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Miller, Kent L., William C. Knudsen, Karl Spenner, "The Dayside Venus Ionosphere, I. Pioneer-Venus Retarding Potential Analyzer Experimental Observations", Icarus, 57, 386-409, 1984.

The Dayside Venus Ionosphere

I. Pioneer-Venus Retarding Potential Analyzer Experimental Observations

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Received August 23, 1983; revised January 2, 1984

These sections have been provided in order to describe some of the problems associated with the intercalibration of the charged particle experiments aboard the PVO spacecraft.

{} indicates subscripted value
[] indicates superscripted value
^ indicates exponentiation
Greek letters are spelled out, in either all lower or all upper case.

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DISCUSSION OF RESULTS

Total ion density measured by the RPA is an independently measured quantity and is not the numerical sum of constituent densities. It is derived from the saturated ion current measured by the RPA (Knudsen et al., 1979a) and the normal component of the bulk ion velocity relative to the RPA surface grid. The constituent densities are derived from differences in ion current measured over an appropriate retarding potential interval. By subtracting the sum of the measured constituents from N{i}, the total concentration of unmeasured constituents can be estimated.

FIG. 9. Median profiles of the particle pressure n{i}k(T{e} + T{i}) within the 65 +/- 5 deg. and 25 +/- 5 deg. SZA intervals. Medians are medians of the local product and not the product of the medians. The altitude scales for the two different SZA intervals are different.

The RPA does not have the mass resolution of an ion mass spectrometer (IMS), and does not, for example, resolve the atomic ions O^+, N^+, and C^+ into separate peaks. We have relied on information supplied by the P-V ion mass spectrometer to verify that O^+ is the dominant ion of the group, and also to estimate the ratio of $(C^+ + N^+)/O^+$ (~0.07) (Taylor et al., 1979a). Use of this ratio makes a 7% difference in the value of O^+ and also improves the ion temperature derived by the RPA. Otherwise, the values reported in this study are derived independently of IMS results.

We have made the assumption in fitting the theoretical values of current differences to measured differences (Knudsen et al., 1979a) that the ratio $(N^+ + C^+)/O^+$ is constant and has the value 0.07. Therefore, the sum $(O^+ + N^+ + C^+)$ measured by the RPA is a factor of 1.07 times the value of O^+ given in Figs. 6 and 7 and Tables I and II. Since at higher altitudes in Fig. 7 the ratio O^+/N_i is approximately 0.86, the ratio $(O^+ + N^+ + C^+)/N_i$ is ~0.93 and all other ions including H^+, D^+, He^+, O^{++}, O_2^+, NO^+, N_2^+, and CO_2^+ (Taylor et al., 1979a; 1980) are approximately 7% of the total.

The RPA does not resolve the ion masses 32(O_2^+, 30(NO^+)), and 28(CO^+, N_2^+)) into separate peaks. However, at the low altitude at which these ions become significant, T_i is relatively small and the single, measured peak is clearly distorted by the presence of more than one ion mass. Therefore, we have assumed in our least-squares analysis that the peak is composed of two ions with masses 32 amu (O_2^+) and 29 amu ($NO^+ + N_2^+ + CO^+$) and have let the least squares fitting program assign separate concentrations to these two constituents as required to minimize the variance of the fit. The separate densities and their sum have been presented in Figs. 6 and 7. We estimate that $(O_2^+ + M29^+)$ is measured to an accuracy of approximately 5% below 200 km altitude but make no estimate for the accuracy of O_2^+ and $M29^+$ separately. It is gratifying that our results are qualitatively similar to those of the IMS (Taylor et al., 1980). The reported IMS results indicate that above approximately 220 km altitude O_2^+ and $M29^+$ are approximately equal in density and that below 220 km altitude O_2^+ clearly becomes the dominant constituent. At ~160 km altitude our results yield a value of approximately 5 for the ratio $O_2^+/M29^+$ whereas the ratio reported by Taylor et al. (1980) is more like 10-15.

The shape and magnitude of the O_2^+ profiles presented in Figs. 6 and 7 differ from those reported by the IMS at low altitudes in both absolute magnitude and shape (Taylor et al., 1979a, 1980). The IMS density is a factor of approximately 2 larger than that measured by the RPA and shows a peak near 175 km altitude. Similarly, the values of CO_2^+ reported by the IMS are approximately a factor of 2-3 times larger than the RPA CO_2^+ results. The values of O^+ reported by the IMS and RPA are approximately equal in the dayside ionosphere. In the next section we discuss the accuracy of the RPA densities.

