"Presunrise Heating of the Ambient Electrons in the Ionosphere due to Conjugate Point Photoelectrons"

by

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ABSTRACT

In winter, as has previously been reported, the electron temperature at Arecibo starts to increase prior to local sunrise following illumination of the conjugate ionosphere.

The mechanism of this increase is examined. The roles played by heat conduction along the field line and by photoelectrons which traverse the field line are investigated. Detailed analyses are made of the escaping photoelectron flux from the conjugate region including the effect of elastic collisions with neutrals in confining the photoelectrons. Comparisons between the theoretical heat input and observed energy losses of amient electrons are presented. Also the theoretical and measured heat fluxes are compared.

I. INTRODUCTION

The presunrise heating of the ambient electrons in the ionosphere was first noticed by a series of experiment performed at the Arecibo Ionospheric Observatory, Puerto Rico by Carlson and Nisbet (1965) in December 1964. Since then it has been discussed by Carlson (1966) using Arecibo data, and by Carru, Petit and Waldteufel (1966) using the data obtained at Saint-Santin de Maurs in France. The observations have indicated an increase in the electron temperature during the predawn period in the ionosphere

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above an altitude which varies with latitude and solar cycle. Under low sunspot condition at Arecibo this altitude is about 300 km. Figure 1 shows the electron temperature as a function of time at 400 km level.

Any theory for the photoelectron heating of the conjugate region must explain two pieces of data. The first is the observed heating of the F-region as a function of altitude and the time and the second the downward heat fluxes from the protonosphere, both during the sunrise period and throughout the day.

II. METHOD OF CALCULATING THE DOWNWARD HEAT FLUXES AND HEAT INPUT TO AMBIENT ELECTRONS

The mechanisms relevant to this pre-sunrise heating will be discussed below. The continuity equation

$$\frac{\partial n}{\partial t} = P - L - \text{div}\,(n\overline{v})$$

can be written for the photoelectrons produced at the conjugate point. The solution of this equation is extremely complicated because in the upper F region losses to the ambient electrons are comparable with those to inelastic collisions with neutral particles while the transport is considerably affected by elastic neutral collisions. At the higher energy levels electrons may lose several electron volts in a single inelastic collision and the angle between the photoelectron velocity and the local magnetic field must be considered.

In the approach adopted here the analysis starts with the assumption of steady state condition and as an initial approximation neglects the transport term. Based on this approximation it is possible to calculate the photoelectron densities as a function of altitude and energy in a manner similar to that employed by Hoegy, Fournier and Fontheim (1965). The approach adopted in this paper is drastically different from that implied in previous analyses. In this paper it has been assumed that the elastic collisions with neutral particles play a dominant role in controlling the diffusion flux of the photoelectrons in an upward direction. When a photoelectron moves downwards into a region of increasing neutral density, the mean free path between neutral elastic collisions is shorter than it is in an upward direction. There is thus a net upward flux at all altitudes depending upon the photoelectron density at a given energy, the velocity of these photoelectrons, the mean free path required to randomize the photoelectrons velocity vector, and the number density and gradient of the density of the neutral particles controlling the collision process. For the simple case when the mean free path is much less than the scale height, the diffusion velocity reduces to $\bar{v} = \frac{v \lambda}{6 H} \cos \Theta \sin I$ for $\lambda \ll H$ where H is the neutral scale height, λ the mean free path of photoelectron in elastic collisions with neutral particles, I the magnetic dip angle, Θ the angle between the velocity of photoelectron and magnetic field line, and v the thermal velocity. Corresponding formulas to that given above have been solved using a digital computer for the case where λ is comparable or greater than H. It is found by these calculations that the divergence of $n\bar{v}$ is small compared to the other terms in the continuity equation and hence it is permissible to use the energy distribution of photoelectrons determined based on the equilibrium assumption to determine the upward-going flux of photoelectrons.

