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FIRST ELECTROSTATIC PROBE RESULTS FROM EXPLORER 17*

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INTRODUCTION

On April 3, 1963, the Explorer 17 satellite was launched into a 58° inclination direct orbit having perigee and apogee altitudes of 258 and 927 km, respectively. In addition to the neutral particle instruments [*Spencer and Reber*, 1963, *Newton et al.*, 1963], two cylindrical electrostatic probes were used, one for the measurement of electron temperature (T_e) and the other for determining the positive ion density (N_i). The purpose of this letter is to report the variations in T_e and N_i observed above the Blossom Point, Maryland, telemetry station (latitude 38°N, longitude 77°W) and to briefly discuss the more immediate conclusions that can be drawn from the data.

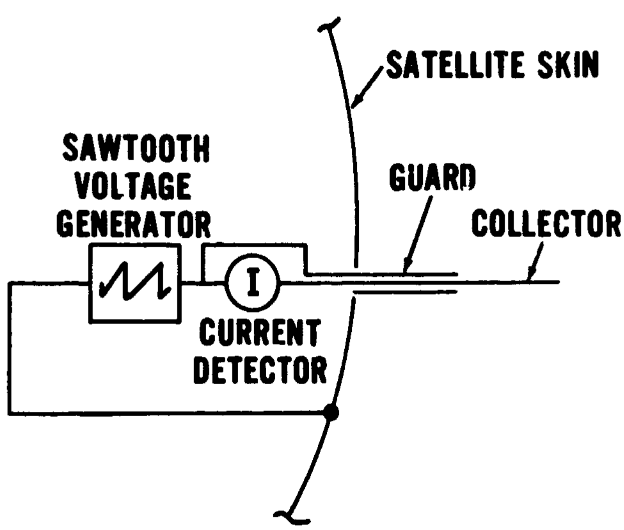

FIGURE 1.—Functional block diagram of either the T_e or N_i probe experiment. A sawtooth voltage applied to the guard and collector produces a volt-ampere characteristic from which either T_e or N_i can be derived, depending on the current sensitivity and sweep magnitude employed.

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THE EXPERIMENTS

Figure 1 is a block diagram illustrating either of the two independent probe instruments. Both instruments employ a two-element sensor consisting of a 10-cm-long guard electrode, concentric with a collector electrode 0.056 cm in diameter and 23 cm long. The collector and guard electrodes were insulated from each other and from the satellite, which served as the reference electrode. An appropriate sawtooth voltage was applied to both collector and guard elements, but only the current to the collector was measured and telemetered. Voltage sweep rates, current sensitivities, and telemetry sampling rates were optimized to permit a measurement of T_e in approximately 50 msec, corresponding to negligible translational and rotational motion of the satellite. The volt-ampere characteristics resulting from operation of the instruments thus permitted computation of electron-temperature and ion-density values that can be considered measurements at a point.

Figure 2 shows a series of raw telemetry points from the T_e experiments which demonstrate the measurement resolution. The computational technique employed has been reported [*Langmuir and Mott-Smith*, 1924; *Taylor et al.*, 1963; *Nagy et al.*, 1963].

To permit greater confidence in the measurement accuracy of the Explorer 17 probe technique, a rocket (NASA 6.07) carrying an ejectable instrumentation employing a probe sensor identical to that of Explorer 17 was launched concurrent with a satellite pass at Wallops Island, Virginia. An ionosonde was also operating simultaneously nearby. The ionosonde and rocket probe data agree with the satellite data within a few percent, confirming that the satellite motion did not perturb the temperature and density measurements. A more detailed documentation of the rocket-

