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PROGRESS REPORT
ON AERONOMY RESEARCH
AT RICHLAND, WASHINGTON,
JULY 1969

September 1969

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PROGRESS REPORT
ON AERONOMY RESEARCH
AT RICHLAND, WASHINGTON,
JULY 1969

By

R. J. Hoch

Aeronomy Department
Applied Physics Division

September 1969

BATTELLE MEMORIAL INSTITUTE
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PROGRESS REPORT ON AERONOMY RESEARCH AT RICHLAND, WASHINGTON

1. INTRODUCTION

This report covers progress in FY 1969 on the "Investigation of Aurora and Airglow." It also covers progress on "Automation of Aeronomy Equipment" which is part of the whole aeronomy program at Richland sponsored by the Division of Research.

According to the usual way of predicting, we should now be in a period of maximum solar and auroral activity. Solar activity, sunspot number, and frequency of magnetic storms have all increased but not nearly as strongly as they did during the 1957-58 maximum.

Based on over 250 years records of sunspot number, the time between maxima has actually varied as much as 4 years about an 11.6 year mean. It is possible that this maximum could be late but it is equally likely that it is on schedule and we will simply have a less spectacular solar season than the corresponding 1957-58 peak.

The auroral phenomena we are recording are both the polar auroras and the Stable Auroral Red (SAR) arcs. They are both occurring, and their appearances are well correlated with solar activity. The SAR arcs, for example, reappeared at midlatitudes in September, 1967, for the first time since the last maximum. They have been recurring sporadically since then. Most of the recent auroral events including the SAR arcs have been much more subtle than might have been expected for a time of maximum activity but this does not necessarily reduce the amount of physical information that we can extract. It does, however, require that observations be made with some finesse.

No international cooperative effort like that of the IGY has been set up to coordinate observations during the present

solar maximum. The distribution of observing stations in operation is such that the task of recording and analyzing the SAR arcs and midlatitude auroral activity in the Western United States falls to us if these events are to be recorded at all.

The SAR arcs remain a primary concern of this research program. When we began our investigation, there were several open questions about the behavior of the arcs and several hypotheses as to the possible cause. In this document we explain how we have contributed to the understanding of the arcs in this last year. In the separate sections we discuss the results of other investigations and other tasks undertaken.

Our primary technique for recording and analyzing auroras and airglow is the systematic mapping of the sky with scanning photometers. Spectra and distribution of intensities in the meridian plane are also obtained with a pair of spectrographs monitoring the vertical plane passing through Banff, Alberta, Canada and Richland, Washington. This arrangement permits triangulation spectroscopy that provides detailed information on the bright auroras with which SAR arcs are often associated. Both the photometric mapping technique and the spectrographic method have proved adequately sensitive to detect and record SAR arcs.

Last year, the yearly progress report was presented as a narrative of what had transpired during the year. That was an appropriate way to report activities for a year in which we had to solve many logistics and construction problems. This year we have changed the reporting format to focus attention more sharply on the technical and scientific aspects of the work. Therefore the report is laid out as a series of topical discussions, each covering a different aspect of the work. Because the whole program is the work of several people, we have identified these contributors in the topical discussions along with the work they did. A brief summary preceding topical discussions provides overview of the work.

2. SUMMARY OF PROGRAM PROGRESS

This has been a year of data accumulation. The basic instrumentation, set up the year before, was kept in operation throughout a winter which was unusually severe for this locale. We established the routine examination and organization of data as they were accumulated. This operation is going smoothly although it is time consuming. We have also begun to report the results of systematic observations.

Early in the year we reported the occasions of the SAR arcs recorded since September, 1967. This prompted a review by Jacques Blamont of photometric data gathered by the OGO-4 polar-orbiting satellite. With the time and place of the SAR arc supplied, he was able to verify our observations and to determine for the first time that the arc indeed spanned the entire dark side of the earth. It was also determined that another arc was present at the conjugate position in the southern hemisphere, a fact which was previously suspected but never before directly verified. We now have the OGO-4 photometric data in hand at Richland and are conducting a more detailed analysis of it.

Our collaborating observer Marovich at Fritz Peak alerted ESSA personnel responsible for Allouette satellite data, to the time and position of the first SAR arc that we observed. We subsequently relayed the time and position of other arcs to assist the scanning of the Allouette data. These Allouette data provide electron density and temperature above the SAR arc and they show that there is sharp increase (5 fold) in electron temperature above the arc and a sharp drop in electron density.

This new information strongly implies electron bombardment causes the arc. Of the three or four hypotheses originally set forth for the cause of the arc (outlined in our original

proposal), the "hot electron" hypothesis seems to be emerging as the correct one. Of course, we now must seek a mechanism for the electron excitation. We have been invited to participate in a collaborative analysis of the Allouette data combined with our photometric data.

Just before preparation of this report, a unique set of spectrograms of a SAR arc was obtained with the spectrograph at the Richland station. The simultaneous records made by our spectrograph at Banff were essentially swamped in [OI] 6300 by the extremely bright polar aurora at that site. Therefore, the long awaited spectrographic triangulation on a SAR arc still eludes us. Unexpectedly, however, the combined records of the two stations permit beautiful triangulations on a bright hydrogen arc which occurred that same night over Banff. Preliminary results based on these records are included in this report.

Records of auroral activity detected by the spectrographs have been compiled on a day by day basis. A graphical summary which gives concurrent visibility and magnetic activity is used for reporting.

The relationship between temporal variations in [OI] 6300 intensity, peak electron density $n(\text{max})$, $dn(\text{max})/dt$ and virtual height $h'F$ were analyzed and an attempt made to evaluate and interpret correlation on a worldwide basis. A consistent relation (Barbier formula or a modification thereof) holds for tropical regions but breaks down at midlatitudes.

A photometric map has been completed of the local galactic light, one of the predominant background components in the night sky. This map surpasses previously available maps in accuracy and detail, and therefore should be of value to the scientific community for work related to ours, as well as being valuable to our own research.

There is a continuum component in the spectrum of the airglow itself, and we are attempting the separation of this rather subtle emission from the other continuum sources (galactic, zodiacal, and stellar). The predictable and systematically changing positions of the three astronomical components provide the key to separation if we can maintain careful and continuous calibration of our scanning equipment for a long and continuous sequence of observations. An additional turret photometer has been added to the scanning mount for this work.

The whole calibration effort has been very much improved this year. We now know the absolute response of the spectrographs and have improved the intercalibration between the spectrographic and photometric equipment. Intensity calibration necessarily requires continual attention. Practically every environmental change as well as simple aging of the system components changes the absolute response. Routine use of a radioactive standard light source that was obtained this year has helped.

The main item of technical progress in instrumentation is the procurement and imminent installation of the automated control recording and display system. Except for some remaining short-lead time system components to be purchased at the beginning of the new FY, putting the new equipment into operation is primarily a matter of interfacing and programming. Of course, the remaining work is not trivial but the finishing of engineering, design, and procurement of the apparatus represents a major step toward taking the lead in advanced observation techniques in this research field.

Useful refinements were made to the observing equipment. These refinements included development and installation of equipment for direct pulse counting to measure photons incident on the photo cathodes of the scanning photometer, for

logarithmic scaling of bright auroral data, for on-line printout of digital data, and for automatic closure of the shutters when a bright source such as the moon is scanned. In addition, new auxiliary equipment, including the magnetometer, an all-sky camera and a semiautomatic analog-to-digital converter were put into use.

The hilltop laboratory facilities are now being greatly improved. We shall soon occupy comfortable, first-class working facilities.

Interaction between personnel of our program and University staff and students was increased with a corresponding increase in exchange of information. Plans were laid for further cooperative research.

Plans were postponed to improve the intensity response of the spectrographs by the addition of image intensifiers. Plans to construct an interferometer to measure the temperature of the emitting gases were also temporarily set aside.

In looking for some way to summarize the general status of the program we are reminded of Dr. Roach's remark earlier this year as he surveyed the data accumulated. He said "We are now in the process of digestion after a large meal." While it is best not to press the analogy further in predicting the end results, his casual remark does summarize the overall situation concisely. We have more work to do with equipment, but we are taking care to report the observations we make which are timely and useful. This has had scientifically productive results that we have already mentioned. As noted in the section of this report on "Planning," we have recognized that our effort must now emphasize interpretation and detailed analysis of the data. As this year closes, we have shifted emphasis of the program in that direction, and new analytical work is underway.

3. RECENT OCCURRENCES OF STABLE AURORAL RED ARCS

R. J. Hoch

INTRODUCTION

Stable Auroral Red (SAR) arcs appeared at midlatitudes during the peak and subsequent decline of the IGY solar maximum. It has been generally assumed that this phenomenon ceased to occur at midlatitudes during the solar minimum, but in view of recent observations to be discussed, this assumption might be questioned. It is certain, however, that since the autumnal equinox of 1967 (when we set up equipment near Richland, Washington and began systematic observations) the SAR arcs have been occurring. These recent SAR arcs have typically been fainter than the ones reported during the last maximum and the occurrences have been somewhat sporadic.

Characteristics of SAR arcs, which have also been called M-arcs, midlatitude arcs, and 1'arc monochromatique^(1,2,3) are given by Barbier^(1,2) who first observed and reported them. Observational data of the last solar season are also summarized by Roach and Roach⁽³⁾. Some of the distinguishing characteristics are:

- SAR arcs occur at midlatitudes; that is they are observed southward of the usual polar auroras.
- In the octave of visible radiation SAR arcs consist predominately of the 6300-6364A red emission lines of atomic oxygen (but none of the arcs ever recorded is believed to have been bright enough to be visible to the unaided eye.)
- The arcs are magnetically controlled, appearing during times of high magnetic activity.
- They are aligned approximately parallel to lines of constant L.
- The brightest region is near 400 km altitude and they typically extend several hundred km in altitude and in north-south width.

- They are quite stable though a motion (often equatorward) of the whole arc is often observed.

In addition to these characteristics, strong though indirect evidence obtained before the solar minimum suggested that a SAR arc might span the entire dark side of the earth and that an arc probably occurred in the conjugate position in the southern hemisphere when one occurred in the northern hemisphere. We report here some recent direct evidence in support of both of these suggestions.

The cause of the SAR arcs has been an open question. The several hypotheses set forth have been summarized by Roach and Roach⁽³⁾ and examined by others including Cole⁽⁴⁾, who has advanced a hypothesis and by Walker & Rees⁽⁵⁾ who have suggested tests of several hypotheses. We shall comment on the status of the hypotheses in view of recent data.

Marovich⁽⁶⁾ and Roach and Roach⁽³⁾ have summarized occurrences of SAR arcs from the IGY to the solar minimum. Hoch, Marovich and Clark⁽⁷⁾ reported the initial reappearance of the arc after the last solar minimum.

