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FINAL REPORT

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SOLAR ECLIPSE EXPERIMENT STUDY

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ABSTRACT

This rocket program consisted of two somewhat unrelated tasks. The first task consisted of the fabrication, integration, test, launch, and data reduction of a Javelin rocket payload intended for the measurement of energetic hydrogen atoms at an altitude of 800 km. This payload was successfully launched during the solar eclipse of 7 March 1970. Analysis of the data indicated the presence of very large fluxes of these particles; a detailed description of the experiment and its results together with some brief consideration of the physical significance of these observations constitute the major fraction of this report. A somewhat condensed version of this experiment description has been accepted for rapid publication in the Journal of Geophysical Research.

The second phase of this program included the partial fabrication of a rocket payload for auroral measurements together with the laboratory test of an electrostatic analyzer for energetic negative hydrogen ions. To date we have fabricated and tested 24 discriminators, 4 low voltage power supplies, 4 channeltron high voltage supplies, and 3 high voltage power supplies for the electrostatic analyzers. Laboratory tests of the energetic negative hydrogen ion energy analyzer have been completed and show that the technique will be adequate for the detection of these particles produced during the aurora. A description of these measurements completes this report.

I. THE MEASUREMENT OF ENERGETIC NEUTRAL HYDROGEN FLUXES DURING THE SOLAR ECLIPSE OF 7 MARCH 1970

A. INTRODUCTION

The neutral hydrogen experiments carried on NASA Sounding Rocket 8:57 CE, which was flown from Wallops Island, Va. on 7 March 1970, were designed to measure fluxes of energetic neutral hydrogen postulated to be associated with the solar wind. Eclipse conditions were chosen for the flight because solar ultraviolet light constituted a possibly serious background source in the detection of the small fluxes of energetic neutral hydrogen atoms expected to be coming from the sun. During totality, the ultraviolet flux would be much reduced, but because the hydrogen would be moving at a small fraction of the speed of light, the neutral flux incident on the earth would continue for some 6 to 10 minutes after the start of the optical eclipse. It was planned to carry out the measurements during this period.

In an attempt to explain the buildup of the equatorial ring current during terrestrial magnetic storms, *Akasofu* [1964] postulated that atomic hydrogen fluxes as large as 10^9 cm^{-2} sec^{-1} reach the earth from a solar flare prominence. Subsequent to this original theory, *Brandt and Hunten* [1966] pointed out that even though large fluxes of neutrals may originate from the flare prominence, the solar ultraviolet radiation will ionize the majority fraction of this neutral flux. *Cloutier* [1966] invoked solar coronal electrons as another ionization source. Either one of these ionization processes are sufficient to reduce the original neutral flux of $\sim 10^9$ cm^{-2} sec^{-1} to $<10^6$ cm^{-2} sec^{-1}.

Some experimental evidence has been obtained to support the concept that a population of neutral atoms can exist in the interplanetary medium. *Axford* [1968] attributes the existence of He^+ in the solar wind to charge exchange of a fraction of solar He^{++} with such neutral atoms. He suggests, from the measured He^+/He^{++} ratio, that the energetic neutral hydrogen flux, produced by charge exchange of solar wind protons with the neutral atoms, should be $<10^7$ cm^{-2} sec^{-1}. *Fahr* [1969] has theoretically investigated the flux of neutral atoms that results from the motion of the solar system through the interstellar medium; he derives a maximum flux of $\sim 10^6$ cm^{-2} sec^{-1} with a maximum energy of 27 ev. *Blum and Fahr* [1970] predict that a flux of $\sim 7 \times 10^5$ cm^{-2} sec^{-1} of energetic neutral atoms would result at 1 AU from charge exchange of solar wind protons with these interstellar neutral atoms. *Patterson et al.* [1963] have reported a doppler broadened component in the Lyman Alpha radiation observed from the interplanetary medium. They attribute this radiation to an inward directed flux of energetic hydrogen atoms generated at a distant shock termination of the solar wind. They estimated a flux of $<4 \times 10^6$ cm^{-2} sec^{-1} at 1 AU. This inward directed neutral flux could also serve as a charge exchange medium for solar wind protons to provide a neutral component in the solar wind. In general, most accepted estimates would thus place an upper limit of $<10^7$ cm^{-2} sec^{-1} to a possible neutral component in the solar wind.

