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STUDY OF BACKGROUND RADIANCE IN UPPER ATMOSPHERE

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January 1980

Final Report

1 July 1975 - 30 September 1979

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This research was sponsored in part by the Defense Nuclear Agency
Subtask I25AAXHX632, Work Unit 42, entitled "SPIRE Instrumentation."

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

19. REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER (18) AFGL-TR-80-0048	2. GOVT ACCESSION NO. AD-A092,927	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (1) STUDY OF BACKGROUND RADIANCE IN UPPER ATMOSPHERE.	5. TYPE OF REPORT & PERIOD COVERED Final Rept. 1 Jul 1975 to 30 Sep 79	6. PERFORMING ORG. REPORT NUMBER (14) UMASS-ARF-80-308
7. AUTHOR(s) (10) Hajime/Sakai (12)	8. CONTRACT OR GRANT NUMBER(s) (15) F19628-75-C-0187	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Astronomy Research Facility University of Massachusetts Amherst MA 01003	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS PE61102F 2310G404 & 2310G408	
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Geophysics Laboratory Hanscom AFB, Massachusetts 01731 Monitor/Richard Nadile/OPR-1	12. REPORT DATE (11) January 1980	13. NUMBER OF PAGES 85
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) (16) 337X, 337Y (17) 43.4	15. SECURITY CLASS. (of this report) Unclassified	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES This research was sponsored in part by the Defense Nuclear Agency Subtask I25AAXHX632, Work Unit 42, entitled "SPIRE Instrumentation."		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Atmospheric emission Radiative transfer Scattering Infrared		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The final report on the analysis of the SPIRE data. The major CO ₂ IR bands are analyzed by using a simplified model.		

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Introduction

→The work of this contract was intended to develop the atmospheric model which integrates the emission and the scattering term in a combined form and to provide analysis of the earth atmospheric emission data gathered by the SPIRE payload in these two terms.

Our work performed throughout the entire period can be divided into five areas:

- (1) incorporation of various computer programs designed to calculate the atmospheric infrared emission level under a specific condition;
- (2) improvement of the algorithm employed in these programs;
- (3) development of an atmospheric infrared radiance model which unifies the emission and scattering term;
- (4) application and evaluation of the developed model to analysis of the SPIRE data; and
- (5) evaluation of some preliminary test data for the coming AFGL balloon-borne atmospheric emission measurement experiment.

The SPIRE experiment¹ was carried out during 1978, and the collected data were made available to us in late 1978. Our effort during the early phase of the contract period, i.e., prior to the SPIRE launching, was focused in the area of (1) and (2). Our Scientific Report No. 1 summarizes our progress made during the early phase.² The present report will describe our work covered in the entire period, with a special emphasis on the progress made since the last report.

Upon inspection of the SPIRE data, it became obvious to us that the existing computation programs are much more elaborate than required in the

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analysis. A quick check on the observed scattering radiance level revealed that the single-scattering theory with the Rayleigh particles^{3,4} produced a result adequate for the analysis. The Monte Carlo code developed by Blattner and his co-workers^{5,6,7} is found unnecessary for the analysis, because the computation based on the single scattering process produced a result which agrees, reasonably well, with the SPIRE observed data. The existing computation programs treat the scattering process entirely separately from the absorption-emission process. We find them rather inadequate for explaining why some molecular bands change their absorptive behavior against the scattering background to become emissive as the altitude increases. A theory which unifies both processes in the radiative formulation is definitely needed for the analysis. A limit placed on time restricted us to develop a computation algorithm which generates the spectral radiance level as a function of frequency and an observation condition in an automatic fashion. We feel that we are on the right track for seeking a solution to the problem. Nonetheless, we came to understand the basic radiative mechanism of the upper atmosphere with an extent that we can place a proper perspective to the analysis of the SPIRE data.

Radiative Process

The radiative transfer in the atmosphere is traditionally analyzed in treating the infrared radiation field as a continuous flow of radiative energy. The interactions between the radiation field and the atmospheric gas is formulated in an integral equation. Several computer programs have been written for analysis of the radiation transfer problem. Our approach taken in the present study is slightly different from the traditional analysis. We tried to analyze the radiative transfer in the upper atmosphere in following the interactive process between the photons and molecules.

The photons incident into a layer of atmosphere would go through one of three processes: (1) they may be absorbed by the atmospheric molecules or atoms; (2) scattered by the Rayleigh particles or by the aerosols; and (3) left unperturbed. We can formulate these interactions between the photon field and the molecular system in terms of the density of these two interacting partners and a quantity which indicates a strength of the interaction.

The interaction between the photons and the molecules (or the atoms) in the absorption process is specified by Einstein's formulation.⁸ The number of molecular transitions N_t in unit time per unit volume, when interacting with the photons of a frequency ν , is given by

$$N_t = (N_l B_{lu} - N_u B_{ul}) \rho(\nu). \quad (1)$$

In this expression, the following notations are used:

- N_l : number of molecules per unit volume in lower state l
- N_u : number of molecules per unit volume in upper state u
- B_{lu} : Einstein coefficient for induced absorption
- B_{ul} : Einstein coefficient for induced emission
- $\rho(\nu)$: spectral density of the radiation field in unit volume at frequency ν

The density $\rho(\nu)$ is related to the photon density N_p given in unit volume per second by

$$\frac{c}{4\pi} \rho(\nu) = N_p h \nu, \quad (2)$$

where h is the Planck constant and c is the speed of light. Combining Eqs. (1) and (2), the molecular transitions N_t is given by

$$N_t = (N_l B_{lu} - N_u B_{ul}) \frac{4\pi N_p h \nu}{c}. \quad (3)$$

This expression can be rewritten by using the molecular absorption

strength S_{lu} (cross-section)⁹

$$N_t = 4N_p N_o S_{lu}, \quad (4)$$

where

$$S_{lu} = \frac{h\nu(N_{\ell} B_{\ell u} - N_u B_{ul})}{N_o c} \approx \frac{h\nu_B}{c} \left(1 - \frac{N_u}{N_{\ell}}\right) \quad (5)$$

with N_o the number of molecules in unit volume. In deriving Eq. (5), it is assumed that

$$N_o \approx N_{\ell}. \quad (6)$$

The Eq. (4) derived above specifies the number of molecular transitions N_t in the photon density N_p , the molecular density N_o , and the molecular absorption strength S_{lu} which is experimentally determined in the laboratory.

The scattering process can be formulated in the same way.⁴ A traditional approach is somewhat different in that the incident radiation field is given in the irradiance; the power scattered toward the direction ϕ by a molecule is given by

$$\sigma_m(\phi) E_o = I(\phi), \quad (7)$$

where E_o is the irradiance of the incident plane wave. We can formulate the incident irradiance by

$$E_o = N_p h\nu, \quad (8)$$

again using N_p , the photon density in unit volume per unit second. Now we find that the power scattered by a molecule is given by

$$I(\phi) = N_p h\nu \sigma_m(\phi). \quad (9)$$

The radiative power scattered toward the direction ϕ per unit solid angle by an ensemble of molecules N_o in unit volume is given by

$$I'(\phi) = N_o h\nu N_p \sigma_m(\phi). \quad (10)$$

Thus we get the desired form for the number of photons scattered toward the

direction ϕ ;

$$N_p(\phi) = N_o N_p \sigma_m(\phi). \quad (11)$$

For the Rayleigh scattering, the scattering cross-section is given by

$$\sigma_m(\phi) = \frac{9\pi^2 \nu^4}{N^2 c^4} \left(\frac{n^2-1}{n^2+2} \right)^2 \sin^2 \phi \quad (12)$$

$$\approx \frac{4\pi^2 \nu^2}{N^2 c^2} (n-1)^2 \sin^2 \phi$$

where N is the number of molecules in a unit volume at S.T.P.⁴

The energy absorbed by a molecule from the radiative field is sooner or later released from it in a de-excitation process. In the upper atmosphere, the de-excitation is done by the radiative process. The photon absorbed by a molecule is re-emitted to the radiation field isotropically. If the original absorption occurs between the ground state and the first excited vibrational state, there is no significant change in the photon energy of the absorbed and of the re-emitted. In the lower atmosphere, a local thermal equilibrium is established; the energy absorbed by a molecule is dissipated into the kinetics energy shared in the molecular ensemble. The interaction between the molecular ensemble and the radiation field under the local thermal equilibrium condition is treated below in calculation of the photon density. The de-excitation under this condition is done predominantly by the collisional process. In a transient region from the lower to the upper atmosphere, the molecular system de-excites by both processes.

Photon Density in Atmosphere

There are two radiation sources which must be considered in the infrared

radiative process of the atmosphere: the solar radiation penetrating the atmosphere from the top, and the radiation going upward to escape to the outerspace from the earth's surface. The energy density $\rho(\nu)d\nu$ of the black-body at temperature T is given by

$$\rho(\nu)d\nu = \frac{8\pi h \nu^3}{c^3} \frac{d\nu}{\frac{h\nu}{kT} - 1} . \quad (13)$$

The photon density N_p in unit volume per unit second per wavenumber interval $d\sigma$ emitted by the same blackbody radiator is

$$\begin{aligned} N_p d\sigma &= \frac{c^2}{4h\nu} \rho(\nu)d\nu \\ &= \frac{2\pi\nu^2}{c} \frac{d\sigma}{\frac{h\sigma c}{kT} - 1} = \frac{2\pi\sigma^2 c}{\frac{hc\sigma}{kT} - 1} d\sigma . \end{aligned} \quad (14)$$

For the telluric radiation, the photon density is calculated by taking T at a value between 225°K and 300°K. For the solar radiation, it is calculated by the same expression with an attenuation factor;

$$N_{p\odot} = \left(\frac{r_s}{R_s}\right)^2 \frac{2\pi\sigma^2 c}{\frac{hc\sigma}{kT} - 1} , \quad (15)$$

where r_s is the solar radius and R_s is the solar distance, T is about 6000°K. The front factor $(r_s/R_s)^2$ is approximately 2.2×10^{-5} . In Figure 1, the photon density for three cases is plotted as a function of the wavenumber σ : (1) the solar radiation calculated by Eq. (15), (2) a blackbody at $T = 300^\circ\text{K}$, and (3) a blackbody at $T = 225^\circ\text{K}$. The telluric photon density in the upper atmosphere is affected by the optical thickness of the lower atmosphere. In some spectral ranges, there is no atmospheric molecular absorption, and the photon density for the 300°K blackbody remains unaffected from the earth's surface to the top of atmosphere. In a region where the atmospheric

absorption is extreme, the photon density in the upper atmosphere is controlled by the energy density of the blackbody radiation at the tropopause temperature $T = 225^\circ\text{K}$. We can observe in Figure 1 that the molecules and the atoms in the upper atmosphere are excited by two types of radiations which have a vastly different spectral characteristic. The telluric photon density remains unaffected by the solar daily motion. The photons in a region below 2000 cm^{-1} are predominantly telluric, while those in a region above 2000 cm^{-1} in the daytime are solar.

The emission due to the CO_2 transitions, one for the $(01101-00001)^{10}$ band at 670 cm^{-1} (the ν_2 band) and another for the $(00011-00001)$ band at 2300 cm^{-1} (the ν_3 band), is ready for a qualitative analysis using the photon density calculated for the curves shown in Figure 1. (A more detailed quantitative analysis will follow later in the report.) Once accepting the photon spectrum shown in Figure 1, we find that the photons available for exciting the ν_2 band are telluric. The temporal characteristics of the telluric photons remain independent of the daily cycle. Thus the ν_2 $(01101-00001)$ band emission at 670 cm^{-1} must remain unchanged between the day and the night time. The SPIRE data shown in Figure 2 for this CO_2 band confirms a stationary nature of the emission. The CO_2 ν_3 $(00011-00001)$ band at day side is excited by the solar photons, and by the telluric photons at night side. Since the ν_3 transition is very strong, the telluric photons available in the upper atmosphere are those of a 225°K blackbody. The difference in these two densities between the solar and the telluric is two orders of magnitude. Thus the radiance level of the transition should undergo a change of about 2 orders of magnitude between the day and the night. The SPIRE data in Figure 3 indicates that the ν_3 band emission primarily undergoes the diurnal change described above. Upon a careful inspection of the data, the radiance level at nighttime is brighter than what can be predicted by the telluric photon level.¹⁷ We will make an analysis on this anomaly later in the report.

