Planet. Space Sci. 1973, Vol. 21, pp. 1301 to 1306. Pergamon Press. Printed in Northern Ireland

THERMAL ELECTRON ENERGY DISTRIBUTION MEASUREMENTS IN THE IONOSPHERE

P. B. HAYS and A. F. NAGY
The University of Michigan, Ann Arbor, Michigan 48105, U.S.A.

(*Received in final form* 30 *January* 1973)

Abstract—Results of electron spectrometer and cylindrical Langmuir probe measurements of ionospheric electron energy distribution in the range from about 0·2 eV to 4·0 eV are presented and discussed in this paper.

1. INTRODUCTION

The energy distribution of the ionospheric electron population has been studied extensively, both theoretically (Hanson and Johnson, 1961; Hanson, 1963; Dalgarno *et al.*, 1963; Hoegy *et al.*, 1965; Geisler and Bowhill, 1965; Nisbet, 1968; Fontheim *et al.*, 1968; Duboin *et al.*, 1968; Whitten, 1968; Dalgarno *et al.*, 1969; Banks and Nagy, 1970; Nagy and Banks, 1970; Nagy and Banks, 1971; Cicerone and Bowhill, 1971; Dalgarno and Lejeune, 1971) and experimentally (Yngvesson and Perkins, 1968; Shea *et al.*, 1968; Rao and Donley, 1969; Evans and Gastman, 1970; Rao and Maier, 1970; Doering *et al.*, 1970; Knudsen, 1972; Hays and Sharp, 1973), but many questions remain unresolved. The least understood range of energy distribution is the transition region where the distribution changes from thermal to non-thermal in character. In this paper the results of measurements of the electron energy distribution in the range from about 0·2 eV to 4·0 eV are presented.

2. EXPERIMENT DESCRIPTION AND RESULTS

A recoverable payload instrumented for twilight airglow studies was launched by an Aerobee 150 (NASA 13·51) from the White Sands Test Range on 8 February 1971 at 13.56 UT ($x \simeq 90°$). This payload consisted of a multichannel photometer, an ion spectrometer, a low energy electron spectrometer (HARP), and a cylindrical Langmuir probe. In this paper, results from the latter two experiments will be described; other results have been published in a separate paper (Hays and Sharp, 1973).

The cylindrical Langmuir probe has been used for nearly a decade to measure the electron temperature in the ionosphere (e.g. Brace *et al.*, 1963; Taylor *et al.*, 1963; Nagy *et al.*, 1963; Spencer *et al.*, 1965; Brace *et al.*, 1971). The experiment has been discussed extensively in the open literature (see Brace *et al.*, 1971). The material (stainless steel) and the dimensions of the probe, as well as the electronics system used on the rocket flight under discussion, are identical to those used on many occasions; therefore, no details will be given here.

The raw FM–FM telemetry data for a typical volt–ampère curve from the probe, obtained near apogee, are shown in Fig. 1(a). The net electron current collected by the probe is obtained by the standard technique, namely a subtraction of the linearly extrapolated ion current from the total current. Figure 1(b) shows the net electron current plotted on a semilogarithmic scale. The dashed lines in Fig. 1(b) show the current slopes corresponding to the temperatures indicated; a best-fit to the data gives a temperature of 2060°K.

The HARP electron spectrometer is a new device designed to make high resolution differential electron flux measurements. Details of the HARP spectrometer, the electronics and analysis of the results are given by Hays and Sharp (1973). The electron energy spectra