B. INSTRUMENTATION

The Javelin sounding rocket was instrumented with two nearly identical neutral-proton energy spectrometers, a total hydrogen ($H^o + H^+ + H^-$) detector, a sun sensor, and an aspect magnetometer. *Bernstein et al.* [1969]

have described a simplified version of the energy spectrometers. In the present case, a single hemispherical electrostatic analyzer had three separate entrance apertures and associated channeltron detectors to provide simultaneous measurements of neutral hydrogen, protons, and background. There were two such analyzers placed back-to-back in the payload.

The neutral hydrogen channel had an electrostatic charged particle deflection system to remove all charged particles with energy <4 kev and a collimator with an $\sim 2\ \mu$ gm cm^{-2} carbon foil situated between this collimator and the entrance to the analyzer. A measured fraction ($\sim 10\%$) of the energetic neutral atoms which impinge on the foil emerge as protons; the energy distribution of these protons was then determined by the electrostatic analyzer. The efficiency, defined as the ratio of the number of counts detected per incident neutral, and the energy lost in transit of the foil were determined experimentally for the foils used in the flight. It should be noted that atoms heavier than hydrogen have extremely low efficiencies because of increased scattering in the foil. A thicker foil was employed for analyzer 1 than for analyzer 2.

The background channel utilized the same collimator and charged particle deflection system used for the neutral particle channel; however, the entrance aperture was not covered with the carbon foil. Thus this channel was insensitive to low energy charged particles or energetic neutrals and provided a measurement of those counts produced by ultraviolet light, high energy protons and electrons, and bremmstrahlung which could contribute background counts to the neutral and proton channels. A second collimator with neither the charge deflection plates nor the carbon foil was used to admit protons into the analyzer for analysis and constituted the proton channel. Laboratory calibration showed that the interplay between the different channels was not important.

For the present instrument, the analyzer resolution was 17%. The geometrical factors for the background and neutral channels were 0.565 cm^2 str; the geometrical factor for the proton channel was 0.228 cm^2 str. The collimator for the neutral and background channels was rectangular and opened to angles of +60° to -23° in the up-down direction and $\pm 23°$ in the perpendicular direction. The proton collimator was circular with a half angle opening of 17.5°. The analyzer and collimator surfaces were coated with platinum black and were also serrated where possible to reduce surface reflection effects.

The analyzer high voltage was stepped through four values; the duration of each step was 0.6 sec long compared to the spin period of 0.12 sec. Independent voltage supplies with slightly different ranges were used for each analyzer.

The two neutral-proton analyzers were employed to provide redundancy in these measurements. The instruments were mounted back-to-back with the apertures aimed upward at an angle of 45° to the rocket axis. With the exception of the aforementioned slightly different analyzer voltage ranges and foil thicknesses, the two instruments were identical. The important characteristics of these instruments are given in Table I.

The total hydrogen flux detector was similar to that described by *Wax and Bernstein* [1967] and provided a nearly energy independent measurement of the integral flux >1 kev. It consisted of a circular 0.334 cm^2 str collimator of 18° half angle followed by an ∿2 μ gm cm^{-2} carbon foil which served to scatter the incident particles. A channeltron detector was placed ∿6 cm behind the foil and 23° below the line normal to the foil surface. A second channel consisting of the identical collimator-channeltron configuration but without the foil was used to provide a measurement of the background. Here again the instrument and collimator surfaces were coated with platinum black and serrated. The characteristics of this instrument are also given in Table I.

C. FLIGHT CONDITIONS

The Javelin rocket was launched at 84° elevation, 90° azimuth from Wallops Island, Virginia at 1847.00 UT on 7 March 1970. Its calculated trajectory was to carry it into the zone of totality at an apogee altitude of 800 km for a period of about one minute. The actual trajectory, which resulted from an effective launch angle of 86°, took the rocket to an apogee altitude of 846 km and through a region of only 60-80% of totality. On the downleg of the flight, at 570 km altitude there was a sudden, complete telemetry failure. On the upleg of the flight from high voltage turn on at 125 seconds into the flight (220 km altitude) until 250 seconds (560 km), the instruments showed symptoms of what we feel to be an outgassing phenomenon which caused the high voltage power supply voltages to drop below the voltage needed to operate the channeltrons. This condition resulted in a severe reduction in the count rate. For these reasons valid data was obtained over the altitude range 560 - 846 - 570 km, or the time period from 250 to 800 seconds after launch.