Photon Density / $\text{cm}^3 \text{sec cm}^{-1}$

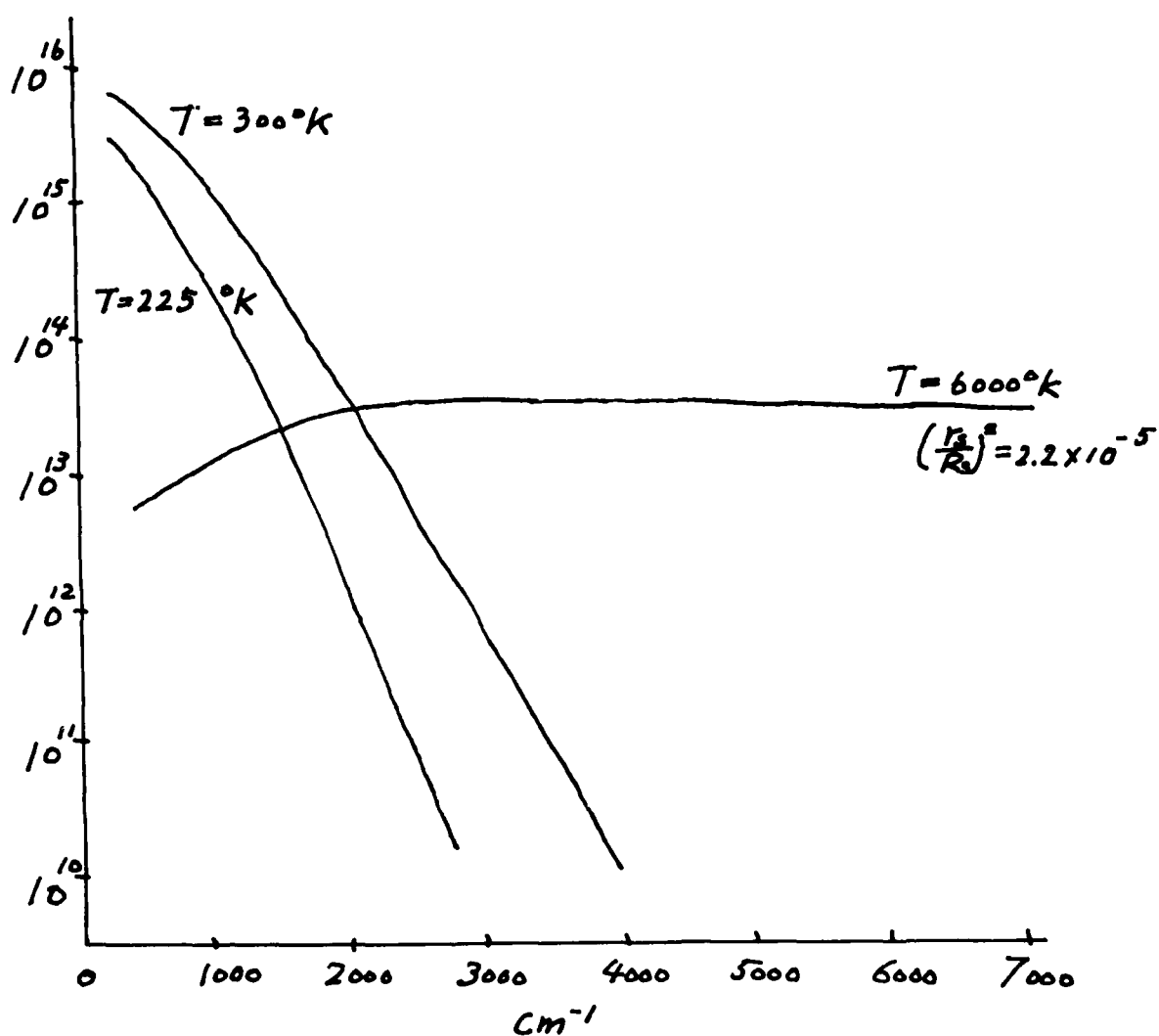


Figure 1

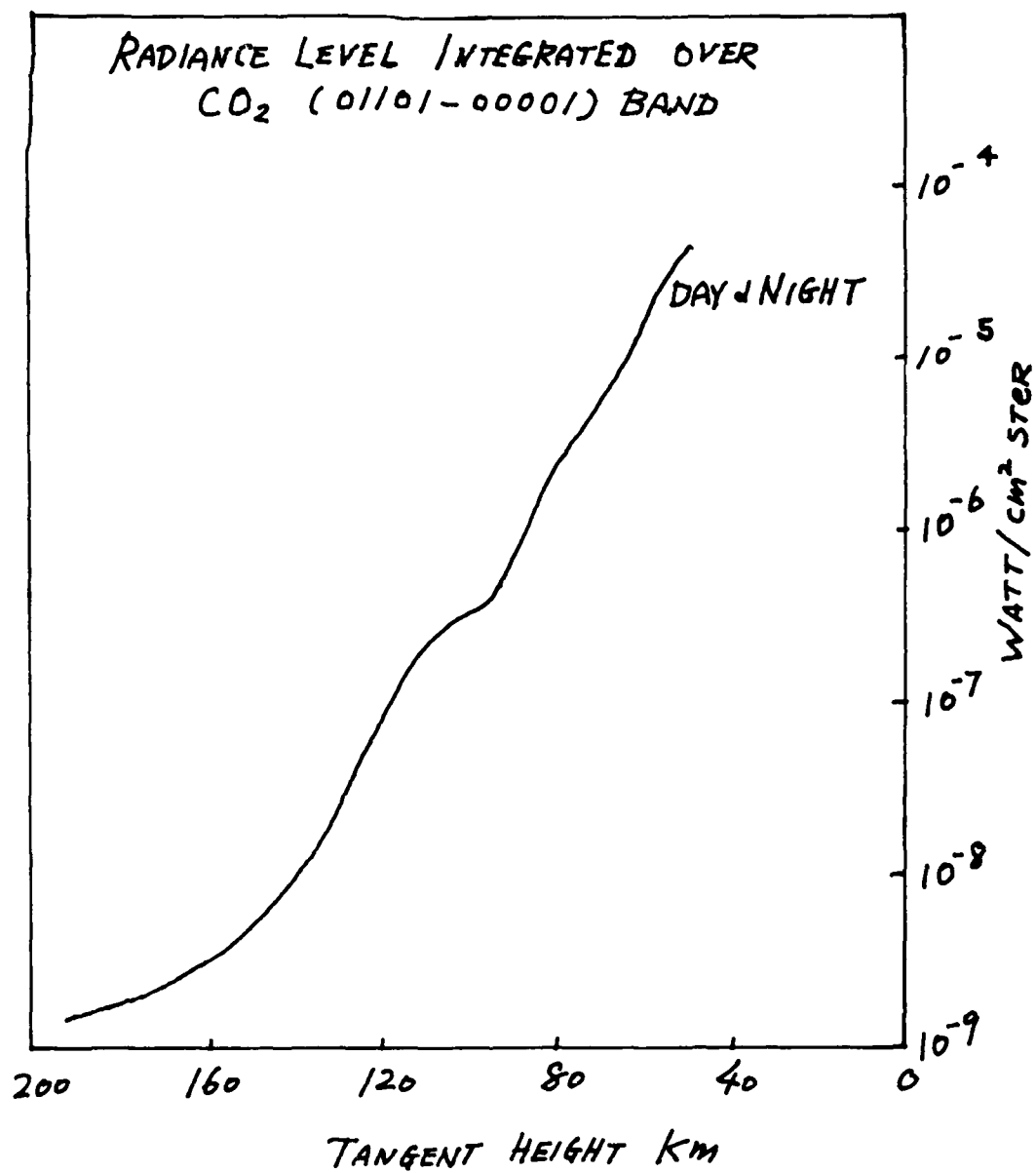


Figure 2

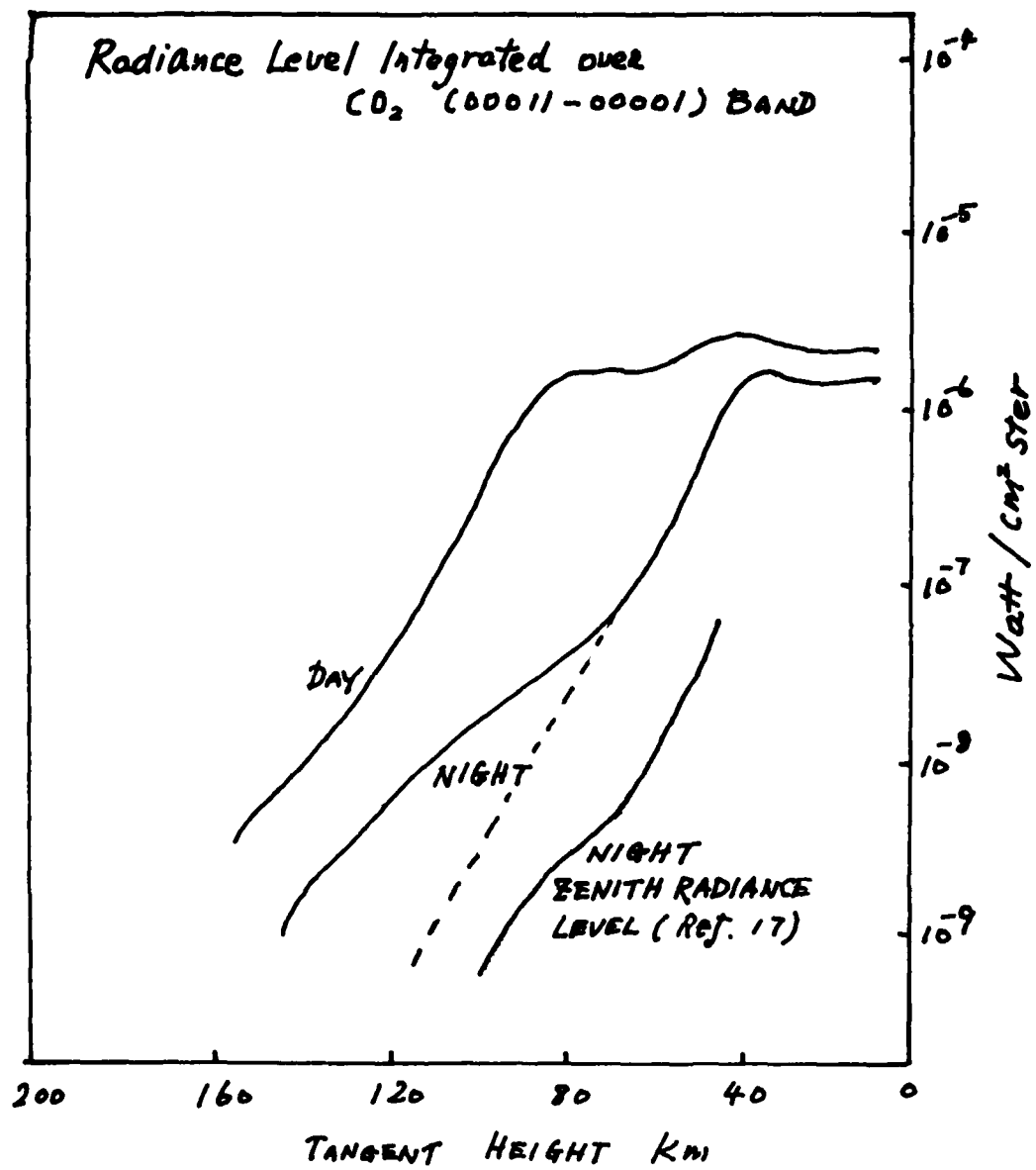


Figure 3

Model for Calculating Atmospheric Radiance Level

The expressions obtained above in Eqs. (4) and (11) are concerned with an individual interacting process in which a single photon is either absorbed or scattered by a molecule. In this section we will develop a model which relates the atmospheric radiance level to the basic interaction process given by these expressions.

The energy absorbed by a molecule in interaction with the photon field must be released in a de-excitation process. In the upper atmosphere, the only process available for de-excitation is a radiative process. A question which must be raised and answered for such a radiative excitation-de-excitation process concerns an establishment of equilibrium population density among various molecular states. Degges and other workers developed the computation program capable of giving an estimate of the radiative level in the normal atmospheric environment at high altitude.^{11,12} We are truly thankful for the existence of these programs which provided a valuable help to develop our insight into the problem.

We modified the Degges program to suit our needs, and to improve the computation efficiency in our CYBER system. A brief description of our effort along this direction will be given later in this report, together with the listing of our modifications. The atmospheric model is judged on its ability for producing a reasonable estimate of the infrared radiance level; in particular, it is questioned on precision and practicality.

The computation scheme to obtain the radiance level must find the equilibrium population distribution which is established among the vibrational states when the molecular system is subjected to balance with the photon field. The precision needed in the computation is somewhat controlled by a spectral resolution of the result. The emission involving

the hot-band transition can be distinguished only with an improved spectral resolution, because it is usually buried under the fundamental transition. We decided to ignore these hot-band transitions from our model in a belief their contribution is not significant to the computation. The assumptions made in our model* are certainly open for debate and all criticisms to our viewpoint are welcome. Our view that all transitions observed in the data occurred from the ground state, in turn, simplified the calculation to a great extent. A direct correlation was resulted in our formulation between the radiance level for a particular tangent height and the molecular density of the concerned molecular system at this altitude.

The total energy emitted by the molecules in a unit volume through the radiative de-excitation is equal to the energy absorbed by the same molecules if that is the only process feasible. The absorbed energy is given by the number of transition times the photon energy: $b' = h\nu N_t$. The energy released in the radiative de-excitation is emitted isotropically. Thus the energy re-emitted per a unit area over a unit solid angle is given by: $b = b'/4\pi = h\nu N_t/4\pi$. The photons released from a molecule are very unlikely absorbed again, since the atmosphere is optically thin.[†] Even if they are absorbed, they are re-emitted in the photon field. The photons which reach a sensor of a unit area with a field view of a unit solid angle are computed simply by accumulating the contribution from each unit volume which falls into a line of sight. Since the optical étendue preserves, the summation which we must take in the calculation is equal to that of each contribution b taken over a column of a unit cross-section extending from the sensor to the space all the way along the line of sight. The radiance level per unit solid angle integrated over the band is then given by

*See the Appendix D.

†The absorption along the limb-view path of 100 km tangent height is less than 5% for the (00011-00001) band of CO_2 .

$$B = \frac{h\nu N_t}{4\pi} = \frac{h\nu S_{ul} N N_p}{\pi} \quad (16)$$

where N is the total number of molecules counted along the line-of-sight per unit area;

$$N = \int N_0 \, d\ell \quad (17)$$

The density of atmospheric molecules falls off approximately exponentially with the altitude. If we can assume the density $N(h)$ as a function of altitude h given by

$$N(h) = N(h_0) e^{-\frac{h-h_0}{H}} \quad (18)$$

with a characteristic constant H , the total number of molecules between two altitudes h and h_0 is given by

$$\begin{aligned} N(h, h_0) &= \int_{h_0}^h N(h) \, dh = N(h_0) \int_{h_0}^h e^{-\frac{h-h_0}{H}} \, dh \\ &\approx N(h_0) H \end{aligned} \quad (19)$$

For the limb view calculation, we need to calculate a distance ℓ between two altitudes, the tangent height x and a height above by H . The distance ℓ is calculated by

$$\ell = (x+H+\rho) \sqrt{1 - \left(\frac{x+H}{x+H+\rho}\right)^2} \approx \sqrt{2H(x+\rho)} \quad (20)$$

where ρ is the earth radius (≈ 6360 km). To calculate the total density N along a line of sight to the tangent height x , we use the approximation Eqs. (19) and (20):

$$N = N_0(x) 2 \sqrt{2H(x+\rho)} \quad (21)$$

where $N_0(x)$ is the molecular density at altitude x . With the approximate total density N derived in Eq. (21) the limb-view radiance at the tangent

height x , is given by an expression

$$B = \frac{h\nu}{\pi} S_{ul} N_o(x) 2 \sqrt{2H(x+p)} N_p. \quad (22)$$

The expression given by the equation above requires an estimate of the photon density N_p . The value shown in Figure 1 is given in a unit wavenumber interval. The photons which contribute to the transition are those within the width of the vibrational-rotational lines. If we take the photon density to be the value over the band, say 100 cm^{-1} for the CO_2 (01101-00001) transition, we obviously get an erroneous result. The effective photon density must be adjusted by multiplying an effective number of the rotational lines within the band times the line width, which we can safely assume the Doppler width for those in the upper atmosphere.

CO_2 Bands, (01101-00001) and (00011-00001)

The CO_2 molecule is relatively stable in the atmosphere, because neither electronic transitions nor photo-dissociation occurs in the entire spectral range below the Schuman-Runge Continuum of O_2 . The mixing ratio remains constant in the atmosphere below 120 km where the O_2 absorption is very effective in blocking those high energy photons in the extreme uv region.

As a result, the equilibrium population distribution is established among various vibrational levels in the electronic ground state with insignificant perturbation from higher excited electronic states. The equilibrium is achieved in balance with the infrared photon field. Under this condition a major concern must be directed to the equilibrium population established for the metastable (10001) and (10002) level, which locates approximately 1300 cm^{-1} above the vibrational ground level. Since there are no optical transitions allowed between those and the ground level, a primary

candidate for pumping these levels is the radiationless collisional process which occurs only in the lower atmosphere. The SPIRE data indicate that the emission by the (10001-01101) and (10002-01101) transitions is definitely observable at low tangent height in both the day and night conditions. At high tangent height both of the emissions become less distinctive. It may be concluded that the radiative pumping mechanism for these metastable states is rather minor. The observation coincides with the results obtained by the Degges' radiation balance computation program.

The limb-view radiative levels of the observable CO₂ bands for high-tangent height are calculated with a reasonable accuracy by the model developed above. There are two clearly observable CO₂ emissions in the SPIRE data, one for the (01101-00001) band and another for the (00011-00001). As mentioned above, the emissions by the (10001-01101) and the (10002-01101) transitions are observable in the low-tangent-height data. Both the (10011-00001) and the (10012-00001) band will be discussed together with the scattering continuum observable in the 3000 cm⁻¹ ~ 10,000 cm⁻¹ region.

The radiance levels shown in Figures 2 and 3 are extrapolated from the SPIRE data by integrating them over the entire band. At a tangent height of 100 km, the (01101-00001) emission is 3×10^{-7} (watt/cm² sterad). Using the expression given in Eq. (22):

$$B = \frac{h\nu S N_o N_p}{\pi}$$

our calculation yields 2.0×10^{-7} watt/cm² sterad. In deriving the value, we take

$$h\nu = 1.32 \times 10^{-20} \text{ Joule}$$

$$S = 8.3 \times 10^{-8} \text{ mol}^{-1}/\text{cm}^2 \text{ cm}^{-1}$$

$$N_o = 5 \times 10^7 \times 10^9 \text{ for the 100 km tangent height, and}$$

$$N_p = 3 \times 10^{15} \times \Delta\sigma \times n = 3 \times 10^{15} \times .001 \times 40,$$

the Doppler width $\Delta\sigma$ calculated by

$$\Delta\sigma = \sigma_0 \frac{\sqrt{3kT}}{mc^2} \approx 0.001 \text{ cm}^{-1} \text{ for } \sigma_0 = 670 \text{ cm}^{-1},$$

and 40 rotational lines as those effectively emitted.

The SPIRE data indicate that the (00011-00001) emission at 100 km tangent height is 3×10^{-7} (watt/cm² sterad) for the daytime level and 3×10^{-8} (watt/cm² sterad) for the nighttime level. Our simple-minded calculation shows that $B = 2.1 \times 10^{-7}$ (watt/cm² sterad) for the day data and 2.1×10^{-9} (watt/cm² sterad) for the night data. In deriving these figures, we take

$$h\nu = 4 \times 10^{-20} \text{ Joule}$$

$$S = 9.6 \times 10^{-17} \text{ mol}^{-1}/\text{cm}^2 \text{ cm}^{-1}$$

$$N_0 = 5 \times 10^7 \times 10^9$$

$$N_p = 3 \times 10^{13} \times .1 \text{ for the day and } 3 \times 10^{11} \times .1 \text{ for the night.}$$

The observed and the calculated data for the day level agree reasonably well. The observed nighttime radiance level is about one order of magnitude higher than our calculation. In Figure 3, a dotted curve shows the nighttime radiance level calculated by our formulation, Eq. (22). Kumer et al¹⁷ analyzed the nighttime zenith radiance data of the same band (00011-00001), which is shown in the same Figure. Both nighttime calculations are remarkably similar. The SPIRE data differ from the data used in the Kumer's analysis in that they are for the limb view. The total CO₂ molecules involved in both data differ by an order of a magnitude. Thus, the radiance level differs by the same magnitude. The deviation from the exponential decay line in the radiance level occurs approximately at the same altitude for both data. Kumer et al interpreted this anomaly in terms of the extra pumping produced by the vibrationally excited N₂ molecules. The SPIRE data indicates that the

difference of the nighttime radiance level from the earthshine figure is more pronounced in the high altitude region where the interaction to the neighbor molecules should decrease. The anomaly in the nighttime radiance level for this band remains mysterious. We studied a possibility of observing the emission by the $W^3\Delta_u - B^3\Pi_g$ transition of N_2 which could be more intense at the altitude above 100 km because of a higher electron density there. A radiance level for the transition estimated on a basis of the known data fails to support the possibility.

Since at a low tangent height the band is completely saturated and the line structure is lost, the photon density available for the absorption is no longer adjusted by the effective number of the rotational lines excited in the band times their width. It is given by the width of the entire band times the photon density: $200 \times 3 \times 10^{11}$ photons/cm²/sec. Taking the photon energy $h\nu = 4.6 \times 10^{-20}$ Joule, we can estimate that the saturation level is given by

$$\frac{N h\nu}{\pi} = 0.9 \times 10^{-6} \text{ (watt/cm}^2 \text{ sterad).}$$

Scattering Radiance Observable Between 6000 cm^{-1} and 7500 cm^{-1} and the $\text{CO}_2\text{-H}_2\text{O}$ Band at 3600 cm^{-1}

The radiance level in a spectral region above 4000 cm^{-1} is strongly influenced by the scattering process, in particular the level observable at a low tangent height. For the Rayleigh process the scattering differential cross-section $\sigma(\phi)$ is given by Eq. (12):

$$\sigma_m(\phi) = \frac{9\pi^2\sigma^4}{N^2} \left(\frac{n^2-1}{n^2+1}\right)^2 \sin^2 \phi \approx 4\pi^2\sigma^4 \left(\frac{n-1}{N}\right)^2 \sin^2 \phi,$$

where σ is the optical frequency in cm^{-1} , both n the refractive index of the atmosphere and N the number density of the air molecule are those values at the S.T.P. condition, and ϕ is the scattering angle. The factor $(\frac{n-1}{N})$ is a slow varying function of σ . The scattering cross-section is thus predominantly controlled by σ and ϕ . Figure 4 shows the front factor $4\pi\sigma^2(n-1/N)^2$ as a function of σ . The radiance level obtained by the SPIRE experiment is compared with the computed value for the Rayleigh scattering in Figure 5. The observed values are replotted as a function of σ and of a tangent height in a unit of $\text{watt/cm}^2 \text{ strad cm}^{-1}$. Irregular structures which can be considered as the molecular absorption or emission are removed by smoothing out. In the computed values, N_p is assumed by the solar value, $3 \times 10^{13} \text{ photons/cm}^3/\text{S/cm}^{-1}$. The observed radiative level supports the computed molecular scattering level even though a minor difference exists, dependent on the tangent height and the spectral frequency.

