in Van Allen Belt

Tadayoshi HIKOSAKA and Kyo YANO

*Faculty of Science, Niigata University, Niigata, Japan*

It is proved that the great intensity ratio of the red to the green line of O-atom accompanied by the strong emission of  $N_2^+$  N.G. is a useful criterion to distinguish the aurora excited by a few keV protons from those of other origins. The red line enhancement is due to the low temperature of the electrons ejected by proton bombardment. The estimated temperature and the red-green ratio is 0.5, 1, 2.5 and 4 eV and 500, 45, 12 and 6.5 for protons of 1, 2, 5 and 25 keV respectively. The efficiency of the red line excitation by the secondary electrons of 3 keV protons is estimated to be about one photon per one electron. If we take as a model of low latitude aurora the following: thickness 100 km, the red line brightness 10 kR at 250 km height and 1 kR at 600 km, and the red-green ratio 20, then the energy of the incident proton must be about 3 keV, and the necessary flux is  $8 \times 10^8/cm^2, sec$  at 250 km and  $3 \times 10^{10}/cm^2, sec$  at 600 km. This large increase of flux with height and many other evidences indicate that they come from Van Allen Belt.

Direct detection of auroral protons has not been done yet, as their energy is too low to be detected by the usual instruments born on rockets. We can get knowledge about them only through the analysis of their behaviors in auroral displays. Therefore we will try here to make clear what are the characteristics of the spectra excited by the protons, and try to answer what type auroras are due to protons of what energy. Estimation of proton flux from the spectral intensity will also be given. Particular attention will be paid to a few keV protons because they are surely the main component of the auroral protons.

#### §1. Red-green ratio

The most remarkable feature of the spectra excited by the protons of a few keV is the

great enhancement of the red oxygen line. This is a consequence of the smallness of the energy of the secondary electrons ejected by the proton bombardment. Let an electron of mass  $m$  be initially free and at rest, and collide with a proton of mass  $M$  and energy  $E$ , then the maximum energy  $\epsilon_m$  got by the electron is

$$\epsilon_m = 4Em/M. \quad (1)$$

This formula can be applied to bound electrons provided the proton energy is high enough. Bates<sup>(1)</sup> and his collaborators have calculated the energy spectra of the secondary electrons ejected from H and Ne by proton bombardment. Fig. 1 shows their results. The dotted parts of the curves are our extrapolation. Eq. (1) has given very powerful aid for the purpose. We believe the ambiguity inherent to the extrapolation

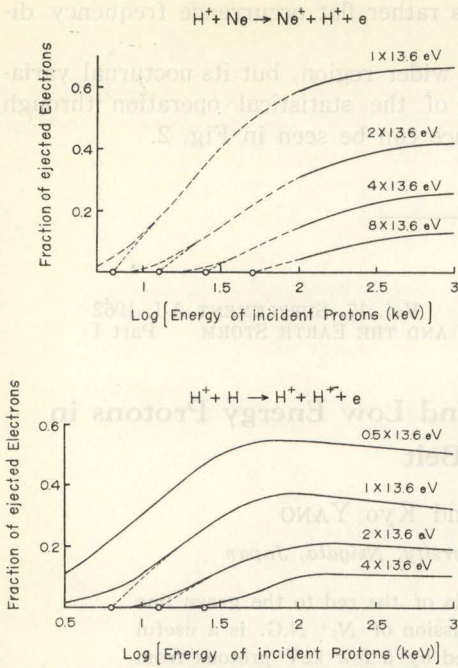


Fig. 1. Fraction of ejected electrons which have more energy than the values indicated on the individual curves. O's are the points derived from Eq. (1).

was largely avoided by it.

Fig. 2 is another representation of the energy distribution of the secondary electrons. For the purpose of comparison, Maxwellian form is also shown. We see these two groups of curves are fairly similar.

