

Balloon-borne Langmuir Probe Measurement of Stratospheric Ions in Low Latitudes

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A balloon carrying a Langmuir probe payload for measuring the positive and negative ion densities in the stratosphere was flown around midnight IST on 23 Mar. 1982 from the National Balloon Facility at Hyderabad, a low latitude station. The Langmuir probe with a guard ring arrangement is given a symmetrical probe voltage of triangular waveform with amplitude ± 4.2 V and with a repetition frequency of 0.28 Hz. The balloon reached a ceiling altitude of 33 km and data were taken from 15 km up to the ceiling altitude. The altitude profiles of the ion density show a peak around 18 km with densities decreasing with altitude. The results are discussed in terms of cosmic ray production and ion chemistry. The structures in the positive ion density profile are interpreted in terms of the presence of aerosol layers.

1 Introduction

The stratosphere presents a complex picture so far as the neutral and charged particles are concerned. In this region, the charged particles exist in the form of positive and negative ions including their heavy cluster formations. A detailed knowledge of stratospheric ion densities and their mobilities is essential for understanding the middle atmosphere electrodynamics. Although these measurements have been carried out at mid and high latitudes by several workers¹⁻³, no significant data are available for low latitudes. Thus there is need for such measurements at low latitudes. Moreover, in view of the starting of middle atmosphere programme (MAP) systematic measurement of these parameters in the low latitude zones of the Indian subcontinent is of interest. Therefore, a balloon-borne Langmuir probe experiment was conducted in March 1982 from Hyderabad, a low latitude station. In this paper, we present the results of this balloon measurement of stratospheric ion densities. The ion density is derived from the measured probe current by using subsonic mobility theory and it is compared with the theoretical ion density profile derived from the steady-state continuity equations. We show that by comparing the experimental and theoretical profiles it is possible to deduce aerosol layer densities.

2 Experiment

The payload for the balloon experiment consisted of a Langmuir probe sensor and associated electronics. The design of the probe sensor arrangement is shown in Fig. 1. A symmetrical probe voltage of triangular waveform and of an amplitude ± 4.2 V, at 0.28 Hz repetition frequency was applied to both the nose tip

probe and the guard ring which is an adjacent section of the nose cone ogival; these two parts are insulated from each other and the balloon's common ground. The electrometer was inserted between the nose tip and the guard ring. The electrometer had a logarithmic response with a dynamic range of three decades with a minimum sensitivity of 5×10^{-11} amp.

The major problem in balloon flight is the very low temperature encountered by the payload at the tropopause in low latitudes. The normal temperature at the tropopause over Hyderabad, a low latitude station, is around -80°C to -90°C at which the payload electronics will have to survive. To overcome this problem the steel gondola which housed the payload, telemetry transmitter, battery packs, etc. was fully covered by thick sheets of thermocole in order to ensure that the inside temperature is maintained

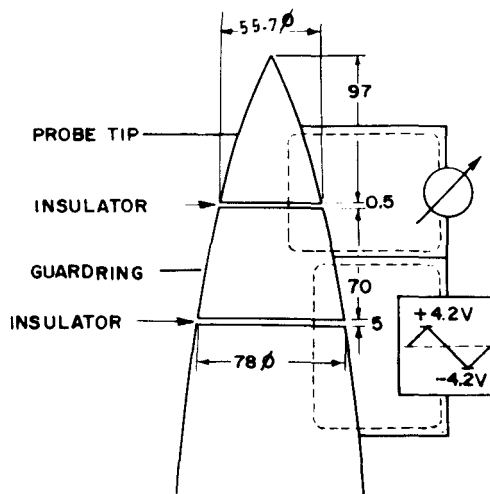


Fig. 1—Details of probe with guard ring arrangement

around 0°C. The instrument was tested on the ground at -2°C for a few hours to qualify it for the balloon flights.

3 Flight Details and Data Analysis

The trajectory of the balloon is shown in Fig. 2. The balloon ascended at the rate of 200 m/min and it took 3½ hr for the balloon to reach the ceiling altitude of 33 km. It was allowed to float at the ceiling altitude for 2 hr before it was cut off.

The current profile for the positive ions obtained during ascent is shown in Fig. 3. The recovery of ion densities from the measured probe currents presents a problem because of high collisions of ions with neutral particles so that the normal Langmuir probe theory is inapplicable in the stratosphere. In the stratosphere, collisions play an important role in the charged

particle collection by electrostatic probes. Hoult⁴ has shown that for a blunt subsonic electrostatic probe ion collection is mobility-controlled. Sonin⁵ has shown that for electrostatic probes of blunt or conical geometry, in the limit of strongly attracting field the ion collection of the probe is independent of flow effects and the expression for the probe current is the same as that for a subsonic or static probe⁴.

The current collected by the probe can be related to ion densities by a simple mobility expression⁴

$$I_+ = N_+ e \mu_+ E A \quad \dots(1)$$

where

I_+ Saturation positive current collected by the probe

E Electric field at the probe surface

μ_+ Mobility of positive ions

N_+ Number density of positive ions

A Area of the probe surface

Using Eq. (1) the probe current is converted into ion density.