The comparison shown in Figure 5 leads us to conclude two characteristic features of the radiance level in the 3000 ~ 7500 cm^{-1} range: (1) the scattering radiance is controlled by the single-scattering process; and (2) its main mechanism is the Rayleigh process. The aerosol particles contribute to the over-all scattering process, not significantly even at a low tangent height of 15 km.

A problem which we will discuss below plays a central importance in calculation of the infrared radiance level in the upper atmosphere. It is a combined effect of the molecular absorption-emission process and the scattering process. It was treated rather lightly, if not completely side-stepped. The computation modeling of the atmospheric radiance developed to cover a region where only one of these processes is important in the radiative process. There were no models developed to treat the situation where the processes are competitive. The data obtained by the SPIRE experiment is in fact the first to observe the radiance level generated by these processes in competition. The data revealed an extremely remarkable feature for the radiance level in the region of the $\text{H}_2\text{O}-\text{CO}_2$ 2.7μ band ($3600 \sim 3800 \text{ cm}^{-1}$). The radiative level observed in the 15 km tangent height data shows an absorptive feature for the band, while that in other data shows an emissive feature. The radiance level remains rather stationary at $10^{-7} \text{ (watt/cm}^2 \text{ strad } \mu)$ or $7.5 \times 10^{-11} \text{ (watt/cm}^2 \text{ strad cm}^{-1})$ over a wide range of the tangent height from 15 km to 41 km.

By means of the molecular absorption process the molecule is excited to a higher vibrational state in interacting with the radiation field. The energy absorbed by the molecule in the excitation to a higher vibrational state is equal to that supplied by the photon field. During the de-excitation stage, the same amount of energy is released. Dependent on the environmental surround to the molecule, the energy release takes place to the photon field or to others. If the interaction with the photon field dominates the de-excitation process, there is no net energy loss in the photon ensemble. The absorbed energy from the photon field is released back to the photon field by the de-excitation process. When the collisional process dominates the de-excitation process, the energy absorbed from the photon ensemble is

not released back. The photon density in the ensemble decreases until the photon ensemble reaches a thermal equilibrium with the molecular ensemble. The photon density which is established under a thermal equilibrium is given by the expression which was used to compute the values for Figure 1:

$$N_p = \frac{2\pi\sigma^2c}{\frac{h\sigma c}{e^{kT-1}}} .$$

The radiative level observable from such an ensemble of the photons and the molecules is given by

$$I = \frac{h\nu N_p}{\pi} .$$

The stationary emission observed for the 2.7μ H_2O-CO_2 band corresponds to the situation described above. What we can observe is the photons generated by the H_2O-CO_2 band which are in a thermal equilibrium at the tropopause temperature. Using the blackbody photon density $N_p .92 \times 10^7$ at 3600 cm^{-1} and $225^\circ K$, and the photon energy $h\nu 7.1 \times 10^{-20}$ Joule at 3600 cm^{-1} , the saturation level I is calculated as 2.1×10^{-11} watt/cm² sterad cm⁻¹. With assuming $T = 260^\circ K$, the computation yields 5×10^{-11} watt/cm² sterad cm⁻¹. This value is independently determined from the internal excitation-de-excitation mechanism of the molecular system. Whenever the molecular system establishes a thermal equilibrium with the environment under the saturation absorption condition, the photon field must be in an equilibrium with it. The stationary photon flux observed for the 2.7μ H_2O-CO_2 band represents this situation, as was the case for the CO_2 (00011-00001) transition at lower altitude. If the saturation photon flux is larger than the scattering photon flux, the radiance level of the band in question is emissive. If it is smaller, the radiance level is absorptive.

$$4\pi^2 \left(\frac{n-1}{N} \right)^2 \sigma^4$$

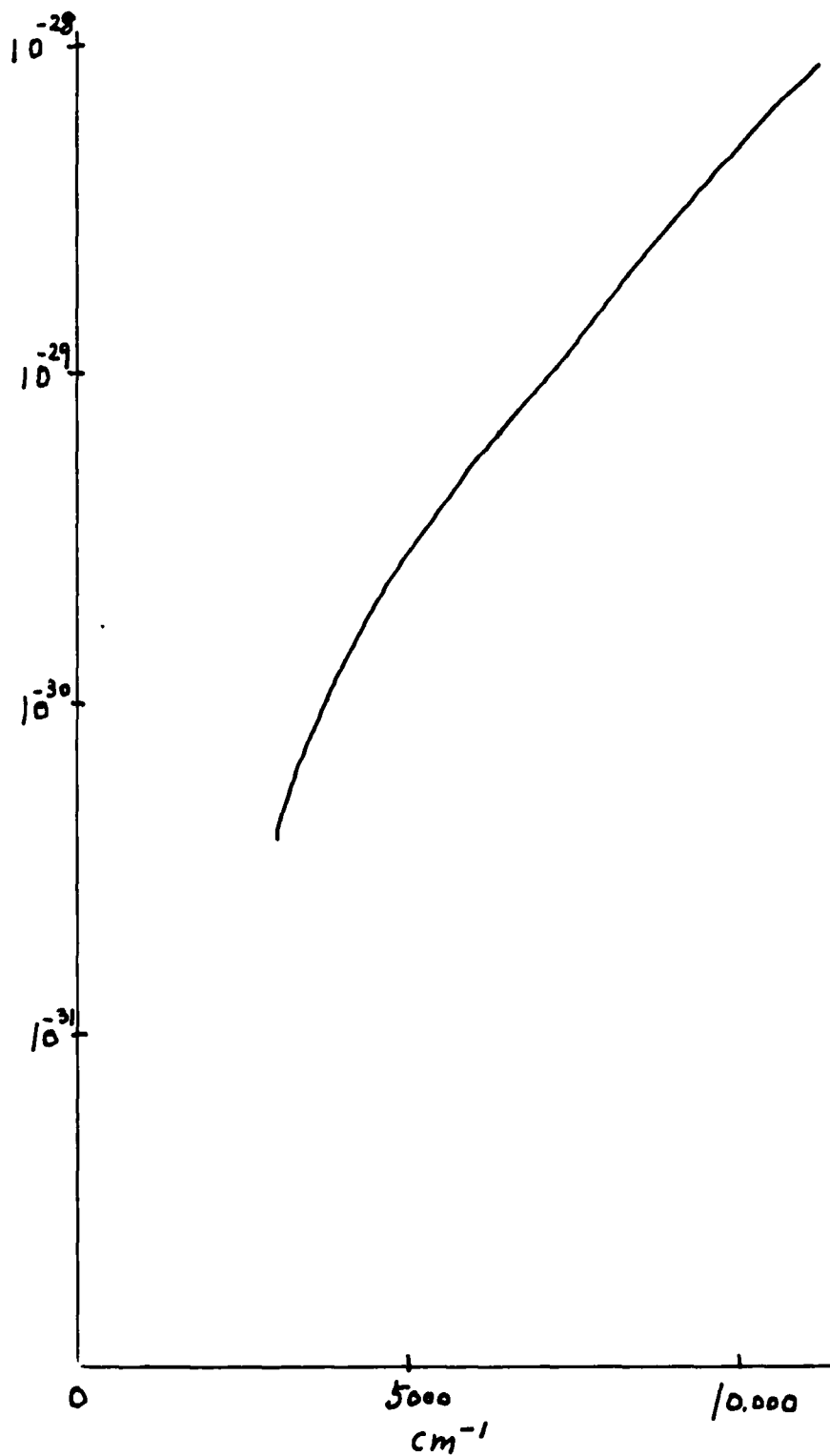


Figure 4

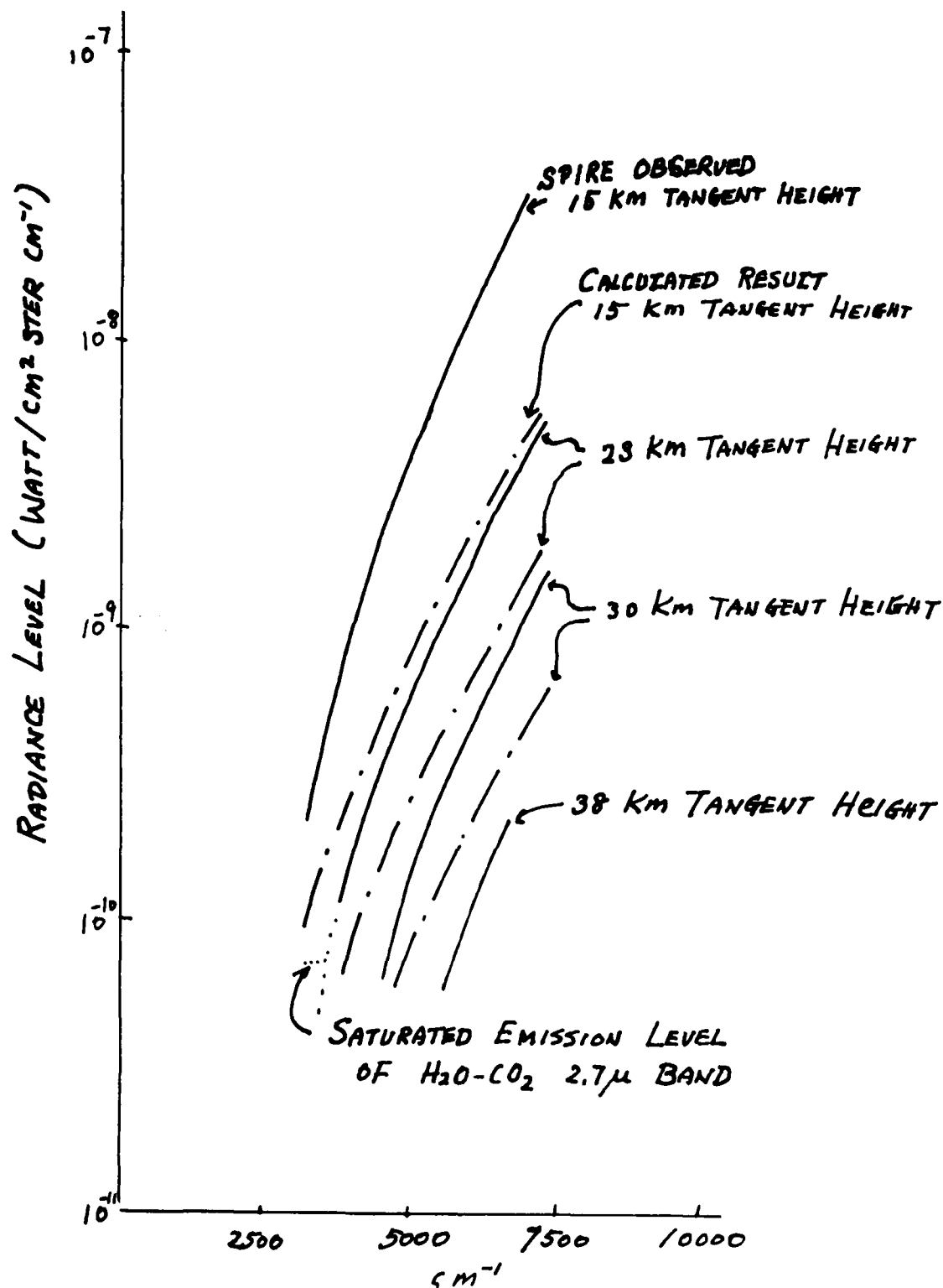


Figure 5

In both cases, the radiation level remains constant.

The Radiance Level of a Molecular Band

In the last two chapters, we discussed the saturated radiance level of the ν_3 band of CO_2 and of the 2.7μ $\text{H}_2\text{O}-\text{CO}_2$ band. We found that the photon flux under the saturation conditions is given by the blackbody radiation formula; i.e., that the molecular system and the photon ensemble come to establish a thermal equilibrium. For a given molecular band, there exists a critical altitude that the photon density is completely specified by the blackbody radiation formula independent from the vibrational-rotational transition. In the atmosphere above the critical altitude, the photon density is specified by the molecular transition equation, Eq. (4):

$$N_t = 4 N_o N_s S.$$

A sensor placed very high in the atmosphere collects the photons generated by the molecular transitions which occur along a line-of-sight. With the approximation of a thin optical density air, the total molecular transitions which contribute to the observation are given by integrating the transitions N_t along the path:

$$N = \int N_t \, dz. \quad (23)$$

Under the approximate expression derived for an observation at a tangent height x , we calculate the total density per a solid angle per a unit cross-section by

$$N(x) = \frac{4N_s}{\pi} N_o(x) \sqrt{2H(x+p)}. \quad (24)$$

In deriving the equation above, an assumption is made that the photon density N_p responsible for exciting the molecular transition is constant along the path. In a spectral region below 2000 cm^{-1} where the telluric photons at the tropopause temperature control the excitation, the assumption is obviously

well justified. In a higher cm^{-1} region where the solar photons are dominant, a blackbody temperature corresponding to the solar photon density is much higher than the tropopause temperature as seen in Figure 6. The radiance level of the molecular emission reaches a maximum plateau at the saturation photon density specified by the temperature of tropopause. Thus the molecular transitions, even when they are integrated along a long path, are much less than the solar photon density flux which has a temperature much higher than the saturation photon temperature. The loss caused by the molecular transition along the path is therefore much smaller than the total solar photon density, and a constant photon density is maintained, as assumed above. This justification obviously breaks down as the radiance level approaches the saturation level.

In a non-saturating region, we find that the observable photons given by Eq. (22) are controlled by the factor $N(x_0)$, the molecular density at the tangent height X . In the first-order approximation, the radiance level at a particular tangent height gives the density of the observing molecule at that altitude. For a stable molecule, its density decreases exponentially as a function of the altitude. We can model the radiance of a molecular band, as shown in Figure 7, by an exponential function with a plateau at the critical altitude. The model certainly agrees with the radiance data collected by the SPIRE for the ν_3 band of CO_2 .^{*} The computed results by the Degges program as well as by the LOWTRAN for various bands support this model.

^{*}The atmospheric sounding technique currently experimented uses this model. It is to observe the saturation photon density at the critical altitude, which varies from a spectral region to another as a function of the absorption strength. The observed radiance level gives a local equilibrium temperature at the altitude. An atmospheric sounding program proposed to NESS will use the (01101-00001) and (00011-00001) transitions of CO_2 .¹³