The next relevant calculation is the amount of heat deposited along the field line by this upward flux of photoelectrons above a height of about 1000 km. The photoelectrons lose their energy to the ambient electrons along the field line through elastic collisions. The loss in each energy and angular range can be readily calculated. The photoelectron energy flux along the field line is given by

$$H_x = \sum_{Eo} \sum_{\Theta} Ex\,(Eo, \Theta)\ \Phi\ (Eo, \Theta)$$

where Φ is the photoelectron flux, and

$$Ex = \sqrt{Eo^2 - \frac{3.9 \times 10^{-12}}{\cos \Theta} \int_0^x n_e\, dX}$$

Under low sunspot condition, the probability that the incoming photoelectrons make a collision with the neutrals above 300 km level is quite small. As the incoming photoelectrons spiral down the field line from 1000 km level, they will lose their energy through elastic collisions to the ambient electrons in the dark ionosphere above Arechibo. The heat input to the ambient electrons due to the incident photoelectron fluxes is given by

$$Q_i = \sum_{Eo} \sum_{\Theta} \frac{1.95 \times 10^{-12} n_e \Phi(Eo, \Theta)}{Ex(Eo, \Theta) \cos \Theta}$$

III. THE ENERGY LOSSES OF AMBIENT ELECTRONS

The energy losses of ambient electrons in the dark ionosphere above Arecibo are calculated using the following equations:

$$Q_{o\,(red)} = -3 \times 10^{-4} n_e n(o) T_e^{-\frac{1}{2}} e^{-\frac{2.3 \times 10^4}{T_e}} \left\{ 3.2 \times 10^{-3} + 1.37 \times 10^{-7} T_e - \frac{0.23}{72.5 + 8.65 \times 10^{-3} T_e} - \frac{72.8 \times 10^{-6} T_e}{525 + 0.125 T_e + 7.5 \times 10^{-6} T_e^2} \right\}$$

(present work)

$$Q_{o\,(elastic)} = -3.74 \times 10^{-18} n_e n(o) T_e^{\frac{1}{2}} \left\{ T_e - T_n \right\}, \text{ (Banks, 1966)}$$

$$Q_{o_2\,(rot.\ vib)} = -1.31 \times 10^{-4} n_e n(o_2) \left\{ 4 \times 10^{-14} T_e - 8 \times 10^{-12} \right\} \left\{ T_e - T_n \right\},$$

(Hanson, 1963)

$$Q_{o_2 (elastic)} = -1.21 \times 10^{-18} n_e n(o_2) \left\{ 1 + 3.6 \times 10^{-2} T_e^{\frac{1}{2}} \right\} T_e^{\frac{1}{2}} \left\{ T_e - T_n \right\},$$

(Banks, 1966)

$$Q_{N_2(rot.)} = -n_e n(N_2)\left\{1.57 \times 10^{-15} - 7.35 \times 10^{-19} T_n\right\}\left\{T_e - T_n\right\},$$

(Dalgarno, 1963)

$$Q_{N_2(elastic)} = -1.77 \times 10^{-19} n_e n(N_2)\left\{1 - 1.21 \times 10^{-4} T_e\right\} T_e \left\{T_e - T_n\right\},$$

(Banks, 1966)

$$Q_{o^+} = -4.82 \times 10^{-7} n_e^{2} T_e^{-\frac{3}{2}}\left\{T_e - T_i\right\},$$ (Hanson and Johnson, 1961),

neglecting helium ion content at and below 400 km level.

IV. THE MODEL ATMOSPHERE AND CROSS-SECTIONS

For calculations of production rates of photoelectrons we have adopted the photon fluxes, absorption cross-sections and photoinonization cross-secfions published by Hinteregger et al. (1964) (mean solar flux at 10.7 cm in July 1963 was 76 and that in December 1964 was 75.2).

The composition of the neutral atmosphere was taken from the Harris and Priester (1964) model.

The electron density at 3000 km level above Jicamarca, Peru, measured by Farley in the early morning on February 3, 1965, is about 10^4 cm^{-3}. According to Brace and Reddy (1965), the electron density at 1000 km level, 50° S - 50° N meg. measured by Explorer XXII at night (0000 - 0330 hrs.) in Nov. - Dec. 1964 is between 10^4 and about 2.5×10^4 cm^{-3}. Based on these measurements it seems reasonable to assume the total electron content of a tube of force above 1000 km to be 10^{13} cm^{-2}.

For the spatial rates of energy loss of photoelectrons to neutrals we used the various inelastic collision cross-sections published by Fite and Brackmann (1959), Boksenberg (1961), Rapp et al. (1965), Engelhardt et al.

(1964), and Dalgarno (1961). For the drift velocity of photoelectrons we employed the total collision cross-sections published by Brode (1933), Sunshine et al. (1966), and Engelhardt et al. (1964).