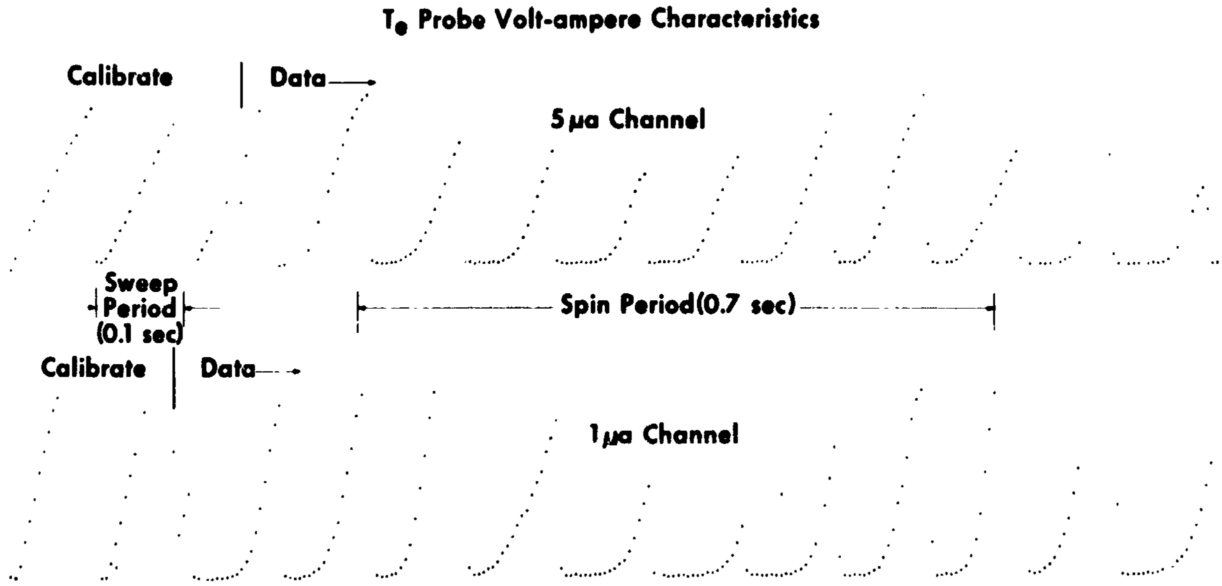

FIGURE 2.—Plot of raw telemetry data from T_e experiment during nighttime perigee pass at Blossom Point. The upper set of volt-ampere characteristics were measured by the 5-μa detector with a sweep of 0→+1.5 volts. The lower set, recorded a few seconds later, were measured by the 1-μa detector with a sweep of 0→+0.75 volts applied to the probe.

satellite experiment will be provided in a later paper.

THE BLOSSOM POINT DATA

During its 100-day operational lifetime (April 3 to July 10, 1963), Explorer 17 was interrogated successfully about 650 times, most responses providing 4 minutes of measurements along the satellite path. The Blossom Point (BP) passes, to be discussed here, provided dense coverage over the eastern United States. During the active lifetime of the satellite, the latitude of perigee, initially 38°N, moved to its maximum northward excursion of 58°, then moved southward, reaching 22°S at the time of battery exhaustion. Accordingly, most of the BP measurements were made near perigee and thus generally represent the F_2 region between 258 and 400 km. Changes in T_e and N_i during these passes reflect latitude and/or local apparent time effects (approximately 10° of latitude and 1 hour of local time) and not altitude change. These changes within passes are evident in Figure 3, which shows data measured over a three-month period. The individual points connected by solid lines are the values of T_e and N_i measured at the beginning and end of some of the individual 4-minute passes. Most of these data are from southward passes during which a consistent decrease in T_e and an increase in N_i were observed. The reverse changes are observed within the northward passes, confirming that the change observed within the pass is a latitude effect. By drawing smooth curves through the end values of T_e and N_i from the individual passes in Figure 3, the gross diurnal variation at the extremes of latitude reached in the BP passes (40° to 55° north magnetic) is made evident.

Several general characteristics of the ionosphere are also evident in Figure 3:

1. A steep morning rise in T_e and a more gradual rise in N_i.
2. A morning maximum in T_e (about 5 hours after local sunrise) and a continuing gradual rise in N_i during the day.
3. A decrease of T_e to an afternoon plateau (its value depending on latitude) and a late afternoon maximum of N_i.
4. A possible minor maximum of T_e during late afternoon.
5. A steep decline of both T_e and N_i at sunset.
6. A nighttime plateau of T_e at about 1150°K, but moderately variable, and a relatively constant value of N_i.