The rocket spin rate was about eight cycles per second. Therefore, the analyzers were fixed in energy for about five spin cycles so that the directional properties of the incident flux could be determined. The spin axis was pointed 4° east of the zenith. The proton detectors scanned the pitch angle range from 20° to 70°. The angle between the spin axis of the rocket and the sun was 59° and fell within the field of view of all detectors. The aspect data provided by the solar sensor and the magnetometers was accurate to at least $\pm 10°$.

The largest magnetic storm of this solar cycle occurred about 18-20 hours after this eclipse flight took place. At the time of the flight there was definite world-wide magnetic activity which decreased slightly before, and then increased greatly during the storm.

D. EXPERIMENTAL RESULTS

The average flux of energetic hydrogen atoms was 5×10^9 atoms cm^{-2} sec^{-1} str^{-1} kev^{-1} at 1 kev. Figure 1 shows a typical energy spectrum obtained near the apogee altitude of 840 Km. The spectrum was exponential with an e-folding energy of 600 ev. Figure 1 also shows the proton spectrum observed at the same time. It showed a slight peak at 750 ev, and fell off with an e-folding energy of 900 ev. Typical proton fluxes were 10^6 cm^{-2} sec^{-1} str^{-1}. This flux appeared consistent with that expected from charge stripping of the incident neutral flux in the ambient atmosphere. The flux observed by the total hydrogen detector was consistent with that observed by the analyzers. However, the total detector was sun sensitive and therefore there was data missing during part of the spin cycle.

The above flux was not isotropic; counting rates increased by a factor of $\sim$5-10 were observed during part of the azimuth scan. The location and extent of the region of increased flux or source region is shown in Figure 2; as can be seen, the sun was located very close to one boundary. From this data, it appears unlikely, but perhaps possible, that the sun was the source of the energetic neutral atoms. There was acceptable data transmission only in the altitude range 650 to 840 to 650 km. During this 500 sec period, the average atomic flux showed a nearly constant magnitude, energy spectrum, and source location.

We believe these experimental results to be valid for the following reasons:

1. The background channel counting rates were a factor of 10^2 less than those observed in the H° channel. Therefore, spurious counts caused by high voltage breakdown, solar ultraviolet, high energy radiation and ionospheric effects were not important.

2. The H° fluxes and energy spectra derived from the two instruments were consistent although the foils were of different thickness and thus had significantly different efficiency factors.

3. The source location was identical for both instruments although they viewed the region at different times in the spin cycle.

E. DISCUSSION

If the observed source were solar, the measured energy fluxes are consistent with those proposed by *Akasofu*[1964]. In this context, it should be noted that *Akasofu* had proposed the emission of such large fluxes to be an infrequent, transient phenomenon associated with solar flares and severe geomagnetic storms. Some eighteen hours after this flight, the largest geomagnetic storm of this solar cycle occurred. Therefore, it is possible that the observed atomic flux may be involved in the production of geomagnetic storms. We emphasize further that the measured atomic flux and its energy density are about a factor of 10^2 greater than those of the solar wind. If these fluxes are solar in origin, severe modifications in current concepts of solar-terrestrial relationships will be in order.

If the flux were interstellar, then we must assume that the observed 600 ev temperature was imparted to the atomic beam within several AU of the earth by solar sources such as the solar wind, solar ultraviolet or possibly gravitational interactions. The observed energies and large fluxes obviously are inconsistent with either *Fahr* [1969] or *Blum and Fahr's* [1970] predictions. Cold hydrogen gas clouds with directed velocities comparable to those observed are known to exist [*Meng*, 1968], but none were thought to be actually impinging on the solar system. However, the high velocity cloud OYH445 lies close to the source region. The observed particle density of $\sim 10^2$ cm^{-3} is also large compared to the usual densities believed to exist in interstellar gas clouds, suggesting that the extent of the high density region is not large. The possible association with geomagnetic storms would also imply that the appearance of enhanced densities is a transient and relatively infrequent occurrence.

Data from the Vela and Pioneer spacecraft (ESSA 1970) indicate that, even though the largest geomagnetic storm of this solar cycle was taking place, the solar wind was not very disturbed and there also was apparently no very large flare in the period 1-7 March 1970. The measured large neutral particle fluxes would be expected to produce significant changes in the solar wind characteristics. Should the flux be solar in origin, it is likely that a significant fraction would be ionized during transit of the outer corona; this ionized fraction should lead to a greatly enhanced solar wind flux. Should the source be interstellar in origin, as implied by Figure 2, the most obvious consequences would be a proton flux directed from north of the ecliptic to the south and a consequent bending of the solar wind magnetic field in a southward direction. Both southward and northward components of particle flux and magnetic field have been observed in the past [*Wolfe et al.*, 1966; *Wilcox and Ness*, 1965].

