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1 Theoretical Program on the F Region

Nisbet and Quinn [1963] showed that the recombination coefficient effective at 300 kilometers in the nighttime F region varies by a factor of approximately 30 over the solar cycle based on the results of ionospheric sounding measurements at Puerto Rico. This work has been extended using computer techniques to six stations at different geomagnetic latitudes. The computer program allows more versatility in the assumptions and a wide range of models has been studied at all stations. The results of this analysis are in good general agreement with the mannally computed values for Puerto Rico. A paper summarizing this work was presented at the Spring 1963 meeting of URSI in Washington.

The methods developed for this work allow the diffusion and the drift velocities in the nighttime F region to be calculated. These in turn allow the ion neutral particle collision frequency to be determined as a function of height and if a neutral atmospheric model is available enable values for the diffusion coefficient to be obtained. This work has progressed throughout the year. Results of this analysis show a value of the normalized diffusion coefficient

$$\frac{Dn[O]}{T^{\frac{1}{2}}} = .5 \pm .2 \text{ cm}^{-1} \text{ sec}^{-1}$$

This value is lower by factor of about two than those presented by Dalgarno [1958] and by an order of magnitude lower than values given by Ferraro, Cowling, and Shimazaki. This is an extremely important conclusion for the Dalgarno values had generally been believed to be too low by at least a factor of two. This work was presented by Quinn and Nisbet at the Winter meeting of URSI in Seattle in December, 1963.

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Because of the complexity of the calculation described above, it was decided to check the result by comparing values of recombination coefficient and diffusion coefficient obtained in the above manner with values calculated from the much simpler nighttime decaying equilibrium layer described by Dungey [1956]. The results of this analysis showed that the nighttime equilibrium layer approximation was not well fulfilled in the ionsophere at Puerto Rico. When suitable modifications were made to take account of the changing layer shape, it was found that good agreement was obtained between the values obtained for the recombination coefficient data as a function of temperature and those produced by the more exact theory. Values of the diffusion coefficient calculated with the simple theory were found to be extremely variable. However, these values agreed very much better with the low values obtained by the more exact method than with the previously accepted higher values. This work was presented by Nisbet at the 1963 Winter meeting of URSI in Seattle.

In the continuation of this project is is intended to continue this work in an effort to obtain more accurate values and error limits for the values for drift velocity, diffusion coefficient and recombination coefficient. One of the most important errors in this work results from uncertainty about the profile in the lower altitude region due to errors caused in the true height reduction of profiles by low lying ionization. It is intended to use the more exact reductuion techniques now available and to compare these with the rocket measurements to be made in our program.

It is of extreme importance in the understanding of the diurnal behavior of the F region and of the F region processes in general to compare values determined from the nighttime analysis described above with those predicted for daytime models. The daytime models available did not seem capable of describing the complexities of the F region as they are now understood and an investigation was started to develop more flexible analytic solutions for the daytime equilibrium F region. Analytic solutions were obtained which allow the inclusion of the effects of non-monochromatic ionizing radiation, freedom of choice of the molecular constituent responsible for the recombination coefficient effective in the atom ion interchange reaction for the model, freedom to specify the electron-ion temperature ratio and which allow the inclusion of the presence of thehelium and hydrogen ions. This work was published by Nisbet in the November 15, 1963 issue of J.G.R. This work has the advantage that analytic expressions were obtained as contrasted with the graphical print out of analog computer solutions of comparable complexity. The two methods do, however, agree within the limits of error of the analog computer method.

One of the parameters which comes out of the daytime equilibrium analysis is the ratio of the recombination coefficient to the diffusion coefficient at the maximum of the layer. As presumably both the values of these parameters and their temperature dependence are available from the nighttime analysis, it is of interest to compare this ratio with that calculated using neutral atmosphere models for the daytime atmosphere. When this is done, it can be shown that if vertical drifts are neglected for the daytime layer, the diffusion coefficients calculated during the day are five times larger than those predicted from the nighttime values. Several possible explanations for this effect exist. Perhaps the most promising has been suggested by recent rocket measurements of Hall, Schweizer and

Hinteregger [1963] which appear to show a diurnal variation in the lower boundary conditions for atomic oxygen and the molecular constituents involved in the recombination coefficient β.

The rather surprising conclusions of this work have been confirmed by Rishbeth at N.B.S. who has independently studied the behavior of the height of the maximum electron density of the F region including in his model the effect of the temperature diurnal variation for the neutral atmosphere.

The model methods also allow the estimation of the ionization production rate for atomic oxygen ions in the F region. It was found that the large variation in the recombination coefficient β with temperature did not, as might be expected, imply an extremely large variation of the ionizing E.U.V. flux with solar activity. It was found that the peak electron densities were consistent with the assumption that the production coefficient

$$q = 2 \times 10^{-9} S_{10.7} n[O] \quad sec^{-1}$$

where

$S_{10.7}$ is the intensity of the 10.7 centimeter solar flux in watts per square centimeter x 10^{-22}.

It is intended to continue this work in an effor t to obtain non-equilibrium solutions to the continuity equation in the F region and in this way it is hoped to obtain analytic expressions for the diurnal behavior of the F region.

The above methods are quite effective in enabling values for the basic physical constants of the production, recombination and transport processes in the F region. They do, however, throw remarkedly little light upon the relative importance of the various processes which have been postulated and as is now becoming apparent there is obviously a rather largediscrepancy between the models now contemplated for the daytime and the nighttime F region as related to current neutral atmospheric models. These factors do, however, affect the relative distributions of the ionospheric ionic constituents in the lower F region. This situatuion has been analyzed theoretically by Nicolet and Swider [1963]. A new series of experiments is proposed, to follow the three experiments now currently contemplated in which an ion mass spectrometer will be included in the payload. A co-ordinated series of experiments will be conducted in which at least three experiments will take place during a single day-night transition. In this way the changes in the electron density profile, distribution of ionic constituents, and the electron ion temperature ratio can be studied in a coherent manner. While this proposal makes no provision for any flight hardware items associated with this contemplated program, it is intended to expand grant funds in a feasiblilty study of the most suitable experiment or experiment sequence.