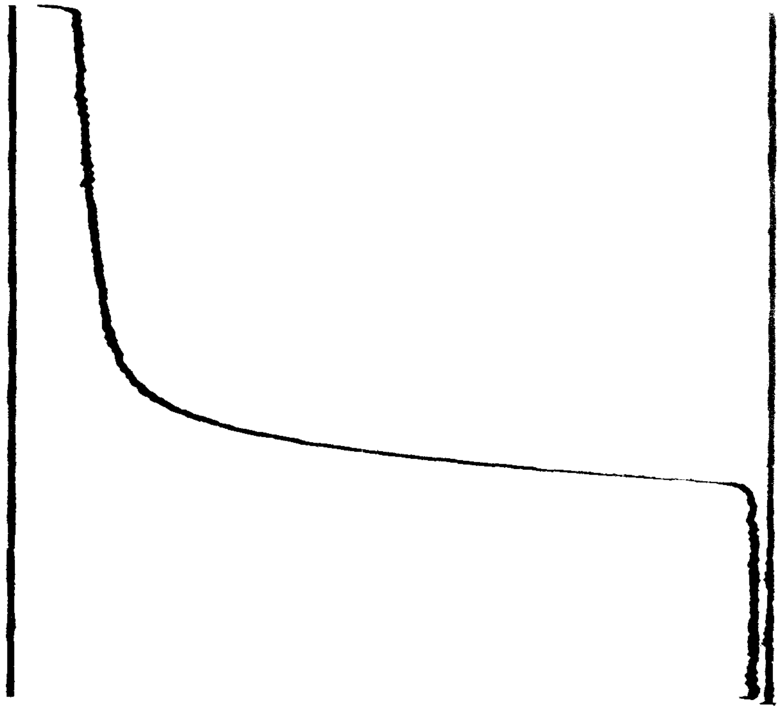

FIG. 1(a). TYPICAL CYLINDRICAL PROBE VOLT–AMPÈRE CURVE, RAW TELEMETRY DATA.

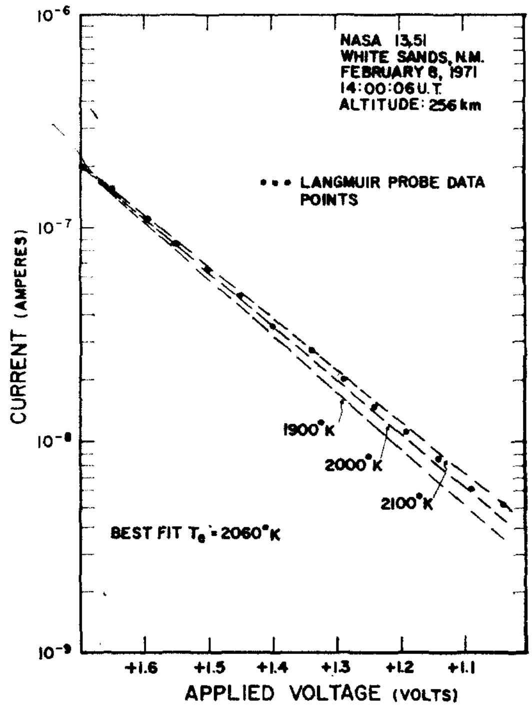

FIG. 1(b). NET ELECTRON CURRENT VS APPLIED VOLTAGE FOR A TYPICAL CYLINDRICAL PROBE VOLT–AMPÈRE CURVE.

are obtained by a 1 MHz counting system which integrates for 30 msec at each of 64 discrete energy steps. Electron temperature is deduced by least-square-fitting the electron energy spectra at low energies with a Boltzmann distribution function. The small uncertainty in the vehicle potential makes determination of the electron densities by this instrument difficult, but has little effect on the derived electron temperatures. A typical set of low energy electron flux data, obtained at nearly the same time as the probe curve of Fig. 1, is shown in Fig. 2. The raw data as well as data corrected for counter-non-linearity are shown in Fig. 2, along with a theoretical curve corresponding to a temperature of 2000°K.

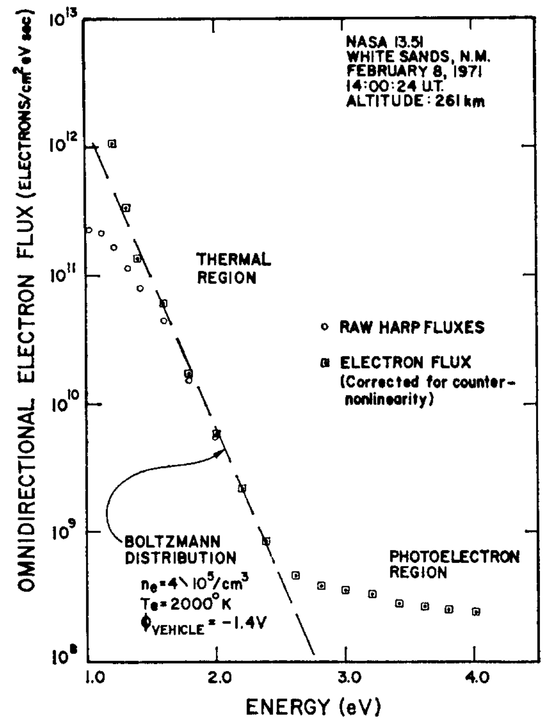

FIG. 2. LOW ENERGY ELECTRON FLUX DATA FROM THE HARP ELECTRON SPECTROMETER.