Assuming that the mobility of the different positive ions is comparable in values and may be represented by an effective small ion reduced mobility⁶, we may write,

$$\mu_+ = \mu_{0+} \frac{T P_0}{T_0 P} \quad \dots(2)$$

where

μ_{0+} Reduced mobility at STP

T_0 Standard temperature

P_0 Standard pressure

The parameters T and P are actual temperature and pressure, respectively, determined either by direct measurement or assumed from a standard atmospheric model such as CIRA. Cole and Pierce⁷ recommended $1.8 \times 10^{-4} \text{ m}^2/\text{V sec}$ as a reasonable value of the reduced mobility. But recent measurements show that μ_{0+} lies between 1.3×10^{-4} and $1.5 \times 10^{-4} \text{ m}^2/\text{V sec}$ (Refs 8,9). In the present study, we have used a value of $1.5 \times 10^{-4} \text{ m}^2/\text{V sec}$ for the reduced mobility based on more recent work of Rosen and Hoffman⁹.

The values of T and P up to 20 km have been taken from the model of Ananthasayanam and Narsimha¹⁰ and from 20 to 30 km the value of the US standard atmosphere¹¹ was used.

The electric field E was calculated from the following expression⁵

$$E = \frac{\alpha V_p}{L} \quad \dots(3)$$

where

E Electric field at the probe surface

V_p Applied probe potential

L Length of the probe-tip

α Constant depending on the geometry of the probe

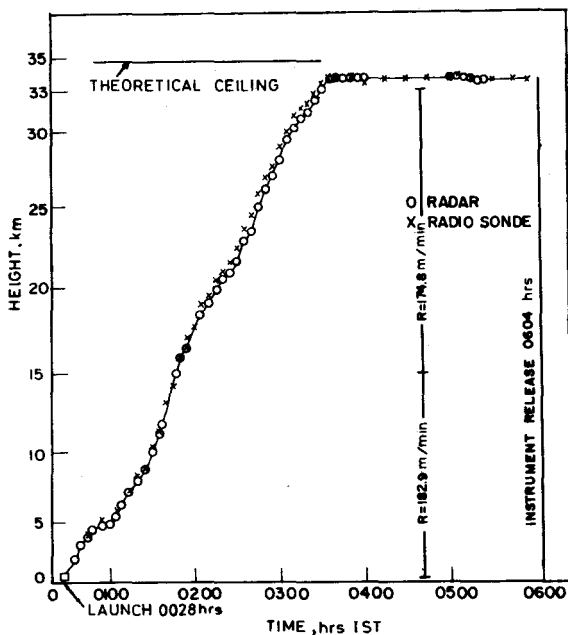


Fig. 2—Trajectory of the balloon

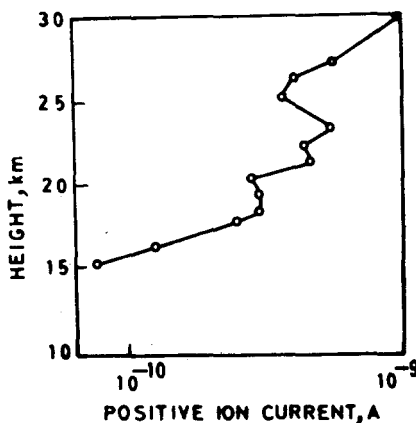


Fig. 3—Positive ion current altitude profile

In our case, the value of α is estimated to be 0.1.

4 Results and Discussion

The positive ion density profile, as derived from the measured probe current by Eq. (1) is shown in Fig. 4. The ion density profile shows a peak around 18.5 km, falling off with altitude and reaching a minimum value at about 26 km; it remains practically constant above this altitude. It may be seen that considerable structure is present in the profile in the altitude range of 18 to 26 km. However, the absolute values derived here seem to be higher by almost two orders of magnitude as compared to those reported by Rose and Widdel¹, Hale¹² and other workers. This discrepancy is perhaps due to some systematic error in the assumed parameters. For example, in the assumption of the reduced mobility value there may be an uncertainty of 20%; the uncertainty in the estimation of E may be by a factor of two or three. This discrepancy is being investigated.

In view of this large uncertainty in deriving the absolute values of ion densities, the ion densities are normalized with respect to the peak value at 18.5 km and are compared with the theoretical ion density profile, computed and normalized to the value at the same altitude of 18.5 km.

In the stratosphere, the main source of ionization is galactic cosmic rays and the ions are lost by the three-body and two-body ion-ion recombinations. The steady state stratospheric ion densities may be expressed by the simple relationship

$$N^+ = \sqrt{\frac{Q}{\alpha_T}} \quad \dots (4)$$

where

- N^+ Positive ion density
- α_T Total ion-ion recombination coefficient
- Q Production rate

The production rate Q for the stratosphere over Hyderabad is calculated from the formula given by

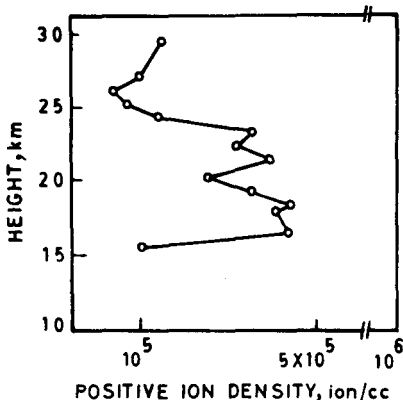


Fig. 4—Positive ion density altitude profile

Heap¹³. The value of α_T is taken from Bates¹⁴ and used in the theoretical ion density profile computed from Eq. (14). Fig. 5 shows this theoretical profile and the altitude profiles of Q and α_T , from which the theoretical profile has been arrived at.