F. CONCLUSION

At the present time, we feel confident that the observed measurements are valid and are not attributable to spurious effects. A more precise definition of the source region and the possible transient nature of the atomic flux and its interaction with the atmosphere require further experimentation.

G. ACKNOWLEDGEMENTS

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CAPTIONS

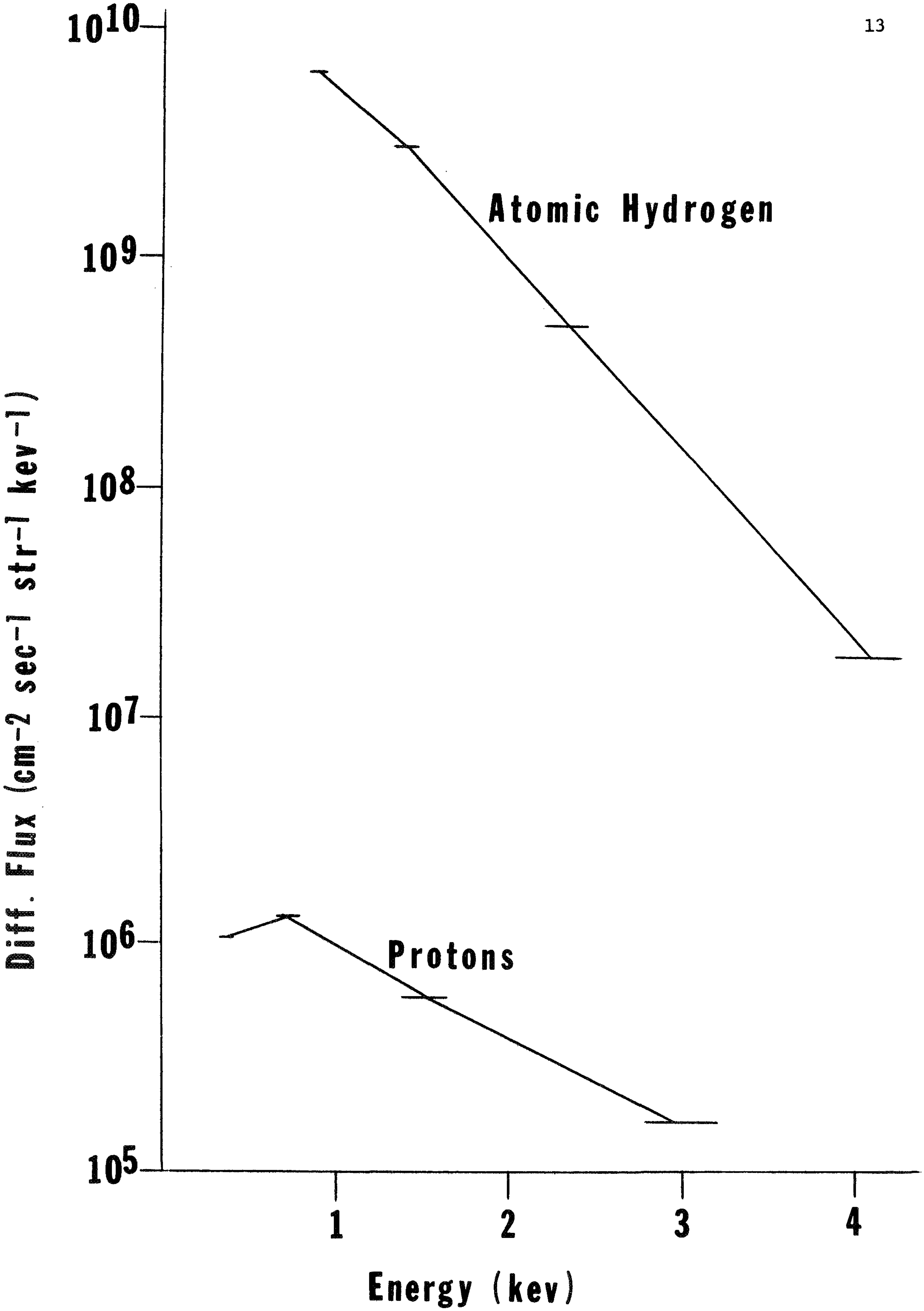
TABLE I. Summary of characteristics of the particle detectors.

