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TEMPERATURE DISTRIBUTION OF THE IONOSPHERIC PLASMA AT F LAYER

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ABSTRACT

Langmuir probe was housed in the sounding rocket to test the probe's performance and to find the environmental parameters at the F layer of the ionosphere. The gold plated cylindrical probe had a length of 14 cm and a diameter of 0.096 cm. The applied voltage to the probe consisted of 0.9 sec fixed positive bias followed by 0.1 sec of down/up sweep. This ensured that the probe swept through the probe's current-voltage characteristic at least once during 1 second quiescent periods enabling the electron temperature to be measured during the undisturbed times of the flight. The experimental results showed good agreement of the temperature distribution with IRI model at the lower F layer. In the upper layer, the experimental temperatures were 100-200K lower than the IRI model's because of the different geomagnetic conditions: averaged conditions were used in IRI model and specific conditions were reflected in the experiment.

1. INTRODUCTION

The SPEAR-3 experiment was designed to study the interaction of a high-voltage system with the ambient ionospheric plasma at low earth orbit (LEO). The experiment intended to test the effectiveness of the four kinds of grounding techniques, to diagnose the relationship of the plasma current and applied potential, and to monitor the undisturbed and disturbed plasma and the neutral gas environments (Raitt *et al.* 1994).

A Neutral Pressure Gauge (NPG) and a Langmuir Probe (LP) served to acquire parameters related to the ambient neutral gas and ionospheric environment of the payload. The NPG provided neutral gas pressure near the payload body, and the LP enabled local electron density and electron temperature to be measured. In order to obtain the characteristics in the experimental environment, the LP and the NPG were deployed from the payload system. The LP measured collected electron and ion currents to the probe from the ionospheric environment. The current-voltage relations provided electron densities and temperatures at the experimental altitude during passive periods introduced between the active experiments (Merlino 1992, White 1992).

2. IONOSPHERIC ENVIRONMENT

The ionosphere is the partially ionized region of the upper atmosphere. The ionized gases are due to the effect of the balance of photo ionization by solar radiation and recombination and transport of electrons and ions. The altitude of the ionosphere starts at approximately 60km and extends to approximately 1000km. The ionosphere is composed of different characteristic regions named the D, E, and F layer, which are characterized by their compositions and density distribution with altitude.

The D layer, ranging from 60km to 90km, is present during the daytime. Lyman Alpha and X-rays of the solar spectrum cause ionization to produce NO^+ and O_2^+. The plasma density increases as altitude increases.

The peak density of the E layer appears around 110km high and the layer spreads up to 150km. The dominant plasmas are NO^+ and O_2^+ produced by Lyman beta and soft X-rays.

The electron density in the F region increases at first, reaches a peak, and then decreases with an increase of altitude. The F layer is divided into two regions: the F1 and the F2 layers range 150-200 km and above 200km, respectively. The ionization source in the F region is the solar extreme ultraviolet (EUV) radiation. The peak in the F region results from the increasing dominance of plasma diffusion as the altitude increases. The F1 layer and below diminish in number density when the influence of solar radiation disappears after sunset. Molecular nitrogen is the dominant gas around the altitude of plasma density peak, but the dominant positive ion is O^+ as a result of photochemical processes.

The altitude of LEO is located in the F2 layer, which exhibits a higher plasma density than exhibited by the F1 layer. The major ion is atomic oxygen, and the average electron density is about $10^{11} - 10^{12}$ m^{-3}. The electron temperature is widely spread in the range of 1000K to 3000K, corresponding to a mean thermal speed of roughly 200km/sec. On the other hand, for ions, the temperature covers 800K to 1500K, which is equivalent to about 1km/sec of mean thermal ion speed for atomic oxygen. The pressure at this region ranges between 10^{-7} and 10^{-8} Torr, and the ionic mean free path is 4.5km to 15km. Accordingly, the ionospheric plasma can be considered as a collisionless gas in the F2 region. The parameters described above lead to Debye length of less than 1cm for electric potential shielding and to plasma frequencies of 3 to 16MHz. The strength of the geomagnetic field at the ionospheric region is about 0.3-0.4 Wbm^{-2}, which corresponds to 0.03-0.05m and 3-4m of gyroradius for electrons and O^+ ions, respectively.

