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Contents

28. Negative Ion Composition of the D and E Regions During a PCA

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Abstract

Rocket-borne, cryopumped, quadrupole mass spectrometers were used to measure the negative ions in the lower ionosphere during the November 1969 PCA event. Measurements were made near midday (1147 LT) and midnight 0029 LT) on 3 November. The PCA day flight showed very large concentrations of ions of 32 amu, probably O_2^-, between 72 and 94 km. In two earlier flights into nighttime quiescent conditions, O_2^- was either undetectable or in extremely small concentrations over this altitude range. The PCA night flight also showed O_2^- present below 80 km but ions of mass 16 amu, probably O^-, were generally the predominant ions between 74 and 94 km. In contrast, O^- ions were found only in very small concentrations in the flights during quiet conditions. (The mass range of the PCA day spectrometer did not include 16 amu.) In both PCA flights, heavy negative ions, similar to those measured previously and normally found predominant, were found below 85 km. These ions have been tentatively identified as $NO_3^-(H_2O)_n$, n = 0 to 5, with some possible admixture of $CO_3^-(H_2O)_n$, n = 0 to 5. Ions of mass 76 amu, perhaps CO_4^-, were present below 78 km. In the E-region, Cl^-(35 amu) and NO_2^-(46 amu) ions were measured, but these species may have resulted from contamination.

28-1 INTRODUCTION

This paper reports the negative ion composition measurements obtained in the lower ionosphere during the PCA project. Data were obtained from four rocket flights; two were launched at night prior to the PCA event and the other two were launched near midday and midnight during the event. A general view of the types and altitude distributions of negative ions found in the lower ionosphere under both disturbed and quiescent conditions is presented here.

The measurements were performed with cryopumped, quadrupole mass spectrometers employing a pulse-counting ion detection system. Figure 28-1 shows a schematic of the instrument in the rocket sampling configuration. The electron mask shown is electrically connected to the vehicle skin and serves to reduce the collecting area for negatively-charged particles (especially electrons) to about one-1000th that for positively-charged particles so that the vehicle skin will not be driven overly negative and repel negative ions. Through several rocket experiments, it was found that about +10 volts on the entrance aperture plate will efficiently gather negative ions above 90 km in the E region, but an increasingly larger

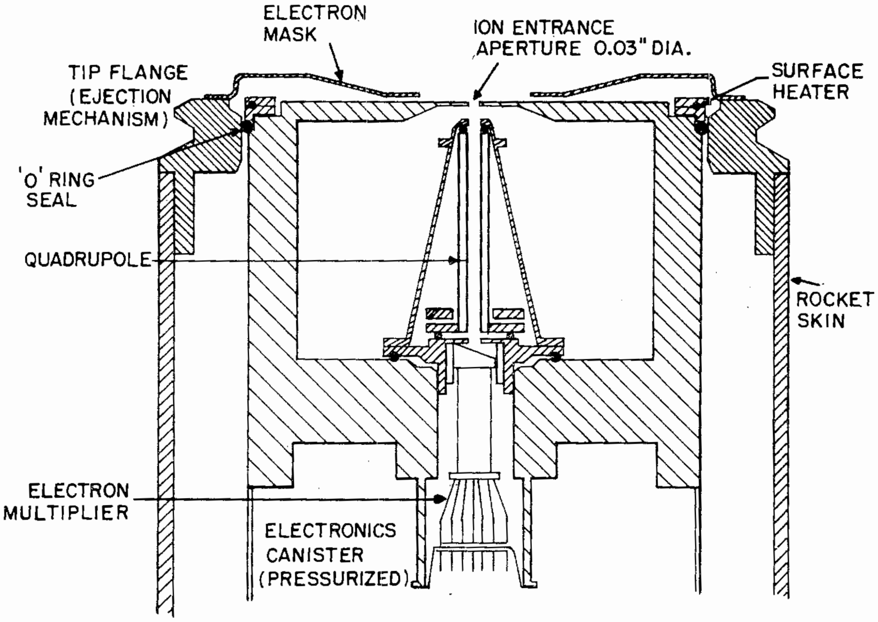

Figure 28-1. Schematic Outline of the Quadrupole Mass Spectrometer in the Rocket Sampling Configuration Showing the Electron Mask Which Reduces the Collection Area for Negative Particles

potential with decreasing altitude was found necessary to draw-in negative ions in the D region. There are still many details concerning the sampling of negative ions that are not understood, and studies of the nature and effects of the electric field are continuing (Narcisi et al, 1971; Sherman and Parker, 1971). Because of these and other complications, the measurements are presented without conversion into ambient concentrations.