V. THE RESULTS AND COMPARISIONS WITH OBSERVATIONS

Fig. 2 shows the upward-going fluxes of photoelectrons at 300 km level. Fig. 3 shows the variations of the photoelectron energy flux along the field line. It can be seen that the energy deposited along the field line above an altitude of 1000 km is about 2×10^9 ev - cm^{-2}- sec^{-1}. The thermal capacity of both the ambient electrons and ions along the field line is very small so they can be heated up rapidly. The time constant for this heating process is about 10 minutes, thus in less than about 1/4 of an hour equilibrium would be established. This heat will be conducted downwards at both ends of the field line. For this calculation some approximation must be made about the temperature gradient at the conjugate region for which no data of this type is available. Fig. 4 shows the measured downward heat flux compared with the theoretical values. Curve A is obtained under the assumption that equal heat fluxes are present at both ends of the field line, and curve B is based on the heat flux observed at Arecibo in summer the same length of time after sunrise. When the measured heat flux is extrapolated to the 1000 km level, it may be somewhere in the neighbourhood of curves A and B.

Fig. 5 shows the heat input from the photoelectrons to the ambient electrons compared with the total heat losses of the ambient electrons. It is apparent that estimates of the photoelectron flux is greater by a factor of approximately two. The distribution of the heat input as a function of altitude is quite similar for the theoretical and measured profiles.

VI. CONCLUSION

It appears that the assumptions we used and the data agree within a factor of two for both the heat flux conducted downwards from the protonosphere and the local heating by migrating photoelectrons in the ionosphere above Arecibo. Whether the errors are in the assumptions employed in the analysis, in the model used, or in the experimental data, remains to be determined. Further measurements at Arecibo and other locations will be valuable in studying the relative energy loss along the field line and the time difference between local and conjugate point sunrise.