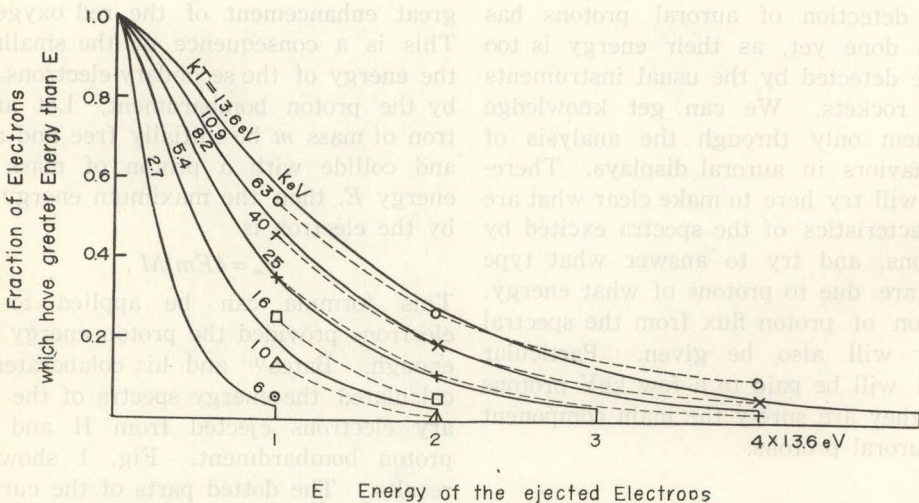


Fig. 2. Dotted curves: Energy distribution of the ejected electrons. Energies of the incident protons are indicated on the individual curves. Full line; Maxwell distribution. The numbers on the individual curves are their  $kT$ -values.

Therefore we can speak about the temperature of the secondary electrons. They are shown in Tab. I. The low energiness is very remarkable.

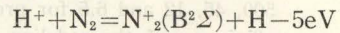
As the mean energy of the secondary electrons are so low, that the only spectra excited with appreciable intensity is the red oxygen line. Even the green line of the same atom should be far weaker. The intensity ratio of these two lines estimated after Seaton<sup>(2)</sup> are shown in the third column of Tab. I.

Table I.

Incident proton energy	Temperature of ejected electrons	Intensity ratio I(6300)/I(5577)
1 keV	0.5 eV	500
2	1	45
5	2.5	12
25	4	6.5

### § 2. Negative Bands of Nitrogen Molecular Ion

Laboratory experiments<sup>(8)</sup> have proved that the process



occurs very easily with protons of a few keV, and the consequent emission of the negative bands is very strong. This fact is important. It shows that the particular enhancement of the lowest level excitation can accompany with the strong emission of

the ionic spectra, if and only if the excitation be done by positive ions of suitable energy. In effect, the large red-green ratio accompanied with the strong emission of the negative bands can be used as a criterion to distinguish the auroras excited by a few keV protons from those excited by electrons or by protons of other energy regions.

### § 3. Low-Energy-Proton-Type Aurora

The above mentioned criterion definitely indicates that the low latitude red auroras are the most typical ones excited by the protons of a few keV energy. In the case of the great aurora on Feb. 11, 1958 the red-green ratio observed from Niigata<sup>4)</sup> was 20. This corresponds to the incident proton energy 2.7keV. The protons of this energy can penetrate into the height 140km if they come along the magnetic lines of force, while the actual base height was about 200km. Therefore they must have repeated many times of mirrorings, that is, they were semi-trapped. This suggests that they came from Van Allen Belt, leaking out of it by some perturbations. Extremely wide longitudinal and latitudinal extension and long steady persistence of that aurora may be understood only by this model.

The estimation of the proton flux from the red line intensity is relatively easy in this case. We may assume that the state is stationary and the deactivation can be ignored. Then the number of  $\lambda 6300$  photons emitted per  $\text{cm}^3$  per sec is

$$i_{21} = n_1(O)n_e\alpha_{12} \quad (2)$$

Here 1 and 2 stands for the state  $^3\text{P}$  and  $^1\text{D}$ ,  $n_1(\text{O})$  is the number density of oxygen atoms in  $^3\text{P}$  and  $\alpha_{12}$  is the coefficient of excitation  $^3\text{P} \rightarrow ^1\text{D}$ . We give  $n_e$  somewhat particular meaning, that is, the density of the electrons whose energy is larger than the excitation potential of the  $^1\text{D}$ -level. These "effective" electrons are born by proton bombardment at the rate  $\xi n_p \Sigma n \alpha_{ion}$  where  $n_p$  and  $\Sigma n$  is the density of protons and air "atoms",  $\alpha_{ion}$  is the ionization coefficient and  $\xi$  is the ratio of the effective electrons to the total secondary electrons. The possible processes that make  $n_e$  decrease are recombination, ionization and excitation. Here ionization have no effect, as the electron temperature

is too low. Recombination may be disregarded too, so long as  $n^+ \alpha_{rec} \ll n_1(\text{O})\alpha_{12}$  and this is surely the case. Because  $\alpha_{12} = 10^{-9} \text{ cm}^3/\text{sec}^{(5)}$  and  $n_1(\text{O})/n^+$  is never smaller than 1000. Finally, among all excitation processes, only  $^3\text{P} \rightarrow ^1\text{D}$  occurs predominantly, as is said already. Therefore we get

$$\xi n_p \Sigma n \alpha_{ion} = \eta n_e n_1(\text{O})\alpha_{12} \quad (3)$$

$\eta$  expresses the circumstance that not all excitation collisions are effective to the loss of  $n_e$  but only  $\eta$ -part of it should be counted as effective. Values of  $\xi$  and  $\eta$  may be estimated by consulting with Fig. 1. From (2) and (3)