Although the data from other sites have not been completely analyzed, they appear to exhibit the same gross characteristics as the data from Blossom Point, the major differences being in the

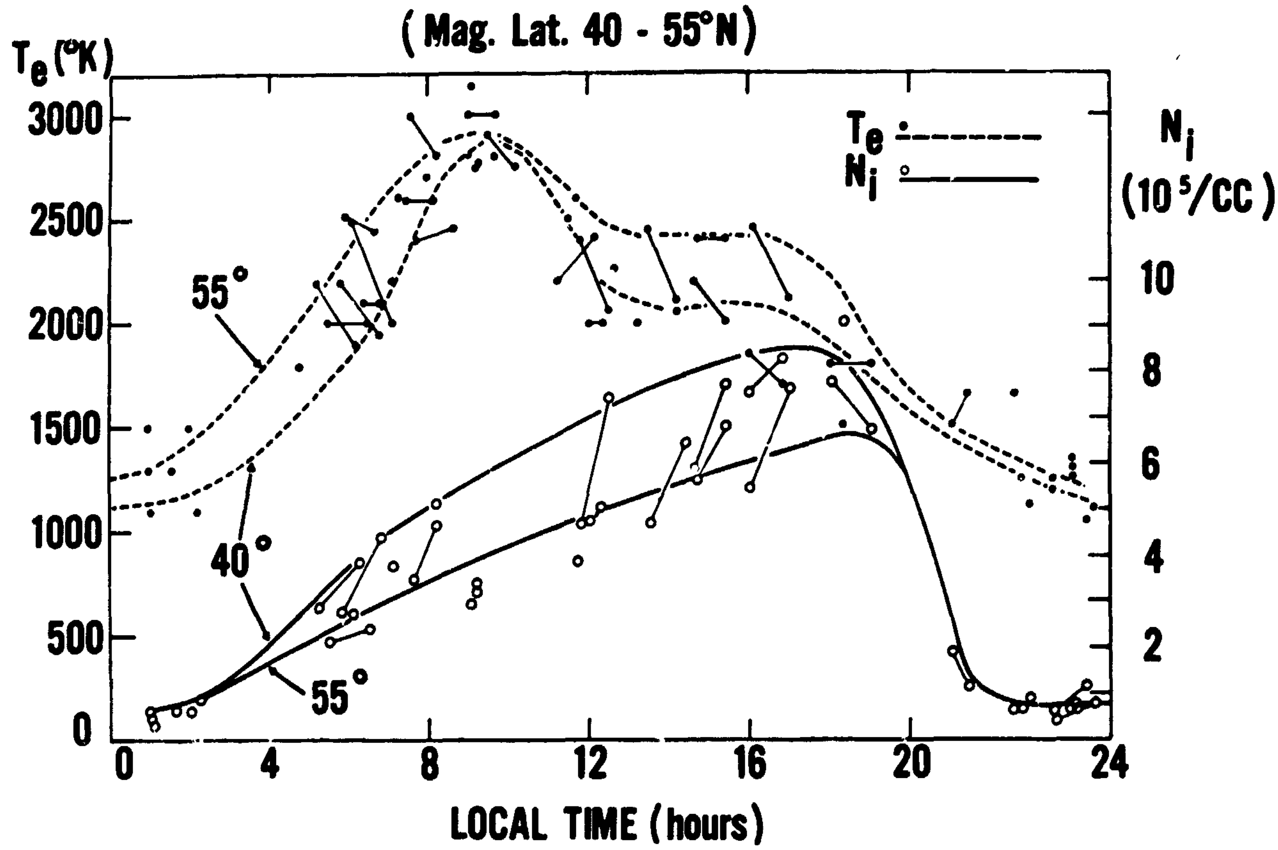

Figure 3.—Blossom Point results in the 260- to 400-km altitude range. The points connected by lines represent values recorded at the beginning and end of particular passes. The inverse variation of T_e and N_i within individual passes has been identified with the latitude change in the pass.

time of the morning T_e maximum and the value of T_e during the afternoon plateau.

GEOPHYSICAL IMPLICATIONS OF THE BLOSSOM POINT DATA

If we consider the neutral gas temperature (T_g) to be between about 700°K (at night) and 1000°K (daytime), the Figure 3 data show that thermal nonequilibrium is the normal condition near the F_2 maximum, both day and night. Thus, the Explorer 17 data confirm our earlier conclusions which were based on rocket probe data [*Boggess et al.*, 1959; *Spencer et al.*, 1962; *Brace et al.*, 1963] that (*a*) the ionosphere is not in thermal equilibrium and (*b*) the degree of nonequilibrium is greater in the auroral zone than at midlatitudes.