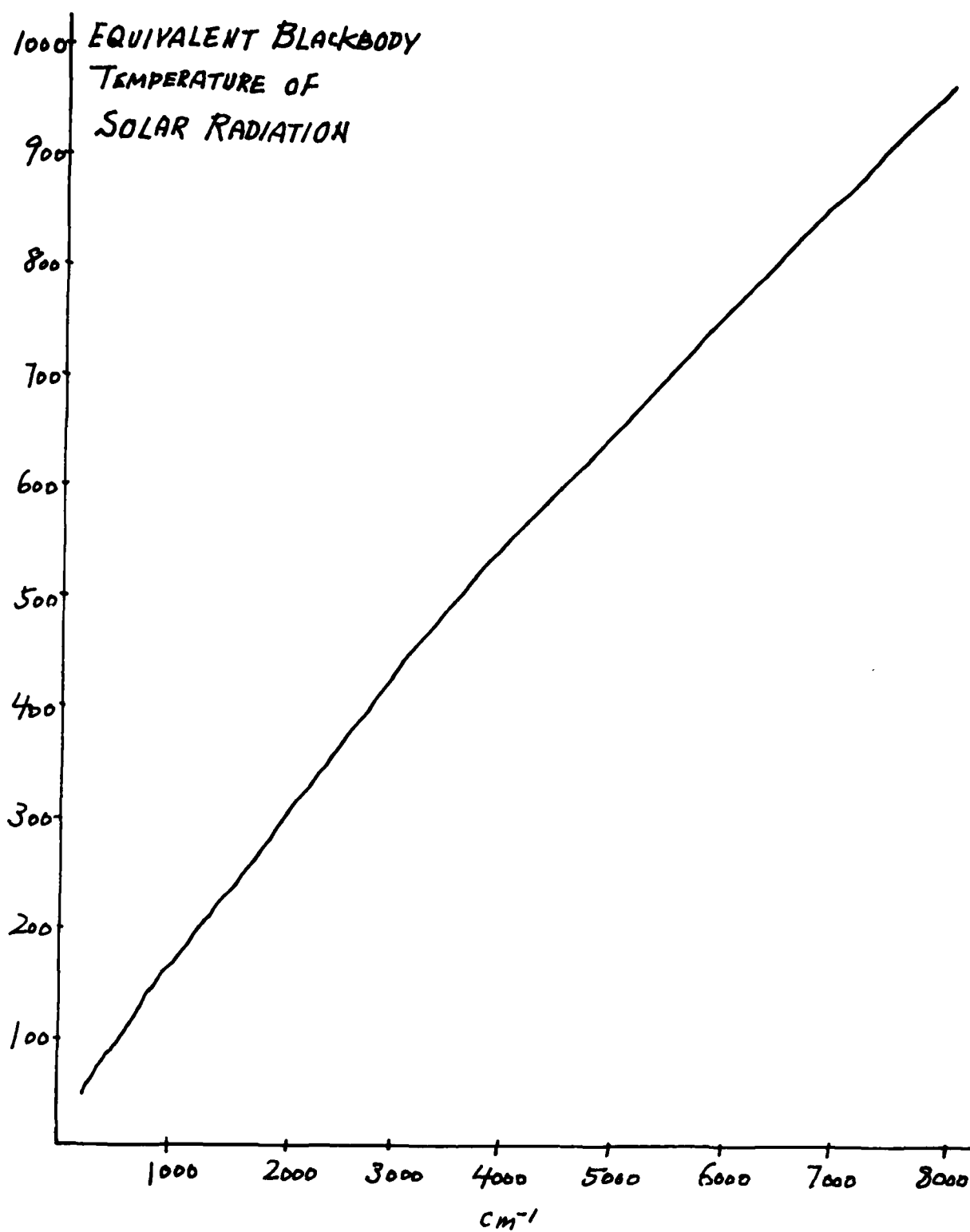


Figure 6

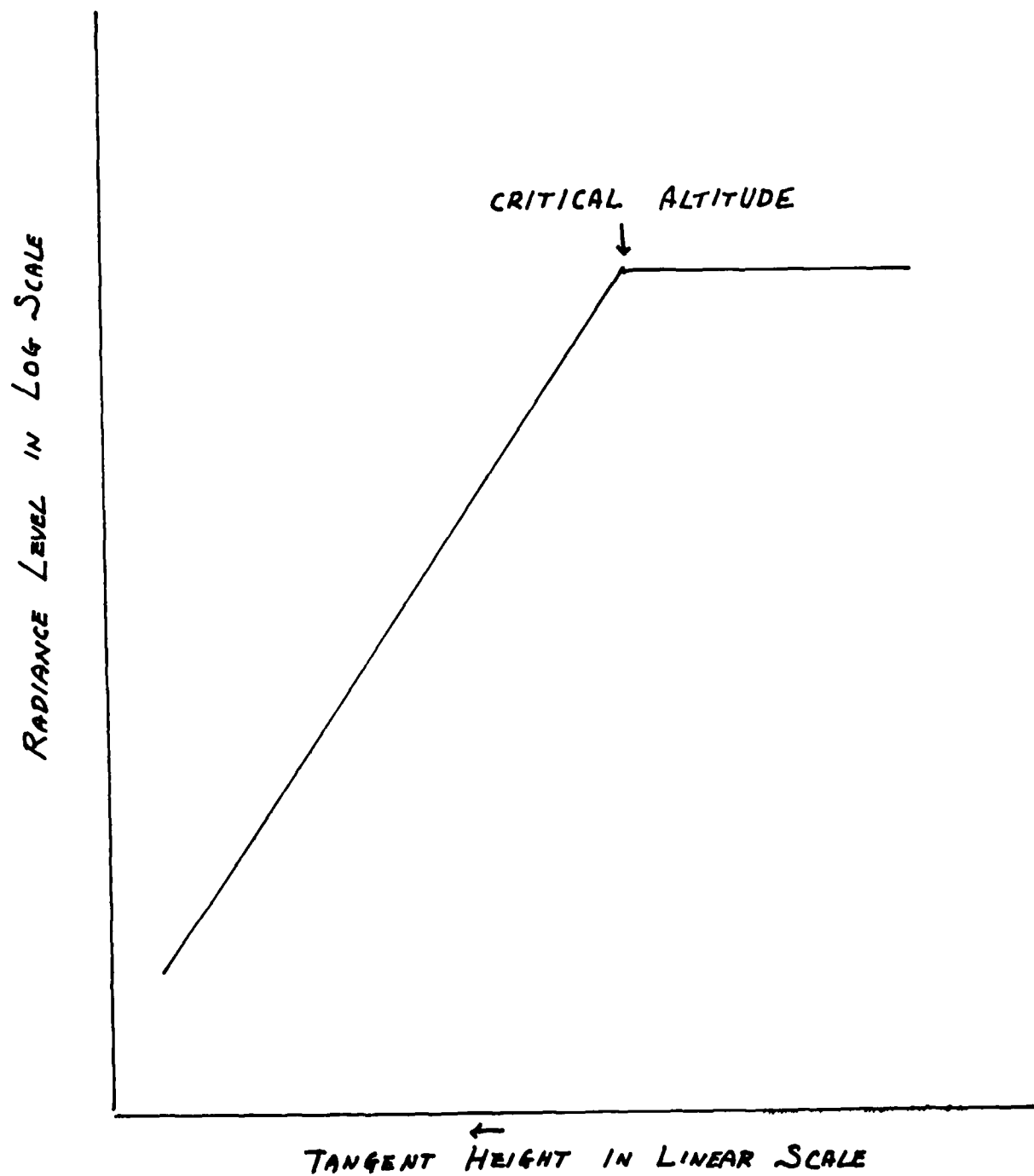


Figure 7

In the upper atmosphere, the radiance level is thus dictated directly by the molecular density. A deviation of the radiance level from the exponential decay is expected if the molecular concentration falls off rather differently from the exponential model. The SPIRE data on the infrared radiance level provide a base to determine the concentration of the observed atmospheric species as a function of the altitude. From our point of view, the radiance level data of O_3 , H_2O and NO and other minor species provided the first measured data which revealed the distribution of these species at high altitude.

The radiance level data of O_3 observed at a tangent height of 80 km show a rather dramatic change from the day to the night side, while the density of the excitation photons remains unchanged between these two periods. A mechanism which causes the diurnal change must be sought in some photo-chemical effect triggered by the ultraviolet photons.

Modification Applied to the BGND Program

In the course of our study, we made an extensive use of four computation programs: the BGND written by Degges of Visidyne, Inc.;^{11,12} the LOWTRAN by Selby of then AFGL;¹⁴ the FLASH by Blattner of Radiation Research Associates, Inc.;^{5,6,7} and the FASCODE by Clough *et al* of AFGL.^{15,16} We applied some modifications to these programs for improvement of the execution efficiency. The operating system of our central site computing facility is designed to accommodate a large number of the remote terminals. Because of the operating system, we found that the program executes more efficiently if its working space required is reduced in size from the original. We divided these programs into small sections, achieving their executions through our remote terminal possible during the regular hour. In addition, inefficient IO operations found in these programs are streamlined to meet our specific needs and to reduce a

computational waste. We have consequently achieved a substantial improvement in running these programs. Our strategy for using the FLASH program was described in our Report No. 1. Overall modifications, except for the BGND, did not extend to rewrite their computation algorithms. We feel that they have no specific merit for their coverage in this report. The case for the BGND is different. Our modification is listed in the Appendix. A general logic flow of the program execution is illustrated in Figure 8.

Other Efforts

- (1) For the balloon-borne experiment, we evaluated the test data on the interferogram PCM telemetry scheme. We found some mysterious bit droppings in the PCM interferogram data string. A substantial effort was poured to resolve this mystery in a joint effort with the Idealab and the AFGL. No conclusions were made on this problem. Our effort was switched after a new contract for the balloon-borne data analysis became effective.
- (2) A very efficient CRT display program for the CYBER system was written by R. Lauzzana. Its listing is given in Appendix B.
- (3) In anticipating a large amount of the CYBER generated plots, we implemented a micro-computer controlled linkage between our plotting machine and the CYBER MODEM scheme. The program implemented on ROM of the 8080 system is listed in Appendix C.

Conclusion

The SPIRE experiment is in a sense a historical event in the progress of atmospheric physics. Even though the data were collected using a simple spectrometer radiometer, their merit is extremely valuable in developing our understanding of the atmospheric radiative process. Our simple-minded model

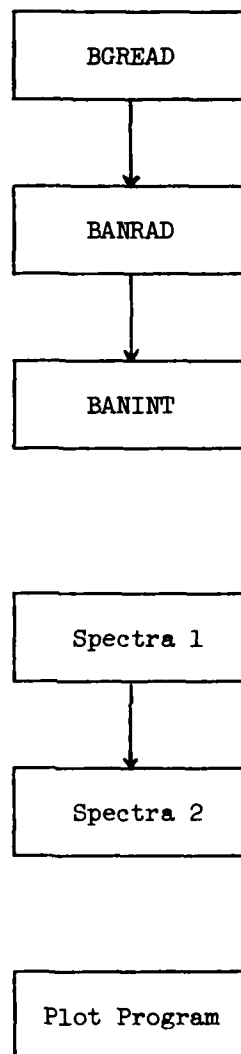


Figure 8

achieved a good success in understanding the radiance level of the major atmospheric CO₂ bands. We believe that our constructed model provides a good insight into the atmospheric radiative process. Ours is no different from the aforementioned computation programs, since all of these are constructed on the same theoretical development. Ours attempted to model the radiative process in the simplest form possible required for providing a good estimate of its level.

There will be no question that the data will be collected with an improved spectral resolution, as time will progress. Then we will come to understand more details of the radiative process in the atmosphere. In so doing, we will be more appreciative of those aforementioned computation programs. At this moment, our simple-minded model functioned reasonably well for analysis of the SPIRE data, revealing a basic character of the infrared radiance level in the upper atmosphere, as well as some abnormal feature which must be studied more carefully in the future.

The following list summarizes our model of the radiative process in the upper atmosphere:

- (1) In the upper atmosphere, the molecular absorption transitions which trigger the emission are well approximated by assuming that they originate from the ground state.
- (2) The photons available for exciting the molecular transitions are either those of the telluric origin or of the solar origin. The cross-over takes place in the vicinity of 2000 cm⁻¹.
- (3) Below the critical altitude, the molecular bands establish a local thermal equilibrium with the photon field. The radiative level given by the blackbody radiation formula is maintained over a large range of altitude if the absorption is very strong. It is independent

of the observation condition and of the scattering radiance level.

- (4) Well above the critical altitude, the radiative level of the molecular band is proportional to the molecular concentration at that altitude in the first-order approximation.
- (5) The scattering radiance level in the near infrared region is primarily determined by the Rayleigh process with a single scattering center.

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Appendix A

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```

210 WRITE (NW,200) K
220 IF (K.EQ.0) GO TO 230
230 WRITE (NW,200) K
240 DC 240 L=K1,K2
250 IF (ALT(L).LT.ALTH) GO TO 240
260 KSET=L
270 GO TO 260
280 CCNTINUE
290 CCNTINUE
300 FORMAT(37HMAX ALT. NOT FOUND CN TEMP DATA CARDS)
310 WRITE (NW,250)
320 CALL INTERF(ALT,STCRE,KSET,2,1)
330 FCRMAT (1X,1E,1P5E12.4)
340 WRITE (NW,260) (J,(CCNC(J,I),I=1,IGAS), T(J),J = 1,201)
350 IGAS=IGAS-1
360 CC 331 II=1,IGAS
370 READ (NR,310) TYPE,NLEV,NBAN,AMAS,CEXT,DEXB
380 FCRMAT (7X,22X,12,3X,12,3X,F6.2,4X,2(E12.4,3X))
390 CC 311 J=1,25
400 IF (TYPE.EQ.CATATY(J)) GO TO 312
410 CCNTINUE
420 WRITE (NW,370)
430 FCRMAT(36HTHE GAS IS NOT LISTED IN THE PROGRAM)
440 STOP 1
450 NSF=J
460 NLEVEL(NSF)=NLEV
470 NBAN(NSF)=NBAN
480 AMAS(NSF)=AMAS
490 CEXT(NSF)=CEXT
500 DEXB(NSF)=DEXB
510 IF (NSF.EQ.2) READ (NR,320) (CC2(I,1),CC2(I,2),I=1,18)
520 FCRMAT (6F5.2,F8.2)
530 IF (NSF.EQ.3) READ (NR,320) (WATVA(I,1),WATVA(I,2),I=1,18)
540 ILEV=0
550 DC 313 I=1,NLEV
560 ILEV=ILEV+1
570 READ (NR,330) LSC(IJ,NSF),LCC(IJ,NSP),RCM(IJ,NSF),BV(IJ,NSP),JGAS,
580 1 JLEVEL
590 FCRMAT (2E,2E12.4,3EX,2I3)
600 IF (NSF.EQ.JGAS) GO TO 314
610 WRITE (NW,340) NSP
620 FCRMAT(64HTHE CODE ON THE DATA DOES NOT AGREE WITH THE FIRST CARD
630 1NFICH IS,I3)
640 STOP 2
650 IF (ILEV.EQ.JLEVEL) GO TO 313
660 WRITE (NW,350) NSF
670 FCRMAT(42H THERE IS A CARD OUT OF SEQUENCE IN GAS NO.,I3)
680 STOP 3
690 CCNTINUE
700 ILEV=0
710 CC 316 IJ=1,NBAN
720 ILEV=ILEV+1
730 READ (NR,360) LBC(IJ,NSP),LEU(IJ,NSP),STR(IJ,NSF),SFLUX(IJ,NSP),
740 1 (IFLUX(IJ,NSF,J),J=1,3),JGAS,JLEVEL
750 STR(IJ,NSF) = 2.4793E+10*STR(IJ,NSP)
760 FCRMAT (2E,1P5E12.4,2I3)
770 FCRMAT (2E,1P5E12.4,2I3,1X,4AE)
780 IF (NSF.EQ.JGAS) GO TO 322
790 WRITE (NW,340) NSF
800 STOP 4
810 IF (ILEV.EQ.JLEVEL) GO TO 316
820 WRITE (NW,350) NSF
830 STOP 5
840 CCNTINUE
850 CCNTINUE
860 FCRMAT (1P5E12.4)
870 READ (NR,370) CHEML
880 READ (NR,370) IGAS,NLTE
890 IF (IGAS.EQ.0) STOP
900 WRITE (NP,370) T
910 WRITE (NP,370) TOTCEN
920 WRITE (NP,370) (CCNC(NZ,IGAS),NZ=1,201)
930 WRITE (NP,360) IGAS,NLTE
940 NLEV = NLEVEL(IGAS)
950 NBAN = NBAN(IGAS)
960 WRITE (NP,335) (XIC(K,IGAS),K=1,4),NLEV,NBAN,AMAS(IGAS)
970 2,CEXT(IGAS),COEXE(IGAS)
980 FCRMAT(4AE,EX,T2,3X,12,3X,F6.2,4X,2(E12.4,3X))
990 DC 381 I=1,NLEV
1000 WRITE (NP,360) LSC(IJ,IGAS),LCC(IJ,IGAS),RCM(IJ,IGAS),BV(IJ,IGAS)
1010 CCNTINUE

```

```

      CC 382 IJ = 1, NEND
      WRITE (NF,360) LFC(IJ,IGAS),LBU(IJ,IGAS),STR(IJ,IGAS)
2     ,SFLUX(IJ,IGAS),TFLUX(IJ,IGAS,1)
382  CONTINUE
      JALT = (IALT(IGAS) - 1)/5
      WRITE (NF,360) IALT(IGAS),JALT
      IF(IGAS.NE.4) GO TO 830
      WRITE(6,378) CHEML
      GO TO 830

      END

      SLBROTIME INTERP(ALT,STORE,KSET,MODE,I)
      DIMENSION ALT(30),STORE(30)
      COMMON CCNC(201,8),T(201),LAMDA(25),
1 TCTDEN(2(1))
      J=1
      A=60
8     CC 120 K=1,KSET
10    IF(A-ALT(K))80,20,20
20    GC TO (30,40),MODE
30    CCNC(J,I)=STORE(K)
      GC TO 50
40    T(J)=STORE(K)
50    IF(K.LT.KSET) GO TO 60
      RETURN
60    IF(J.GE.91) GO TO 70
      A=A+1.
      GC TO 110
70    A=A+5.
      GC TO 110
80    FR=(A-ALT(K-1))/(ALT(K)-ALT(K-1))
      GC TO (90,100),MODE
90    CCNC(J,I)=STORE(K-1)+FR*(STORE(K)-STORE(K-1))
91    J=J+1
      IF(J.GT.91) GO TO 92
      A=A+1.
      GC TO 10
92    A=A+5.
      GC TO 10
100   T(J)=STORE(K-1)+FR*(STORE(K)-STORE(K-1))
      GC TO 91
110   J=J+1
120   CONTINUE
      RETURN
      END

```