A large portion of the data used for the theoretical investigations of the F region consists of electron density height profiles. These have been mostly obtained from ionograms, from both ground-based and satellite-borne ionosondes. The techniques for reducing the new ionograms to profiles are being investigated, as much uncertainty still exists in the results due to a number of factors not, at present, adequately taken into account. The neglect of ionization below the low-frequency cut-off of the equipment can lead to very large errors at night. The minimization of these errors will be further investigated. Errors can alos occur due to minima in the electron density profiles. On the topside, proper account must be taken of the variation of gyrofrequency with altitude. In addition, techniques are being devised, based on a least-squares solution, which can, at the same time, minimize the effects of scaling errors and missing portions of records.

It is proposed to investigate these effects by using records available from elsewhere, by making model studies, and by using records obtained at University Park on a new Swedish Ionosonde which has just been installed. Dr. Schmerling is a member of the International group (under Commission III of URSI) which has been charged with investigating these problems.

2 Experimental Program

A contract has been awarded by NASA G.S.F.C. for an experimental program consisting of three rocket flights to eleven hundred kilometers using the Javilin vehicle. This program has been conducted by Space Craft, Inc. with J. Holtz, NASA as project manager and J. S. Nisbet of the Ionosphere Research Laboratory as technical director.

Work on the prototype is nearing completion and all electrical, thermal and mechanical tests are expected to be completed by February 4, 1964 .

Electron topics associated with the hardware supervision portions of the grant have so far provided topics for five master's thesis in Electrical Engineering. Four reports on these topics have been completed and supplied to the hardware contractor.

The Mother-Daughter separation system provided several interesting dynamical problems associated with the stability of the sections of the vehicle and the mechanical test program necessary for the evaluation and testing of the separation system. Two master's thesis in Aeronautical Engineering have been written and these reports have also been forwarded to the hardware contractor.

Instruments for measuring ion density and composition and electron temperature have been designed and constructed for use in the Mother-Daughter payload. These instruments utilize planar multi gridded structure of the Bennett-Pearse type. The complete instrument weighs less than 1 1/2 pounds and the electronics includes linear feedback automatic range switching electrometer with in-flight calibration and in-flight taking of the derivative of the V I characteristic.

In the course of designing the probe instrumentation, problems involving the design of stable rocket borne d.c. amplfiers arose, and an extensive theoretical and experimental study of transistor d.c. amplifiers was made, leading to design methods for minimizing drift in feedback stabilized transistor d.c. amplifiers.

The prototype and flight units are completed and successful flights are necessary before work in data reduction and theoretical analysis can proceed.

The work in d.c. amplifiers has been essentially completed. The problems of electronics connected with probe instrumentation and electrometers are largely solved, although it is thought that work in basic electrometry involving new solid state devices would be of interest if time permits.

3 D-region rocket program

A program was begun to design instruments for the measurement of ion density (positive and negative) in the D-region of the ionosphere. Most of this work was of a preliminary nature because of lack of graduate student personnel. This condition has changed, and three new graduate students have started to work in the areas described below.

It is thought that the most basic problem associated with rocket borne D-region experiments involves choosing of the proper geometry to minimize aerodynamic effects upon the measurement. Accordingly, a program has been initiated in conjunction with the Aeronautical Engineering Department to perform theoretical, and, if necessary, experimental studies of various probe geometries which will lead to a probe geometry capable of making easily interpreted results of D-region measurements.

3. Publications

A. Papers presented at Scientific Meetings:

"Factors controlling the Decay of the Nighttime F Region Under Equilibrium Conditions", by J.S. Nisbet. Presented at the URSI-IRE meeting in Seattle, Washington, December 9-12, 1963.

"A Study of the Ion-Neutral Particle Collision Frequency and the Diffusion Coefficients for Atomic Oxygen Ions in the F Region", by T. P. Quinn and J. S. Nisbet. Presented at the URSI IRE meeting in Seattle, Washington, December 9-12, 1963.

B. The following papers were published:

"The Reduction of Ionograms to Electron Density Profiles", by E. R. Schmerling. Published in J.A.T.P., Vol. 25, No. 10, 609, October, 1963.

"Factors Controlling the Shape of the Upper F Region under Daytime Equilibrium Conditions", by J. S. Nisbet. Published in J.G.R., Vol. 68, No. 22, 6099-6112, November 15, 1963.

C. Scientific Reports published:

No. 191(E). "Analysis of Dynamics of Mother-Daughter Rocket Separation Systems", by D.R. Barnes, August 15, 1963.

No. 194. "Factors Controlling the Shape of the Upper F Region under Daytime Equilibrium Conditions", J. S. Nisbet, September 20, 1963.

No. 196. "The Normal Mode Approach to the Solution of the Initial Value Problem for Plasma Oscillations", by P. E. Bolduc, October 10, 1963.

No. 199(E). "A Procedure for Predicting the In-Flight Behavior of a Payload from both Rigid Body and Elastic Body Considerations", C. G. Scott, November 15, 1963.

No. 202. "The Analysis of Ionospheric h'(f) Records using the Method of Least Squares", by D. J. Brown, January 1, 1964.

No. 203(E). "An Analysis of a Transistor D.C. Feedback Amplifer Suitable for Rocket Probe Instrumentation", by C. Wilk, February 15, 1964.