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REDUCTION AND SCIENTIFIC ANALYSIS OF DATA FROM THE CHARGE-ENERGY-MASS (CHEM) SPECTROMETER ON THE AMPTE/CCE SPACECRAFT

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G. Gloeckler, Lead Investigator
D.C. Hamilton, Co-Investigator
F.M. Ipavich, Co-Investigator

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Department of Physics and Astronomy
and the
Institute of Physical Science and Technology
University of Maryland
College Park, MD 20742

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Steven Curtis, Technical Officer
NASA, GSFC

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INTRODUCTION

The Charge-Energy-Mass (CHEM) Spectrometer instrument on the AMPTE/Charge Composition Explorer (CCE) spacecraft is designed to measure the mass and charge-state abundances of magnetospheric and magnetosheath ions between 0.3 and 315 keV/e, an energy range that includes the bulk of the ring current and the dynamically important portion of the plasma sheet population. We have have conducted a continuing program of research using the AMPTE mission data set, and in particular, that of the CHEM spectrometer which has operated flawlessly since launch and still provides excellent quality data. The required routine data processing and reduction, and software development continues to be performed. Scientific analysis of unique composition data in a number of magnetospheric regions including the ring current region, near-earth plasma sheet and subsolar magnetosheath continues to be undertaken. Correlative studies using data from the sister instrument SULEICA, which determines the mass and charge states of ions in the energy range ~10 to 250 keV/e on the IRM, as well as other data from the CCE and IRM spacecraft, particularly in the upstream region and plasma sheet have also been undertaken.

SUMMARY OF ACCOMPLISHMENTS

Lithium Tracer Releases

In the first year after the launch of AMPTE our efforts were concentrated on the observation by CHEM of the artifical ions releases by the IRM in the solar wind and geomagnetic tail. None of the ions were detected by the CCE, thus placing upper limit constraints on magnetospheric entry models.

The sister instrument SULEICA on the IRM observed lithium "pick-up" ions in the 5 to 20 keV energy range. The created ions were "picked-up" by the solar wind and moved in cycloidal trajectories in a plane perpendicular to the magnetic field. The observation of the energetic Li "pick-up" ions represented the first time such classical cycloidal ion motion was seen in nature and will prove to be useful in the detection and investigation of natural pick-up ions, such as atmospheric $O_2 \rightarrow O_2^+$.

Ring Current

The first paper on the ring current composition reported that even though protons supplied the largest fraction of the ring current number and energy density (5 to 315 keV/e) in the strongly asymmetric geomagnetic storm of September 4-7, 1984, the contribution of O^+ (at about 30%) was still significant. We found direct evidence for solar wind ions in the ring current (oxygen and carbon ions characterized by high ionization states) and that their entry and subsequent acceleration did not depend strongly on their mass or charge state.

We later reported the discovery of energetic (>100 keV) molecular ions, predominately NO^+ and O_2^+ in the outer ring current at an abundance relative to O^+ of up to ~0.03 during the same geomagnetic storm. These observations, along with the discovery of energetic N^+, convincingly demonstrated that ionospheric plasma is injected into the storm-time ring current and accelerated to >100 keV on a time scale of a few hours or less after magnetic storm onset.

Radial profiles of the energy density, number density, and mean energy for H^+, O^+, O^{+2}, He^+, and He^{+2} were presented for the main phase of the same geomagnetic storm. The O^+ ions showed the largest increase above quiet time levels. The energy density and mean energy of each of the species at L=7 was tracked for a 3-1/2 day period from pre-storm to recovery phase. It was found that the relatively large increase in O^+ energy density during the storm resulted not only from an increase in number density but also from a major increase in mean energy.

We have examined the near equatorial storm-time energy spectra of H^+, O^+, He^+ and He^{+2} ions over the energy range 1-300 keV/e in L=3-6 range. The data were obtained during geomagnetic storms from September 1984 to November 1985, during which period the CCE orbit precessed through the full range of local times. We are reporting on the comparison of the observed local time and radial dependencies of the spectra with those predicted by standard models of magnetospheric convection and loss, using a Volland-Stern electric field potential and both charge exchange and strong pitch angle diffusion losses. Convection and loss processes can explain most but not all of the local time variation in the observed ion spectral features.

In other studies on compositional variations of the ring current, we have found charge exchange to be the dominant factor in determining the temporal behavior of the He^+/He^{+2} and O^+/H^+ ratios during the decay phase of magnetic storms. The N^+/O^+ ratio appears to be anti-correlated with magnetic activity contrary to the expected behavior based only on charge exchange. Recently available data is also being used to explore possible solar cycle composition variations at energies ~100 keV.

The charge state distributions of oxygen and carbon in the magnetosphere have been investigated in detail. The distributions of the various charge states as a function of radial distance, local time, and magnetic activity have been determined. These distributions show the importance of both the solar wind and ionosphere as plasma sources. Their relative importance depends on magnetic activity.