3. EXPERIMENTAL SYSTEM

The payload body was cylindrical shaped, 7.02m in length (in the launch configuration) and 0.438m in diameter, and weighed 496.2kg. The payload was comprised of eight sections included science-1 and science-2 module. Langmuir probe was installed in the science-2 module, which was the lower part of the payload, in order to avoid direct contact with undisturbed plasma (Roosta 1992).

The length and weight of the science module-2 were 1.21m and 87.17kg, respectively. This section contained the LP, and the NPG. The LP and the NPG provided data related to the ionospheric environmental characteristics (*e.g.*, electron density and temperature, and neutral pressure). The LP measured plasma currents during the flight to find the electron density and temperature in the ionospheric environment, and the NPG was intended to obtain the ambient neutral gas pressure near the payload surface (Merlino 1992, White 1992).

The LP was deployed on a short boom near the payload surface. The LP had a long cylindrical shape, 14cm in length and 0.24cm in diameter, in order to neglect edge effect. The surface was coated with gold. Figure 1 shows the electrode configuration of the Langmuir probe (White 1992).

To bias the probe, a potential waveform was applied for 1 sec of quiescent time. The sweep voltage applied potential ranged from +5V to -5V. The applied potential waveform had a period of 1 sec and consisted of a fixed positive potential for 0.9 sec followed by an up/down sweep followed for the remaining 0.1 sec. During every quiescent period, the LP collected the return current from the ambient plasma. The LP data provided the ambient plasma density and temperature by analyzing the current-voltage relationship during the sweep periods in the quiescent periods between capacitor discharges (Rhee 1997).

4. RESULTS AND CONCLUSIONS

Since Langmuir & Blodgett (1923a, 1923b, 1924) studied the characteristics of current collection on different geometric electrodes, the Langmuir probe has been used as a device to identify plasma density and temperature. The currents, either electron or ion, absorbed on the surface of an electric probe depend on the probe's potential, geometry, surface area, and the plasma distribution function. The relation of current to potential provides data about the electron density and temperature during the flight. Data collection for the electron and ion current was performed during quiescent periods between capacitor discharges because the measurement in the quiescent period enabled us to obtain the plasma temperatures and densities under an undisturbed condition.

Figure 2 illustrates the characteristic curve of a probe potential to normalized electron current; the curve appears in a typical cylindrical probe (Chen 1965, Kelly & Heelis 1989).

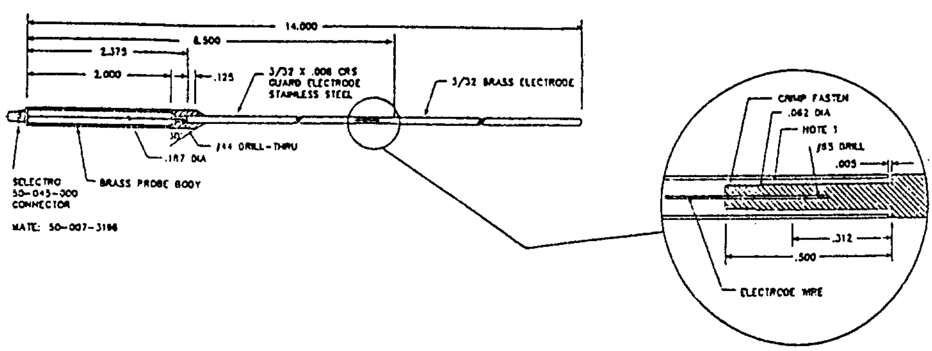

Figure 1. Langmuir probe configuration.