Figure 1. Differential energy spectra for atomic hydrogen and protons obtained from one 2.4 second energy sweep. Each energy step was averaged over several full azimuthal scans. These data are from Analyzer #1.

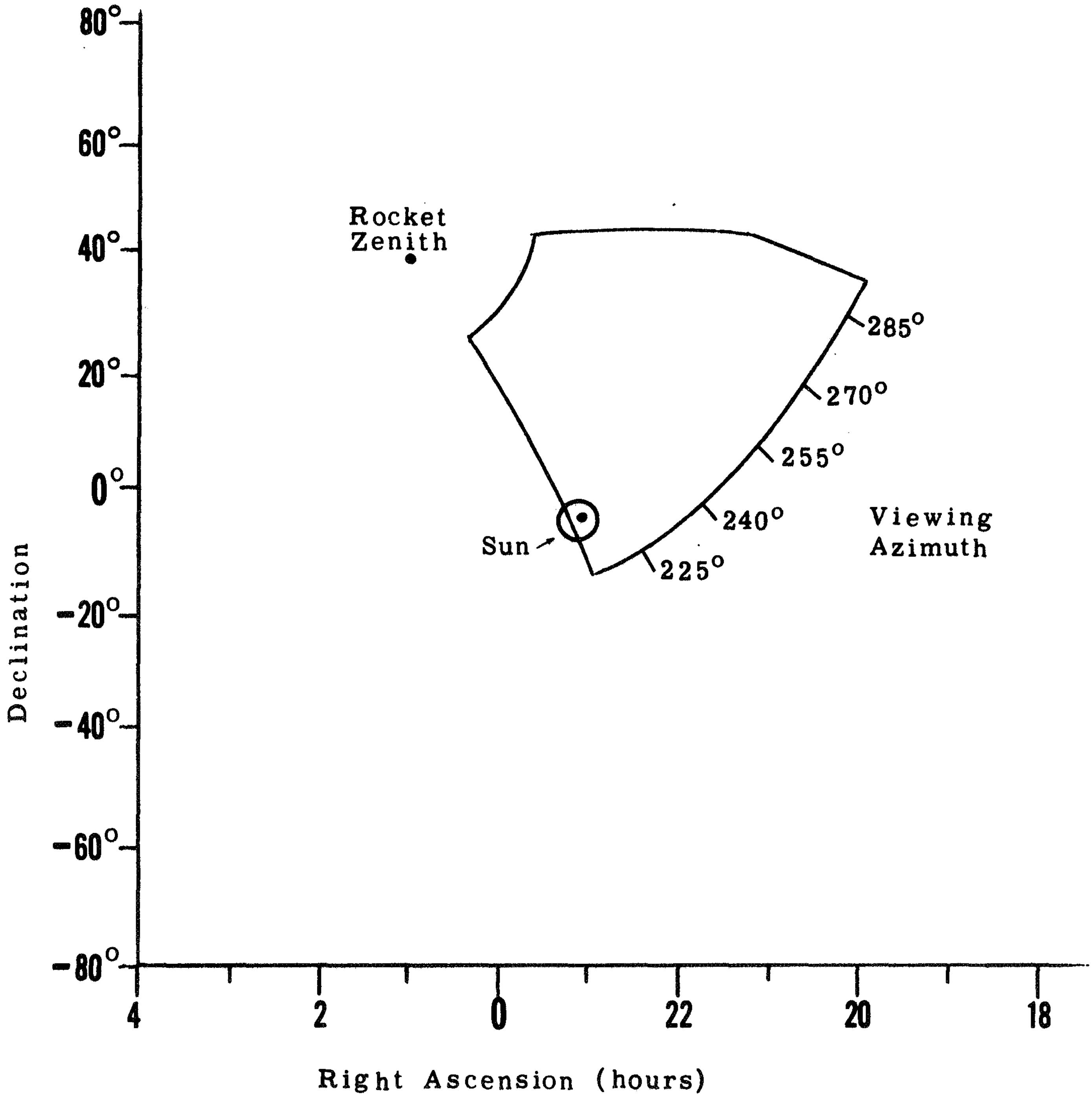
Figure 2. The region of enhanced neutral flux outlined on a sky map. The instruments were scanning in azimuth in a clockwise direction on this map.