OBSERVATIONAL ARRANGEMENT

Photoelectric scanning photometers are operated during clear moonless night hours at a station on Rattlesnake Mountain near Richland, Washington. Altitude of the site is 1100 m and coordinates of the station are 52° 51'N, 298° 51'E Geomagnetic. The remote desert locale of the station provides relatively clear viewing conditions and a low stray light level. The McIlwain's L coordinate associated with the site (2.7 at altitude 400 km) locates it near the middle of the zone where SAR arcs were observed with highest statistical frequency before the last solar minimum⁽³⁾.

The sky is routinely scanned with the photometers every 5 min by a sequence of five almucantar sweeps and a zenith

reading. The sweeps are spaced to give approximately even coverage of an imaginary surface at 300 km altitude. A 5° field of view is used in the photometers and the data of each sweep are recorded in analog and digital form. The digital data are divided into 432 samples which are recorded together with time, angular coordinates, and other data for data processing. Narrow pass band interference filters (10-20Å) are used to select the wavelength to be mapped. The filters are kept at constant temperature to assure stability of transmission characteristics. One photometer monitors only 6300Å while another maps 4278, 5577 and 6300Å sequentially. A third photometer maps 5350, 6080 and 7150Å sequentially to provide data on the underlying continuous spectrum of the airglow, zodiacal, stellar, galactic and man-made light.

Sensitivity of the equipment is such that a region that is 25 Rayleighs (R) brighter than its background will be delineated on the sky maps. Extraction of galactic, stellar, and zodiacal background light and correction for geometrical effects are done numerically by high speed electronic data processing. For objects at 400 km altitude the circle of coverage is approximately 3000 km in diameter.

This photometric installation has been in essentially continuous operation during clear weather moonless nighttime hours since late September of 1967. Weather has permitted approximately 40% of these moonless hours to be monitored. Backup data for hours when the moon is up and the photometer is not operated are provided by a pair of meridian spectrographs, one at Rattlesnake Mountain and one at Banff, Alberta. These spectrographs are described in Section 4 of this report. The spectrographs provide a check of whether or not any bright SAR arc occurred on a clear night when the photometers were not operated because of moonlight. One such arc was recorded by the Richland spectrograph when the moon was up on the night of 23/24 March, 1969.

The spectrograms show no evidence in the SAR arc of any emissions in the optical wave region other than the [OI] 6300A doublet.

THE DATA

Table 3.1 lists nights on which SAR arcs were definitely recorded at Richland, Washington along with other nights on which there is some evidence of a SAR arc but some circumstance such as poor weather or faintness of the emission makes the identification uncertain.

TABLE 3.1 *Occasion of Definite and Probable SAR Arcs*

<u>Occasion of Definite SAR Arcs</u>	<u>Occasion of Probable SAR Arcs</u>
28/29 Sept 67	3/4 Nov 67
30/31 Dec 67	1/2 Mar 68
2/3 Jan 68	2/3 Mar 68
27/28 Feb 68	30/31 Oct 68
28/29 Feb 68	19/20 Mar 69
31 Oct/ 1 Nov 68	24/25 Mar 69
20/21 Mar 69	
23/24 Mar 69	
14/15 May 69	

A SAR arc typically persists for several hours and the identifications in Table 3.1 are based on some three hundred and fifty sky maps of the SAR arcs. The occasions of recorded SAR arcs are displayed along a time axis in Figure 3.1.

The position of the brightest region of eight definite SAR arcs at the time each was best defined on our records is shown in Figure 3.2. On every occasion of a SAR arc there has been a polar auroral display to the north of the arc. 6300A emission was almost always more intense in the northward auroral display than in the brightest region of the SAR arc. The only exceptions have been cases in which the polar aurora

was almost out of range. The figures show the area of the sky (marked PA) where the polar aurora was brighter than the SAR arc.

OCCASIONS OF SAR-ARCS

FIGURE 3.1. Occasions on Which SAR Arcs Have Been Recorded at Richland, Washington from Late September 1967 Through Mid-June 1969

The distinct SAR arcs observed have the general characteristics described in the introduction. Rather than describe each arc, we will discuss some features and results that seem to us to add something new or help resolve a questionable point.

Occasionally the suggestion has arisen that the SAR arcs are simply the top most part of a normal auroral display⁽⁸⁾ and that there only appears to be a separate arc from the vantage point of the observations. Figure 3.2b, f, and h show that this is not the case. On these maps the SAR arc is plotted when it was overhead or south of the station while the auroral display was to the north of the station. This situation occurred on several other nights as well when the SAR arc passed over the station. The light maps shown were selected on the basis of when the arc was best defined which is not necessarily the time when the arc was overhead or south of the station.

Thus the SAR arc and the auroral display are spatially separate. We often "see" the SAR arc to our south or overhead while the polar aurora is to our north. However, we know of

MAPS OF SAR ARCS

FIGURE 3.2 Maps of SAR Arcs. The Shaded Region (PA) Marks the Portion of the Sky in Which [OI] 6300A, from the Poleward Aurora was Brighter than the Region of the SAR Arc. The Intensities Shown are Rough Averages of the Brightest Region Taken Along the Length of the SAR Arc. Each Map Covers a Circle Approximately 3000 km in Diameter. Geographic coordinates of the Center of the Maps are $46^{\circ} 25'N$ and $119^{\circ} 38'W$.

no instance in which there was a SAR arc without a bright poleward aurora occurring simultaneously. Therefore, although the SAR arc is not the top part of a polar aurora, there is some close connection between these two phenomena.

There appears to be no lower limit on the intensity of a SAR arc. We have cases where repeated scans show that there is a systematically brightened arc-like zone of 6300A emission south of the main aurora. However, on a single map the arc would be difficult to discriminate from noise. Thus, Figure 3.2b shows a SAR arc of only 50 R. We believe it entirely possible that there is usually (perhaps always) an incipient or faint arc equatorward of the polar aurora but that the arc is often too faint to be detected by present instrumentation.

No enhancement of [OI] 5577 could be found in the region of any of the SAR arcs recorded photometrically. The spectrographic record of a SAR arc on 23/24 March 1969, shows no emission other than [OI] 6300 doublet enhanced in the region of the SAR arc.

Several SAR arcs with intensity greater than one kR were recorded before the solar minimum, but many fainter ones were also recorded. A comparison of the records of recent arcs with ones recorded during the last solar season show no apparent difference between the recent SAR arcs and the ones recorded before the minimum except, as mentioned, we have recently delineated some arcs which are fainter than those reported in the past.

Some of the arcs shown in Figure 3.2 were so far north at the time they were best defined that they would not have been easily observed from the established stations southward of ours. Fritz Peak is the most northerly of those stations which were operated routinely during the solar minimum. The SAR arcs shown on maps 3.2a, b, f, and h were within range of Fritz Peak. The circumstance, of location of our station coupled with the

tendency of auroral phenomena to occur generally nearer the poles during times of low activity and also coupled with the fact that we began recording SAR arcs occasionally as soon as we set up equipment northward of other stations, leads us to suggest that it is not at all certain that the SAR arcs stopped occurring during the solar minimum. The arcs may simply have been very faint and/or out of range during the solar minimum.

There have been recent occasions when the SAR arcs have been relatively strong and well defined. The first of these (Figure 3.2a) has led to some new information of interest through correlation of these ground based data with data gathered by satellites.

Blamont⁽⁹⁾ and Reed have examined OGO-4 polar orbiting satellite data for evidence of the SAR arc we detected 28/29 September, 1967 and have found that the arc shown in Figure 3.2a extended around the entire dark side of the earth. Furthermore, they found a similar SAR arc to have been present simultaneously in the magnetically conjugate position in the southern hemisphere. This is the first direct verification of both the east-west extent of the arc and the presence of the conjugate arc.

Norton⁽¹⁰⁾ has examined Allouette I and II satellite top-side ionosonde data taken at approximately 1000 km and 1800 km respectively. Norton indicates that for the 28/29 September, 1967 event there was a sharp rise, actually a pair of peaks in electron temperature approximately above the arc. The electron temperature at the highest peak was about 6000 °K compared to about 3000 °K in the region immediately northward of the arc. Electron density showed a striking depression in the vicinity of the arc falling nearly 10^4 cm^{-3} to about $6 \times 10^2 \text{ cm}^{-3}$ in a region about as wide as the half width of the arc. Going northward, the density increased slowly to about $8 \times 10^3 \text{ cm}^{-3}$ at L=5.0.

The several candidate hypotheses tendered as SAR arc mechanisms include: excitation by proton bombardment⁽¹¹⁾, a postulated electric field perpendicular to the field,⁽¹²⁾⁽¹³⁾⁽¹⁴⁾ a flux of 400 eV electrons,⁽¹⁵⁾ and a thermal electron mechanism⁽¹⁶⁾⁽¹¹⁾⁽⁴⁾. Of these, Cole's "thermal electron" mechanism seems to us to be strongly favored by these recent data which show a region of high temperature electrons to be present. Should subsequent measurements and analyses bear out these recent findings, there remains to be clarified the details of the energy transfer to the electrons.

CONCLUSIONS

While SAR arcs may be very subtle in intensity, at least nine distinct arcs have occurred since 27/28 September, 1967. Evidence that SAR arcs did not occur during the solar minimum is at best inconclusive. The nature of the connection between SAR arcs and polar-type auroras deserves further investigation because the two phenomena are temporally connected in that a polar aurora always seems to accompany a SAR arc. However, it is not clear whether a SAR arc always accompanies a polar aurora. If it does, it must be very faint. The main regions of [OI] 6300A emission of the SAR arcs and polar type auroras are spatially separate. There is direct evidence that a SAR arc may span the entire dark side of the earth and that a conjugate pair of SAR arcs may occur simultaneously. There is also direct evidence that a region of hot electrons is temporally and spatially correlated with a SAR arc. The fact that the major spectral emission of a SAR arc in the visual wavelength region is the 6300-6364A doublet has been checked spectrographically.

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4. SPECTROGRAPHIC MONITORING OF AURORAL ACTIVITY AT MID-LATITUDES

F. I. Carver, L. L. Smith, and R. J. Hoch

Meridian spectrographs of the type described by Clark and Romick⁽¹⁾ which function automatically and continuously at night have been used to monitor auroral activity in the two following locations:

- Sulphur Mountain near Banff, Alberta, Canada (since November 1967), Altitude 7,465 ft, geomagnetic latitude and longitude $58^{\circ} 6'$ and $300^{\circ} 36'$, respectively
- Rattlesnake Mountain near Richland, Washington (since March 1966), altitude 3,568 ft, geomagnetic latitude and longitude $52^{\circ} 51'$ and $289^{\circ} 57'$, respectively. 298

The base line between the stations is approximately 600 km. Each spectrograph is oriented to accept light only from the common vertical plane passing through the two stations; and each instrument records light from horizon to horizon in this plane. The geographic bearing of the common plane is $30\ 1/2^{\circ}$ to the east of north at Banff, and $27\ 1/2^{\circ}$ to the east of north at Richland.