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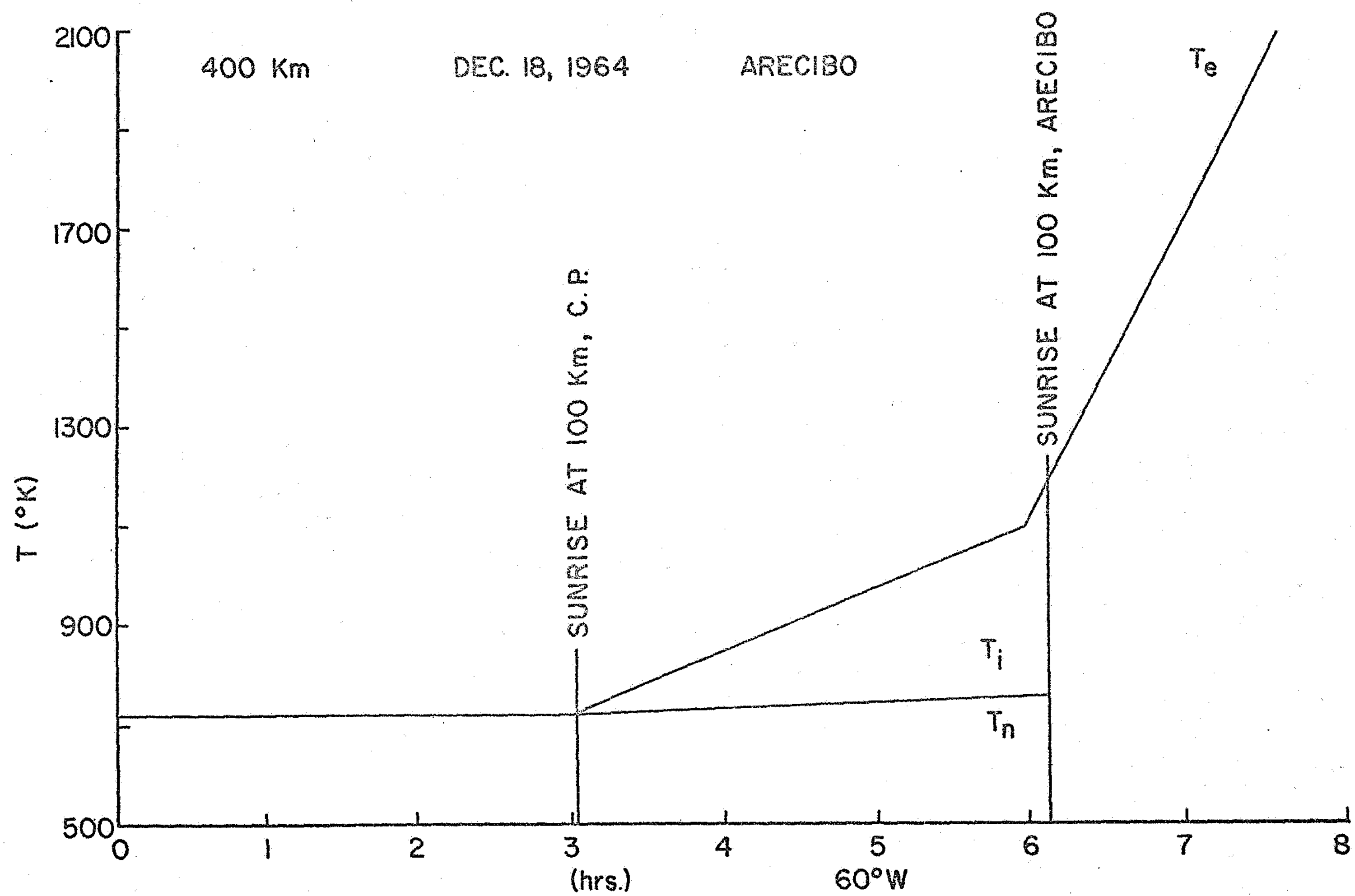
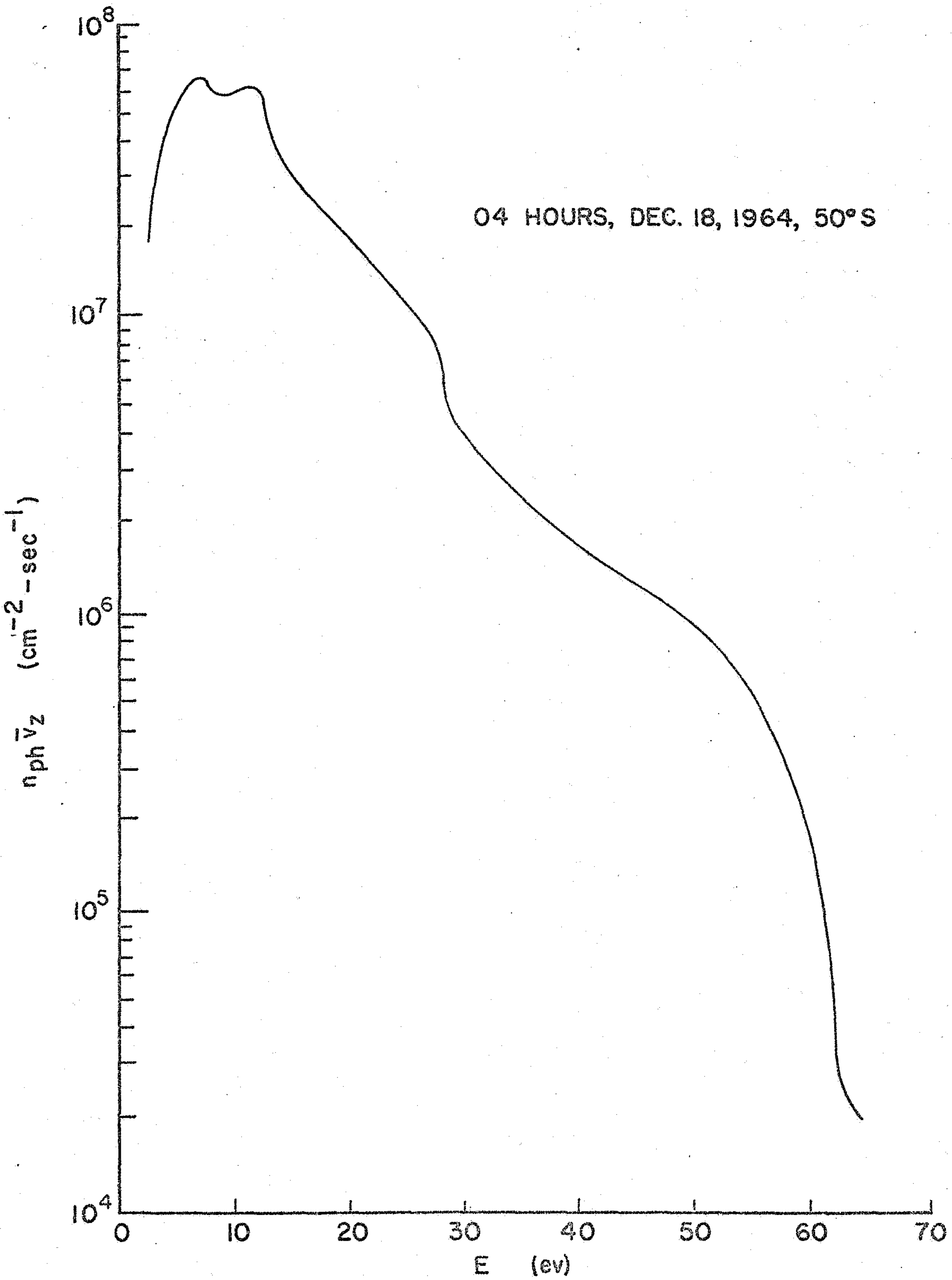