TABLE I

		Energy Steps (kev)	Efficiencies	Typical Count Rate in Lowest Energy Channel cps
Analyzer #1 (thicker foil)	H^+	0.38, 0.75, 1.50, 3.00	≈ 1	18,000
	H^o	0.91, 1.40, 2.33, 4.11	$1.4 \times 10^{-5}\ E^{1.67}$ (where E is the energy in kev)	3,000
	Back			10
Analyzer #2	H^+	0.38, 0.75, 1.50, 2.25	≈ 1	18,000
	H^o	0.68, 1.14, 2.02, 2.86	$8.5 \times 10^{-5}\ E^{1.67}$	2,000
	Back			100
Total Detector		Integral $\sim$1 - 20 kev	2×10^{-4}	10,000



Diff. Flux (cm-2 sec-1 str-1 kev-1)
10^10
10^9
10^8
10^7
10^6
10^5
Atomic Hydrogen
Protons
1
2
3
4
Energy (kev)


80°
60°
40°
20°
0°
-20°
-40°
-60°
-80°
Declination
Rocket
Zenith
Sun
285°
270°
255°
240°
225°
Viewing
Azimuth
4
2
0
22
20
18
Right Ascension (hours)

II. NEGATIVE ION DETECTOR

As a result of charge changing collisions which occur during their transit of matter, an incident low energy proton beam will contain both neutral (H^o) and negatively charged (H^-) components in addition to the positively charged component (H^+). *Allison* [1958] has tabulated the expected equilibrium fractions for each component at a variety of energies above 3 kev. In oxygen, at 3 kev, these fractions are H^o = 88%, H^+ = 10.5% and H^- = 1.5%. Since low energy protons precipitated during the aurora encounter an equilibrium thickness at altitudes between 300-400 km, the composition of the precipitated proton flux will be primarily in the neutral state at lower altitudes; a significant fraction will also appear in the negative ion state. Although expected physical effects of large fluxes of 1-10 kev negative ions have not been identified, a direct measurement of the flux and energy spectrums at the three components will provide greater confidence in our understanding of the interaction of protons with matter and more particularily, with the upper atmosphere. The purpose of this investigation was to demonstrate that the flux and energy spectrum of the anticipated auroral negative ions could be determined in the presence of the usually measured precipitated electron fluxes. Our previous measurements [*Bernstein et al.*, 1969a] had indicated that comparable 1-10 kev electron and total hydrogen fluxes were precipitated during the breakup phase. Since the anticipated negative ion component is only 1-2% of the precipitated hydrogen flux, an electron rejection factor of $\sim 10^4$ was selected as a requirement for the unambiguous measurement of the negative ion fraction.

The negative ion detector utilizes a hemispherical electrostatic analyzer, as described by *Bernstein et al.* [1969b], but incorporates a magnetic deflection system in front of the analyzer aperture to remove electrons. This transverse magnetic field was produced by permanent magnets; the field intensity was $\sim$250 gauss for a length of 2 cm. The magnitude of the fringing field at the nearby analyzer was $\sim$10 gauss which should not have a significant effect on the negative ion trajectories.

Our experimental arrangement did not permit determination of the negative ion response in the presence of large electron fluxes and therefore separate independent measurements were used to evaluate the instrument response to each class of particles. The negative ions were produced by charge changing collisions of accelerated monoenergetic protons in the relatively poor vacuum of the experimental arrangement. A simple hot filament was used as the electron source.

Figure 1 shows the response of the electrostatic analyzer to an incident beam of 2 kev negative ions and 10 kev electrons; the dashed curve shows the response to H^- without the magnetic deflection system and the dotted curve shows the response to H^- with the deflection system in place. Without the magnetic field, the measured 10 kev electron flux was 10^5 c/s; the solid curve shows its reduction to $\sim$10 c/s by the presence of the magnetic field. This rejection factor is almost the required 10^4; we believe that with further effort in the reduction of reflection and scattering effects, significant improvement is possible. We attribute the slight reduction in the detection efficiency for H^- with the magnetic field in position to the slight changes in the angle of incidence of the negative ion beam on the analyzer aperture produced by the magnetic field. This effect is entirely amenable to laboratory calibration.