For either instrument, the effective light source is a very narrow strip of sky which is optically transformed to a line image and dispersed by a grating to display wavelength and intensity as a function of angle of incidence. Each instrument automatically records sequential 5- and 25-min exposures on Kodak 103 AF 35 mm spectrographic film every 30 min from dusk until dawn.

A conventional F-ratio cannot be used to give a meaningful measure of photographic sensitivity of the equipment because of the elongated entrance aperture. However, in functional terms, the sensitivity is such that a record of the 5577A air-glow is routinely obtained on the 25-min exposures but never obtained on the 5-min exposures. Therefore, when visibility is good, auroral activity brighter than about 500 R at 5577A will be recorded on the 25-min spectrograms. The spectral range covered is approximately 3700A to 7000A.

FIGURE 4.1 Spectrogram and Densitometer Tracing, 15 Min Exposure
23/24 March, 1969 - 0258 PST Richland Station
(Measurements are in Angstroms.)

Such optical data are, of course, mitigated by local cloud cover which may diminish or entirely mask incident auroral light. The visibility conditions at the site of the measurements are reported here to indicate when such attenuation may have occurred.

Figure 4.1 presents an example of the raw data recorded by the spectrographs and also gives a corresponding densitometer tracing across the 25-min exposure shown. There is, of course, much detailed information that can be extracted from these spectrograms. Here we will only discuss the first part of the analysis which is concerned with describing presence or absence of activity. This analysis primarily uses the [OI] 5577A emission line radiance to describe the auroral activity as "no aurora" when the [OI] 5577A emission is <500 R; "faint aurora:" when >500 R but <1 kR; and "distinct aurora:" when >1 kR. To avoid confusion with airglow in faint auroras we also require that there be some evidence of spectral emissions in the first negative system of N_2^+ . A review of the accumulated data from both stations for this analysis shows that the best set of data is from Banff for the period of April, 1968 through March, 1969.

The graphical representation of the auroral activity, as described above, for the period April, 1968 through March, 1969 for the Banff station is given in Figures 4.2, 4.3 and 4.4. For convenience of this and other analysis, the concurrent planetary magnetic index (A_p) is also plotted. The visibility plot accompanying the auroral data is meant to suggest whether an auroral display would have been hidden or attenuated by local clouds. The visibility information presented has been deduced from the spectrograms by noting the intensity of cloud-reflected city lights (mostly mercury emission spectra). It is usually possible to make a qualitative distinction between a hazy sky and a cloudy sky by comparing the ratio of reflected blue mercury lines (e.g., 4358A) to yellow mercury lines

FIGURE 4.2 Auroral Activity Recorded at Banff,
April 1968 Through July 1969

FIGURE 4.3 Auroral Activity Recorded at Banff
August 1968 Through November 1968

FIGURE 4.4 Auroral Activity Recorded at Banff
December 1968 Through March 1969

(5770-90A). This spectrographic information is supplemented by local weather observations of the general cloud cover for the particular light. Particularly brilliant auroras are noted by an asterisk on the graphical data.

From this year's data at Banff, we find that the percentage of clear nights on which there was no aurora was 47%, faint aurora 19% and distinct aurora 34%. It is interesting to compare the frequency of auroral activity to magnetic activity. The comparison is best displayed in terms of an arithmetic scale of magnetic indices (A_p) rather than the popular logarithmic index (K_p). For convenience, a plot of K_p versus A_p is given in Figure 4.5. In Figure 4.6 we have shown the frequency distribution of clear nights for which A_p was in a given interval, and we have also plotted the corresponding number of those nights on which auroras were recorded. It appears that there is a certain threshold of magnetic activity above which auroral activity occurs. For the most frequently occurring values of magnetic index (A_p in the interval [4,6]) we note that auroral activity seldom occurred. However, for the expectation value of A_p , which is in the [10,12] interval, an aurora was recorded on 10 of the 20 nights for which magnetic activity was in that interval. This suggests that the probability of recording an aurora at Banff on any clear night picked at random is approximately one half. In fact, we find the quotient of all auroras recorded over all clear nights is 120/230 for the year.

Figure 4.6 indicates that the probability of recording an aurora increases with increasing A_p . This correspondence is specifically displayed in Figure 4.7 where we have plotted the fraction of clear nights on which auroral activity was recorded when magnetic activity was in a certain interval. The fewer data at high A_p have required the use of a broader interval (6 units A_p) on the abscissa. These data show that it is virtually certain that there will be a distinct aurora

if A_p exceeds 32. One exception may be noted in Figure 4.6 where A_p was in the interval [50, 52], but no aurora was logged. However, on that night (October 4, 1968), the continuum spectrum of moonlight made the analysis somewhat difficult. Moonlight usually does not mask the auroral lines entirely since the continuum is only recorded for a short time when the moon is in or near the field of view.

FIGURE 4.5 Logarithmic Planetary Magnetic Index (A_p) Versus Arithmetic Index K_p

FIGURE 4.6 *Distribution of Auroral Activity as a Function of A_p Magnetic Index on Clear Nights*

FIGURE 4.7 *Fraction of Clear Nights on Which Auroral Activity was Recorded Versus A_p Index*

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5. SPECTROGRAPHIC STUDIES

C. R. Batishko and R. J. Hoch

The meridian spectrographs described in the preceding section have a resolution of $20 \text{ \AA}$ and a dispersion of $310 \text{ \AA/mm}$.

Some of the most interesting data of the year were recorded on the night of March 23, 1969 when both the Banff and Rattlesnake Stations simultaneously recorded strong auroral activity. During this activity a stable auroral red arc occurred well southward of the main auroral display and the sequence of spectrograms recorded at Richland show this arc clearly. For this reason this set of spectrograms is unique and the spectrogram and densitometer tracing shown in Figure 5.1 are, to our knowledge, the first such data published. The spectrogram shows the [OI] 6300 emission of the arc approximately 40° south of the Richland zenith. Assuming a height of 400 km for the brightest region, the north-south width of the arc between half maximum intensities was approximately 210 km. The SAR arc is clearly separate from the main auroral display. In the region of the arc there is no trace of enhancement of any other emission than [OI] 6300 to be found on the spectrogram.*

At Banff, the auroral display was essentially overhead and so intense that the SAR arc some 700 km south was too faint to appear on the spectrograms. Figure 5.2 shows the very intense and profuse auroral spectrum at 0307 MST at Banff. Figure 4.1 (See Section 4) shows the simultaneous exposure from Richland, when even there the aurora became so bright the SAR arc could not be distinguished clearly on the spectrogram.

* The light in the upper right hand corner of the spectrogram is due to local reflected man-made light and is to be ignored.

FIGURE 5.1 Spectrogram and Densitometer Tracing from North to South along the 6300 Å Line, 23/24 March 1969, 2023 PST, Richland Station

FIGURE 5.2 Spectrogram and Densitometer Tracing. 25 min,
23/24 March 1969, 0307 MST Banff Station
(Measurements are in Angstroms)

These spectrograms also show a strong hydrogen arc over Banff. The hydrogen arc is caused by protons which are incident along field lines at the latitude of Banff. The hydrogen arc was flattened horizontally above the Banff station and recorded "edge-on" from Richland. The relatively long optical path through the hydrogen arc along the line of sight from Richland enhanced the intensity so the record was obtained despite the distance and atmospheric attenuation.

The simultaneous records from the Banff and Richland stations permit triangulation to determine the position of the emitting volume of the hydrogen arc. Figure 5.3 shows the positions of the volume and extent of the half-maximum regions. The H α emission was used for these triangulations. The height of the emitting volume ranges from 110 km to 150 km according to these data. It is of interest to compare these measurements to the theoretical prediction of Davidson shown in Figure 5.4. Both the height and general horizontal spread appear to agree reasonably well in measured and predicted values.

The aurora of 23/24 March, 1969 was so intense that normally faint, weak lines were easily recorded. For example, the usually faint 5296A and 6127A emissions are identified in Figure 5.2. Further analysis of these data for this aurora is scheduled for completion in coming months.

Among the studies being conducted on the 23/24 March, 1969 data are temporal and spatial comparisons between the red arc and other standard auroral emissions, comparison with photometric data, and absolute intensity measurements of various emissions.

Four studies are also underway using spectrograms of 5 or 6 strong auroras. The first of these is a temporal study of the ratio of intensity of N $_2^+$ (1N) at 4278.1A to the [OI] line at 5577.3A. This ratio has been predicted to be about 3 if the common excitation mechanism is primary electrons.

FIGURE 5.2 Spectrogram and Densitometer Tracing. 25 min,
23/24 March 1969, 0307 MST Banff Station
(Measurements are in Angstroms)

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The simultaneous records from the Banff and Richland stations permit triangulation to determine the position of the emitting volume of the hydrogen arc. Figure 5.3 shows the positions of the volume and extent of the half-maximum regions. The $H\alpha$ emission was used for these triangulations. The height of the emitting volume ranges from 110 km to 150 km according to these data. It is of interest to compare these measurements to the theoretical prediction of Davidson shown in Figure 5.4. Both the height and general horizontal spread appear to agree reasonably well in measured and predicted values.

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FIGURE 5.3 Position of the H_α and H_β Emitting Regions Determined by Triangulation. The Extent of the Emitting Volume (at half-maximum) is Indicated.

FIGURE 5.4 Intensity (in ergs/proton - cm^3) and the Latitudinal Distribution of $\text{H}\alpha$ Emission Excited by Protons and Hydrogen Atoms Entering the Atmosphere at Geomagnetic Latitude 67.1° , with an Isotropic Injection Pitch Angle and Injection Energy of 10 keV (Davidson 1955)

Accurate measurements of intensity are computed from microdensitometer tracings across the 5-min exposure spectrograms on which these emissions do not saturate the film as they do in the 25-min exposures.

A second study is being conducted to examine the temporal variation of the Na I emission at 5589.9A-5895.9A with respect to the N_2^+ band system: 1N [0-0] at 3914.4A, 1N [0-1] at 4278.1A, and 1N [0-2] 4709.2A. Usually the sodium airglow emissions are explained independently of short term magnetic variations and incident primary particle radiation. However, there appears to be some enhancement of the sodium doublet during auroras and this is to be measured and explained. We have also noted and are studying an occasional inversion of the expected intensities of 1N [1-3] 4651.8A and [0-2] 4709.2A. Apparently nonequilibrium thermal distributions prevail in such cases and a temporal correlation with other emissions such as $H\alpha$ is sought.