```

PROGRAM BANRAC(TAFE2=103E,TAFF4=107B,T/PE3,OUTFUT=103E
2 ,TAFE6=CLTFL1)
C THIS IS A MODIFIED VERSION OF DEGG'S SUBROUTINE BANRAC
C LAST CHANGE AUG 30, 1978
C DIMENSION FCWER(40),KL(40),XIC(4)
C DIMENSION TFLUX(40),SFLUX(40)
C DIMENSION GFAC(40)
C DIMENSION LSC(40),LCC(40),LPU(40),LPC(40)
C DIMENSION WAVE(40),STR(40),RV(40),PNCLAM(40),FACC(40)
C DIMENSION GNDSTE(201),TEMP(201),CENTCT(201),VIE(40,3)
C DIMENSION ENCRAD(201,40),ENCTAL(201,40)
C COMMON VIEFCF(201,25)
C COMMON /CCL/ TVSIG(201),VTSIG(201),VLSIG(201),VVDSIG(201)
2 ,VVNSIG(201),VVRSIG(201)
C COMMON /CFDATA/ NALT,NLEVEL,NBAND,7FAC,KP(40),EA(40),GUF(40)
2 ,GDCWN(40),TTUP(40),TTECHN(40),LPSTA(40),COWN(40),TTF(201,40)
3 ,CCNC(201),CHEML(201)
C EQUIVALENCE (GNDSTE(1),VIEFCF(1,1))
C EQUIVALENCE (TFLUX,CLP),(SFLUX,GDCWN)
C EQUIVALENCE (TTF,ENCTAL),(TTF,ENCRAD)
C EQUIVALENCE (LSC(1),VIE(1,1)),(LCC(1),VIE(1,2)),(LPU(1),VIE(1,3))
C EQUIVALENCE (GFAC,COWN),(CENTCT(1),TTF(1,1))
C EXTERNAL CO2,H2O,FAC,C3
ZFAC=1.0
C READ IN TEMPERATURE AND MOLECULAR PROFILE
C READ(2,378) TEMP
C WRITE(4,378) TEMP
C READ(2,378) CENTCT
C READ(2,378) CCNC
378 FCFMAT(1FEE12.4)
C READ IN WHICH GAS AND CONDITION (NLTE=3 NIGHT, NLTE=4 DAY)
C READ(2,368) IGAS,NLTE
368 WRITE(4,368) IGAS,NLTE
CFMAT(2IE,1FEE12.4)
C NOTE 1 IN LEGGS IS IGAS IN THIS PROGRAM
C READ IN LEVEL INFO
C READ(2,310) (XIC(K),K=1,4),NLEVEL,NBAND,FM,CCEXT,CCEXE
310 WRITE(4,310) (XIC(K),K=1,4),NLEVEL,NBAND,FM,CCEXT,CCEXE
CFMAT(4IE,EX,12,3X,12,3X,F6.2,4X,2(1FE12.4,3X))
C DO 1 I=1,NLEVEL
C READ(2,368) LSC(I),LCC(I),WAVE(I),RV(I)
1 WRITE(4,368) LSC(I),LCC(I),WAVE(I),RV(I)
C READ IN ENCRAD INFO
C DO 2 I=1,NBAND
2 READ(2,368) LEC(I),LPU(I),STR(I),SFLUX(I),TFLUX(I)
C READ(2,368) NALT,NALT
C IF(IGAS.EQ.4) READ(2,50) (CHEML(I),I=1,161)
50 FCFMAT(6E12.4)
C THIS SECTION COMPLETES POPULATION OF VIBRATIONAL LEVELS.
C COMPUTE THERMAL POPULATION
C DO 130 NZ = 1, NALT
C SUM = 0.0
C TMP = TEMP(NZ)
C DO 110 NL = 2, NLEVEL
C XYN = MOD(LSC(NL)/10,10)
C AA = EXP(-1.43875*WAVE(NL)/TMP)*XYN
C VIBFCF(NZ,NL) = AA
110 SUM = SUM + AA
C CONTINUE
C SUM = SUM + 1.0
C GNDSTE(NZ) = CCNC(NZ)/SUM
120 VIBFCF(NZ,NL) = CCNC(NZ)*VIBFCF(NZ,NL)/SUM
C CONTINUE
130 CONTINUE
C FIND LEVEL COUPLED WITH NITROGEN
C DO 135 NL = 2, NLEVEL
C IF (LCC(NL).EQ. 1) VVWAVE = 2331. - WAVE(NL)
C IF (LCC(NL).EQ. 2) VVWAVE = 1556.4 - WAVE(NL)
C FAC = 2331.0
C IF (LCC(NL).EQ. 2) FAC = 1556.4
135 CONTINUE
C IF(NLTE.EQ.1) GO TO 170
C FIND COLLISION EXCITATION AND DE-EXCITATION COEFS
C DO 160 NZ = 1,NALT
C TEMPNZ = TEMP(NZ)
C TEMP13 = EXP(ALOG(TEMPNZ)/3.0)
C IF (IGAS.EQ. 3) GO TO 136
C IF (IGAS.EQ. 2) GO TO 140
C VTSIG(NZ) = 6.69E-10*EXP(-24.07/TEMP13)
C VVRSIG(NZ) = 1.71E-6*EXP(-175.3/TEMP13)
1 + 6.07E-14*EXP(15.27/TEMP13)

```

```

VVD SIG(NZ) = 1.0E-15 + 5.1E-11*EXP(-76.75/TEMP13)
VVNSIG(NZ) = VVRSIG(NZ)/EXP(1.43879/TEMP(NZ)*18.0)
VVUSIG(NZ) = VVD SIG(NZ)*VIEFCF(NZ,8)/VIEPOP(NZ,5)
GO TC 150
136 CONTINUE
FAC = 0.0
VVNSIG(NZ) = 4.0E-13
VTSIG(NZ) = 5.37E-16*EXP(-70.0/TEMP13)
VVR SIG(NZ) = VVNSIG(NZ)*EXP(-1.43879/TEMP(NZ)*1594.73E)
GO TC 150
140 CONTINUE
VTSIG(NZ) = CDEXT
VVNSIG(NZ) = CDEYE
VVR SIG(NZ) = VVNSIG(NZ)*EXP(-1.43879/TEMP(NZ)*VVWAVE)
150 CONTINUE
TVSIG(NZ) = VTSIG(NZ)/GNDSTE(NZ)*VIEPCP(NZ,2)
VTSIG(NZ) = VTSIG(NZ)*TENTOT(NZ)
TVSIG(NZ) = TVSIG(NZ)*TENTCT(NZ)
TNNV = TEMP(NZ)
IF (ALTE .LT. 5) GO TC 154
IF (NZ .GT. 41 .AND. NZ .LT. 51) TNNV = TEMP(NZ)+FLCAT(NZ-41)
1 IF (NZ .GE. 51) TNNV = 3000.0
154 CONTINUE
FACTOR = EXP(-1.43879*FAC/TNNV)
VVNSIG(NZ) = VVNSIG(NZ)*TENTCT(NZ)*FACTOR/(1.0 + FACTOR)
VVR SIG(NZ) = VVR SIG(NZ)*TENTCT(NZ)/(1.0 + FACTOR)
160 CONTINUE
C COMPUTE VIEFCP FOR TEMP=180
CC 160 NZ = 1, NALT
SUM = 0.0
TMP = 180.0
CC 162 NL = 2, NLEVEL
XYN = MOI(LSC(NL)/10,10)
AA = EXP(-1.43879*WAVE(NL)/TMP)*XYN
VIEFCP(NZ,NL) = AA
SUM = SUM + AA
162 CONTINUE
SUM = SUM + 1.0
GNDSTE(NZ) = CCNC(NZ)/SUM
CC 164 NL = 2, NLEVEL
VIEFCP(NZ,NL) = CCNC(NZ)*VIEFCP(NZ,NL)/SUM
164 CONTINUE
166 CONTINUE
170 CONTINUE
C COMPUTE OPTICAL DATA
CC 180 NE = 1, NEANC
NBC = LEC(NB)
NI = MOI(NBC/100,100)
NF = MOI(NBC,100)
KL(NF) = MCC(LBU(NB)/10,10)
KB(NF) = MCC(LBU(NF),10)
TWAVE = WAVE(NI) - WAVE(NF)
ENCLAM(NB) = 1.0E+4/TWAVE
IF (TFLLX(NB) .EQ. 0.0) TFLLX(NB) =
1 5.957E+6*TWAVE**4/(EXP(1.43879*TWAVE/TEMP(1)) - 1.0)
XYM = MCC(LSC(NF)/10,10)
XYMM = MCC(LSC(NI)/10,10)
EA(NF) = STR(NB)*2.804/ENCLAM(NF)**2*XYM
1 *EXP(1.43879*WAVE(NF)/296.0)/XYMM
FCHER(NF) = 1.580E-20/ENCLAM(NB)
GFAC(NB) = 3.72E-24*STR(NB)*ENCLAM(NB)**2
1 *EXP(1.43879*WAVE(NF)/296.0)
GUP(NB) = GFAC(NB)*TFLLX(NB)*12.4864
IF (ALTE .LT. 3) GLP(NB) = 0.0
GDOWN(NB) = GFAC(NB)*SFLUX(NB)
IF (ALTE .LT. 4) GDOWN(NB) = 0.0
KBN = KE(NF)
KLN = KL(NF)
ENL = BV(1)
ENCL = ENCLAM(NB)
FACC(NB) = FCHER(NB)*EA(NB)
SNB = STR(NB)*EXP(1.43879*WAVE(NF)/296.0)
CC 180 NZ = 1, NALT
ENDTAU(NZ,NB) = TAU MAX(KLN,KBN,RM,BVN,TEMP(NZ),ENCL,SNB)
1 VIEFOP(NZ,NF)
IF (ALTE .GT. 1) GO TC 180
ENDRAC(NZ,NB) = VIEFCF(NZ,NI)*FAC
180 CONTINUE
CC 175 NE=1,NEANC
175 WRITE(4,360) LBC(NF),LEL(NB),STR(NB),ENCLAM(NB),FACC(NB)
WRITE(4,360) NALT,JALT

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      IF (NLTE.EQ. 1) GO TO 900
      ITMAX = 5
      IF (IGAS.EQ.2) ITMAX = 10
      AC = 3
      ITER = 0
C     START OF BALANCE LOOP
101  ITER = ITER + 1
      NMIN = NALT - 1
C
      CC 190 NB = 1, NBAND
      LOOK CUT ENCTAU AND TTH ARE EQUIVALENT
      TTHL = SIMF(ENCTAU(1,NB),1.0E+5,1)
      CC 182 NZ=2,NMIN
      NZM = NZ-1
      TTHNZ = SIMF(ENCTAU(NZM,NE),1.0E+5,2)
      TTH(NZM,NB) = TTHL
      TTHL = TTHNZ
182  CCNTINUE
      TTH(NMIN,NE) = TTHL
      SUM = 0.0
      IF (NLTE.LE.3) GO TO 186
      CC 184 NZ=1,NMIN
184  SUM = SUM + TTH(NZ,NB)
186  TTDOWN(NB) = SUM
      TTUP(NB) = 0.0
      DOWN(NB) = SUM
      UPSTA(NB) = 0.0
190  CCNTINUE
200  CCNTINUE
C     NIAL SHOULD BE A POWER OF TWO
      NIAL = 4
      WRITE(3,1000)
1000  FORMAT(* VIBFOP *)
      CC 1030 NZ=1,201
1030  WRITE(3,8) (VIBPOF(NZ,NL),NL=1,NLEVEL)
      WRITE(6,8) (VIBPOF(12,NL),NL=1,NLEVEL)
      WRITE(6,8) (VIBPOF(32,NL),NL=1,NLEVEL)
      WRITE(3,1001)
1001  FORMAT(* NALT,NBAND,ZFAC,KB(40),EA(4) *)
      WRITE(3,*) NALT,NEANC,7FAC
      WRITE(3,*) (KB(NB),NB=1,NEANC)
      WRITE(3,1008) (EA(ICUT),ICUT=1,16)
1008  FORMAT(1F2E12,4)
      GO TO (210,220,230,240,250,260), IGAS
210  CCNTINUE
      GO TO 350
220  CCNTINUE
      CALL CAL2(C2,NIAL,AC,VIB)
      GO TO 350
230  CCNTINUE
      CALL CAL2(F2C,NIAL,AC,VIB)
      GO TO 350
240  CCNTINUE
      CALL CAL2(FNO,NIAL,AC,VIB)
      GO TO 350
250  CCNTINUE
      GO TO 350
260  CCNTINUE
      CALL CAL2(C3,NIAL,AC,VIB)
      GO TO 350
350  CCNTINUE
      CC 360 NB = 1, NBAND
      NEC = LEC(NB)
      NF = MOC(NEC,100)
      KLN = KL(NE)
      KFN = KE(NE)
      EVN = BV(1)
      SNB = STR(NB)*EXF(1.43879*HVE(NF)/296.0)
      BNCL = BNCLP(NB)
      CC 360 NZ = 1, NALT
      ENCTAU(NZ,NB) = TAU*MAX(KLN,KFN,RP,BVN,TEMP(NZ),BNCL,SNB,
1  VIBFOP(NZ,NF))
360  CCNTINUE
400  CCNTINUE
500  IF (ITER.LT. ITMAX) GO TO 181
      IF (NLTE.LE. 2) GO TO 920
      CC 910 NZ = 1, NALT
      WRITE(4,8) (VIBFCF(NZ,NL),NL = 1, NLEVEL)
910  CCNTINUE
      CC 910 NZ=1,NALT
915  WRITE(4,8) (ENCTAU(NZ,NE),NE=1,NBAND)
920  CCNTINUE

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70  CC 70 NB=1,NEAND
    UFSTA(NB)=TTUP(NB)
    CCWN(NB)=TTCCWN(NB)
    NEXT=NIAL
C    HAS SAFETY FACTOR AGAINST OSCILLATION OF 2.
    IF((ATEST*4.)<.LT.AC) NEXT=NEXT*2
    RETURN
    END

C
C
C    SLRCLTIME TTSET(NZST,NIAL,MCC)
    MCC=1 IS TAU FROM UFSTA AND CCWN
    MCC=2 TAU FROM TTLP AND TTCCWN
    COMMON /CFDATA/ MALT,NLEVEL,NEAND,ZFAC,KB(40),EA(40),GUF(40)
2  ,GDCWN(40),TTUP(40),TTCCWN(40),LPSTA(40),DOWN(40),TTF(201,40)
3  ,CONC(201),CHEML(201)
    IF(MCC.NE.1) GO TO 20
    CC 10 NB=1,NEAND
    TTUP(NB)=UFSTA(NB)
    TTDOWN(NB)=CCWN(NB)
    NZF=NZST+NIAL-1
    CC 30 NZ=NZST,NZF
    CC 30 NB=1,NEAND
    TA=TT(NZ,NE)
    TTUP(NB)=TTUP(NB)+TA
    TTDOWN(NB)=TTDOWN(NB)-TA
    RETURN
    END

C
C    FUNCTION RTFUN(NZ,NUS,NBS)
    NLS IS THE NUMBER OF THE LEVEL, NBS IS THE NUMBER OF THE BAND
    DIMENSION GNDSTE(201)
    COMMON VIEFCF(201,25)
    COMMON /CFDATA/ MALT,NLEVEL,NEAND,ZFAC,KB(40),EA(40),GUF(40)
2  ,GDCWN(40),TTUP(40),TTCCWN(40),LPSTA(40),DOWN(40),TTF(201,40)
3  ,CONC(201),CHEML(201)
    EQUIVALENCE (GNDSTE(1),VIEFCF(1,1))
    RTFUN=
1  (XFER(VIEFCF(1,NLS),TTF(1,NBS),NZ,1,1,KB(NBS))
2  + XFER(VIEFCF(NZ,NLS),TTF(NZ,NBS),MALT,NZ,2,KB(NBS)))*EA(NBS)
3  +GDCWN(NBS)*SM1(KB(NBS),ZFAC*TTCCWN(NBS))
4  +GUF(NBS)*SN12(KB(NBS),TTUP(NBS))
    RETURN
    END

C
C    SLRCLTIME CC2(VIEI,NZ)
    DIMENSION VIEI(40),GNDSTE(201)
    COMMON /CGL/ VTSIG(201),VTSIG(201),VVUSIG(201),VVDSIG(201)
2  ,VVNSIG(201),VVRSIG(201)
    COMMON VIEFCF(201,25)
    COMMON /CFDATA/ MALT,NLEVEL,NEAND,ZFAC,KB(40),EA(40),GUF(40)
2  ,GDCWN(40),TTUP(40),TTCCWN(40),LPSTA(40),DOWN(40),TTF(201,40)
3  ,CONC(201),CHEML(201)
    EQUIVALENCE (GNDSTE(1),VIEFCF(1,1))
2  VIRI(8)=ALOG(GNDSTE(NZ)*VVUSIG(NZ)+RTFUN(NZ,N,5))
    VTS=VTSIG(NZ)
    VTS=VTSIG(NZ)
    FOP3=VIEFCF(NZ,3)
    FOP4=VIEFCF(NZ,4)
    FOP7=VIEFCF(NZ,7)
    FOP2=((VTS+RTFUN(NZ,2,1))*GNDSTE(NZ)
2  + FOP3*(EA(2)+VTS)+FOP4*(EA(3)+VTS)
3  + FOP7*(EA(7)+VTS))/(VTS+EA(1)+VTS)
    VIRI(2)=ALOG(FOP2)
    FOP8=VIEFCF(NZ,8)
    FOP7=((VTS*0.25+GLF(7)*SN12(KB(7),TTUP(7))
1  +GDCWN(7)*SM1(KB(7),TTCCWN(7)))*FOP2
2  +EA(8)*FOP8+EA(15)*VIEFCF(NZ,9)+EA(16)*VIEFCF(NZ,10))
3  /(EA(7)+VTS)
    VIEI(7)=ALOG(FOP7)
    FOP5=VIEFCF(NZ,5)
    FOP6=VIEFCF(NZ,6)
    FOP3=((FOP2*(0.25*VTS+GUF(2)*SN12(KB(2),TTLP(2))
1  +GDCWN(2)*SM1(KB(2),TTCCWN(2)))+FOP5*(EA(4)+VTS)
2  +EA(10)*FOP6+EA(13)*VIEFCF(NZ,9)+EA(14)*VIEFCF(NZ,10))
3  /(EA(2)+VTS+VTS)
    VIEI(3)=ALOG(FOP3)
    FOP4=((FOP2*(0.5*VTS+GUF(3)*SN12(KB(3),TTLP(3))
1  +GDCWN(3)*SM1(KB(3),TTCCWN(3)))+FOP5*EA(5)
2  +FOP6*(EA(6)+VTS))/(EA(3)+VTS+VTS)

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VIEI(4)=ALCG(POP4)
POP5=(FCF3*(TVS+GLP(4)*SN12(KE(4),TTUF(4))
1 + GDOWN(4)*SM1(KE(4),TTDOWN(4)))
2 + FCP4*(GUP(5)*SN12(KE(5),TTUP(5))
3 + GDOWN(5)*SM1(KE(5),TTDOWN(5))) + POP8*VVDSIG(NZ)
4 /(EA(4)+EA(5)+VTS+VVUSIG(NZ))
VIEI(5)=ALCG(POP5)
FCP6=(FCF4*(0.5*TVS+GUP(6)*SN12(KE(6),TTUF(6))
1 + GDOWN(6)*SM1(KE(6),TTDOWN(6))))/(EA(6)+VTS)
VIEI(6)=ALCG(POP6)
VIBI(9)=ALCG((VIEFOP(NZ,3)*(VVNSIG(NZ)+RTFLN(NZ,9,13))
1 + GNDSTE(NZ)*RTFUN(NZ,9,11)+VIBPCP(NZ,7)*RTFUN(NZ,9,15))
2 /(VVRISIG(NZ)+EA(11)+EA(13)+EA(15)))
VIBI(10)=ALCG((VIBFCP(NZ,7)*(VVNSIG(NZ)+RTFLN(NZ,10,16))
1 + VIBFCF(NZ,3)*RTFUN(NZ,10,14)+GNDSTE(NZ)*RTFUN(NZ,10,12))
2 /(VVRISIG(NZ)+EA(12)+EA(14)+EA(16)))
VIBI(11)=CCNC(NZ)-(POP8+POP6+POP5+POP7+POP4
1 + PCP3+FCF2)
IF (VIBI(11).LE.0.6) VIPI(1)=0.05*CCNC(NZ)