The temperatures obtained from both the probe and the HARP, measured during the upleg and downleg of the flight, are shown in Fig. 3. There is general agreement between the electron temperatures derived from the probe, corresponding to an energy range of about 0·2–0·9 eV, and from HARP, corresponding to the energy range of about 1·0–2·5 eV. These results indicate that a single temperature could describe the energy distribution of the thermal electrons between about 0·2 and 2·5 eV during this rocket flight.

In order to assign absolute energy values to the measured energy distribution, a knowledge of the sensor potential with respect to the ambient plasma is needed. The absolute values of the cylindrical probe and the HARP potential can be obtained from an analysis of the volt–ampère curves. The general methods used for cylindrical probes were discussed by Nagy and Faruqi (1965) and the HARP analysis was described by Hays and Sharp (1973). An accuracy of a few hundred millivolts is typical for these potential determinations. The potential values obtained by the probe and the HARP on this flight differed by about 0·35 V, which is a very reasonable value considering the contact potential differences due

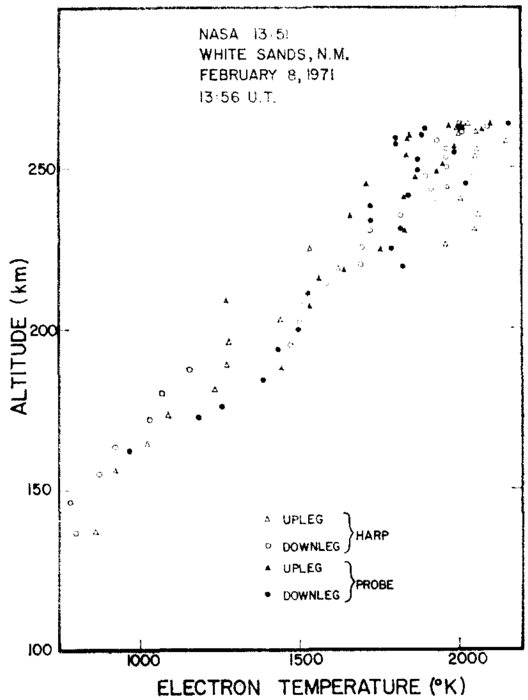

FIG. 3. ELECTRON TEMPERATURES FROM NASA 13.51.

to the different materials used. Furthermore it should be pointed out that the use of an incorrect value of potential will not affect the deduced temperatures and shape of the energy distribution; it would cause false electron densities to be deduced and could hide a possible 'shoulder' in the energy distribution in the region where measurements were not made (between about 0·5 and 1·3 V).

3. DISCUSSION

A detailed knowledge of the temperature of the ionospheric thermal electron population is necessary in order to study and understand the physics and chemistry of the upper atmosphere. Our present-day knowledge of electron temperatures comes from measurements made during the last decade by either *in situ* probes (Booker and Smith, 1970), or by the radar backscatter technique (Evans, 1969). A discrepancy between the electron temperatures measured by these two techniques has been found to exist (e.g. Hanson *et al.*, 1969; Carlson and Sayers, 1970; McClure *et al.*, 1973). It has been suggested (Waldteufel, 1969; Hoegy, 1971) that the ionospheric 'thermal' electron population may have a non-Maxwellian energy distribution which could cause this discrepancy. The results presented here cannot answer the question of what the energy distribution is below about 0·1 eV, which corresponds to nearly half of the thermal electron population, and therefore cannot provide any definitive information concerning the discrepancy between probe and radar measured electron temperatures. However, it is difficult to imagine a good physical reason which would cause a sharp change in temperature at 1–2 kT_e.

It has been known for many years that the energy distribution of the electron gas can be deduced from the measured probe characteristics (Druyvesteyn, 1930; Loeb, 1961). The electronics and data format of the cylindrical probe experiment is not well-suited for taking second derivatives of the current with respect to the applied voltage, which is needed to obtain the distribution function. Nevertheless, it was felt important to emphasize the range over which the measurements presented here were obtained. Therefore, Fig. 4 shows the energy distribution measured by the two experiments, near apogee, at the times corresponding to Figs. 1 and 2. Despite the significant scatter in the probe data caused by crude double differentiation, the measured data points clearly follow the theoretical energy distribution curve over nearly five decades of density.

Here we have presented data from only one rocket flight so it is not known whether similar results would be obtained at different times and/or altitudes. Another series of rocket flights is planned and results will be published as they become available. The work presented here should be considered only a first step in a very necessary attempt to measure and understand the energy distribution of the ionospheric thermal electron population.