Finally, we are examining the temporal variation of the O_2^+ emission 1N [2-0] at 5295.7A relative to the OI emission at 5577.3A and N_2^+ emission 1N [0-1].

CALIBRATION

The intercalibration of the spectrograph and the photometers is of crucial importance in determining absolute intensities of the emissions. This calibration is being continually improved. Essentially, there are four standard light sources involved, three of which are used as routine references. One standard source is particular stars of known intensity which are detected during photometric scanning. The second standard source is the apparent surface brightness of the Milky Way. The third is a portable radioactive light source and the fourth is a tungsten filament quartz iodide source. For laboratory calibrations of the spectrograph we use the last of these four. For the photometer, particular

stars and the radioactive source are used routinely and we are beginning to use the Milky Way. Potentially, the Milky Way is the best standard for photometric work since use of discrete stars raises problems involving nonuniformity of the photocathode surfaces. The centering of the star in the field of view is also important, because incorrect centering can compromise the results. Absolute calibrations of the spectrographs are perhaps more difficult than for the photometer since spectrographic work involves the peculiarities of photographic emulsions as well as the method of determining photographic densities. We used the following procedure for the Rattlesnake spectrograph, using the geometry of Figure 5.5. The tungsten filament used for spectrographic calibrations was operated at a measured 2 A for which current it had been calibrated by C. S. Deehr at the University of Alaska. The graph in Figure 5.6 is the measured standard lamp output. A mercury arc lamp was used as a wavelength reference and appeared at the opposite edge of the spectrogram from the continuum. Exposures of various durations were made, some incorporating neutral density filters for intensity reduction. A diffuse white reflecting screen was used to simulate a distant light source. The screen was found to have an 18% loss due to anisotropic reflective properties and 3% loss due to absorption. It was assumed and experimentally confirmed that recorded intensity is independent of diffuse screen-to-instrument distance providing the instrument slit doesn't "see" the edge of the diffuse screen. This allows film densities produced by an aurora at typical distances in excess of 400 km to be compared directly to film densities produced by the same exposure duration in the lab at a distance of 2 to 3 meters.

All data, both calibration and observational are recorded on Kodak type 103-a spectroscopic film. The film is developed 7 min at 68 °F in Kodak D-19 developer using standard agitation, washing, fixing and drying procedures. Data are then

FIGURE 5.5 Calibration Geometry

FIGURE 5.6 Standard Lamp Output Used for Calibration

densitometered, a wavelength reference template produced from the mercury spectrum, and densities calculated from the densitometer trace pen deflection, allowing for film background fog level. The densities are related to the energy reflected from the screen. They are then normalized to 5- and 25-min exposure durations by use of emulsion reciprocity curves provided by Kodak to allow direct comparison to observational data.

Calibration is accomplished for a number of key wavelengths, and extrapolation using instrument spectral response curves allows the calibration to be used for other wavelengths at the loss of a few percent accuracy. Accuracy of the calibrations are estimated to be in the 10% to 20% range.

6. PHOTOMETRIC MAP OF THE MILKY WAY

L. L. Smith

The light of the night sky includes terrestrial, solar, and astronomical components. The terrestrial components includes night airglow emissions, continuum radiation, and, at high latitudes, auroral radiations. The solar component, zodiacal light, is due to sunlight scattered from interplanetary matter in the solar system. The astronomical component involves radiations from individual stars, integrated starlight, galactic light, and cosmic light.

In photometric investigations of night airglow and weak auroral emissions, the total background must be subtracted from the observations. Normally, a background filter is chosen near the wavelength of the emission of interest and the sky scanned with both the background and the emission filters. To eliminate the total background, the background observations are multiplied by an appropriate factor and the results subtracted from the emission observations. This two-color technique works satisfactorily but doubles the observation program and data processing. Another technique is to tilt the emission filter or the light beam with respect to the filter so that the filter transmission characteristics shift significantly to the short wavelength side of the emission line, resulting in only background transmission. By alternating the tilt and non-tilt modes, the background can be electronically subtracted. However, the mechanics and electronics are considerably more complicated and are apt to have failures compared to the stationary filter system.

Roach and Smith (1964)⁽¹⁾ found that at the wavelength of 5300Å, the combination of the zodiacal light (ZL) and integrated starlight (SL) radiations, was 85% of the total background at Haleakala, Maui, Hawaii (latitude 20.7° N) and 77% at FRITZ Peak, Boulder, Colorado (latitude 39.9° N). The spectra of the ZL

and SL are, to a first approximation, continua. Consequently, it should be possible through analysis to eliminate these two components from the emission filter observations. Of course, the radiance of the ZL and SL as a function of the coordinate system in which each of these radiations can be predicted must be known. Smith, Roach, and Owen (1965)⁽²⁾ published a ZL map as a function of the ecliptic coordinates deduced from observations at 5300A, Figure 6.1. The unit of brightness in Figure 6.1 is S10 (VIS) which is equivalent to the number of tenth magnitude (visual) stars per square degree. By using this map and the SL map⁽³⁾, attempts were made to eliminate through analysis the ZL and SL backgrounds from emission observations. The results were encouraging but the SL map was not accurate because milky way crossings were not properly allowed for. Roach and Smith (1964)⁽¹⁾ discuss the inaccuracies of the available SL maps. It was obvious from this work that a new photometric map of the milky way would be useful. We (F. E. Roach and L. L. Smith) have recently completed such a map. This map was compiled from background observations at 5300A taken at Haleakala, Maui, Hawaii (latitude 20.7° N) and El Leoncito, Argentina (latitude 31.8° S). Figure 6.2 includes the new milky way values for galactic latitudes $<|20^\circ|$. For latitudes away from the milky way, (latitudes $>|20^\circ|$) we used the results of Roach and Megill (1961).⁽³⁾ We now find that for emission radiations as low as 50 Rayleighs observed with interference filters with half-bandwidths of 15-20A, the background can be essentially eliminated through analysis by subtracting the ZL and SL values of Figures 6.1 and 6.2.

LAMBDA	ECLIPTIC LATITUDE																		
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
0	9999	9999	9999	6150	1820	995	525	330	250	215	180	175	185	185	155	160	150	135	110
5	9999	9999	9999	9999	9999	9999	9999	9999	245	210	180	175	185	185	155	160	150	135	110
10	9999	9999	9999	9999	9999	9999	9999	9999	240	210	180	175	185	185	155	155	150	135	110
15	9999	9999	9999	9999	9999	9999	9999	9999	235	205	180	180	185	185	155	155	150	135	110
20	9999	9999	9999	9999	9999	9999	9999	9999	230	205	180	185	190	180	150	150	145	130	110
25	9999	9999	9999	9999	9999	520	9999	245	225	200	180	190	190	175	150	150	145	130	110
30	2330	9999	9999	905	545	465	300	230	220	195	180	195	185	170	145	150	145	125	110
35	1595	1145	845	690	450	410	270	225	215	190	185	200	175	165	145	145	140	125	110
40	1185	870	655	505	390	360	250	220	215	190	195	205	170	160	140	140	135	125	110
45	945	735	555	425	345	315	240	215	210	190	205	190	170	155	140	140	135	120	110
50	745	610	485	370	315	285	230	205	205	195	205	170	160	150	135	135	130	120	110
55	600	505	430	330	290	255	225	205	205	200	180	160	155	150	125	135	135	120	110
60	500	425	380	305	270	240	215	205	205	195	165	145	145	145	135	135	130	115	110
65	425	370	345	285	255	225	205	205	200	170	150	140	140	140	130	135	130	115	110
70	370	335	310	265	240	210	205	185	175	145	145	130	135	135	130	135	130	115	110
75	320	300	285	245	225	200	185	175	160	135	145	130	125	130	125	130	130	110	110
80	290	275	255	230	210	190	165	170	155	135	140	130	125	125	125	125	130	110	110
85	265	255	235	215	195	180	155	165	155	135	140	130	125	125	125	125	130	110	110
90	250	235	215	200	185	175	155	160	150	135	135	130	125	125	125	125	125	110	110
95	235	215	205	190	180	170	155	155	145	135	135	130	125	125	120	115	115	110	110
100	220	205	195	185	175	170	155	150	145	135	135	130	125	125	120	115	115	110	110
105	210	200	190	180	175	170	150	150	145	135	135	130	125	125	120	115	115	110	110
110	200	190	185	175	170	165	150	150	140	135	135	125	125	125	120	115	115	110	110
115	190	185	180	175	170	165	145	150	135	135	135	125	125	125	120	115	115	110	110
120	185	180	180	170	165	160	145	150	135	135	135	125	125	125	120	115	115	110	110
125	180	175	175	165	165	160	145	145	135	135	135	125	125	125	115	115	115	110	110
130	175	175	170	165	160	155	145	145	135	135	135	125	125	125	115	115	115	110	110
135	175	170	170	160	160	155	145	145	135	135	135	120	125	125	115	115	115	110	110
140	175	170	165	160	155	155	145	145	130	135	130	120	125	125	115	115	115	110	110
145	175	170	165	155	155	155	145	140	125	135	130	125	125	125	115	115	110	110	110
150	170	165	160	155	150	150	145	140	125	130	125	125	125	125	115	115	110	110	110
155	170	165	160	155	150	145	145	135	125	130	125	125	125	125	115	115	115	110	110
160	175	170	160	155	145	145	145	135	125	130	125	120	125	125	115	115	115	110	110
165	175	170	165	160	150	145	145	135	125	130	120	125	125	125	115	115	115	110	110
170	185	175	170	160	155	150	145	135	125	130	120	125	125	125	115	115	115	110	110
175	195	190	175	165	160	150	150	135	125	130	125	125	125	125	115	115	115	110	110
180	205	195	185	175	165	155	150	140	125	130	125	125	125	125	115	115	115	110	110

FIGURE 6.1 Zodiacal Light Map (S10VIS)