VIPI(1)=ALCG(VIBI(1))
RETURN
END

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SUBROUTINE H2C(VIEI,NZ)
DIMENSION VIEI(40),GNDSTE(201)
COMMON VIEPCP(201,25)
COMMON /CCL/ TVSIG(201),VTSIG(201),VVUSIG(201),VVDSIG(201)
2 ,VVNSIG(201),VVRISIG(201)
COMMON /CPDATA/ NALT,NLEVEL,NBAND,ZFAC,KB(40),EA(40),GUF(40)
2 ,GDOWN(40),TTUP(40),TTDOWN(40),UPSTA(40),COWN(40),TTH(201,40)
3 ,CONC(201),CHEML(201)
EQUIVALENCE (GNDSTE(1),VIBFCF(1,1))
VIBI(2)=ALCG((TVSIG(NZ)+VVNSIG(NZ)
1 + RTFUN(NZ,2,1)*GNDSTE(NZ)+VIEFCF(NZ,3)*EA(5))
2 /(VTSIG(NZ)+EA(1)+VVNSIG(NZ)))
VIBI(3)=ALCG((TVSIG(NZ)+VVUSIG(NZ)
1 + RTFUN(NZ,3,5)*VIEFCF(NZ,2)+
2 RTFLN(NZ,3,2)*GNDSTE(NZ)+VIBPCP(NZ,6)*EA(11))
3 /(EA(2)+EA(5)+VTSIG(NZ)+VVNSIG(NZ)))
VIBI(4)=ALCG((RTFUN(NZ,4,3)*GNDSTE(NZ)
1 + RTFUN(NZ,4,6)*GNDSTE(NZ))/(EA(3)+EA(6)))
VIBI(5)=ALCG((RTFUN(NZ,5,4)*GNDSTE(NZ)
1 + RTFLN(NZ,5,7)*VIBPCP(NZ,2))/(EA(4)+EA(7)))
VIBI(6)=ALCG((RTFLN(NZ,6,8)*VIBPCP(NZ,8)
1 + RTFUN(NZ,6,12)*GNDSTE(NZ))/(EA(8)+EA(11)
2 +EA(12)))
VIBI(7)=ALCG((RTFLN(NZ,7,9)*VIBPCP(NZ,2)
1 + RTFUN(NZ,7,13)*GNDSTE(NZ))/(EA(9)+EA(13)))
VIBI(8)=ALCG((RTFUN(NZ,8,10)*VIEFOP(NZ,2)
1 + RTFUN(NZ,8,14)*GNDSTE(NZ))/(EA(10)+EA(14)))
VIBI(9)=ALCG((CONC(NZ)-(VIEFCF(NZ,8)+VIBPCP(NZ,7)+VIBFCF(NZ,6)
2 +VIBFOP(NZ,5)+VIEFCF(NZ,4)+VIBFCF(NZ,3)+VIBFCF(NZ,2)))
RETURN
END

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SUBROUTINE RNC(VIBI,NZ)
DIMENSION VIBI(40),GNDSTE(201)
COMMON VIBPCP(201,25)
COMMON /CCL/ TVSIG(201),VTSIG(201),VVUSIG(201),VVDSIG(201)
2 ,VVNSIG(201),VVRISIG(201)
COMMON /CPDATA/ NALT,NLEVEL,NBAND,ZFAC,KB(40),EA(40),GUF(40)
2 ,GDOWN(40),TTUP(40),TTDOWN(40),UPSTA(40),COWN(40),TTH(201,40)
3 ,CONC(201),CHEML(201)
EQUIVALENCE (GNDSTE(1),VIEFOP(1,1))
VIBI(2)=ALCG((TVSIG(NZ)+VVNSIG(NZ)
1 + GLP(1)*SN12(KE(1),TTUF(1))
2 + (XFER(VIBPCP(1,2),TTH(1,1),NZ,1,1,KB(1))
3 + XFER(VIBPCP(NZ,2),TTH(NZ,1),NALT,NZ,2,KB(1)))*EA(1)
4 + GDOWN(1)*SM1(KE(1),TTDOWN(1))*GNDSTE(NZ)
5 + (EA(3)+VTSIG(NZ))*VIBFCF(NZ,3)+2.0*CHEML(NZ))
6 /(EA(1)+VTSIG(NZ)+VVUSIG(NZ)+TVSIG(NZ)))
VIBI(3)=ALCG((TVSIG(NZ)
1 + GLP(3)*SN12(KE(3),TTUF(3))
2 + GLP(2)*SN12(KE(2),TTUF(2))
3 + GDOWN(2)*SN12(KE(2),TTDOWN(2))
4 + GDOWN(3)*SN12(KE(3),TTDOWN(3))*VIBPCP(NZ,2)
5 + 2.0*CHEML(NZ))/(EA(2)+EA(3)+TVSIG(NZ)))
VIBI(1)=ALCG((CONC(NZ)-VIBFCF(NZ,2)-VIBPCP(NZ,3))

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IF (T.GT. 1.0) GO TC 110
X = (T - 0.5)*2.0
SLO3 = (((2.583E-4*X - 6.014E-3)*X - 0.1027233)*X
1 + 0.12528221*ALCG(T)*T + (0.4035503)*T
RETURN
110 CONTINUE
IF (T.GT. 4.0) GO TC 120
X = (T - 2.5)/1.5
SLO3 = (((1.17E-4 - 3.51E-4*X)*X - 1.0464E-3)*X
1 + 2.7618E-3)*X - 7.9E-3)*X + 0.0219502)*X
2 - 0.0625550)*X + 0.1575702)*T
RETURN
120 CONTINUE
IF (T.GT. 10.0) GO TC 130
X = (T - 7.0)/3.0
SLO3 = (((1.7495E-4*X - 4.9991E-4)*X + 0.00113772)*X
1 - 0.00234938)*X + 0.0100981)*X - 0.03090774)*X
2 + 0.10486302)*T
RETURN
130 CONTINUE
Y = ALCG(T)
IF (T.GT. 100.0) GO TC 140
X = 5.21034037197E/Y - 3.0
SLO3 = (((1.97E-5 - 5.78E-5*X)*X + 2.458E-4)*X
1 - 0.0012858)*X + 0.0340297)*X + 0.3210431)*Y
RETURN
140 CONTINUE
IF (T.GT. 1000.0) GO TC 150
X = 27.631021115E3/Y - 5.0
SLO3 = (((8.3E-6 - 2.01E-5*X)*X - 1.843E-4)*X
1 + 0.0129309)*X + 0.2729344)*Y
RETURN
150 CONTINUE
X = 13.815510557E/Y - 1.0
SLO3 = (((5.39E-4*X - 0.0015838)*X + 0.0016309)*X
1 - 0.0001371)*X - 0.0023757)*X + 0.0301341)*X
2 + 0.2315830)*Y
RETURN
200 CONTINUE
IF (T.GT. 1.0) GO TC 210
X = (T - 0.5)*2.0
SLO3 = (((1.607E-4*X - 4.056E-3)*X - 0.0880225)*X
1 + 0.097407381*ALCG(T)*T + 0.4161293)*T
RETURN
210 CONTINUE
IF (T.GT. 4.0) GO TC 220
X = (T - 2.5)/1.5
SLO3 = (((1.5904E-4 - 2.794E-4*X)*X - 8.069E-4)*X
1 + 2.2244E-3)*X - 6.6504E-3)*X + 0.0197235)*X
2 - 0.0631582)*X + 0.2307133)*T
RETURN
220 CONTINUE
IF (T.GT. 10.0) GO TC 230
X = (T - 7.0)/3.0
SLO3 = (((1.47E-4*X - 4.291E-4)*X + 1.0472E-3)*X
1 - 3.316E-3)*X + 0.0107584)*X - 0.0356259)*X
2 + 0.1310340)*T
RETURN
230 CONTINUE
Y = ALCG(T)
IF (T.GT. 100.0) GO TC 240
X = 5.21034037197E/Y - 3.0
SLO3 = (((4.18E-4 - 1.21E-4*X + 3.79E-5)*X)*X
1 + 7.79E-5)*X + 9.84E-5)*X - 0.0022069)*X
2 + 0.0320889)*X + 0.4187794)*Y
RETURN
240 CONTINUE
IF (T.GT. 1000.0) GO TC 250
X = 27.631021115E3/Y - 5.0
SLO3 = (((1.6E-5*X - 3.642E-4)*X + 0.0134767)*X
1 + 0.3700889)*Y
RETURN
250 CONTINUE
X = 13.815510557E/Y - 1.0
SLO3 = (((1.0049E-3 - 4.412E-4*X)*X - 8.441E-4)*X
1 + 9.451E-4)*X - 3.476E-3)*X + 0.0335987)*X
2 + 0.3254546)*Y
RETURN
300 CONTINUE
SLO3 = 0.0
RETURN
END

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FUNCTION SN12 (K,TAL)
T = ABS (TAL)
IF (T .EQ. 0.0) GO TO 300
IF (K .(T. 1) GO TO 200
IF (T .GT. 1.0) GO TO 110
T = 25.26767337*T
SN12 = ((((((5.54E-16*T - 1.3747E-13)*T + 3.11717E-11)*T
1 - 6.434609E-9)*T + 1.24762E-6)*T - 2.57626E-4)*T
2 - 0.08264246 + 0.01984964*ALOG(T))*T + 1.0)*0.5
RETURN
110 CONTINUE
IF (T .GT. 4.0) GO TO 120
X = (T - 2.5)/1.5
SN12 = ((((((3.00591E-3 - 1.41466E-3*X)*X - 3.98085E-3)*X
1 + 9.48736E-3)*X - 0.0279407)*X + 0.0523088)*X
2 - 0.1045984)*X + 0.1862743)*0.5
RETURN
120 CONTINUE
IF (T .GT. 10.0) GO TO 130
X = (T - 7.0)/3.0
SN12 = ((((((5.08470E-4 - 1.90181E-4*X)*X - 5.27594E-4)*X
1 + 2.24274E-3)*X - 5.54268E-3)*X + 0.01290804)*X
2 - 0.02636975)*X + 0.06552257)*0.5
RETURN
130 CONTINUE
IF (T .GT. 100.0) GO TO 140
Y = ALOG(T)
X = 9.210340371976/Y - 3.0
SN12 = ((((((7.836E-4*X - 1.5181E-3)*X + 9.0128E-4)*X
1 - 6.494E-4)*X - 1.0632E-3)*X + 0.0149364)*X
2 + 0.4378273)*0.5/T
RETURN
140 CONTINUE
Y = ALOG(T)
X = 9.210340371976/Y - 1.0
SN12 = ((((((5.0746E-3 - 4.681E-4*X)*X - 1.5848E-3)*X
1 + 0.014752F)*X + 0.4079074)*0.5/T
RETURN
200 CONTINUE
IF (T .GT. 1.0) GO TO 210
T = 25.0729185*T
SN12 = ((((((2.71E-16*T - 6.8372E-14)*T + 1.58314E-11)*T
1 - 3.39873E-9)*T + 7.01818E-7)*T - 1.61594E-4)*T
2 - 0.0656453 + 0.01494384*ALOG(T))*T + 1.0)*0.5
RETURN
210 CONTINUE
IF (T .GT. 4.0) GO TO 220
X = (T - 2.5)/1.5
SN12 = ((((((2.32E-3 - 1.12(3E-3*X)*X - 3.0489E-3)*X
1 + 7.9345E-3)*X - 0.0213281)*X + 0.0521586)*X
2 - 0.1213660)*X + 0.2508902)*0.5
RETURN
220 CONTINUE
IF (T .GT. 10.0) GO TO 230
X = (T - 7.0)/3.0
SN12 = ((((((4.727E-4*X - 1.2459E-3)*X + 2.5263E-3)*X
1 - 6.7323E-3)*X + 0.0174765)*X - 0.0421443)*X
2 + 0.0958415)*0.5
RETURN
230 CONTINUE
IF (T .GT. 100.0) GO TO 240
Y = ALOG(T)
X = 9.210340371976/Y - 3.0
SN12 = ((((((9.1E-5*X - 1.5056E-3)*X - 1.8059E-3)*X
1 + 0.0263129)*X + 0.6392594)*0.5/T
RETURN
240 CONTINUE
Y = ALOG(T)
X = 9.21034037976/Y - 1.0
SN12 = ((((((6.444E-4*X + 3.453E-4)*X - 5.099E-4)*X
1 + 0.0216100)*X + 0.691052)*0.5/T
RETURN
200 CONTINUE
SN12 = 1.5
RETURN
END

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C      FUNCTION SJMAX (KL,KB,SIG)
C      SJMAX COMPUTES THE RELATIVE STRENGTH OF THE STRONGEST LINE
C      IF KB = 1, SIGMA-SIGMA TRANSITION
C      IF KB = 2, SIGMA-PI TRANSITION
110    GO TC (110,120,130), KE
        CONTINUE
        TJM = 0.5*(SGRT(C.25 + 2.0/SIG) - 1.5)
        A = C.5*(TJM + TJM + 1.0)
120    GO TC 200
        CONTINUE
        TJM = 0.5*(SGRT(2.0/SIG) - 1.0)
        A = TJM + 1.0
130    GO TC 200
        CONTINUE
        SJMAX = C.0
        RETURN
200    CONTINUE
        SJM = A*EXP(-SIG*TJM*(TJM + 1.0))
        SJMAX = SJM/GJPART(KL,SIG)
        RETURN
END

C      FUNCTION GJPART (K,SIG)
C      GJPART COMPUTES THE ROTATIONAL PARTITION FUNCTION FOR A
C      RIGID ROTATOR, SIG .LE. 0.2.
C      K = 1, ALL LEVELS POPULATED
C      K = 2, EVEN LEVELS POPULATED
C      K = 3, ODD LEVELS POPULATED
        IF (SIG .GT. 0.2) STOP
        X = SIG
        IF (K = 2) 110,120,130
        COEFFICIENTS ARE FROM RUN CALTE-EV
110    CONTINUE
        GJPART = (((((0.0038650272*SIG + 0.0125718235471)*X
1      + 0.0666756164530)*X + 0.333333133379)*X + 1.00000000017)/SIG
        RETURN
120    CONTINUE
        GJPART = ((((((62.5879214103*SIG - 29.5697177693)*SIG
1      + 8.496922670006)*SIG - 0.202572235608)*SIG
2      + (.0257378193546)*SIG + 0.0328350909506)*SIG
3      + 0.166670220770)*SIG + 0.499999999456)/SIG
        RETURN
130    CONTINUE
        GJPART = (((((((29.5703117876 - 62.5874596502*SIG)*SIG
1      - 5.49579373669)*SIG + 0.505750942701)*SIG
2      - 0.0100397551676)*SIG + 0.0338315285069)*SIG
3      + 0.1666663112387)*SIG + .500000000244)/SIG
        RETURN
END

FUNCTION SIMP (A,H,K)
DIMENSION A(3)
IF (K = 2) 100,110,120
100    CONTINUE
    SIMP = (8.0*A(2) + 5.0*A(1) - A(3))*H/12.0
    RETURN
110    CONTINUE
    SIMP = (8.0*A(2) + 5.0*A(3) - A(1))*H/12.0
    RETURN
120    CONTINUE
    SIMP = (4.0*A(2) + A(1) + A(3))*H/3.0
    RETURN
END
```

```

FUNCTION SM1 (K,TAU)
  T = ABS(TAU)
  IF (T .GE. 0.1) GC TC 300
  IF (K .GE. 2) GC TC 200
  IF (T .GT. 4.0) GC TC 110
  X = (T - 2.0)/3.0
  SM1 = (((12.35450E-03)*X - 8.90535E-03)*X + 2.56223E-02)*X
  1 - 7.07877E-02)*X + 1.63735E-01)*X - 3.01749E-01)*X + 0.426845
  RETURN
110 CONTINUE
  IF (T .GT. 10.0) GC TC 120
  X = (T - 7.0)/3.0
  SM1 = (((15.92257E-04)*X - 1.79043E-03)*X + 4.05109E-03)*X
  1 - 1.04749E-02)*X + 2.59109E-02)*X - 6.01702E-02)*X + 0.134123
  RETURN
120 CONTINUE
  IF (T .GT. 100.0) GC TC 130
  Y = ALOG(T)
  X = 5.210340371976/Y - 3.0
  SM1 = (((11.62451E-04)*X - 6.79378E-04)*X + 2.98590E-03)*X
  1 - 1.28150E-03)*X - 6.31784E-03)*X + 3.78904E-02)*X
  2 + 8.90441E-01)/T
  RETURN
130 CONTINUE
  Y = ALOG(T)
  X = 5.210340371976/Y - 1.0
  SM1 = (((16.12038E-04)*X - 2.93434E-04)*X - 4.36163E-04)*X
  1 + 1.30037E-02)*X - 3.80082E-04)*X + 3.23441E-02)*X
  2 + 8.17407E-01)/T
  RETURN
200 CONTINUE
  IF (T .GT. 4.0) GC TC 210
  X = (T - 2.0)/3.0
  SM1 = (((11.39071E-03)*X - 5.29904E-03)*X + 1.58249E-02)*X
  1 - 4.74039E-02)*X + 1.26175E-01)*X - 2.86333E-01)*X + 0.517573
  RETURN
210 CONTINUE
  IF (T .GT. 10.0) GC TC 220
  X = (T - 7.0)/3.0
  SM1 = (((13.76420E-04)*X - 1.25384E-03)*X + 3.41168E-03)*X
  1 - 1.05360E-02)*X + 3.07476E-02)*X - 8.14705E-02)*X + 0.1941308
  RETURN
220 CONTINUE
  IF (T .GT. 100.0) GC TC 230
  Y = ALOG(T)
  X = 5.210340371976/Y - 3.0
  SM1 = (((7.53415E-03)*X - 8.87124E-03)*X + 6.62199E-02)*X
  1 + 1.30424E-01)/T
  RETURN
230 CONTINUE
  Y = ALOG(T)
  X = 5.210340371976/Y - 1.0
  SM1 = (((11.99067E-03)*X - 5.82519E-04)*X + 1.59569E-03)*X
  1 + 1.21174E-02)*X + 4.76165E-02)*X + 1.18445)/T
  RETURN
300 CONTINUE
  SM1 = 1.0