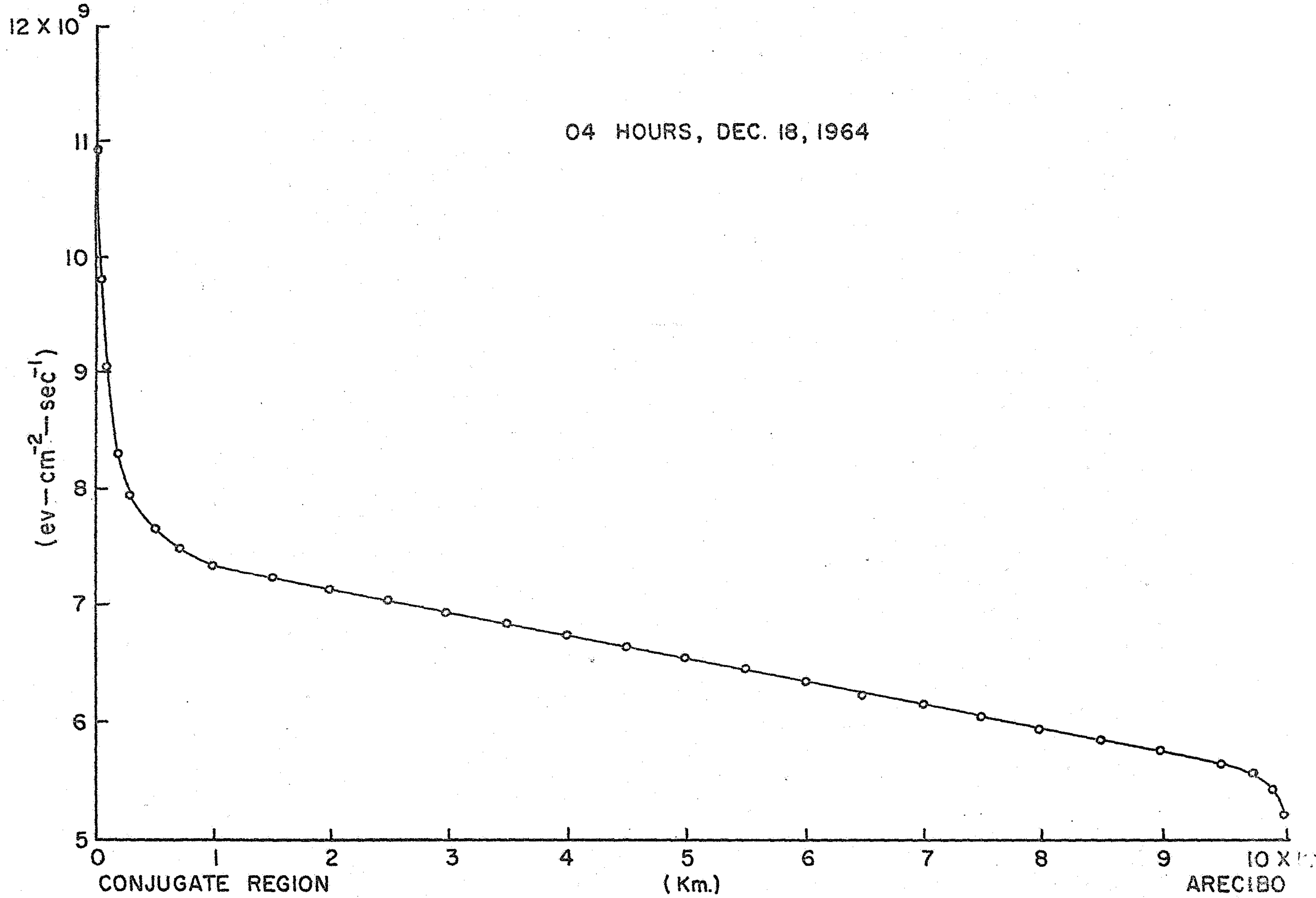
ELECTRON TEMPERATURE, ION TEMPERATURE AND NEUTRAL TEMPERATURE AT 400 Km.