28-2 FLIGHTS OF AUGUST AND OCTOBER 1969

Nighttime measurements of the negative ion composition in the D and E regions were performed on two rocket flights from Ft. Churchill, Canada during quiescent conditions. Both instruments were programmed to study the dependence of the negative ion signal on both the draw-in potential and configuration of the electric field. More details concerning these two flights may be found in Narcisi et al, (1971).

Figure 28-2 shows the voltage programming of the quadrupole and the sampling plate for the two flights. In the August flight, the mass spectrum was swept from

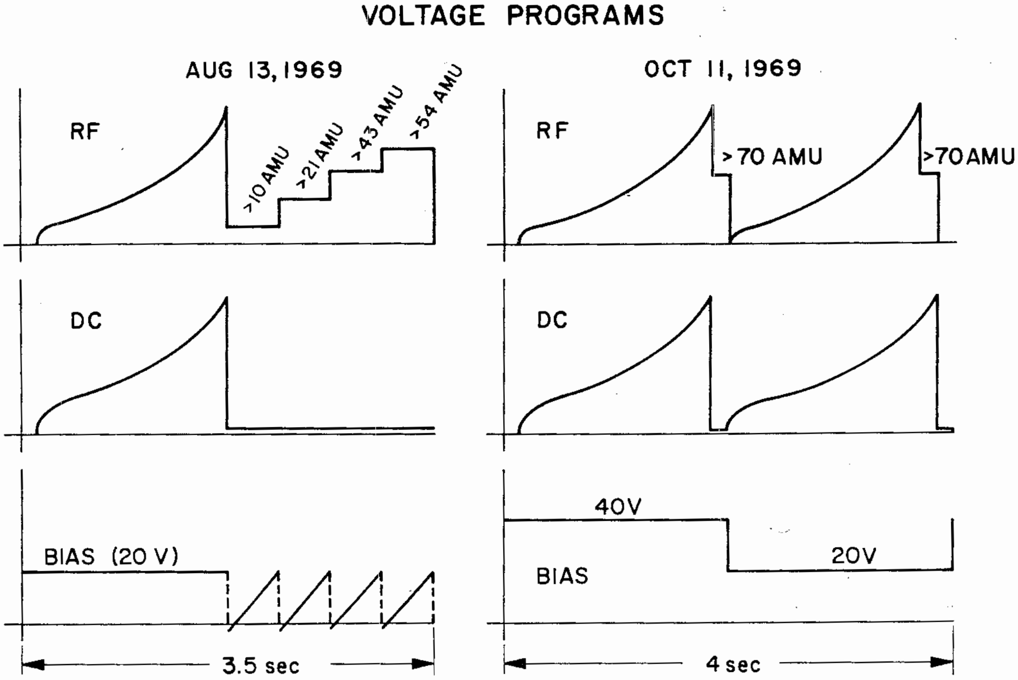

Figure 28-2. Instrument Voltage Programs. Included are the DC and RF quadrupole voltages and also the voltages applied to the sampling plate

12-79 amu, and the total ion transmission mode was stepped so that all negative ions >10, >21, >43 and >54 amu were measured. The sampling plate bias was fixed at 20 volts during the mass scan, but during the total ion steps the plate bias was swept from about 0 to +20 volts. Additionally, the electron mask was switched at apogee and connected to the sampling plate potential throughout descent.

The October flight instrument was adjusted to scan the mass range 12-162 amu because the results of the August flight indicated the presence of heavier mass ions. The sampling plate was alternately biased at 40 and 20 volts, the former because it was found that 20 volts was insufficient for drawing in negative ions efficiently, and the latter for comparison with the August flight results.