ACCURACY

We have estimated the accuracy with which the RPA measures N_i, O^+, ($O_2^+ + M29^+$, CO_2^+), and T_i as approximately 5% and the accuracy of T_e as approximately 10% (Knudsen et al., 1979a). These accuracies apply when the concentrations are well within the design range of the RPA. The accuracies are estimated from accuracies with which the RPA electrometer sensitivity, grid transparencies, and instrument dimensions are measured and are not estimated from calibration of the RPA against a standard instrument in a laboratory plasma chamber. Because of its simple and open geometrical configuration, we consider it a good standard instrument. There is also the question of how well a laboratory plasma approximates the natural conditions on orbit, were a laboratory standard instrument more accurate than the RPA available.

FIG. 15. Solar longitude variation of normalized T_e.

In Fig. 18 we have plotted the median plasma density derived from the Pioneer-Venus RPA, IMS, Langmuir probe (LP), and radio occultation (RO) experiments. The median RPA profile was constructed as explained heretofore from all RPA data recorded in the first 780 orbits. The IMS median profile was derived from the IMS data deposited in the Pioneer-Venus low-frequency unified abstract data system (UADS) for the first 780 orbits. Experimental data are interpolated to common universal times (UT) at 12-sec intervals throughout each periapsis pass by the P-V experimenters and stored in UADS. We have summed the IMS component densities at each UT to get total plasma density, collected all the data falling with 65 +/- 5 deg. SZA, ordered the data in altitude, and taken medians of successive groups of 11. The electron density reported by the Langmuir probe experiment $N_{e,LP}$ has been treated similarly except that summing constituent densities was unnecessary. The radio occultation experiment measures $N_{e,RO}$ remotely and does not report density in UADS. The median $N_{e,RO}$ profile was derived by taking all occultation profiles which fell within a small SZA interval centered close to that used for the in situ experiments. Eight profiles fell within the interval 58 +/- 4 deg. These profiles were obtained over a period of approximately two Earth years. A "median" profile was found from these eight profiles by assigning the log $N_{e,RO}$ of the median value midway between the log N_e values of the middle two profiles at each altitude. The temporal variance bars for $N_{e,RO}$ extend from the second to the seventh profile sequenced by magnitude at each altitude. Three-fourths of the profiles lie within the variation range.

FIG. 16. Solar longitude and latitude variation of normalized particle pressure. Below 600 km altitude the normalized particle pressure exhibits an enhanced value at the dusk terminator over that at the dawn terminator reflecting the enhanced value of N_i.

The IMS and LP data were taken from the UADS data available as of February 1982. By common agreement among P-V experiments the UADS files may be updated. L. Brace (private communication) has updated his files since February 1982 which might change the $N_{e,LP}$ median curve were it to be redone using his more recent (but unavailable at the time of this study) data.

We infer from the data in Fig. 18 that the accuracy of the RPA total density measurement is within the approximately +/- 5% claimed. All four experiments are in satisfactory agreement above 200 km altitude where O^+ is approximately 90% of the total ion density (Fig. 7). Below 200 km altitude the total ion density $n_{i,IMS}$ measured by the IMS systematically departs from the other three and reaches a factor of approximately 2.5 larger than that reported by the other experiments at an altitude of ~165 km. The factor then decreases toward 160 km altitude, below which IMS data are not reported in UADS. From a comparative study of the O^+, O_2^+, and CO_2^+ densities reported in UADS by the

IMS and RPA for the dayside hemisphere, we have found that the IMS O^+ densities are reasonably consistent with those of the RPA, but that both the IMS O_2^+ and CO_2^+ densities are on the order of 2.5 times too large. The O_2^+ ion is the dominant ion below an altitude of approximately 180 km, as revealed by both the IMS (Taylor et al., 1980) and the RPA (this study; Knudsen et al., 1979b).

FIG. 17. Solar longitude and latitude values of the solar radio flux $F_{10.7}$.