FIGURE 1



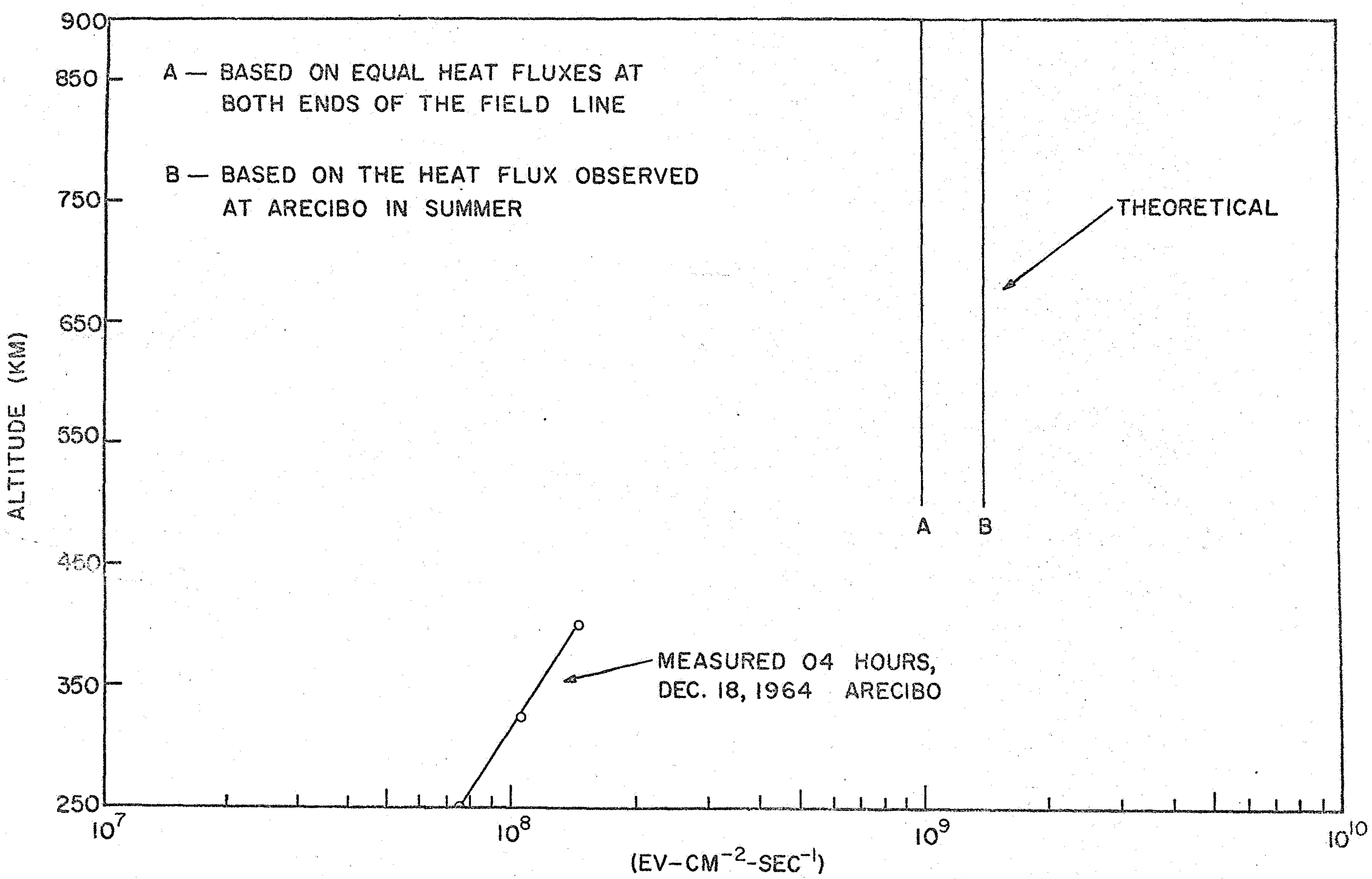
VERTICAL DRIFTING FLUX OF PHOTOELECTRON AT 300 KM.