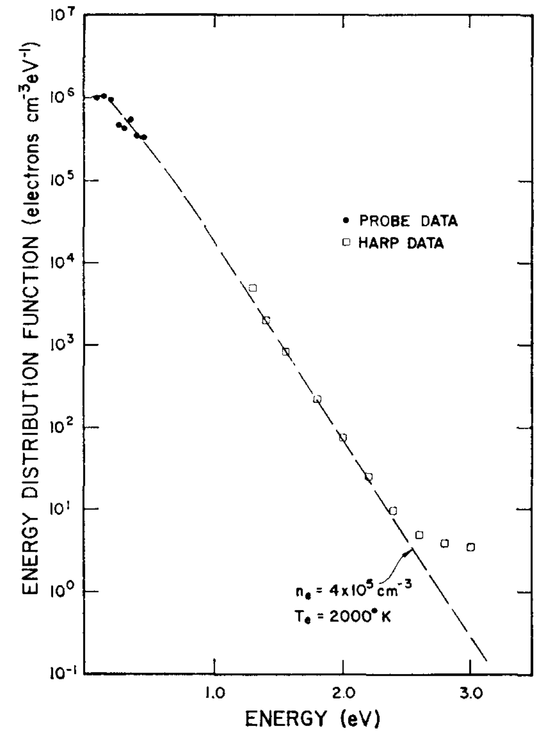

FIG. 4. ELECTRON ENERGY DISTRIBUTION DERIVED FROM HARP AND LANGMUIR PROBE DATA NEAR APOGEE.

Acknowledgements—The research reported here was supported under NASA Grants NGR23-005-015 and NGR23-005-360.

REFERENCES

BANKS, P. M. and NAGY, A. F. (1970). Concerning the influence of elastic scattering upon photoelectron transport and escape. *J. geophys. Res.* **75**, 1902.

BOOKER, H. G. and SMITH, E. K. (1970). A comparative study of ionospheric measurement techniques. *J. atmos. terr. Phys.* **32**, 467.

BRACE, L. H., CARIGNAN, G. R. and FINDLAY, J. A. (1971). Evaluation of ionospheric electron temperature measurements by cylindrical electrostatic probes. *Space Research*, Vol. XI, p. 1079.

BRACE, L. H., SPENCER, N. W. and CARIGNAN, G. R. (1963). Ionosphere electron temperature measurements and their implications. *J. geophys. Res.* **68**, 5397.

CARLSON, H. C. and SAYERS, J. (1970). Concerning the discrepancy in electron temperatures deduced from Langmuir probes and from incoherent scatter radars. *J. geophys. Res.* **75**, 4883.

CICERONE, R. J. and BOWHILL, S. A. (1971). Photoelectron fluxes in the ionosphere computed by a Monte Carlo method. *J. geophys. Res.* **76**, 8299.