The major implication of the nonequilibrium is that significant sources of local heating for the electrons are present and that some of these sources exist at night as well as during the day. This is borne out by calculations of the local electron heat flux density (Q) using the equation given by *Hanson* [1963];

$$Q=-\frac{3kN_e}{2}\left[\frac{dT_e}{dt}\bigg|_{\mathrm{O}}+\frac{dT_e}{dt}\bigg|_{\mathrm{N}_2}+\frac{dT_e}{dt}\bigg|_{\mathrm{O}_2}+\frac{dT_e}{dt}\bigg|_{+}\right]\quad (\text{ev cm}^{-3}\text{ sec}^{-1}) \quad (1)$$

where the derivatives represent the cooling rates of electrons to ions and to the indicated neutral species. In a calculation using the measured values of T_e and N_i and the Harris and Priester model values ($S=90$) for the neutral particle concentrations and temperatures, the locally deposited energy (Q) at 400 km was determined to be approximately 250 ev cm^{-3} sec^{-1} at midday and 15 ev cm^{-3} sec^{-1} at night [*Brace et al.*, 1964]. The daytime value is in reasonable agreement with the predictions of both *Hanson* [1962] and *Dalgarno et al.* [1963], but differs significantly from Ariel satellite data given by *Willmore* [1964], who finds about

100 ev cm^{-3} sec^{-1} at 400 kilometers. The nighttime value of 15 ev cm^{-3} sec^{-1} indicates a significant heating source, not yet identified.

The calculations further show that both the diurnal and latitudinal variations of electron temperature in the daytime ionosphere (Figure 3) are primarily reflections of corresponding variations in the local electron density [*Willmore*, 1964]; thus there is no reason to believe that the observed latitude variation of T_e in the daytime is related to atmospheric heating by particles as a function of latitude [*Willmore et al.*, 1962; *Spencer et al.*, 1962; *Brace et al.*, 1963].

It is particularly useful to compare BP data with the radar backscatter data of *Evans* [1964], because the measurements are from essentially the same latitude, longitude, and altitude. In March 1963, a month before Explorer 17 was launched, Evans found that T_e/T_i, at 330 km reached a maximum value of 3 at midmorning, exhibited an afternoon plateau of about 2.3, and was variable between 1.3 and 2 at night. The satellite results at Blossom Point, expressed in terms of T_e/T_g, provide an essentially identical picture.

Inherent in this comparison of T_e/T_i and T_e/T_g is the assumption of equilibrium between ions and neutrals ($T_i = T_g$). In the altitude region below 400 km where these data are compared, it is reasonable to make this assumption. However, as *Hanson* [1963] has pointed out, because the neutral particle scale height is less than the ion-electron scale height, the thermal contact between ions and electrons will predominate above some altitude and the ion temperature will approach that of the electrons. *Hanson* [1963], using an assumed model atmosphere, has calculated that T_i will exceed T_g above about 600 km and will approach T_e at 900 km. Accordingly, T_i was predicted to lie about midway between T_e and T_g at 750 km. Similar calculations using Explorer 17 BP data show that this transition occurs near 500 km rather than 750 km [*Brace et al.*, 1964].

In summary, Explorer 17 measurements of T_e and N_i in the F_2 region above Blossom Point have shown that thermal nonequilibrium ($T_e > T_g$) is the normal condition both day and night and, further, that the degree of nonequilibrium is strongly latitude dependent in the daytime and moderately variable at night. The data also reveal a strong inverse relationship between the local values of T_e and N_i (or N_e), which is consistent with the equations Hanson and Dalgarno used in their studies of ionospheric heating. There is no evidence that the observed latitude dependence of T_e, seen in previous rocket flight data and apparent in Ariel satellite measurements, is related in an important way to particle fluxes at higher latitudes. Instead, the data suggest that the latitude dependence of T_e primarily reflects the global distribution of electron density and its controlling mechanism.

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