  RETURN
END

```

```

      PROGRAM EANTINT (CLUTET, TAPE3, TAPE4, TAPE6)
      THIS PROGRAM IS LIKE THE LAST PART OF CEGG'S ECND
      LAST CHANGE AUG 22, 1978
      DIMENSION XIC(4), FAC(25), FLAM(25)
      DIMENSION LSC(25), LCC(25), FCM(25), BV(25)
      DIMENSION ZANG(7), STAU(7), SFAC(8)
      DIMENSION LEC(25), LBU(25), STR(25)
      COMMON /FCFCOM/ VIBPCF(201,10)
      COMMON TAU(201,25), RAD(201), T(201)
      DATA(ZANG(1),I=1,7)/0.0,20.0,40.0,60.0,70.0,80.0,90.0/
      360 FORMAT(2I6,1P5E12.4,2I3)
      362 FORMAT(2I6,1P5E12.4,2I3,1X,4A6)
      READ(4,378) T
      READ(4,362) IGAS, NLTE
      READ(4,310) (XIC(K), K=1,4), NLEVEL, NEAND, AMASS
      310 FORMAT(4A6, EX, I2, 3X, I2, 3X, F6.2)
      WRITE(3,378) T
      371 FORMAT(1F6E12.4)
      WRITE(3,360) IGAS
      WRITE(3,362) NLEVEL, NEAND, AMASS, IGAS, NLTE, (XIC(K), K=1,4)
      DO 381 IJ=1, NLEVEL
      READ(4,360) LSC(IJ), LCC(IJ), FCM(IJ), BV(IJ)
      WRITE(3,360) LSC(IJ), LCC(IJ), FCM(IJ), BV(IJ)
      381 CONTINUE
      DO 382 IJ=1, NEAND
      READ(4,360) LBC(IJ), LBL(IJ), STR(IJ), FLAM(IJ), FAC(IJ)
      WRITE(3,360) LBC(IJ), LBL(IJ), STR(IJ), FLAM(IJ), FAC(IJ)
      382 CONTINUE
      READ(4,360) IALT, JALT
      WRITE(3,360) IALT, JALT
      8 FORMAT(1F8E10.4)
      118 FORMAT(1F8E12.4)
      DO 331 NZ=1, IALT
      READ(4,118) (VIBPCF(NZ, NL), NL=1, NLEVEL)
      DO 335 NZ=1, IALT
      WRITE(3,8) (VIBPCF(NZ, NL), NL=1, NLEVEL)
      DO 337 NZ=1, IALT
      READ(4,118) (TAU(NZ, NE), NE=1, NEAND)
      337 JSET=NEAND
      DO 840 J=1, JSET
      AFC=LEC(J)
      NI=MOD(NEC/100,100)
      DO 606 NZ=1, IALT
      600 RAD(NZ)=FAC(J)*VIBPCF(NZ, NI)
      700 FORMAT(1F1,4A6,8HEAND NC, I3, EX, 7HLANDP =, F6.2, 7HMTORC M, 4X, 4A6//)
      WRITE(6,700) (XIC(K), K=1,4), J, FLAM(J), (XIC(K), K=1,4)
      IF (NLTE.GT.1) GO TO 707
      704 FORMAT(4H ASSUMES LOCAL THERMODYNAMIC EQUILIBRIUM/)
      705 WRITE(6,704)
      GO TO 715
      706 FORMAT(28H LACK OF THERMAL EQUILIBRIUM, I6/)
      707 WRITE(6,706) NLTE
      710 FORMAT(118H EXOATMOSPHERIC VIEWING $? - - - - - E N C
      1 O A T M C S P H E R I C V I E W I N G - - - - - )
      715 WRITE(6,710)
      720 FORMAT(118H TAN HT LINE BAND RAD $? ALTE - - - - - BAND RAD I
      1 ANCE AS A FUNCTION OF ZENITH ANGLE (WATTS/CM2-STER)- - - - - )
      WRITE(6,720)
      730 FORMAT(118H (KM) (WATTS/CM2-STER) $? (KM) C DEG - UP 20 DEG
      1 40 DEG 60 DEG 70 DEG 80 DEG 90 DEG-HCRZ )
      WRITE(6,730)
      740 FORMAT(F5.0,1P5E14.4,0FF12.0,1X,1P7E12.4)
      KTAU = MCC(LBU(J),10)
      KSET=IALT-1
      DO 830 K=1, KSET, 5
      IF(K.GT.91) GO TO 750
      HT=K+59
      GO TO 760
      750 HT=150+(K-91)*5
      760 C1=HT*6371.
      IF 6 IN THE DO LOOP MAKES IT ONLY CALCULATE VALUES FOR 0 AND 90 DE
      DO 810 L=1,7,6
      P1=K+1
      PHI=ZANG(L)*.017453292
      SAVTAL=0.0
      STAU(L)=0.0
      SL1A = 0.0
      SRAD(L)=0.0
      RANG=0.0
      KACT=IALT

```

```

DC 790 M=M1,MSET
IF (M.GT.91) GC TO 770
C2=M+59+6371
GC TO 780
770 C2=150+(M-91)*5+6371
780 ANG=ASIN(SIN(PHI)*C1/C2)
CS=SQRT(C1*C1+D2*C2-2*C1*D2*CCS(PHI-ANG))
DELS=(CS-RANG)*1.0E+5
RANG=CS
DELTAU = DELS*(0.5*(TAU(M,J)+TAU(M-1,J)))
STAU(L) = STAU(L) + DELTAU
SL1E = SL1(KTAU,STAU(L))
RADA = RAD(M-1)/TAU(M-1,J)
RACB = RAD(M)/TAU(M,J)
SFAC = (RACB - RADA)/DELTAU
SRAD(L) = SRAD(L) + SFAC*(SL1A - SL1B)
SL1A = SL1E
SAVTAU=STAU(L)
790 CCNTINUE
SRAD(L) = SRAD(L) + RACE*SLC(KTAU,SAVTAU)
810 CCNTINUE
SAVTAU=0.0
STAU(7)=0.0
SL1A = 0.0
VRANG = 0.0
SRAD(8)=0.0
MSET=IALT
DC 815 M=K,MSET
L=MSET-M+K
IF (L.GT.91) GC TO 811
C2=L+59+6371
GC TO 812
811 C2=150+(L-91)*5+6371
812 CS=SQRT(C2*C2-D1*C1)
IF (L.LT.MSET) GO TO 813
RANG=CS
GC TO 815
813 DELS=(RANG-CS)*1.0E+5
VRANG = VRANG + DELS
RANG=CS
SAVTAU = STAU(7)
DELTAU = DELS*(0.5*(TAU(L,J)+TAU(L+1,J)))
STAU(7) = STAU(7) + DELTAU
SL1B = SL1(KTAU,STAU(7))
RADB = RAD(L)/TAU(L,J)
RADA = RAD(L+1)/TAU(L+1,J)
SFAC = (RADA - RADB)/DELTAU
SRAD(8) = SRAD(8) + SFAC*(SL1A - SL1B)
SL1A = SL1E
815 CCNTINUE
M1=K+1
RANG=0.0
MSET=IALT
DC 818 M=M1,MSET
IF (M.GT.91) GC TO 816
C2=M+59+6371
GC TO 817
816 C2=150+(M-91)*5+6371
817 CS=SQRT(C2*C2-D1*C1)
DELS=(CS-RANG)*1.0E+5
VRANG = VRANG + DELS
RANG=CS
SAVTAU = STAU(7)
DELTAU = DELS*(0.5*(TAU(M,J)+TAU(M-1,J)))
STAU(7) = STAU(7) + DELTAU
SL1B = SL1(KTAU,STAU(7))
RADA = RAD(M-1)/TAU(M-1,J)
RACB = RAD(M)/TAU(M,J)
SFAC = (RACB - RADA)/DELTAU
SRAD(8) = SRAD(8) + SFAC*(SL1A - SL1B)
SL1A = SL1E
818 CCNTINUE
SRAD(8) = SRAD(8) + RACE*SLO(KTAU,STAU(7))
WRITE(3,4444) HT,SRAD(8),SRAD(1),SRAD(7)
4444 FORMAT (F6.1,1P3E17.4)
WRITE(6,7409) HT,SRAD(8), HT,(SRAD(M), M= 1,7)
830 CCNTINUE
840 CCNTINUE
STOP 77
END

```

0
0

0
0

0
0

```

FUNCTION SLO (K,TAL)
T = ABS (TAL)
IF (K.EQ. 2) GC TC 200
IF (T.GT. 4.0) GC TC 110
X = (T - 2.0)*0.5
1 SLO = (((((0.0004110*X - 0.0018496)*X + 0.0008378)*X
- 0.0210060)*X + 0.0792553)*X - 0.2701023)*X + 0.0569377)*T
RETURN
110 CONTINUE
IF (T.GT. 10.0) GC TC 120
X = (T - 7.0)/3.0
1 SLO = (((((0.0001918*X - 0.0007254)*X + 0.0023078)*X
- 0.0080348)*X + 0.0274865)*X - 0.0912082)*X + 0.3539295)*T
RETURN
120 CONTINUE
Y = ALOC(T)
IF (T.GT. 100.0) GC TC 130
X = 9.210340371976/Y - 3.0
1 SLO = (((((0.0000000*X - 0.0001530)*X - 0.0001490)*X
+ 0.0013943)*X - 0.0003060)*X + 0.0837063)*X + 1.1415564)*Y
RETURN
130 CONTINUE
X = 9.210340371976/Y - 1.0
1 SLO = ((((((0.0007142 - 0.000222*X) + 0.005211)*X
- 0.004896)*X - 0.005477)*X + 0.007743)*X - 0.015900)*X
2 + 0.122528)*X + 0.940111)*Y
RETURN
200 CONTINUE
IF (T.GT. 4.0) GC TC 210
X = (T - 2.0)*0.5
1 SLO = (((((0.00002431*X - 0.00010901)*X + 0.00041830)*X
- 0.0100764)*X + 0.0581769)*X - 0.2013270)*X + 0.7182944)*T
RETURN
210 CONTINUE
IF (T.GT. 10.0) GC TC 220
X = (T - 7.0)/3.0
1 SLO = ((((((0.0001169*X - 0.0004699)*X + 0.0016637)*X
- 0.0005345)*X + 0.0255562)*X - 0.1003592)*X + 0.4282944)*T
RETURN
220 CONTINUE
Y = ALOC(T)
X = 4.60517018598809/Y - 1.0
1 SLO = ((((((0.0000000*X - 0.035886*X)*X + 0.062211)*X
- 0.056895)*X - 0.048818)*X + 0.045072)*X + 0.009249)*X
2 - 0.000887)*X - 0.062059)*X + 0.163319)*X + 1.399769)*Y
RETURN
END

```

FUNCTION SL1 (K,TAL)

IF (K.EQ. 1) COMPUTE FUNCTION VALUE FOR PARALLEL BAND.
IF (K.EQ. 2) COMPUTE FUNCTION VALUE FOR PERPENDICULAR BAND.

```

I = ABS (TAL)
IF (K.EQ. 2) GC TC 200
IF (T.GT. 1.0) GC TC 110
X = (T - 0.5)*2.0
1 SL1 = (((((1.0E-5*X - 1.5452E-4)*X + 0.00276149)*X
- 0.0353735)*X + 0.1613947)*T*T
RETURN
110 CONTINUE
IF (T.GT. 4.0) GC TC 120
X = (T - 2.5)/1.5
1 SL1 = (((((3.497E-4 - 5.49E-5*X)*X - 2.0328E-3)*X
+ 0.0114087)*X - 0.0613964)*X + 0.3531337)*T*T
RETURN
120 CONTINUE
IF (T.GT. 10.0) GC TC 130
X = (T - 7.0)/3.0
1 SL1 = ((((((7.771E-4 - 1.836E-4*X)*X - 2.9392E-3)*X
+ 0.0120034)*X - 0.0501139)*X + 0.2354310)*T*T
RETURN
130 CONTINUE
IF (T.GT. 100.0) GC TC 140
Y = ALOC(T)
X = 9.210340371976/Y - 3.0
1 SL1 = ((((((6.67E-5*X - 6.76E-4)*X + 0.0021934)*X
+ 0.0011841)*X - 0.0098382)*X + 0.2538769)*T*Y
RETURN
140 CONTINUE
IF (T.GT. 1000.0) GC TC 150
Y = ALOC(T)

```

```

X = 27.63102111E93/Y - 5.0
SL1 = (((1.636E-4*X - 1.5604E-3)*X + 1.6892E-3)*X
1 + 0.861629E)*T*Y
RETURN
150 CONTINUE
Y = ALOG(T)
X = 13.8155105579E/Y - 1.0
SL1 = (((((2.58E-4*X + 2.70E-3)*X - 7.600E-3)*X
1 + 6.917E-3)*X + 2.37E-4)*X - 1.279E-2)*X
2 + 0.030224)*X + 0.838671)*T*Y
RETURN
200 CONTINUE
IF (T.GT. 1.0) GO TO 210
X = (T - 0.5)*2.0
SL1 = (((7.09E-4*X - 1.212E-4)*X + 1.87580E-3)*X
1 - 0.078322E)*X + 0.4E67333)*T*T
RETURN
210 CONTINUE
IF (T.(T-2.5)/1.5) GO TO 220
X = (T - 2.5)/1.5
SL1 = (((((2.14E-4 - 3.26E-5)*X)*X - 1.3290E-3)*X
1 + 8.3419E-3)*X - 0.0520254)*X + 0.3801694)*T*T
RETURN
220 CONTINUE
IF (T.GT. 10.0) GO TO 230
X = (T - 7.0)/3.0
SL1 = (((((5.230E-4 - 1.152E-4*X)*X - 2.2120E-3)*X
1 + 0.0102E27)*X - 0.04942E2)*X + 0.2718101)*T*T
RETURN
230 CONTINUE
IF (T.GT. 100.0) GO TO 240
Y = ALOG(T)
X = 9.21074037197E/Y - 3.0
SL1 = (((((1.06E-4*X - 1.3224E-3)*X + 3.8304E-3)*X
1 + 8.1840E-3)*X - 6.60820E-2)*X + 1.057781)*T*Y
RETURN
240 CONTINUE
IF (T.GT. 1000.0) GO TO 250
Y = ALOG(T)
X = 27.63102111E93/Y - 5.0
SL1 = (((2.66E-4*X - 2.2012E-3)*X
1 - 0.0181E6E)*X + 1.1488715)*T*Y
RETURN
250 CONTINUE
Y = ALOG(T)
X = 13.8155105579E/Y - 1.0
SL1 = ((((((4.96E-4*X - 2.2191E-3)*X + 3.6173E-3)*X
1 - 2.8417E-3)*X + 3.3482E-3)*X - 0.0192525)*X
2 + 3.6151E-3)*X + 1.1747922)*T*Y
RETURN
END

```

```

PROGRAM SFCTFA1 (CL1FLT,TAFEL,TAPF1,TAPF2,TAPF5)
DIMENSI (N LSC(25),LCC(25),FCM(25),RV(25),LPC(25),LBL(25),STR(25))
DIMENSI (N CCN(201,10),TEMP(201),FROE(201))
DIMENSI (N AVTEMP(40,25),EVTEMP(40,25))
DIMENSI (N COLCNT(40,25),HRCNT(40,25))
DIMENSI (N RADA( 50),RADF( 50),RADC( 50))
COMMON /ISFCCM/ ISP
READ (1,12) TEMP
DC 500 NCASES = 1, 2
REWIND 5
READ (1,6) NSPTOT
DC 400 NSF = 1, NSPTOT
READ (1,6) ISP
READ (1,41) NLEVEL,NEAND,RM
DC 210 I = 1, NLEVEL
READ (1,41) LSC(I),LCC(I),FCM(I),RV(I)
210 CONTINUE
DC 220 I = 1, NBAND
READ (1,41) LPC(I),LBL(I),STR(I)
220 CONTINUE
READ (1,6) NALT,NLEV
DC 221 N2 = 1, NALT
READ (1,42) (CCN(N2,NL), NL = 1, NLEVEL)
221 CONTINUE
C COMPUTE MEAN TEMPERATURES AND COLUMN COUNTS
K = NLEV
DC 120 NL = 1, NLEVEL
DC 112 I = 1, NALT
FROE(I) = CCN(I,NL)*TEMP(I)
112 CONTINUE
TF = 0.0
TC = 0.0
NA = NALT
DC 120 I = 1, K
TF = TF + SIMP(FROE(NA - 2),1.0E+5,2)
1 + SIMP(FROE(NA - 3),1.0E+5,3) + SIMP(FROE(NA - 5),1.0E+5,3)
TC = TC + SIMP(CCN(NA - 2,NL),1.0E+5,2)
1 + SIMP(CCN(NA - 3,NL),1.0E+5,3) + SIMP(CCN(NA - 5,NL),1.0E+5,3)
COLCNT(K - I + 1,NL) = TC
AVTEMP(K - I + 1,NL) = TF/TC
NA = NA - 5
HRCNT(I,NL) = 0.0
120 CONTINUE
REASE = 6.431E+8
DC 120 I = 1, K
TPH = 0.0
TCH = 0.0
NA = NALT
RE2 = REASE*REASE
RTOP = REASE*RTOP*RTOP - RE2
SVH = SQR(TOP*RTOP - RE2)
KK = K - I + 1
DC 120 J = 1, KK
RTOP = RTOP - 1.0E+5
STH = SQR(RTOP*RTOP - RE2)
H5 = SVH - STH
SVH = STH
RTOP = RTOP - 1.0E+5
STH = SQR(RTOP*RTOP - RE2)
H4 = SVH - STH
SVH = STH
RTOP = RTOP - 1.0E+5
STH = SQR(RTOP*RTOP - RE2)
H3 = SVH - STH
SVH = STH
RTOP = RTOP - 1.0E+5
STH = SQR(RTOP*RTOP - RE2)
H2 = SVH - STH
SVH = STH
RTOP = RTOP - 1.0E+5
STH = SQR(RTOP*RTOP - RE2)
H1 = SVH - STH
SVH = STH
TPH = TPH + GINT(FROE(NA - 2),H4,H5,2)
1 + GINT(FROE(NA - 3),H3,H4,3) + GINT(FROE(NA - 5),H1,H2,3)
TCH = TCH + GINT(CCN(NA - 2,NL),H4,H5,2)
1 + GINT(CCN(NA - 3,NL),H3,H4,3) + GINT(CCN(NA - 5,NL),H1,H2,3)
NA = NA - 5
125 CONTINUE
HRCNT(I,NL) = TCH
EVTEMP(I,NL) = TFH/TCH

```