Figure 28-3 shows the more striking results of the August flight. Plotted in this figure are the measurements for two of the total ion steps: >10 amu >54 amu. Since the count rate in both steps is about equivalent below 90 km, this indicated that the majority of the ions was heavier than 54 amu. Since the ion count rates measuring up to 79 amu in the mass scan were insufficient to account for the large total ion count rates, this meant that the more abundant negative ions were >79 amu. Mass peaks at 32, 35, 37, 61 ± 1, 63 ± 1, 76 ± 1, 78 (?) amu were measured between 78 and 90 km (Narcisi et al, 1971).

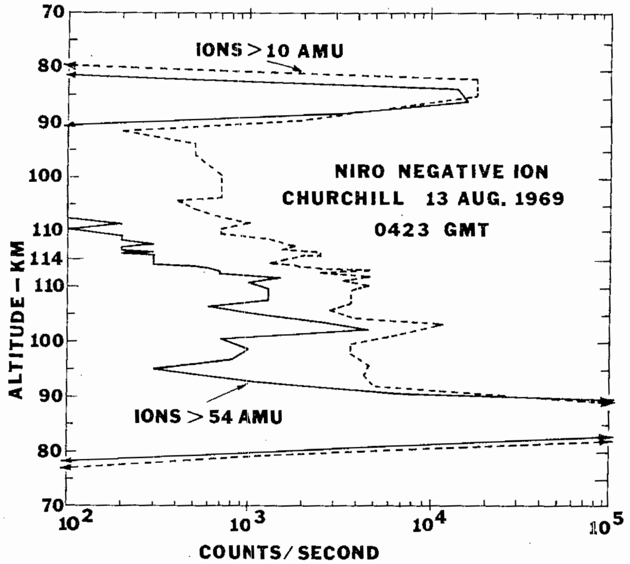

Figure 28-3. Counts/Sec vs Altitude for Ions >10 amu and for Ions > 54 amu for the Flight of 13 Aug 1969. The cutoff below 80 km is due to insufficient draw-in potential and is not real. On ascent, the vehicle angle of attack between 70 and 103 km was less than 10° and increased to 90° near apogee. On descent, the angle of attack attained a maximum of 137° at 100 km and decreased uniformly to 82° at 83 km

The precipitous decrease in the negative ion concentrations between 90 and 92 km is apparent on both ascent and descent in Figure 28-3. The total ion steps separate in the E region, indicating that most of the ions have masses between 10 and 54 amu, and indeed the only negative ions measured were 16(O^-), 35/37(Cl^-), and 46(NO_2^-). The Cl^- and NO_2^- probably arise from contaminants, and O^- may result from the reaction $e + O_2 \rightarrow O^- + O$ which becomes energetically possible when the electrons gain kinetic energy in the attractive electric field. In any case, the negative ion concentrations in the E region are relatively small.

Based on the August results, an instrument was adjusted to scan up to 162 amu to mass analyze the heavy ions, and launched at night at 0200 GMT on 11 Oct 1969. Figure 28-4 is a photograph of the telemetry data in the D region on upleg. Shown are the RF sweep monitor and three spectrum outputs corresponding to 15, 127 and 1025 counts full scale. A digital-to-analog converter in the instrument samples and reads out the counter every 10 msec. Therefore, to obtain counts/sec the counts in the spectra must be multiplied by 100. It is seen that a group of heavy negative ions are present with masses near 62, 80, 98, 116, 134 and 152 amu. Because the mass resolution is low, there are uncertainties concerning the absolute values of these mass numbers, but they do appear to be 18 amu apart, suggesting a multiple hydration of some basic ion. These ions were tentatively identified as $NO_3^-(H_2O)_n$, n = 0 - 5, but possible admixtures of $CO_3^-(H_2O)_n$ cannot be ruled out since multiple peaks may be present within the large peak widths. There is also evidence of a 76 amu peak, perhaps CO_4^-, at lower altitudes. The signal intensity with the 40 volt bias is clearly larger than that for the 20 volt bias. Furthermore, mass 134 appears only at the 40 volt bias, indicating that the draw-in potential affects both the absolute and relative intensities. The 134 amu ion may result from collisional fragmentation of a larger cluster ion after it acquires the dissociation energy in the draw-in field.