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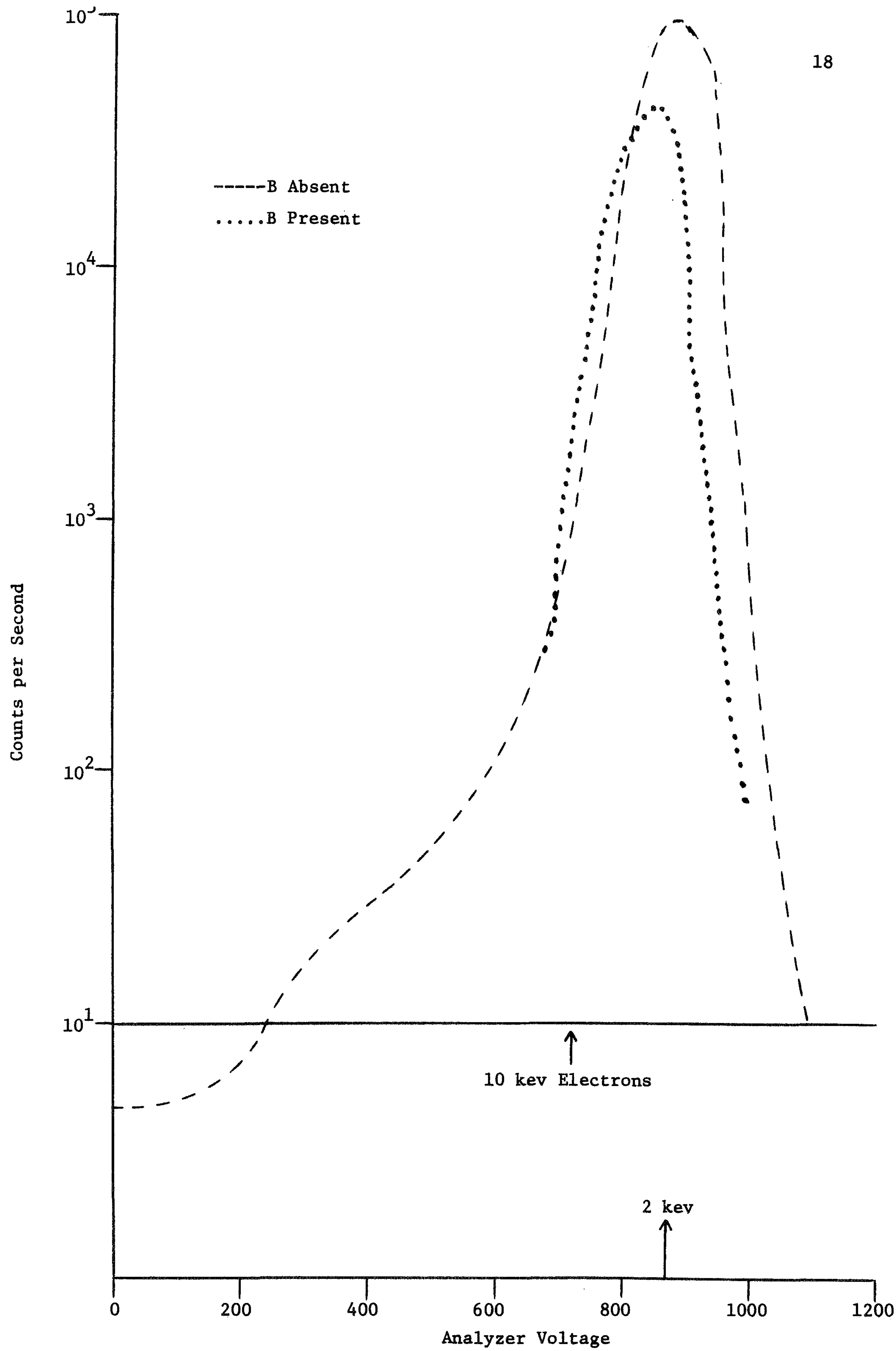
Bernstein, W., R. L. Wax, N. L. Sanders, and G. T. Inouye, An energy spectrometer for energetic (1-25 kev) netural hydrogen atoms, in Small Rocket Instrumentation Techniques, North-Holland Publ. Co., Amsterdam, 1969b.

FIGURE CAPTION

Figure 1. Response of the analyzer to 2 kev H^- ions with and without the magnetic deflection system and its response to 10 kev electrons with the magnetic deflection system in position.



------B Absent
.....B Present
Counts per Second
10^1
10^2
10^3
10^4
10 kev Electrons
2 kev
0
200
400
600
800
1000
1200
Analyzer Voltage