Fig. 6 gives the normalized profiles of both measured and theoretical ion densities for comparison. It is observed from Fig. 6 that the measured ion density falls off more steeply than the theoretical profile almost by a factor of 2 at 30 km.

It is now well known that there is a permanent aerosol layer at about 20 km, in which large nuclei are found¹⁵. In the presence of aerosols, stratospheric ions can be lost quickly by attachment to aerosol particles, which is much faster than the mutual neutralization or three-body recombination. If an aerosol layer is present in the stratospheric altitude this would cause the ion density with altitude to fall faster than that derived assuming loss by either mutual neutralization or three-body recombination. The steeper fall in the measured profiles in contrast to the theoretical profile supports this view. On this hypothesis we may now proceed to derive the aerosol layer density which

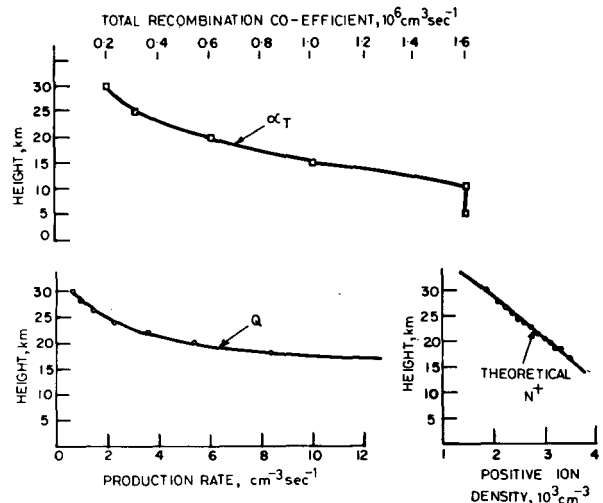


Fig. 5—Profiles showing assumed production and loss rates and the computed theoretical positive ion density

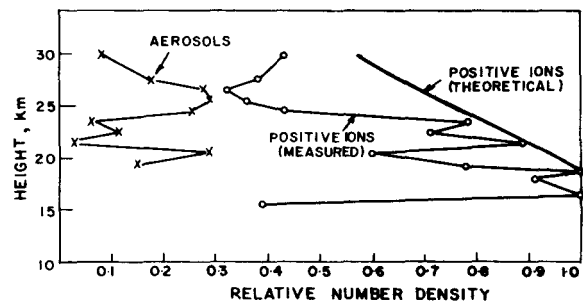


Fig. 6—Altitude profile of relative concentrations of stratospheric positive ions (measured and theoretical) and aerosols

would account for the features observed in the normalized measured ion density profile of Fig. 6.

Under equilibrium condition, Eq. (4) will be modified due to presence of aerosols and given by

$$Q = \alpha N^{+2} + \beta N^+ N \quad \dots (5)$$

where

N Number density of aerosols
 β Combination coefficient of small ions and large aerosol particles (β has a rough value of $3 \times 10^{-6} \text{ cm}^3 \text{ sec}^{-1}$.)

For a reference altitude corresponding to the peak ion density, we write

$$Q_0 = \alpha_{T_0} N_0^{+2} \quad \dots (6)$$

where α_{T_0} and N_0^+ are the values of α_T and the positive ion density, respectively, at the reference altitude.

By a manipulation of Eqs (5) and (6), we may obtain the aerosol number density as

$$\frac{N}{N_0^+} = \frac{\alpha_{T_0}}{\beta} \cdot \frac{N^+}{N_0^+} \left(\frac{Q}{Q_0} \cdot \frac{N_0^{+2}}{N^{+2}} - \frac{\alpha_T}{\alpha_{T_0}} \right) \quad \dots (7)$$

Eq. (7) is used to derive the aerosol layer profile and shown in Fig. 6, in which the theoretical and measured positive ion density profiles are also plotted for comparison. Results from Eq. (7) were also computed with the detailed ion scheme¹⁶. The detailed calculations essentially verified the aerosol profile derived using Eq. (7). The layer peak is located at 21 km above the tropopause. It may be pointed out that the tropopause in the equatorial region of Indian subcontinent is about 16-18 km.

5 Conclusions

It is thus observed that the ion density measurements in stratosphere would provide a powerful way of monitoring the aerosol layer. The balloon-borne Langmuir probe experiment looks very promising in this respect. In order to optimize future ion density measurements the following additional experiments would be needed.

- (i) Temperature sensor
- (ii) Cosmic ray background monitor
- (iii) Aerosol measurement

This has to be coordinated with ground-based experiments for (ii) and (iii).

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