FIGURE 2



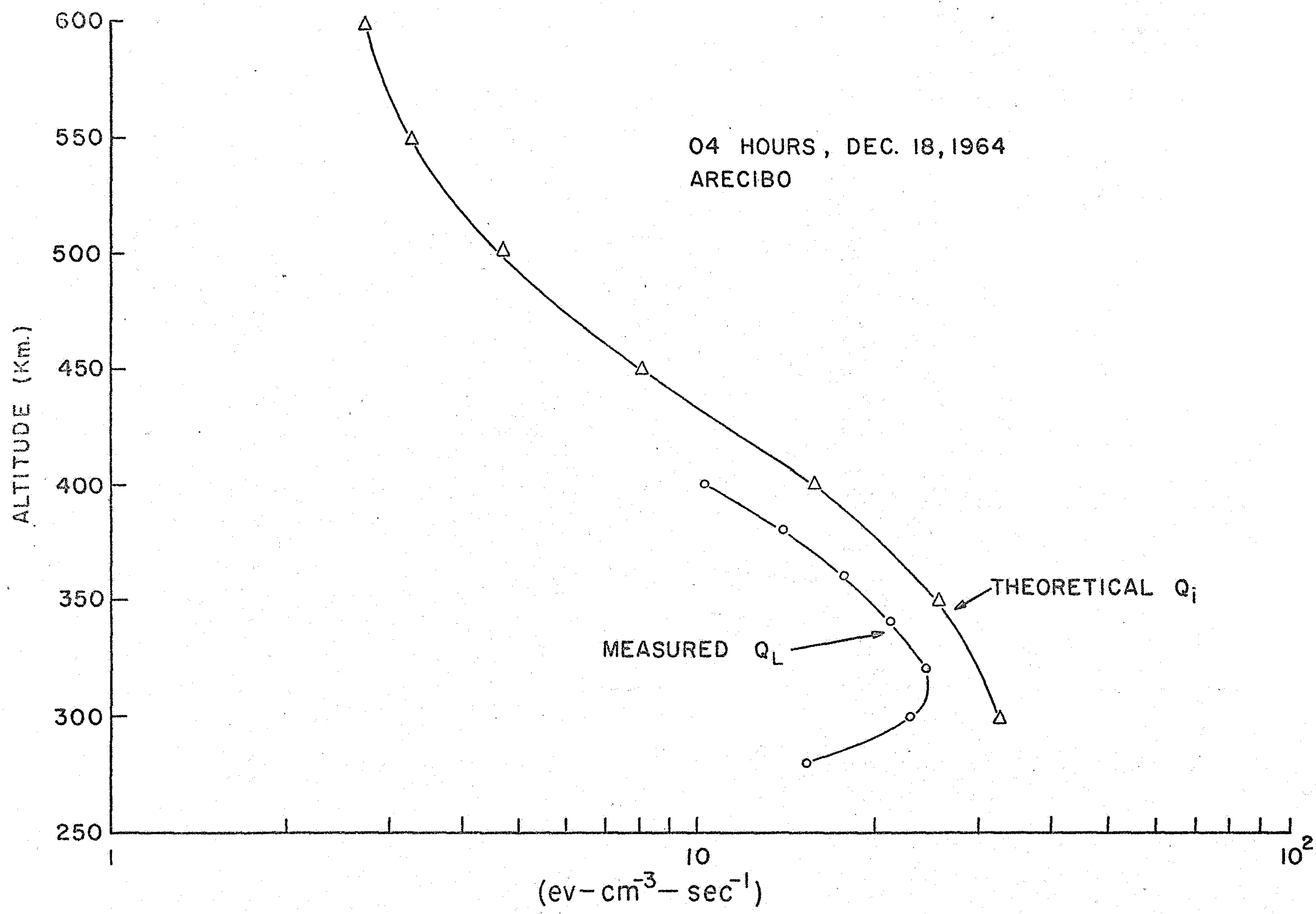
PHOTOELECTRON ENERGY FLUX ALONG THE FIELD LINE

FIGURE 3



DOWNWARD HEAT FLUX DUE TO CONDUCTION

FIGURE 4



HEAT INPUT AND TOTAL ENERGY LOSSES OF AMBIENT ELECTRONS

FIGURE 5