In Fig. 19, contours of median values of the ratio $(n_{i,1} + n_{i,2})/N_i$ are plotted as a function of altitude and solar zenith angle. The quantities $n_{i,1}$ and $n_{i,2}$ are the ion densities derived from the two major ion peaks telemetered to Earth in the most frequently used RPA mode of operation (Knudsen et al., 1979a). Above 250 km altitude in the dayside ionosphere (SZA < 90 deg) only one peak was usually detected corresponding to the ion group $O^+ + N^+ + C^+$. This group had a median number density equal to approximately 93% of N_i which is consistent with the composition reported by the IMS. At the lowest altitude, the major ion peak $n_{i,2}$ became $O_2^+ + M29^+$ with $n_{i,1}$ being either $O^+ + N^+ + C^+$ or CO_2^+. The RPA measurements indicate $O_2^+ + M29^+$ is approximately 90% of N_i which is close to that (~95%) indicated by the IMS (Taylor et al., 1980). We conclude that since N_i, O^+, and $O_2^+ + M29^+$ are essentially independent measurements and N_i is measured to approximately 5% (Fig. 18), O^+ (=0.93 x ($O^+ + N^+ + C^+$)) and $O_2^+ + M29^+$ measured by the RPA are also accurate to within approximately 5% whenever they individually are a substantial fraction of N_i.

FIG. 18. Vertical profiles of median plasma density measured by several Pioneer-Venus experiments in the same solar zenith angle interval.

The principles of operation and the onboard peak selection criteria of the RPA are such that the RPA is limited in its ability to detect a minor ion of small fractional concentration (Knudsen et al., 1979a). The limit of detectability depends on the ion composition, ion temperature, small-scale ion density irregularity magnitude, and instrument noise level. Prior to the P-V launch, we conducted a very realistic numerical simulation of the RPA operation in an ionosphere with an irregularity level of 0.5% and temperature of 500 deg. K and in which the ratio O^+/O_2^+ was varied. We found that when the O^+/O_2^+ ratio dropped below the range 5-10%, the O^+ peak was not detected consistently because of the RPA restrictive peak selection criteria. When the O^+ peak was detected, the accuracy of the derived concentration was not significantly degraded below that obtained when O^+ was the dominant ion. Minor ions with mass larger than that of the major ion such as O_2^+ and CO_2^+ in O^+ or O^+ in H^+ are detectable at smaller fractional concentrations. Thus, in Figs. 2 and 3, the O+ curve terminates at an altitude below which the ratio $O^+/O_2^+ + M29^+$ drops beneath approximately 5%. On the other hand, CO_2^+ and $O_2^+ + M29^+$ were detectable at altitudes at which their fractional concentrations were as small as 0.1 and 1.0%, respectively. However, the percentage of RPA sweeps in which the minor ions were detected decreased significantly as their respective lower limits was approached.

Because the detectability of a minor ion increases with increasing fractional density, the possibility exists that the median densities reported in this paper for O^+, $O_2^+ + M29^+$, and CO_2^+ may not accurately represent the true median in the altitude range corresponding to their minimum detectability. That is, if the actual density of the minor ion is varying temporally, the RPA would more frequently detect the ion when its density was greater than the true median value. This statement applies only near the limit of detectability. The possibility exists, therefore, that the measured medians are larger than the true medians at altitudes where a minor ion density is near the limit of its detectability. From a comparison of RPA medians with IMS medians derived from UADS data, we believe a significant bias does not exist in our medians near the limits of their detectability. Due allowance was made in the comparison for the systematic difference in IMS sensitivity described above. Any bias that may be present is probably small in comparison with the variation range indicated.

FIG. 19. Contours of the ratio $(n_{i,1} + n_{i,2})/N_i$, where $n_{i,1}$ and $n_{i,2}$ are the ion concentrations corresponding to the two major ion peaks measured by the RPA.

ACKNOWLEDGMENTS

We thank Dr. Arvydas J. Kliore for supplying the radio occultation profiles required to make the median $N_{e,RO}$ profile in Fig. 13. We also thank H. A. Taylor, Jr., and L. H. Brace for use of their UADS data in constructing the median $N_{e,LP}$ and $\Sigma(n_{i,FMS})$ profiles in the same figure. We are grateful to Tom Canty for his assistance in organizing and plotting the data. Support for K. L. Miller and W. C. Knudsen was provided by NASA Contract NAS2-9481 and Lockheed Independent Research Funds.

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