$$i_{21} = n_p \Sigma n \alpha_{ion} \cdot \xi / \eta \quad (4)$$

The observed brightness was 20kR at 400km height at 1230UT, Feb. 11. If we adopt as the thickness in the line of vision (which was nearly horizontal) the US data 400km, then  $i_{21} = 5 \times 10^2 / \text{cm}^2, \text{sec}$ . Putting  $\Sigma n = 3 \times 10^8$  at 400km height,  $\alpha_{ion} = 1.1 \times 10^{-8} \text{ cm}^3/\text{sec}^{(6)}$  for 2.7keV protons and  $\xi/\eta = 1$ , we get as the flux

$$N_p = n_p v_p = 1 \times 10^{10} \text{ protons}/\text{cm}^2, \text{sec}$$

We notice that this very strong and abnormally thick flux have produced only medium brightness. Flux of ordinary intensity ( $\sim 10^7$ ) would likely produce invisible aurora if their height is not below 200km. In this connection we remind that Barbier's<sup>7)</sup> sub-visible red arc has perfect similarity to the low latitude red aurora in many respects. Only difference seems to lie in the lower intensity and the more frequent occurrence of the former. We believe that these are the same phenomenon. Smaller perturbations will probably occur more frequently and smaller perturbation will send weaker flux into the atmosphere. This will explain the difference of the two. New Zealand group<sup>8)</sup> at Scott Base has found recently that the sub-visible auroras of Type-A are most common in that place. If they are also the auroras of the kind, then the proton-induced auroras are not so rare as is usually thought.

### References

- 1) D. R. Bates et al: Proc. Phys. Soc. **A66** (1958) 961; J. Atm. Terr. Phys. **10** (1957) 51.
- 2) M. J. Seaton: *The Airglow and the Aurora*, Pergamon Press, (1955) 289.

- 3) N. P. Carleton: Phys. Rev. **107** (1957) 110.      6) Il'in et al: J. Exp. Theor. Phys. **36** (1959) 41.  
 4) T. Hikosaka: Rep. Ionosph. Res. Japan, **12**      7) D. Barbier: Ann. Geophys. **14** (1958) 334.  
 (1958) 469.      8) B. P. Sandford: J. Atm. Teerr. Phys. **21** (1961)  
 5) M. J. Seaton: loc. cit.      177.

### Discussion

**Roach, F. E.:** Prof. Barbier has found that the N. G. of  $N_2^+$  are not exist in his "mono-chromatic" arc.

**Hikosaka, T.:** The process is endo-thermic by  $\Delta E = -5$  eV. Therefore, as Massey's criterion shows, the cross section should be small if the energy of the incident protons becomes too low. This might explain the fact.

**Tohmatsu, T.:** Protons of several kiloelectron volts have rather long life time for geomagnetic mirror motion. Can you explain the duration of the red aurora? Did you assume the possibility of primary excitation of  $N_2^+$  bands?

**Hikosaka:** (1) This long life is just the needed feature. Because the aurora of this type persists for even several hours without remarkable change. This long persistence and the extremely large latitudinal and longitudinal extension of the arc, I believe, can only be explained by the "leakage-proton model", that is, the protons which leak out from the Van Allen Belt. (2) There are direct experimental proves that our process occurs with large probability.

**Takayanagi, K.:** You have used the energy distribution for the secondary electrons calculated by Bates et al for neon. Because of the big difference in ionization potentials, I am afraid, one can not apply their result on the case of oxygen and nitrogen to draw any quantitative conclusions.

**Hikosaka,:** Some small difference may exists, but the essential conclusion that the energy of the ejected electrons must be small will not fail. It is certified by the conservation law of momentum.

---

JOURNAL OF THE PHYSICAL SOCIETY OF JAPAN      Vol. 17, SUPPLEMENT A-I, 1962  
 INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM      Part I

## I-4-10. Balloon Observations of Auroral Zone X-Rays\*

Rovert R. BROWN

*Department of Physics, University of California, Berkeley 4,  
 California, U.S.A.*

A series of balloon flights launched from the vicinity of College, Alaska during the summer months of 1960 show that auroral zone X-Rays are detectable with Geiger counters approximately 10% of the time at pressure altitudes in the range 10-15 mb. The results of these flights indicate that the daily flux of electrons with energies greater than

50 keV over the auroral zone was  $6 \times 10^{10}$  particles/cm<sup>2</sup> at this time. The results from a similar series of flights carried out in 1961 will be compared with the earlier observations. In addition, observations of X-ray events during periods of extreme geophysical disturbance will be presented, showing the extent to which the electron bombardment of the atmosphere can grow during such conditions.

\* No manuscript has been received and the preprint is reprinted.