Figure 28-5 shows the descent spectra obtained in the D region from the October flight. It is seen that the measurements are essentially identical to those on upleg in Figure 28-4.

28-3 PCA MEASUREMENTS

During the 2-4 November 1969 PCA event at Ft. Churchill, Canada, D and E region negative ion composition measurements were performed near midday and midnight. Figure 28-6 presents the results from the night flight (0029 CST, $\chi = 136^\circ$). The mass 16 amu peak is clearly enhanced during the PCA; only very small peaks at 16 amu are seen in Figures 28-4 and 28-5 during quiescent conditions. Unfortunately, the signal intensity was diminished on upleg because of the slow

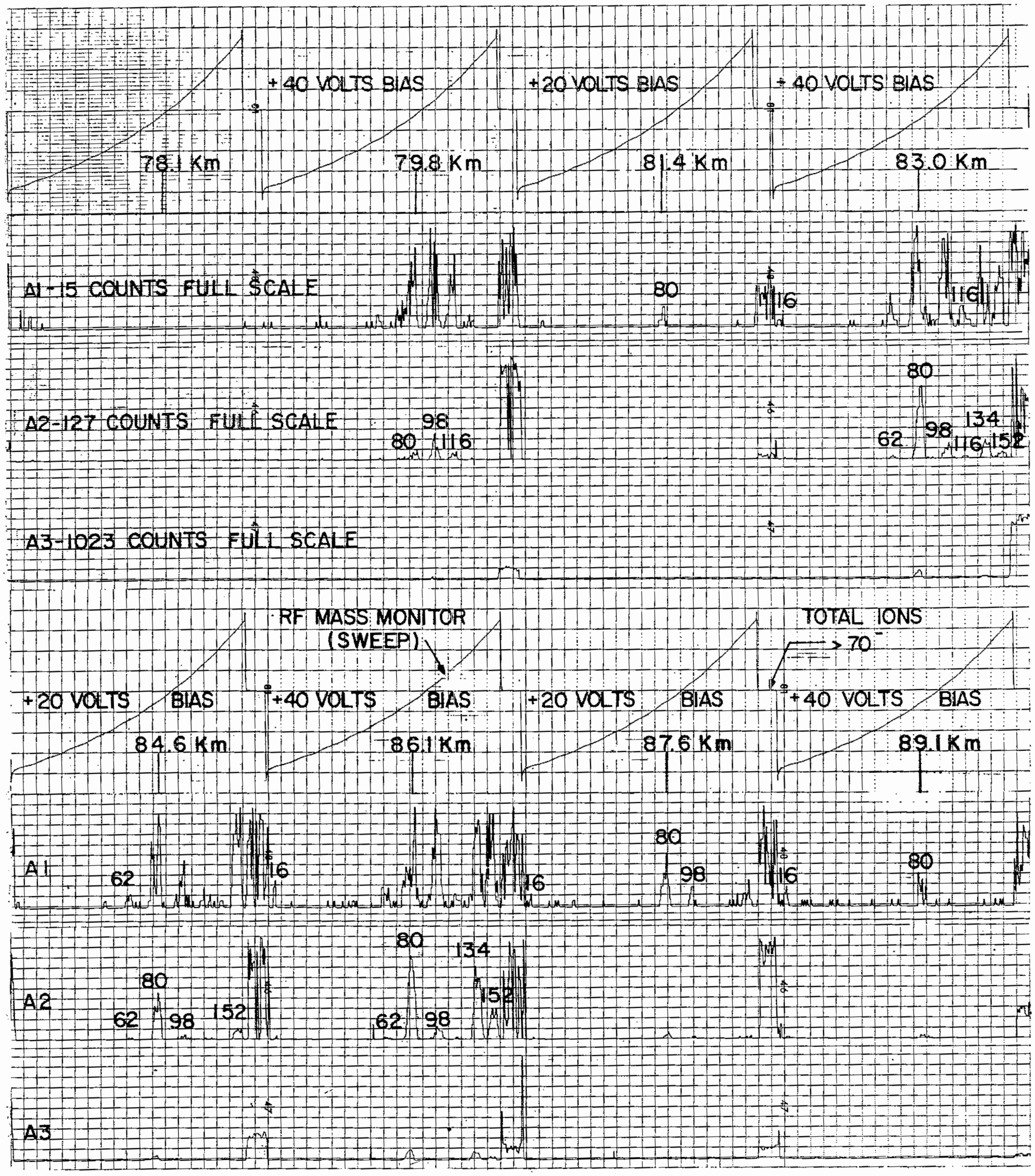

Figure 28-4. Strip Chart Record of Ascent Data Between 77 and 90 km for the Flight of 11 Oct 1969. The vehicle angle of attack was between 15° and 21° over the 77–90 km range