LONG	GALACTIC LATITUDE																
	-40	-35	-30	-25	-20	-15	-10	-5	0	5	10	15	20	25	30	35	40
0	65	80	90	125	240	325	510	795	455	295	245	170	100	70	65	60	50
10	65	80	95	130	270	365	525	685	460	305	245	185	90	70	65	60	50
20	60	75	90	120	225	310	390	405	300	170	155	115	85	80	75	65	55
30	60	70	85	110	200	220	255	335	275	185	225	170	105	95	80	70	55
40	55	65	75	95	165	190	240	305	230	235	190	125	85	105	85	70	60
50	55	60	65	85	140	180	250	450	225	230	180	145	115	120	90	75	60
60	50	55	65	80	145	265	285	355	280	305	220	170	120	120	90	75	60
70	50	55	60	80	115	210	265	295	345	360	210	180	125	110	85	70	55
80	50	55	65	85	110	195	270	305	280	265	215	145	135	90	75	65	55
90	50	60	70	95	140	160	240	295	300	250	190	150	80	80	65	60	50
100	50	65	75	100	145	185	220	325	280	205	190	120	95	70	60	55	50
110	50	65	80	100	140	155	195	240	260	190	180	130	90	60	55	50	45
120	50	65	75	90	130	135	205	290	280	175	140	135	110	60	55	50	45
130	50	60	65	75	145	185	190	255	250	170	130	105	105	60	55	50	45
140	45	50	55	60	185	170	190	205	175	160	125	110	105	65	55	50	45
150	45	45	50	55	180	235	220	260	170	140	115	110	105	65	55	50	45
160	40	45	45	50	210	180	175	160	190	180	170	130	120	65	55	50	45
170	40	40	45	50	160	145	150	180	230	200	210	125	115	65	55	50	45
180	40	45	45	50	150	175	235	250	265	210	170	155	145	65	60	50	45
190	45	45	50	60	135	135	180	280	235	240	210	160	165	70	60	50	45
200	45	55	60	75	110	235	245	275	225	245	180	150	135	75	60	50	45
210	50	65	70	90	190	190	130	170	215	205	205	260	100	80	65	50	40
220	55	65	80	105	105	125	180	200	235	215	170	150	100	85	65	50	45
230	55	70	80	110	115	150	250	325	250	225	150	110	95	90	65	50	45
240	55	70	80	110	110	165	360	340	320	260	155	110	85	85	60	50	45
250	55	65	75	100	110	140	215	255	275	235	165	105	85	80	65	55	45
260	50	65	70	95	215	160	250	310	250	200	145	110	95	75	65	55	50
270	50	60	65	85	120	185	255	295	230	210	155	110	95	75	65	60	50
280	50	55	65	80	125	190	290	425	380	270	195	125	90	80	70	65	55
290	50	55	65	80	125	190	265	375	545	350	195	140	105	90	75	65	55
300	55	60	65	80	70	115	195	345	580	435	235	185	100	105	80	70	60
310	55	60	65	80	70	165	230	330	550	345	240	170	130	115	85	70	60
320	60	65	70	85	140	225	305	390	340	275	245	205	125	115	80	70	60
330	60	70	75	95	150	225	330	460	390	280	260	200	115	105	75	65	55
340	65	70	80	105	175	245	365	360	315	185	160	140	115	90	70	60	55
350	65	75	90	120	230	300	390	550	440	355	275	205	170	75	65	60	50
360	65	80	90	125	240	325	510	795	455	295	245	170	100	70	65	60	50

FIGURE 6.2 Milky Way Map (SIOVIS)

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7. FORBIDDEN TRANSITIONS IN THE UPPER ATMOSPHERE

F. E. Roach

INTRODUCTION

It is convenient to consider that the upper atmosphere spawns optical radiations in the following ways:

- as the result of the direct impingement of solar radiation (dayglow and twilight).
- by the release of stored solar energy (nightglow).
- as a consequence of excitation by impact of energetic particles (aurora).

In the lower atmosphere (troposphere), the overwhelming optical effect of impinging sunlight is the Rayleigh scattering which produces the daytime sky. In the domain above about 70 kilometers, ultraviolet solar radiation is responsible for profound changes in the physical, chemical and electrical composition of the atmosphere. As the number density of the atmosphere decreases with increasing height, atoms, molecules and their ions excited to metastable states are able to emit observable radiations in competition with collisional processes which de-excite ("quench") the excited atom or molecule without emission. The upper-atmosphere analyst is interested in both the interpretation of the mechanism of excitation into the metastable states and in the radiation/de-excitation processes which exhaust the states.

FORBIDDEN ATOMIC LINES

In the absence of any collisional de-excitation, the relationship between the observed intensity, Q , of a particular emission from state b to a and the Einstein transition probability, A_{ba} , is

$$Q = \int_0^\infty n_b \cdot A_{ba} \cdot dh \quad \text{quanta} \cdot \text{cm}^{-2} \cdot \text{sec}^{-1} \quad (1)$$

$$n_b(\text{max}) \cdot A_{ba} \cdot H \quad (2)$$

where n_b is the number density of the atom in state b, h is the height in the atmosphere, and H is the effective "thickness" of the emitting layer referred to the emission at the peak. To a very rough approximation, the effective thickness of the layer may be taken as the scale height. In units of Rayleighs, Equation (2) becomes:

$$Q = 10^{-6} \cdot n_b(\text{max}) \cdot A_{ba} \cdot H \text{ Rayleighs} \quad (3)$$

In the case of forbidden transitions from metastable states, the transition probability or quantal rate, A , is very small compared with permitted transitions. Thus a forbidden transition emission must result from a proportionally larger density of atoms in the upper state than a permitted emission of the same intensity. In general, the atmospheric mechanisms of excitation into an excited state are completely independent of the mechanisms of depletion of the state. Therefore, if collisional de-excitation is rapid, depletion of the upper state by the two processes, de-excitation and radiation, will be in competition.

Table 7.1 shows the present knowledge concerning emissions from forbidden atomic transitions in the upper atmosphere. An x in one of the last four columns implies that the emission has been observed in the dayglow, twilight, aurora or nightglow. The absence of an x indicates that the radiation has not been observed which may be due to its actual absence in the phenomenon or to the difficulty of its observation.

MOLECULAR BAND SYSTEMS

Table 7.2 differs from Table 7.1 in that it includes the molecular band systems, both permitted and forbidden, observed in the upper atmosphere. The transition probabilities vary from the three cases of low probability (the Vegard-Kaplan bands of N_2 , the IR atmospheric and the atmospheric bands of O_2) to the Second Positive (N_2) and First Negative (N_2^+) with transition probabilities greater than 10^7 transitions/sec. The

TABLE 7.1 *Forbidden Atomic Emissions in the Upper Atmosphere*

Atom	Transition		Wavelength (Å)	E.P. (eV)	Transition Probability (quanta/second)	Emissions in Upper Atmosphere			
	Lower Level	Upper Level				Dayglow	Twilight	Aurora	Nightglow
N I	$4s^0$	$2d^0$	5198.5; 5200.7	2.37	1.06×10^{-5}	X	X	X	X
	$2d^0$	$2p^0$	10396; 10404	3.56	0.079			X	
	$4s^0$	$2p^0$	3466	3.56	0.0054			X	
OI	$3p$	$1d$	6300; 6364	1.96	0.0091	X	X	X	X
	$1d$	$1s$	5577	4.17	1.28	X	X	X	X
	$3p$	$1s$	2972	4.17	0.078			X	X
N II (I.P. = 14.54 eV)	$3p$	$1d$	6548; 6584	1.89	0.004			?	
	$1d$	$1s$	5755	4.04	1.08			X	
	$3p$	$1s$	3063	4.04	0.034				
O II (I.P. = 13.61 eV)	$4s^0$	$2d^0$	3726; 3729	3.31	7.7×10^{-5}			X	
	$2d^0$	$2p^0$	7320; 7330	5.00	0.16			X	
	$4s^0$	$2p^0$	2470	5.00	0.046				

* From Chamberlain (Physics of the Aurora and Airglow, Appendix VI, 1961)

TABLE 7.2 Molecular Band Systems Observed in the Upper Atmosphere

Molecule	Transition		Band System	E.P. (eV)	Transition Probability (Quanta/Second)	Emissions in Upper Atmosphere			
	Upper State	Lower State				Dayglow	Twilight	Aurora	Nightglow
N_2	$A^3\Sigma_u^+$	$X^1\Sigma_g^+$	Vegard-Kaplan	6.2	0.077			X	
	$B^3\Pi_g$	$A^3\Sigma_u^+$	First Positive	7.3	$8.3 \times 10^{+4}$			X	
	$A^1\Pi_g$	$X^1\Sigma_g^+$	Lyman-Birge-Hopfield	8.6	$5.9 \times 10^{+3}$			X	
	$C^3\Pi_u$	$B^3\Pi_g$	Second Positive	11.0	2.1×10^7	X		X	
O_2	$A^1\Delta_g$	$X^3\Sigma_g^-$	IR Atmospheric	0.98	2.78×10^{-4}	X	X	X	X
	$b^1\Sigma_g^+$	$X^3\Sigma_g^-$	Atmospheric	1.60	0.143	X	X	X	X
	$A^3\Sigma_u^+$	$X^3\Sigma_g^-$	Herzberg	4.3	10^3				X
	$A^2\Pi_u$	$X^2\Sigma_g^+$	Meinel	1.1	3.3×10^5		?	X	
O_2^+	$A^2\Pi_u$	$X^2\Pi_u$	Second Negative	4.8	1.4×10^6				
	$b^4\Sigma^-$	$a^4\Pi_u$	First Negative	6.1	9.1×10^5			X	
(I.P.=12.6 eV)									
NO		$A^2\Sigma^+$	$X^2\Pi$	$\checkmark$ Bands	5.5	5×10^5	X	X	
OH			$^2\Pi$	Rotation-Vibration ($\nu=9$) 3.23					X

relationship between the transition probability and the intensity of a particular band is not as straightforward as in the atomic case since the relative intensities of bands within a band system require the application of the Franck-Condon principle.