DALGARNO, A. and LEJEUNE, G. (1971). The absorption of electrons in atomic oxygen. *Planet. Space Sci.* **19**, 1653.
DALGARNO, A., MCELROY, M. B. and MOFFETT, R. J. (1963). Electron temperatures in the ionosphere. *Planet. Space Sci.* **11**, 463.
DALGARNO, A., MCELROY, M. B. and STEWART, A. I. (1969). Electron impact excitation of the dayglow. *J. atmos. Sci.* **26**, 753.
DOERING, J. P., FASTIE, W. G. and FELDMAN, P. D. (1970). Photoelectron excitation of N_2 in the day airglow. *J. geophys. Res.* **75**, 4787.
DRUYVESTEYN, M. J. (1930). De invloed der energieverliezen bij elastische botsingen in de theorie der electronendiffusie. *Physica* **10**, 61.
DUBOIN, M. L., LEJEUNE, G., PETIT, M. and WEILL, G. (1968). Excitation of oxygen lines and ionospheric heating by conjugate photoelectrons. *J. atmos. terr. Phys.* **30**, 563.
EVANS, J. V. (1969). Theory and practice of ionosphere study by Thomson scatter radar. *Proc. IEEE* **57**, 496.
EVANS, J. V. and GASTMAN, I. J. (1970). Detection of conjugate photoelectrons at Millstone Hill. *J. geophys. Res.* **75**, 807.
FONTHEIM, E. G., BEUTLER, A. E. and NAGY, A. F. (1968). Theoretical calculations of the conjugate predawn effects. *Annls Géophys.* **24**, 489.
GEISLER, J. E. and BOWHILL, S. A. (1965). Exchange of energy between the ionosphere and protonosphere. *J. atmos. terr. Phys.* **27**, 119.
HANSON, W. B. (1963). Electron temperatures in the upper atmosphere. *Space Research*, Vol. III, p. 282. North-Holland, Amsterdam.
HANSON, W. B., BRACE, L. H., DYSON, P. L. and MCCLURE, J. P. (1969). Conflicting electron temperature measurements in the upper *F*-region. *J. geophys. Res.* **74**, 400.
HANSON, W. B. and JOHNSON, F. S. (1961). Electron temperatures in the ionosphere. *Mém. Soc. r. Sci. Liège* **5**, 390.
HAYS, P. B. and SHARP, W. E. (1973). The twilight airglow: 1. Photoelectrons and (OI)5577 Å. *J. geophys. Res.* **78**, 1153.
HOEGY, W. R. (1971). Probe and radar electron temperatures in an isotropic non-equilibrium plasma. *J. geophys. Res.* **76**, 8333.
HOEGY, W. R., FOURNIER, J. P. and FONTHEIM, E. G. (1965). Photoelectron energy distribution in the *F*-region. *J. geophys. Res.* **70**, 5464.
KNUDSEN, W. C. (1972). Latitudinal variation of differential photoelectron flux at 560-kilometers altitude. *J. geophys. Res.* **77**, 1233.
LOEB, L. B. (1961). *Basic Processes of Gaseous Electronics*. University of California Press, Berkeley.
MCCLURE, J. P., HANSON, W. B., NAGY, A. F., CICERONE, R. J., BRACE, L. H., BARON, M., BAUER, P., CARLSON, H. C., EVANS, J. V., TAYLOR, G. N. and WOODMAN, R. F. (1973). Comparison of T_e and T_i from Ogo 6 and various incoherent scatter radars. *J. geophys. Res.* **78**, 197.
NAGY, A. F. and BANKS, P. M. (1970). Photoelectron fluxes in the ionosphere. *J. geophys. Res.* **75**, 6260.
NAGY, A. F. and BANKS, P. M. (1971). Photoelectrons and related ionospheric effects. *Space Research*, Vol. XI, p. 1123. Academie, Berlin.
NAGY, A. F., BRACE, L. H., CARIGNAN, G. R. and KANAL, M. (1963). Direct measurements bearing on the extent of thermal non-equilibrium in the ionosphere. *J. geophys. Res.* **68**, 6401.
NAGY, A. F. and FARUGI, A. Z. (1965). Ionospheric electron density and body potential measurements by a cylindrical Langmuir probe. *J. geophys. Res.* **70**, 4847.
NISBET, J. S. (1968). Photoelectron escape from the ionosphere. *J. atmos. terr. Phys.* **30**, 1257.
RAO, B. C. N. and DONLEY, J. L. (1969). Photoelectron flux in the topside ionosphere measured by retarding potential analyzers. *J. geophys. Res.* **74**, 1715.
RAO, B. C. N. and MAIER, E. J. R. (1970). Photoelectron flux and protonospheric heating during the conjugate point sunrise. *J. geophys. Res.* **75**, 816.
SHEA, M. F., SHARP, R. D. and MCELROY, M. B. (1968). Measurements and interpretation of low-energy photoelectrons. *J. geophys. Res.* **73**, 4199.
SPENCER, N. W., BRACE, L. H., CARIGNAN, G. R., TAEUSCH, D. R. and NIEMANN, H. B. (1965). Electron and molecular nitrogen temperature and density in the thermosphere. *J. geophys. Res.* **70**, 2665.
TAYLOR, H. A., JR., BRACE, L. H., BRINTON, H. C. and SMITH, C. R. (1963). Direct measurements of helium and hydrogen ion concentration and total ion density to an altitude of 940 kilometers. *J. geophys. Res.* **68**, 5339.
WALDTEUFEL, P. (1969). Influence sur les mesures ionosphériques par diffusion de Thomson d'une distribution électronique non maxwellienne. *Annls Géophys.* **25**, 381.
WHITTEN, R. C. (1968). Non-local energy deposition in the ionosphere and the photoelectron escape flux. *J. atmos. terr. Phys.* **29**, 949.
YNGVESSON, K. D. and PERKINS, F. W. (1968). Radar Thomson scatter studies of photoelectrons in the ionosphere and Landau damping. *J. geophys. Res.* **73**, 97.