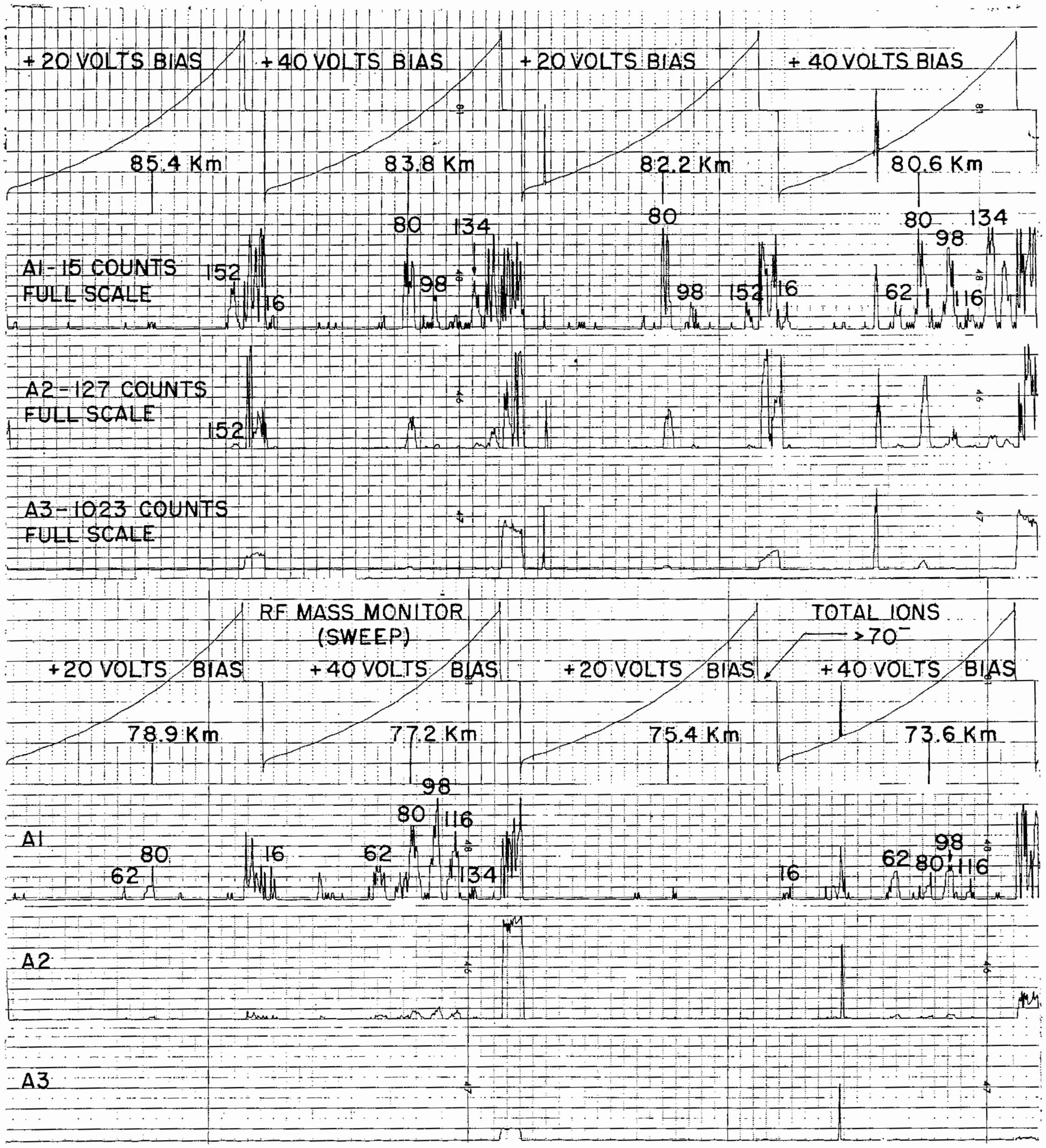

Figure 28-5. Strip Chart Record of Descent Data Between 86 and 73 km for the Flight of 11 Oct 1969. The vehicle angle of attack decreased monotonically from 82° to 11° from 86 to 74 km

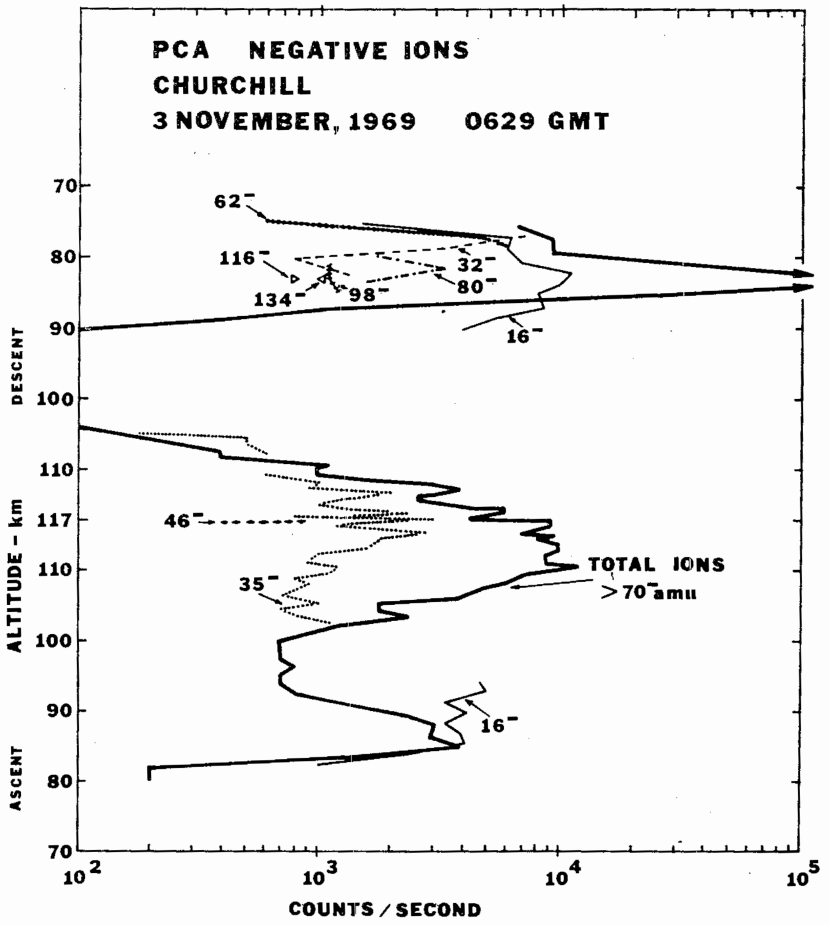

Figure 28-6. Nighttime Negative Ion Composition Measurements in the D and E Regions During a PCA

pump recovery following the pressure burst on nose cone ejection. Collisional loss in the instrument accounts for the absence of the heavy ions in the mass scans on upleg. As the vehicle went over apogee, the pump recovered and the heavy ions appeared in the mass scans on downleg. Heavy ions greater than 70 amu were measured in the more sensitive total transmission mode of the quadrupole and are shown in Figure 28-6. The signal intensity for the ions >70 amu was about equivalent to that for mass 16 on upleg, but on downleg, when the instrument pressure was lower, the signal was off scale (>102, 500 counts/sec). Signal cutoff below 77 km on descent is due to increasing pressure in the quadrupole.