SOME GENERAL CONSIDERATIONS OF DE-EXCITATION OR QUENCHING

Reactions involving the de-excitation of an atom may be written:

or

where the * implies an excited state. The rate at which such reactions proceed is given either as a cross section, σ , or as a rate coefficient, k . The two quantities are related by

$$\bar{v} \cdot \sigma = k \text{ cm}^3 \cdot \text{second}^{-1} \quad (6)$$

where $\bar{v}$ is the mean relative speed of the atoms. In the case of reactions (4) or (5) we have

$$n(A) \cdot k = L(B^*) \text{ second}^{-1} \quad (7)$$

where $L(B^*)$ is the loss rate of particle B from the excited state as a consequence of reaction (4) or (5) and is directly comparable with the loss rate by spontaneous radiation given by the transition probability A. In Table 7.3 we show some atmospheric properties illustrating these relationships. Column 6 gives the kinetic values of the collision frequencies. If each kinetic collision resulted in a de-excitation, it is apparent that the rate of collisional de-excitation would be much greater than the radiative rate from metastable levels except at very high altitudes. For example, the transition rate of the [OI] 5577A radiation is 1.28 quanta/sec (Table 7.1) and it is known to occur near 100 kilometers. The kinetic collision frequency at 100 kilometers is 3620/sec

TABLE 7.3 Some Properties of the Atmosphere

h (km)	Cross Section σ (cm ²)	Mean Speed $\bar{v}$ (cm sec ⁻¹)	Collisional Rate Coefficient k (cm ³ sec ⁻¹)	Number Density n (cm ⁻³)	Collisional Frequency $\nu = kn$ (sec ⁻¹)	Quenching Frequency for k (assumed)=10 ⁻¹³ cm ³ sec ⁻¹	Corresponding Cross Section (cm ²)
0	5.9 (-15)	4.59 (4)	2.71 (-10)	2.55 (19)	6.92 (9)	2.55 (6)	2.08 (-18)
50	↓	4.55 (4)	2.69 (-10)	2.25 (16)	6.06 (6)	2.25 (3)	2.20 (-18)
100		4.08 (4)	2.42 (-10)	1.50 (13)	3.62 (3)	1.50	2.45 (-18)
150		6.21 (4)	3.68 (-10)	4.44 (10)	16.34	4.44 (-3)	1.61 (-18)
200		8.22 (4)	4.86 (-10)	2.96 (9)	1.44	2.96 (-4)	1.21 (-18)
250		9.35 (4)	5.53 (-10)	5.59 (8)	0.309	5.59 (-5)	1.07 (-18)
300		10.3 (4)	6.11 (-10)	1.52 (8)	0.093	1.52 (-5)	0.97 (-18)
Columns 2, 5, 6, from U. S. Extension to the ICAO Standard Atmosphere							
Note: In the entries $a \times 10^x \equiv a (x)$							

(column 6 of Table 7.3). If each collision resulted in a de-excitation of the 1S level of OI and if there were a constant rate of production of OI(1S) not directly related to the de-excitation process, then the depletion of the 1S state would be

$$3620/3621.28 = 0.9996 \quad \text{by collisional quenching}$$

and

$$1.28/3621.28 = 0.0004 \quad \text{by emission of 5577}$$

This numerical example illustrates that in the upper atmosphere de-excitation must occur as a result of only a fraction of the kinetic collisions. In column 7 on Table 7.3, a quenching (de-excitation) frequency is shown based on the assumption of a numerical value of k equal to 10^{-13} cm³/sec (one de-excitation per 3000 kinetic collisions). Under this assumption the observed emission of [OI] 5577 near 100 kilometers is possible, the radiative and quenching rates being approximately equal. On the other hand the OI(1D) state will be seriously quenched at 100 kilometers where the quenching rate (1.50 de-excitation/sec from column 7 of Table 7.3) is 160 times the radiative rate (0.0091 quanta/second). Thus a quenching coefficient of 10^{-13} referred to all the atmosphere components rationalizes the occurrence of 5577A and the absence of 6300A in the 100-kilometer region. The excitation to the 1D level must, in this case, be at least equal to that of the 1S level as each emission of 5577 leaves the oxygen atom in the 1D state. The problem is more complicated than indicated here since all the atmospheric components are not necessarily active in quenching a particular state. Here, however, we merely desire to indicate the general nature of the problem.

SOME REACTIONS INVOLVING METASTABLE STATES

In the previous section, reactions which depopulate metastable states were treated as mechanisms which prevent the emission of optical emissions from the state. However, many

such reactions have an inherent interest, and in this section we propose to briefly mention a few.

He (2^3S) and Twilight Emissions of Helium

The observation of HeI 10,830 Å ($2^3S \leftarrow 2^3P^0$) in sunlit aurora and in the twilight has been explained as caused by resonance scattering of sunlight from the metastable 2^3S state with subsequent emission. The observed emissions are caused by permitted transitions, but the excitation to the upper level is by way of a metastable level rather than from the ground level some 19.8 eV lower.

He (2^3S) and Penning Reactions

A Penning reaction is one in which ionization of a neutral atom or molecule is caused by an interaction with another atom or molecule in an excited metastable level. Such a reaction has been suggested by Ferguson, Fehsenfeld and Schmeltekopf (1965)⁽¹⁾ to account for helium loss from the atmosphere:

In such reactions there is evidence that the excess energy can be imparted as kinetic energy to the products of the reaction. If 2.4 eV of energy goes to the He (1^1S) it is sufficient to expel it from the earth. Actually, reaction⁽⁸⁾ has been written in a simplified form. It seems that there is an intermediate step in which a HeO or HeO⁺ molecule is formed with a potential minimum that intersects a He(1^1S) - O repulsive potential curve. At the intersection, a radiationless transition occurs yielding He(1^1S) and O(4S).

O⁺(${}^2D^0$) and the Excitation of O(1D)

Mahadevan and Roach (1968)⁽²⁾ have recently suggested that a mechanism somewhat analogous to a Penning reaction might contribute to the population of O(1D) in the high upper atmosphere:

The speed of the reaction would be enhanced by the intersection of repulsive potential curves of excited $\text{O}_2^+(\text{b}^4\Sigma_g^-)$ and of $\text{O}_2^+(\text{}^2\Delta_g)$. Such a crossing seems likely, but is not known to occur, so the speed of the reaction relative to competing reactions of $\text{O}^+(\text{}^2\text{D}^0)$ with N_2 and with electrons is not known and therefore its importance in contributing to $\text{O}(\text{}^1\text{D})$ is speculative.

Metastable $\text{O}_2(\text{}^1\Delta)$ as a Source of Ionization in the D Region

Hunter and McElroy (1968)⁽³⁾ have suggested that metastable $\text{O}_2(\text{}^1\Delta)$ contributes significantly to the ionization in the ionospheric D region by the reaction

Solar radiation of wavelengths shorter than 1027\AA is able to ionize O_2 from the ground level ($\text{X}^3\Sigma_g^-$). This ionization produces the O_2^+ ion well above the D region but the radiation is depleted before it reaches the D region and cannot produce the observed O_2^+ ionization there observed. On the other hand, solar radiation in the wavelength domain 1027\AA to 1118\AA can penetrate to the D region. The other principal ionization found in the D region is NO^+ which can be produced by hydrogen Lyman alpha.

$\text{O}(\text{}^1\text{D})$ AND THE [OI] 6300, 6364 EMISSIONS

The few randomly selected reactions mentioned in the previous section indicate the complexity involved in understanding the chemistry of the upper atmosphere. The very active field of chemical aeronomy has developed rapidly, especially during the last two decades. A part of the stimulation responsible for interest in the field has resulted from the observation of emissions due to forbidden transitions. It is obvious that an important element in the analysis is a knowledge of rate coefficients for reactions leading to both

the excitation and the de-excitation of atomic, molecular and ionic states. Reference is made to a recent paper by Donahue (1968)⁽⁴⁾ who has synthesized the complexities of the ionosphere into a flow diagram with productivity, transfer, and removal of the ions O_2^+ , N_2^+ , NO^+ , and O^+ indicated for altitudes 130, 160 and 220 kilometers. [OI] 6300, 64 is known to have a close association with the ionosphere and it is here selected as an example of particular interest.

It has already been mentioned that there is a well-defined region of nightglow emission of [OI] 5577 ($^1D \leftarrow ^1S$) near 100 kilometers. The transition produces OI (1D) by cascade and there would be emission of [OI] 6300A comparable in intensity with that of 5577A were it not for the quenching of OI (1D) by collisions as mentioned in Section 5. Rocket traversals through the 100-kilometer region clearly indicate both the presence of 5577A and the absence of 6300A.

On the other hand, at a height of about 250 kilometers a nightglow emission of [OI] 6300A occurs along with 5577A, the latter having 1/4 to 1/5 the quantal output of the former. In the tropics this 250-kilometer emission is especially interesting because of frequent large changes in intensity. The reactions responsible for the optical excitation are also important in the maintenance of the balance of ionization in the F region.

followed by

The rate of the process is controlled by the slower Equation (11). The 6.96 eV is available for excitation of either or both of the atomic oxygen products to the 1D state, or one (but not both) to the 1S state. A copious literature has developed with respect to these reactions and the emission of [OI] 6300A. It

is possible to derive a relationship between the observed intensity, Q , of 6300 and ionospheric parameters (see for example Peterson, 1968)⁽⁵⁾:

$$Q_{6300} = A + B \cdot n_e(\text{max}) \cdot \exp -[(h'f - 200)/H] \quad (13)$$

where $h'f$ is the virtual height of the F layer, $n_e(\text{max})$ is the peak number density of electrons in the F region, and H is the atmospheric scale height referred to molecular oxygen. The reference height, 200 km, is chosen for convenience. Equation (13) is an adaptation of the Barbier (1959)⁽⁶⁾ formula. Other formulations are discussed by Peterson (1968)⁽⁵⁾.

Equation (13) is very successful in correlating changes in Q_{6300} with concomitant changes in the ionosphere. During the post twilight period, as the F region is steadily decreasing in $n_e(\text{max})$ and increasing in virtual height, Q_{6300} decreases in value. In the tropics rapid changes in Q_{6300} which are not associated with the post twilight also show excellent agreement with the predictions of Equation (13). The additive quantity, A , presumably due to some mechanism of excitation other than Equations (11) and (12) is small in the tropics but usually measurable. In mid and high latitudes there are other nocturnal emissions of [OI] 6300 which do not "obey" the Barbier formula. For example, in mid latitudes there is a general increase of Q_{6300} with geomagnetic activity (Truttse, 1968)⁽⁷⁾ which is not predicted by the formula. At times this general increase in intensity includes a localized high altitude (peak at 400 kilometers) arc which does not include a measurable enhancement of [OI] 5577A (see Roach and Roach⁽⁸⁾, 1963, for a summary of knowledge of this phenomenon). Also, during times of geomagnetic activity (a) visual red (6300A) arcs are often observed near the auroral zone and (b) widespread red "auroras" have been seen even in tropical regions. The heights of the well-defined arcs, both in the auroral zone and in mid

Maximum	22h 24m	01h 36m	Unit
Q_{6300}	535×10^6	310×10^6	$\text{qu.cm}^{-2} \text{ sec}^{-1}$
$\frac{-dn(\text{max})}{dt}$	400	230	$\text{el.cm}^{-3} \text{ sec}^{-1}$
$-\tau \frac{dn(\text{max})}{dt}$	2000×10^6	1150×10^6	$\text{el.cm}^{-2} \text{ sec}^{-1}$
ϵ	0.27	0.27	

The quantal efficiency by this analysis may be compared with that found by Brown and Steiger (1967)⁽⁴⁾ who found an efficiency of 0.15 based on time rate of changes at Maui of total electron content.