The characteristic curve is divided into three sections depending on applied probe potential. When the probe potential is sufficiently negative to repel electrons and to attract ions, ion current is dominant in the ion saturation region. In contrast, when the probe potential is adequately positive to repel ions and to attract electrons, electron current is common in the electron saturation region. The electron retardation region is the part in which electron current dominates until the thermal electrons are retarded. In the electron retardation region, the current-potential relationship is

$$i_e = n_e e A (k_B T_e / 2m_e)^{1/2} exp(-eV/k_B T_e) \quad (1)$$

where n_e is the electron density, A is the probe area, k_B is the Boltzmann constant, T_e is the electron temperature, m_e is the electron mass, and V is the probe potential. Logarithmic expression for the above equation provides Equation (2) that the electron temperature is readily found as a slope of the linear relation

$$ln(i_e) = -eV/k_B T_e + constant \quad (2)$$

The electron temperature distribution derived from the LP is compared with that from the International Reference Ionosphere (IRI) model 1990 version, which is an averaged statistical model to describe ionospheric conditions. The IRI model requires a few parameters to calculate the electron temperature and density as a function of altitude. The SPEAR-3 flight data provides the required data: 37.8 degrees latitude and 284.4 degrees longitude on the payload launching side; 37.3 degrees latitude and 286.9 degrees longitude on the other side. The launching time was 21:13 (local time), and the flight lasted V-I characteristic curve for approximately 9minutes on March 15, 1993. The National Geophysical Data Center provides the records of selected geomagnetic and solar activity indices that show the geophysical environments of the experiment. According to the records, the Zurich sunspot number Rz12 was 60.0, the solar particle effects on the earth's magnetic field were medium disturbance at the index 4 and 1/3, and solar radio flux was around 125 watt m^{-2} sec^{-1} (Rhee 1996).

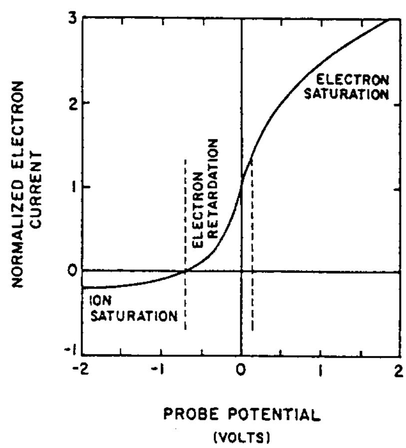

Figure 2. Typical Current-Voltage Characteristic Curve.

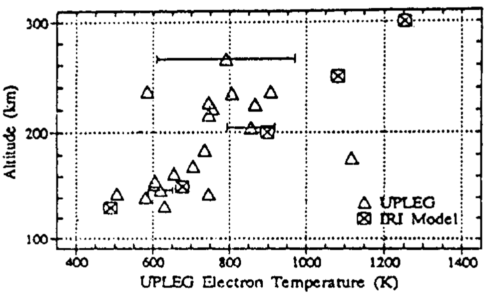

Figure 3. Temperature distribution of the ionospheric plasma at the F layer on upleg side.

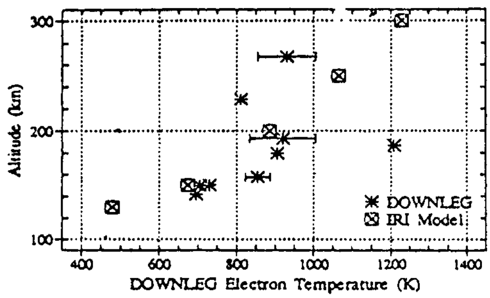

Figure 4. Temperature distribution of the ionospheric plasma at the F layer on downleg side.

At the experimental altitudes ranging from 120 to 290km, Figure 3 and Figure 4 present the electron temperature distribution derived from the LP and the IRI model on both of the upleg and downleg side. Figure 3 shows on the upleg side that SPEAR-3 data agree with the IRI model below 200km, but deviate to a lower temperature than the IRI model above 200 km. In Figure 4, the LP electron temperatures are more widely spread, but above 200 km in altitude, they show a similar pattern to the temperature distributions at a lower temperature part. The temperatures from the IRI model are included in the experimentally observed range.

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