Magnetosheath

The first measurements of the solar wind number density ratios of carbon ($C^{6+} + C^{5+}$), nitrogen ($N^{7+} + N^{6+} + N^{5+}$), relative to oxygen ($O^{8+} + O^{7+} + O^{6+}$) obtained from four solar active periods when CCE traversed the subsolar magnetosheath of the compressed magnetosphere have been reported. On these occasions active solar wind compressed the earth's magnetosphere sufficiently to allow the AMPTE/CCE spacecraft (apogee ~9 earth radii) to enter the magnetosheath, thereby sampling solar wind plasma heated by the bow shock. From simultaneous measurements of energy-per-charge, total energy, and time-of-flight, CHEM allowed the first determination of both mass and charge state of ions in the energy range ~1 to 300 keV/e. It is thus possible to separately identify ions with the same mass-per-charge but with different masses, e.g. He^{+2} and C^{+6}. We have found that the Carbon "freezing-in" temperature in the solar corona is generally less than that of Oxygen. We observed that both the composition and temperature (charge state distributions) are variable on a time scale of $\gtrsim$1 hr. We have now extended composition measurements to heavier elements, up to and including iron. Our preliminary abundance ratios relative to oxygen (in equal energy/charge intervals of 0.3 to 12 keV/e) for Ne, Mg, Si-Ar, and Fe are 0.08, 0.20, 0.20, and 0.23 respectively. These ratios are in good agreement with solar energetic particles (SEP) abundance ratios as well as SEP-derived coronal abundances of these elements. Our solar wind C/O ratio is substantially below the generally accepted photospheric value of 0.60.

Plasma Sheet

We have reported the first measurements of the spin-averaged, time-averaged distribution functions of H^+, He^{+2}, $(CNO)_{\gtrsim}^{2+}$, O^+, He^+, N^+, and O^{2+} in the near-earth ($\sim 9R_E$) plasma sheet on March 23, 1985 during quiet times (K_p=0 to 1^-) in the dynamically important energy range of ~1 to 315 keV/e. We found that the spectra of ionospheric origin ions had identical shapes as a function of energy per charge which may be fitted by a Kappa function with a temperature of ~2 keV/e and a power-law exponent of -4.5. The spectra of solar wind origin ions (He^{+2} and CNO) were also identical in terms of energy per charge; however, their shape was distinctly different from the ionospheric ions (they may be fitted with a shifted [by ~6 keV/e] Kappa function of temperature ~1keV/e and index -4.5). The spectrum of protons had a shape between these two extremes and could be fitted by a superposition of the "solar-wind" spectrum and the "ionospheric" spectrum. We estimated from these fits the amount of ionospheric hydrogen to be about 20 to 25% of the total H^+.

The presubstorm spectra of H^+, O^+, He^+, and He^{+2} obtained by SULEICA at ~15 R_E in the plasma sheet at another time (April 8, 1985) are remarkably similar to the CHEM quiet time spectra both in shape and absolute intensity. Simultaneous with the substorm onset on the same day and with strong earthward plasma flow, SULEICA detected strong increases in ionospheric origin energetic ions and significant hardening of the spectra, most pronounced for O^+. The enhancement ratios were found to be organized in terms of energy per charge. We interpreted these observations as an indication for particle acceleration by electric fields with additional injection of ionospheric plasma into the plasma sheet after substorm onset.

Upstream Ions

The SULEICA instrument on IRM detected a short burst of energetic O^+ in the upstream region. The onset of this burst of O^+ coincided with a short burst of electrons. We found the O^+ streaming predominantly into the sunward direction while the energetic (20 to 80 keV/e) H^+ and He^{+2}, which were observed to have the classical step function time-intensity profiles lasting several hours, exhibited a second order anisotropy perpendicular to the almost radial magnetic field. Furthermore, the energy spectrum of O^+ was significantly harder than those of the solar wind accelerated H^+, He^{+2}, and CNO ions. We interpreted these results in terms of two different particle populations (since they had different temporal evolutions, anisotropies and energy spectra): (1) the bow shock accelerated population of H^+, He^{+2}, and CNO ions and (2) the energetic magnetospheric ions (O^+, e^-) injected during a short time interval into the upstream region.

Interstellar Helium

Using data from the SULEICA sensor on AMPTE/IRM we reported the first direct observations of interstellar helium. As the neutral interstellar helium penetrates the solar system it is ionized by solar UV and charge exchange with the solar wind. The resulting He^+ pick-up ions have a maximum velocity equal to twice that of the solar wind. In addition to observing this maximum velocity, we also found that the He^+ ions are isotropic in the solar wind frame, implying that the ions have undergone substantial pitch angle scattering. We also observed a significant flux increase of the interstellar helium in the month of December, consistent with gravitational focusing of the interstellar neutral wind on the "downwind" side of the sun. With the CHEM instrument we detected these interstellar He^+ pick-up ions in the magnetosheath.

DATA REDUCTION AND SOFTWARE MAINTENANCE

In addition to the routine processing and color slide production performed by the Science Data Center, a number of routine processing tasks are performed on the CHEM data at the University of Maryland. These tasks utilize the SDC VAX 785 computer but are initiated at UMD and produce their output at the UMD. They are:

1. A daily listing is made and archived of the CHEM housekeeping parameters on a 3.2 minute basis from data (both MDRs and Real Time) processed by the SDC the previous day. Examination of this listing provides a current check of CHEM health.
2. A daily log of the messages produced by the CHEM basic processor during the previous days real time data processing is printed and archived. This log is examined to discover processor problems.
3. A daily listing is made and archived of all CHEM counting rates for a particular voltage step on a 3.2 minute basis from MDR data processed the previous day. This listing provides a quick overview of magnetospheric conditions.
4. The science pool color slides and line plots produced by the SDC for CHEM data and the microfiche data from other CCE experiments are logged in, sorted, labelled, and stored for easy access.
5. Copies of CCE pool data (slides and line plots) and CHEM Summary Data Files on magnetic tape are distributed to the CHEM co-investigators at MPAe.
6 Maintenance is performed on all the standard CHEM processing and science pool generation programs as the need arises.

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