THE TROPICAL IONOSPHERE

The example given in the previous section is for a night of significant though not unique photometric activity accompanied by co-varying ionospheric changes. That we are dealing with a general problem of ionospheric dynamics becomes apparent upon examination of systematic plots of critical frequency and virtual height at a tropical station such as that of Maui. Figure 8.2 shows the median hourly values of $n(\text{max})$ for October, 1957 for Maui (magnetic dip latitude $21^\circ.3$) and for Washington (dip latitude $55^\circ.45$). The contrast between the two stations is immediately apparent.

The Maui plot exhibits a maximum at about 21h 30m local standard time which is greater in absolute value than the day-time maximum. At Washington, on the other hand, there is a general uninterrupted decline in $n(\text{max})$ during the night until just before dawn. Figure 8.3 illustrates that at Maui there is a minimum in the virtual height which, as in the case of the example of the previous section, coincides with the region of greatest rate of loss of electrons following the $n(\text{max})$ peak.

FIGURE 8.2 Comparison of the Diurnal Variation of $n(\max)$ at Stations in the Tropics (Maui) and in a Mid-Latitude (Washington) Based on Median Values for the Month of October, 1957.

FIGURE 8.3 Above - Diurnal Variations of $h'F$ at Maui and at Washington; Median Values for October, 1957. Below - Corresponding Plot of $dn(max)/dt$ Based on $n(max)$ from Figure 8.2. Note Positions of m_1 (Time of Maximum of $h'F$), M (Time of Minimum of $h'F$) and m_2 (Time of Maximum of $dn(max)/dt$) Indicated on the Maui Curves of both Figure 8.2 and 8.3.

The coincidence in time of the minimum virtual height and the greatest rate of loss of electrons has been observed without exception on a large number of plots of Maui data and must be considered to be a general property of the tropical ionosphere. The implications of this empirical fact become apparent by placing the following statements in juxtaposition:

- In the case of a static nocturnal ionosphere the period following a general influx of ionization should be one of increasing virtual height as the lower regions of ionization in the denser parts of the neutral atmosphere are preferentially eaten away by recombination processes.
- If, contrary to the expectations of the time sequence of a static ionosphere, the virtual height decreases following an influx of nocturnal ionization it must be concluded that we are dealing with a dynamic ionosphere.

The dynamicism required is that of a downward movement of ionization which may either be naturally timed to follow the influx of ionization or possibly one which becomes apparent only after such an influx.

The example in Figures 8.2 and 8.3 exhibits only a single maximum of $n(\text{max})$ in contrast with that of Figure 8.1 which has two maxima. In our systematic examination of Maui records, we have noted frequent occurrence of both single and double maxima.

We showed in the previous section that the nightglow intensity changes maximized with the time of high loss rate of electrons for the night of September 11/12, 1961. This is a general property of the [OI] 6300A nightglow at the tropical station of Maui and has been observed systematically. Observations have continued at Maui regularly since 1961. During the sunspot minimum period of 1964-1965 the nightglow photometric activity was very low, suggesting a significant solar cycle effect. The reason is apparent on inspection of

Figure 8.4 which shows a comparison of $n(\text{max})$ median variations at Maui for October, 1957 (sunspot maximum) and October, 1964 (sunspot minimum). The 1964 values are approximately a factor of 10 lower than those of 1957. A definite maximum is noted, however, at about midnight for the lower curve, about 2-1/2 hours later than that occurring in 1957. Although the amplitude of the 1964 maximum is much smaller than that of 1957 in absolute value, its relative amplitude is comparable.

In addition to the sensitivity of the tropical ionosphere to the sunspot cycle, we should mention that there are marked ionospheric seasonal variations which are reflected in the nightglow [OI] 6300A activity. In this short review, it is probably only necessary to say that the relationships between the temporal variations in the nightglow, $n(\text{max})$, $dn(\text{max})/dt$ and $h'F$ which have been discussed for a single night in the first section and for particular months in this section are general.

THE TROPICAL IONOSPHERE AND THE EQUATORIAL ANOMALY

The critical frequency, f_oF_2 , and hence the peak electron density, $n(\text{max})$, has an equatorial (magnetic) trough in its latitudinal distribution at noon during the equinoxes (Appleton, 1946).⁽⁵⁾ There is actually a maximum in peak electron density some 15° to 20° from the magnetic equator, hence the appellation anomaly. The considerable literature on the subject, both descriptive and interpretive may be approached by way of the references in Hanson and Moffett (1966)⁽⁶⁾ who made a definitive analysis of the problem of ionization transport in the equatorial F region. Their analysis includes evaluations of the effects of photo-ionization, re-combination, diffusion, neutral winds and electromagnetic drift. An important factor is the electromagnetic drift. Hanson and Moffett, following an early suggestion of Martyn (1955)⁽⁷⁾ found that upward drifts over the magnetic equator with speeds of $\sim 10 \text{msec}^{-1}$ could result in a

FIGURE 8.4 Diurnal Variation Plotted on a Logarithmic Scale of $n(\max)$ at Maui for October, 1957 (Sunspot Maximum) and October, 1964 (Sunspot Minimum).

concentration of ionization some 15° to 20° away from the equator in agreement with observations during the middle of the day. Recently the existence of drifts of this order has been confirmed at Jicamarca (near the dip equator), upward in the daytime and downward at night (Balsley, 1969);⁽⁸⁾ (Woodman and Hagfors, 1969).⁽⁹⁾

Maeda (1962)⁽¹⁰⁾ has calculated ionization drifts in the F region on a world-wide scale based on the electric fields associated with the E-region current systems, which electric fields are assumed to be transmitted to the F region along the geomagnetic lines of force. A plot of Maeda's calculations of mean drifts for the period 1932-33 (sunspot minimum) and for times of geomagnetic quiet is shown in Figure 8.5. The daytime upward drift assumed by Hanson and Moffett in their analysis and measured by the Jicamarca observers is clearly evident, not only at the geomagnetic equator but also in the tropical region in general. Also a general downward drift at night of one or two tens of meters sec^{-1} is apparent in Figure 8.5. The world-scale plot is consistent with the observational fact that at night, the tropical ionosphere is driven down. There is a suggestion in the Maeda plot that a horizontal movement of ionization resulting in the nocturnal bulges in $n(\text{max})$ may be predominately in the west to east direction, corresponding to a movement from the late afternoon into the night regions of the ionosphere.

THE MID-LATITUDE IONOSPHERE AND 6300A EMISSIONS

The 6300A emission in mid-latitudes ($>35^\circ$ magnetic latitude) does seem to include a contribution due to the recombination process [Equations (1,2)] but also another from some other process. In a recent study Truttse (1968)⁽¹¹⁾ has shown that in mid-latitudes (in contrast with low latitudes such as that of Maui) Q_{63} increases markedly with geomagnetic activity. A value of a_p of 200 gives an increase of Q_{63} by a factor of 10. It is

FIGURE 8.5 Graphical Representation of Electromagnetic Drift Speeds (not Fluxes) of Ionization in the F Region Based on the Calculations of H. Maeda (1962)(10). The Time for Which the Calculations were Made was the Second Polar Year, 1932-33 (Sunspot Minimum), for the Equinox, and for Geomagnetically Quiet Conditions. The Horizontal Component is Shown Vectorially by Arrows, the Vertical Component is Indicated by Circles; Solid Circles Downward Drift; Open Circles Upward. The Scale Shown to the Right Applies to both the Horizontal and the Vertical Components.

well known that, in these same latitudes, geomagnetic activity results in a decrease in foF2 and hence of n_m and an increase in ionospheric height [hm, the height of ionization maximum, is better as an indicator of ionosphere height than h'F, the virtual height during magnetic storms in mid-latitudes (Thomas and Robbins, 1958)].⁽¹²⁾ Both of these ionospheric changes are in the opposite sense from that required to give an increase in Q_{63} . Even the known mid-latitude increase in general atmospheric temperature with geomagnetic activity cannot offset the deleterious effect of the h'F(up) and foF2(down) changes.

It appears that some excitation mechanism is operative which becomes efficient at high altitudes. An interesting conjecture is that the general increase in Q_{63} with geomagnetic activity discovered by Truttse may be associated with the discrete Q_{63} activity of the mid-latitude M (or SAR) areas. If so, the absence of 5577A in the mid-latitude F region phenomenon under discussion also requires that reactions (1,2) are not responsible for the emission.

CONCLUSION

The use of the virtual height, h'F, as an indicator of ionosphere height variations is subject to the criticism that it may not be reliable. As already mentioned the parameter is especially unsatisfactory in mid-latitudes during times of geomagnetic activity (Thomas and Robbins, 1958).⁽¹²⁾ For the purpose of the present discussion it is deemed to be satisfactory, however, as an appropriate height indicator in the tropics since Peterson (1968)⁽¹³⁾ has found it to better represent the photometric observations in Barbier-type formulas than two alternative parameters: MUF, the maximum usable frequency, and $h'(f = 0.815 \text{ foF2})$.

Attention is called to recent papers which treat the problem of the tropical nightglow and the ionosphere. King (1968)⁽¹⁴⁾ has called attention to a similarity in equatorward

movements of tropical nightglow and nocturnal movements of the ionospheric crests associated with the equatorial anomaly. VanZandt and Peterson (1969)⁽¹⁵⁾ discuss the spatial complexity of nightglow patterns at Maui and some of the ionospheric implications. They also refer to the inter-relationship between vertical ionospheric drifts near the dip equator (Jicamarca) and nightglow intensities.

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9. AUTOMATION OF AERONOMY EQUIPMENT

L. L. Smith and R. J. Ausere

A large portion of the available manpower is presently invested in observational and data processing programs. The primary purpose of the automation of the aeronomy equipment is to maximize the analysis and reporting output of our group by:

- reducing the amount of professional time required in the observational program so this can be invested in other aspects of the research,
- increasing the reliability of the present observing equipment, thereby, optimizing the availability and accuracy of data for analysis,
- obtaining better spatial and temporal resolution with more sophisticated photometers and recording devices,
- decreasing the time and manpower required to process the raw data into forms necessary for analysis, and
- providing means of presenting reduced data in forms for analysis which are now not available.

To accomplish these goals, an automated system built around a small computer has been designed. Figure 9.1 is a block diagram of the automated system. The following items are now ordered and the expected delivery is July, 1969:

- Varian Computer 620I
- Teletypewriter KSR 35
- High speed paper tape punch
- High speed paper tape reader
- Magnetic tape
- Three interfacing items

Remaining items shown on the diagram which include the disc, CRT display, and plotter, will be purchased as soon as funds become available. Initial checkout and programming of the system can be done with the equipment ordered but, lacking

FIGURE 9.1 Block Diagram of Automated System

the data storage capacity of the disc, the system cannot be used on-line until that item is in place.