On downleg, the mass 32 amu (O_2^-) concentration becomes larger than the 16(O^-) concentration below 76 km, in contrast to quiescent conditions when O_2^- is present in relatively small concentrations. The E region ions are Cl^- and NO_2^-, which again are probably contaminants.

The daytime (1147 CST, $\chi = 73.9^{\circ}$) PCA measurements are shown in Figure 28-7. Unfortunately, the instrument did not scan down to mass 16, so the profile of O$^-$ is unknown. Clearly the 32 amu ion, identified as O$_2^-$, is a dominant daytime ion above 76 km to 94 km. The heavy cluster ions are still present along with CO$_4^-$(76 amu) below 77 km. The downleg measurements, although affected by vehicle aspect, appear to agree qualitatively with the upleg measurements.

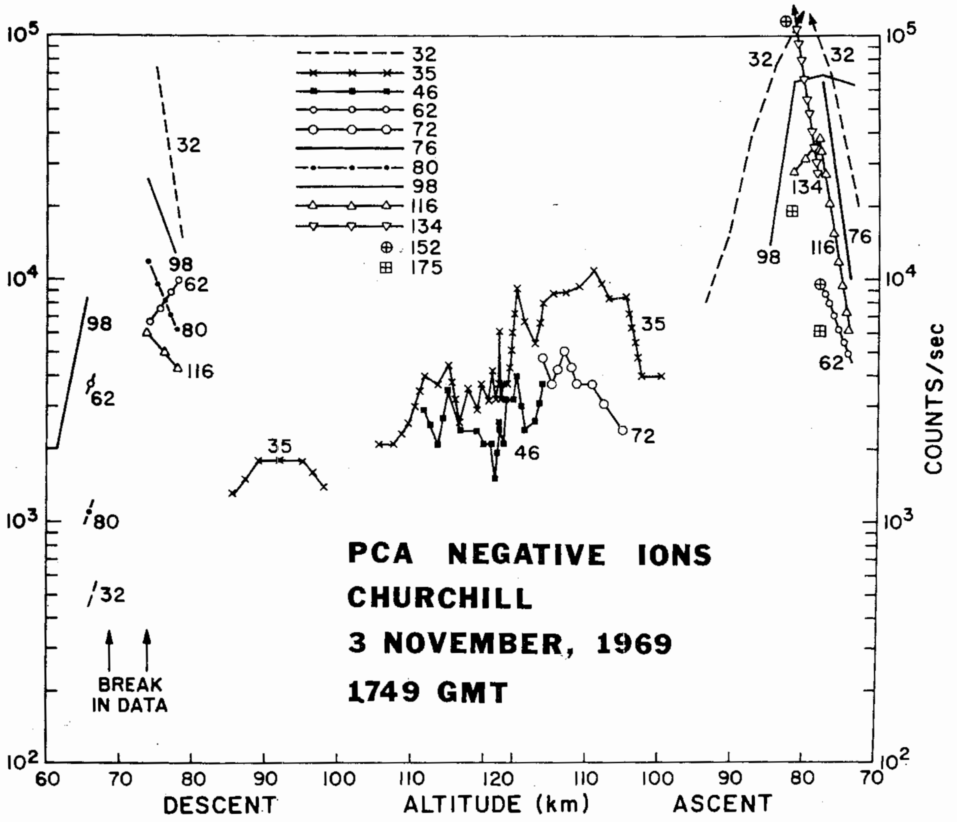

Figure 28-7. Daytime Negative Ion Composition Measurements in the D and E Regions During a PCA

The aeronomical implications of these measurements are discussed by Narcisi (these proceedings).

Acknowledgments

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