The basic organization of the computer includes four interdependent sections: Core memory, control, arithmetic logic, and input/output. All transfers of data are executed in parallel. The random access ferrite core memory contains 8,192 words and can be expanded to 32,768 words. The core memory, data and instruction words are 16 binary bits in length. The read-restore cycle time is 2.1 μ sec and the basic add instruction requires 4.2 μ sec. The computer contains the following registers;

- A register which performs the major programmed arithmetic and logic operations and serves as a program-controlled data input/output register,
- Program counter register determines the core memory address from which the next instruction of a stored program is to be taken,
- Memory address register determines the location in core memory from which an instruction, an address, or data is to be read,
- Memory buffer register serves as a buffer for all information passing between the processor and the core memory,
- Instruction register receives and holds the operation code and indirect addressing indicator bit as each instruction work is fetched from memory, decoded and executed,
- Switch register consists of toggle switches mounted on the operator console providing a means of manually establishing a word to be set into the accumulator.
- Multiplier-quotient register operates with the A register to perform multiplication and division operations.
- B register functions with the A register to perform arithmetic and logical operations.
- Index register, in addition to the normal indexing functions, has the capability of being directly added

to the memory address of an indexed memory reference instruction to form the new address of the information.

The computer is capable of individually selecting and addressing 32 different devices. The input/output (I/O) instruction has 4 bits available for microprogramming. Programmed data transfers using the A and B registers have data rates of 10^5 words per second. The (I/O) devices are as follows:

- A KSR-35 Teletypewriter machine is interfaced to the computer. This unit operates either on-line, in half duplex, or off-line.
- A high-speed paper tape punch which operates at a speed of 100 characters per second using the 8 bit ASCII code.
- A paper tape reader which has a speed of 300 characters per second also using the 8 bit ASCII code.

The software provided for the computer are as follows:

- A Fortran compiler to allow expression of a problem in English and Mathematical-like statements fully U.S.A.S.I. Fortran (Fortran IV)
- A symbol assembler which processes a machine-oriented language.
- A correction program which enables corrections and additions to be made on source program statements through the keyboard.
- An operating system which includes a (I/O) control system and executive for compilation, assembly, loading execution, dumping, system maintenance, definition of (I/O) units, and magnetic tape positioning.
- Arithmetic subroutines for elementary functions (log, exponential, square root, sine, cosine, tan and arctan) for single precision (multiply and divide) and for double precision (add, subtract, multiply and divide).

A program consisting of (I/O) subroutines for the purpose of transmitting data to and from peripheral devices and data ready for processing.

- Maintenance programs which enable testing of the entire central processor and all the peripheral equipment connected to the processor for the purpose of locating hardware malfunctions.

The automated system is expected to provide an immediate increase in the amount of useful data obtained. Because on-line display of data will permit the operator to optimize measurements, we expect an improvement in the quality of the data as well.

We are establishing the system parallel to the existing control and recording equipment and will use it initially on a trial basis until reliability and intercalibration are established. Our plan is to first program the new equipment to assume control of the scanning mount and accumulate data from three photometers. Programming partial data reduction in real time to provide on-line display will follow.

10. SPECIAL EQUIPMENT AND FACILITIES DEVELOPMENT

SPECIAL EQUIPMENT DEVELOPMENT

R. L. Skaugset

Photometric Scanner Improvements

In order to provide an on-line readout of the digital data in addition to the paper tape output, an ASR teletype was installed. This included the design and fabrication of interface circuitry. In association with this, the control program was modified to provide the proper timing for the teletype control functions, as well as to make the data easier to read by inserting a "space" between data samples.

It is advantageous during periods of high auroral activity to be able to scan a portion of the sky while the moon is up. This problem was attacked in two ways. First, a simple, low-sensitivity photometer was built to sense when the mount scans near the moon. When the moon appears in the field of view of the photometers, the signal is amplified to operate a relay which closes the shutters on the primary photometer. Secondly, a new control program was made up so that the mount would scan only half the sky without scanning near the moon.

An additional turret photometer has been installed on the mount. The operation of this photometer is controlled from the console as with the other turret photometer but differs in that its output is recorded on a strip chart recorder only and is not digitized. This turret is equipped with the following filters: 6080A, 7150A and 5350A. The data obtained with this instrument are used to deduce the contribution of the continuum spectra to auroral and airglow data and to establish the apparent surface brightness of the milky way which serves as a standard brightness reference.

Pulse Counting

In the present photometric system the analog output is an integration of the pulses caused by individual photons. The photomultiplier senses these pulses over a certain length of time. This analog signal is then converted back to pulses which are counted to give us our digital signal. A more straightforward method of data gathering would be to amplify the pulses from the photons and count these pulses. This method would also eliminate the problem of dark current offset on the analog signal which varies with photomultiplier temperature and voltage.

A pulse counting system is presently under development and is being tested prior to installation in our system.

The pulse counting system consists of a high impedance solid state preamplifier located with the dynode chain in the photomultiplier housing. The pulses are amplified by this preamp then applied to a pulse height discriminator which can be adjusted to cut out all noise pulses. These are then amplified by a pulse amplifier and counted by the counter in the system console. (See Figure 10.1a).

Logarithmic Amplifier

During a bright aurora the sensitivity has to be reduced by several orders of magnitude in order to keep the record of the aurora within the range of the recording equipment. This of course reduces the background variations to nearly nothing. In order to improve this situation, a logarithmic amplifier is being tested on one of the photometers. This amplifier compresses three decades of sensitivity onto one scale, eliminating the need for sensitivity switches.

In this system a Zeltex FET operational amplifier is used as a preamp with its gain adjustable to one or ten. The logarithmic amplifier used is a Burr-Brown type 4008/40. It has an input range of 0.01 V to 10 V, and an output of ± 10 V which drives an Esterline Angus recorder. (See Figure 10.1b)

Figure 10.1a. Pulse Counting

Figure 10.1b. Logarithmic Amplifier

FIGURE 10.1 Special Equipment Development

Magnetometer

The magnetometer loaned to us by Boeing has been installed in an abandoned telephone manhole near the facilities. This keeps it out of the weather and places it far enough away from the observatory that there is no major electrical interference. The only interference is from passing vehicles. We have enclosed the magnetometer in an aluminum shroud to shield it from radio interference as well as protect it from weather conditions.

The magnetometer circuitry which we have constructed consists of 2 dc amplifiers with a combined gain of 30,000 and a 0.01 to 2 Hz filters. This is used to filter out all magnetic interference outside the range of frequency of changes in the earth's magnetic field in which we are interested. The resulting signal is recorded on a strip ^{CHART} recorder. (See Figure 10.1c) Absolute calibration prior to data analysis remains to be done.

FACILITIES DEVELOPMENT

L. L. Smith

Several additions and improvements have been made to the facilities at the Rattlesnake Observatory since the last progress report. Some of these have greatly enhanced the research capabilities of our operation and should be mentioned.

Another photometer has been borrowed from the Environmental Science and Services Administration (ESSA). This gives us the capability to scan the night sky at seven different wavelengths. Presently we are monitoring emission radiations [OI] 5577A, [OI] 6300A, and N_2^+ 4278A and background radiations at 5300A, 6080A, and 7150A. The [OI] 6300A emission is monitored by two photometers giving us maximum coverage possible for detailed studies of the 6300A mid-latitude red arc. Figure 10.2 is a photograph of the bank of photometers now in use. Figure 10.3

FIGURE 10.2 Photometers in Use

shows the control room for programming the mount and recording the observations from the three photometers.

An all-sky camera is being tested to provide cloud cover information. An automated observing program will require this type of system. Also, during the photometric non-observing period, the meridian spectrograph is operating with no observer on duty. Consequently, cloud cover information is needed for these periods.

A data processing system (Figure 10.4) borrowed from ESSA this year facilitates conversion of analog data to digital form. A strip chart of raw analog data is mounted in the recorder on the desk. The operator starts the system and follows the tracing on the chart with a hand-operated indicator. The amplitude of an analog signal is proportional to the position of the indicator. The system samples the signal at a rate determined by the operator and punches a BCD value on paper tape corresponding to the amplitude of the signal. Since only one of our photometer outputs can be digitized on line under the present control and recording system, this is an important addition to our data processing program since it gives us a way to convert the data of the two undigitized photometers to useful form.

The working area at the Rattlesnake Observatory is constantly being improved as local funds become available. Figure 10.5 is a photograph of the data editing and storage area and Figure 10.6 is one of six offices presently available for the staff.

FIGURE 10.3 *Control Room for Programming Mount and Recording Observations from Photometers*

FIGURE 10.4 ESSA Data Processing System

FIGURE 10.5 Data Editing and Storage Area

FIGURE 10.6 Staff Office Facilities

11. PLANNING

Last year we found we had to undertake some tasks not anticipated and abandon some we'd planned. This suggests that in stating plans here it might be wiser to set out broad general objectives rather than specific tasks and then plan to undertake those tasks that are necessary to accomplish the end results. There are three such general objectives:

- (1) analysis, (2) completion of the automated system and,
- (3) improving and continuing the all-sky mapping program.

The first objective requires that emphasis be shifted toward detailed analysis of the data that have been accumulated and are being obtained. We expect to realize some relief from other time-consuming tasks when the automated system becomes operational this year. Even if the benefits of automation should accrue more slowly than we now anticipate, we plan to make adjustments within the program to concentrate attention on analysis and reporting.

The analysis planned is expected to include a fairly complete treatment of the SAR arc phenomenon. This analysis has been started. Other analytical tasks which we have also begun include spectrographic studies of strong auroral features and a more detailed summary of activity based on the spectrograph records. The latter study considers angular coordinates and intensity for particular emission and thus goes considerably beyond the summary of auroral activity reported this year. Data for investigation of the continuum component of the airglow spectrum are also being taken. This serves the two-fold purpose of providing information necessary to establish the milkyway as a 'standard' surface brightness source and permits analysis of the continuum radiation component of the airglow itself.

The other general objectives for the year are to improve and continue the routine sky mapping, which has been the

backbone of the research program, and to complete the automated control and recording system which is being installed. Funds permitting, the design and development of the high speed optical scanner is planned. Within the general scope of these objectives, individual tasks of testing, calibrating and working out new measuring techniques are to be undertaken as necessary.

In terms of long-range plans, we want to move toward a better overall balance between observing, theoretical analysis and experimentation. By theoretical analysis we refer to studies of both the macroscopic and the microscopic processes in the aurora and airglow. The need for certain laboratory measurements of low energy collision processes becomes ever more apparent. For example, we need low energy charge exchange cross sections for hydrogen incident on neutral atoms to understand the auroral hydrogen (Balmer) arcs that we have observed. A natural and expedient way to start development of the experimental portion of the program appears to be through cooperative work with our colleagues at the University of Washington. We have discussed the possibility of arranging for complementary efforts in both groups on problems of common interest.

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