```

      RBASE = REASE + 5.0E+5
128  CONTINUE
129  CONTINUE
      CC 400 NE = 1, NBAND
      CC 230 I = 1, NPLEV
      READ (1,43) HT, RACC(I), RADA(I), RADB(I)
230  CONTINUE
      WRITE(4) (LSC(I), I=1,25)
      WRITE(4) ((PCRCNT(I,J), J=1,25), I=1,40)
      WRITE(4) ((EVTEMP(I,J), J=1,25), I=1,40)
400  CONTINUE
500  CONTINUE
      STOP
      6  FORMAT (E16)
      8  FORMAT (1FEE11.3)
      14  FORMAT (1X)
      12  FORMAT (1FEE12.4)
      16  FORMAT (1F11)
      41  FORMAT (2I6,5E12.4)
      42  FORMAT (8F10.4)
      43  FORMAT (F6.1,3E17.4)
      END

```

```

      FUNCTION SIMP (A,F,K)
      DIMENSION A(3)
      IF (K = 2) 100,110,120
100  CONTINUE
      SIMP = (8.0*A(2) + 5.0*A(1) - A(3))*F/12.0
      RETURN
110  CONTINUE
      SIMP = (8.0*A(2) + 5.0*A(3) - A(1))*H/12.0
      RETURN
120  CONTINUE
      SIMP = (4.0*A(2) + A(1) + A(3))*H/3.0
      RETURN
      END

```

```

      FUNCTION GINT (A,F1,F2,K)
      DIMENSION A(3)
      FS = H1 + F2
      IF (K = 2) 100,110,120
100  CONTINUE
      GINT = ((A(2)*HS - A(1)*F2 - A(3)*H1)*H1/(6.0*H2*FS)
      1  + (A(1) + A(2))*0.5)*F1
      RETURN
110  CONTINUE
      GINT = ((A(2)*HS - A(1)*H2 - A(3)*H1)*H2/(6.0*H1*HS)
      1  + (A(2) + A(3))*0.5)*F2
      RETURN
120  CONTINUE
      GINT = (A(2)*HS - A(1)*F2 - A(3)*H1)*(H1**3 + H2**3)
      1  /((6.0*FS*F1*H2) + (A(1)*H1 + A(2)*FS + A(3)*F2)*0.5)
      RETURN
      END

```

```

PROGRAM SPECTRA2 (CUTPUT,TAPE4,TAPE1,TAPE2,TAPE5)
DIMENSION LEC(25),LSC(25)
DIMENSION CCN(10),TEMP(201)
DIMENSION PORCNT(4),EVTEMP(4),ISF(25)
DIMENSION RACA(50),RADC(50),RACC(50)
COMMON /ISFCOM/ ISF
COMMON WVNLN(2500),ENLS(2500),STPL(2500),HRAC(2500)
COMMON SPEC(1801)
CC 600 J=1,14
REWIND 1
REWIND 4
READ (1,12) TEMP
CC 500 NCASES = 1, 2
REWIND 5
CC 100 I = 1, 1801
SPEC(I) = 0.0
100 CONTINUE
READ (1,6) NSPTCT
CC 400 NSF = 1, NSPTCT
READ (1,6) ISF
READ (1,41) NLEVEL,NEANC,FM
READ (4)(LSC(I),I=1,25)
READ (4)(PORCNT(I,JKK),JKK=1,25),I=1,40)
READ (4)(EVTEMP(I,JKK),JKK=1,25),I=1,40)
CC 210 I = 1, NLEVEL
READ (1,41) LSCC,LCC,RCM,EV
210 CONTINUE
CC 220 I = 1, NEANC
READ (1,41) LBC(I),LBU,STR
220 CONTINUE
READ (1,6) NALT,NRLEV
CC 221 NZ = 1, NALT
READ (1,42) (CCN(NL),NL=1,NLEVEL)
221 CONTINUE
IF (ISF .NE. 3) GO TO 225
CNTHR = 2.0*PORCNT(J,1)
CALL ROTATE (5,LINES)
C ROTATE WILL READ FROM TAPES
CALL WATSTR (RACC(J),FM,EVTEMP(J,1),CNTHR,1,LINES)
CALL FILTER (SPEC,HRAC,WVNLN,LINES)
225 CONTINUE
CC 400 NE=1,NEANC
CC 230 I=1,NRLEV
READ (1,43) FT,RACC(I),RACA(I),RADC(I)
230 CONTINUE
NEC=LEC(NE)
NI=MOE(NEC/100,100)
NF=MOE(NEC,100)
IF ((NB .GT. 10) .AND. (ISF .EQ. 3)) GO TO 400

CALL ROTATE (5,LINES)
CALL WATSTR (RADC(J),FM,EVTEMP(J,NF),2.0*PORCNT(J,NF),2,LINES)
CALL FILTER (SPEC,HRAC,WVNLN,LINES)
400 CONTINUE
WRITE (2,16)
WRITE (2,8) SPEC
500 CONTINUE

600 CONTINUE
STOP
6 FORMAT (E16)
8 FORMAT (1PEF11.3)
14 FORMAT (1X)
12 FORMAT (1PEE12.4)
16 FORMAT (1F1)
41 FORMAT (2IE,5E12.4)
42 FORMAT (PE10.4)
43 FORMAT (FE.1,7E17.4)
END

SUBROUTINE WATSTR (RAC,FM,I,CEN,N,LINES)
COMMON /ISFCOM/ ISF
COMMON WVNLN(2500),ENLS(2500),STR(2500),HRAC(2500)
TGFAC = (256.0/T)**1.5
IF (ISF .EQ. 2) TGFAC = 256.0/T
IF (ISF .EQ. 4) TGFAC = 256.0/T
GO TO (100,200,300), N
100 CONTINUE
RADFAC = 1.58065E-20*CEN*TGFAC
TAUFAC = 4.8815E-19*SCRT(PM/T)*TGFAC*CEN
CC 110 I = 1, LINES

```

```

      PHCLAM = 1.0E+4/WVNLN(I)
      TAU = TAFAC*STR(I)*EXP(-1.43879*ENLS(I)/T)
1      * (1.0 - EXP(-14387.9/(PHCLAM*T)))
      ROTEFA = 2.0*STR(I)/HHCLAM**2
      HRAD(I) = RACFAC*FCTEA*SFUN(TAU)
1      *EXP(-1.43879*(1.0E+4/HHCLAM + ENLS(I))/T)
110  CONTINUE
      RETURN
200  CONTINUE
      TAFAC = 4.2815E-18*SGFT(RV/T)*CEN
      TEFAC = (T - 296.0)/(T*296.0)*1.43879
      SUM = 0.0
      DO 210 I = 1, LINES
      FSTR = TGFAC*STR(I)*EXP(TEFAC*ENLS(I))
      PHCLAM = 1.0E+4/WVNLN(I)
      TAU = TAFAC*HHCLAM*HSTR
      FRAC(I) = TAL*SFUN(TAU)*EXP(-14387.9/(PHCLAM*T))
1      /HHCLAM**4
      SUM = SUM + HRAD(I)
210  CONTINUE
      RADFAC = FAC/SUM
      DO 220 I = 1, LINES
      FRAC(I) = HRAD(I)*RADFAC
220  CONTINUE
      RETURN
300  CONTINUE
      RETURN
      END

      FUNCTION SFUN (TAU)
      T = ABS(TAU)
      IF (T .GT. 4.0) GO TO 110
      X = (T - 2.0)*0.5
      SFUN = (((((0.0010E1*X - 0.004288)*X + 0.013686)*X - 0.042491)
1      *X + 0.114932)*X - 0.2E7057)*X + 0.5E648E
      RETURN
110  CONTINUE
      IF (T .GT. 10.0) GO TO 120
      X = (T - 7.0)/3.0
      SFUN = (((((0.00347*X - 0.001167)*X + 0.003148)*X - 0.005545)
1      *X + 0.028248)*X - 0.081972)*X + 0.247900
      RETURN
120  CONTINUE
      Y = ALOG(T)
      X = 1.0/Y
      SFUN = (((((0.0E787E*X - 0.2E6E8)*X + 0.264E68)*X
1      - 0.2691E7)*X + 0.32E3E8)*X + 1.128379)*SORT(Y)/T
      RETURN
      END

C  SUBROUTINE FILTER (SPEC,RAC,WVNUM,N)
      FIVE WAVELENGTH RESOLUTION, TWO WAVELENGTH INTERVAL
      DIMENSION SPEC(1801),RAD(450),WVNUM(450)
      COMMON /ISFCOM/ ISF
      DO 150 I = 1, N
      RT = WVNUM(I)
      RACT = RAD(I)
      JS = (RT - 405.0)*0.5 + 2.0
      JF = (RT - 395.0)*0.5 + 1.0
      IF (JS .LT. 1) JS = 1
      IF (JF .GT. 1801) JF = 1801
      IF (JS .GT. JF) GO TO 150
      DO 120 J = JS, JF
      RNUM = (J - 1)*2.0 + 400.0
      SPEC(J) = SPEC(J) + (5.0 - AES(RNUM - RT))*RACT*0.04
120  CONTINUE
150  CONTINUE
      RETURN
      END

      SUBROUTINE RCTATE (NIN,LINES)
      COMMON /ISFCOM/ ISF
      COMMON WVNUM(2500),ENLS(2500),STR(2500),HFAC(2500)
      READ (NIN) LINES
      IF (ECF(NIN)) 121,100
190  READ (NIN),(WVNUM(I),STR(I),ENLS(I),I=1,LINES)
      IF (ECF(NIN)) 121,110
119  CONTINUE
121  RETURN
      END

```

Appendix B

```

C      PROGRAM FLOTK(INPUT,OUTPUT=/5000,TAPE1=INPUT,TAPE2=OUTPUT,TAPE3)
      LAST CHANGE FEB 15, 1979

      DIMENSION K(16)
      DATA COL /"F"/
1      REWIND 3
      READ(3,500) TYPE
500     FORMAT(A1,A7,2I8,7F18.11)
      IF(TYPE.EQ.COL) GC TO 10
      REWIND 3

      WRITE(2,1000)
1000    FORMAT(* ENTER DELT,START,STOP,AMP,OFFSET,START0*)
      READ(1,*) DELT,WIND,XEND,AMP,OFF,START
      GC TO 15
10      REWIND 3
      READ(3,500) TYPE,TITLE,NUM,IREV,AE,DELT,START
      WRITE(2,550)
550     FORMAT(* ENTER START,STOP,AMP,OFFSET*)
      READ(1,*) WIND,XEND,AMP,OFF

15      REWIND 2
          XDDEL=PCO./(XEND-WIND)
          XDDEL=DELT*XDDEL
      WRITE(2,560) TITLE
560     FORMAT(/,15X,A7)
          WRITE(2,20000) WIND,XEND
20000    FORMAT(3X,*INTERVAL BETWEEN *,F8.3,* AND *,F8.3)
          WRITE(2,30000) OFF,AMP
30000    FORMAT(3X,*AMPLITUDE RANGE(*,F7.0,* TO *,F7.0,*)*)

      REWIND 2
      CALL FLOTS
      CALL FRAME

      IX2=8
      IY2=10
      X2=10
      XN=START
      DO 100 I=1,100000
          READ(3,40000) (K(J),J=1,16)
+0000    FORMAT(16I5)
          IF(EOF(3)) 900,80,90
80        X=XN
          XN=XN+16*DELT
          IF(XN.LT.WIND)GOTO 100
          DO 90 J=1,16
          XJ=X+FLOAT(J-1)*DELT
          IF(XJ.LT.WIND)GOTO 90

          IX=IX2
          IY=IY2
          X2=X2+XDDEL
          IX2=X2
          IF(IX2.GT.900)GOTO 800
          IY2=500.+(K(J)-OFF)/(AMP-OFF)+18.5
          IF(IY2.LE.1) IY2=1
          CALL LINE(IX,IY,IX2,IY2)
90        CONTINUE
100       CONTINUE

800       REWIND 3
          CALL XMTT
          READ(1,*)JUNK
          REWIND 2
          GOTO 1
900       STOP 7
          END

```

00000

THIS ROUTINE INITIALIZES THE PLOT BUFFER
AND THE INDEXES INTO THE PLOT BUFFER.

SUBROUTINE PLCTS

COMMON/IXY/IT,ICX,ICLY,ICHY,IOLX,IOHX
COMMON/BUFFER/LB,LW,IB(500)

LE=1
IT=0
LW=36
IB(1)=00070000000000000000
RETURN
END

00000

THIS SUBROUTINE PACKS A 12-BIT
PLOT INSTRUCTION FOR THE TEKTRONIX INTO
THE BUFFER (IB). IT IS FORMATTED TO THE
PECULIAR BIT STREAM REQUIREMENTS FOR TEMPO.

SUBROUTINE SEND(I)
COMMON/BUFFER/LB,LW,IB(500)
IF (LW.GE.0) GOTO 2
LW=LW+1
LB=LB+1
IB(LB)=OR(AND(IB(LB),SHIFT(MASK(48),LW)),SHIFT(I,LW))
LW=LW-12
FORMAT(3X,I4,3X,I4)
RETURN
END

0000

SUBROUTINE XMIT
COMMON/IXY/IT,ICX,ICLY,ICHY,IOLX,IOHX
COMMON/BUFFER/LB,LW,IB(500)
CALL SEND(ICHY)
CALL SEND(ICLY)
CALL SEND(ICHX)
CALL SEND(IOLX)
DO 1 K=1,9
IF (LW.EQ.0) GOTO 2
CALL SEND(0)
BUFFER OUT(2,0) (IB(1),IB(LB))
IF (UNIT(2)) 3,3,3
CALL PLCTS
RETURN
END

000

SUBROUTINE PAGE

CALL SEND(4032E)
CALL SEND(4014E)
CALL SEND(4007E)
CALL SEND(0)
CALL XMIT
RETURN
END

C

SUFFOLTINE COPY

CALL SEND(4033B)
CALL SEND(4027E)
CALL XMIT
RETURN
END

X

SUBROUTINE FRAME
CALL LINE(10,509,900,509)
CALL LINE(10,766,900,766)
CALL LINE(10,8,900,8)
CALL LINE(9,768,9,9)
CALL LINE(898,768,898,9)
CALL LINE(10,768,900,768)
CALL LINE(10,767,900,767)
CALL LINE(10,10,900,10)
CALL LINE(10,9,900,9)
CALL LINE(10,768,10,9)
CALL LINE(11,768,11,9)
CALL LINE(900,768,900,9)
CALL LINE(899,768,899,9)
RETURN
END

C

SUBROUTINE LINE(J,I,JJ,II)
COMMON/BUFFER/LB
CALL SEND(4035B)

K=OR(AND(SHIFT(I,-5),-MASK(55)),40400)
CALL SEND(K)
K=OR(AND(I,-MASK(55)),4140E)
CALL SEND(K)
K=OR(AND(SHIFT(J,-5),-MASK(55)),4040B)
CALL SEND(K)
K=OR(AND(J,-MASK(55)),4100B)
CALL SEND(K)
K=OR(AND(SHIFT(II,-5),-MASK(55)),4040R)
CALL SEND(K)
K=OR(AND(II,-MASK(55)),4140E)
CALL SEND(K)
K=OR(AND(SHIFT(JJ,-5),-MASK(55)),4040B)
CALL SEND(K)
K=OR(AND(JJ,-MASK(55)),4100E)
CALL SEND(K)

IF(LB.GT.480)CALL XMIT

RETURN
END

Appendix C

```

PLOTTR EQU GF5H
PLTCS EQU OF7H
MDMCS EQU OFEH
MDMDT EQU OFEH
TXRDY EQU 01
RXRDY EQU 02
BMODQ EQU 80H
EOCHR EQU 80H
NDCHR EQU OFEH
LFTPN EQU 40H
ORPEN EQU 80H
LWAIT EQU 50
SWAIT EQU 255
OVRIT EQU 10H
DICMP EQU 10010001B
NXORG EQU 0600

ORG 0800H

IN MMDT
MVI A, 'R'
CALL XMIT
MVI A, 'N'
CALL XMIT
MVI A, 'H'
CALL XMIT
CALL SDCR
CALL HEXIN
MVI A, BMODQ

SET55 EQU 0
OUT PLTCS

LXI H, BUFR
SHLD PNTER

LXI H, 0
SHLD CURRX
SHLD CURRY

MNITR EQU 0
CALL NXCHR
ADD A
MOV C, A
MVI B, 0
LXI H, COMND
DAD B
MOV E, M
INX H
MOV D, M
XCHG
PCHL

COMND EQU 0
DW PNLEFT

DW PNDFP
DW XGRAF
DW YGRAF
DW TXPLT
DW RETCR
DW SETCR
DW ENDIT

: COMMAND ROUTINES

```

```

:*****
:***
:***

```

```

:

```

```

:

```

```

: TIME DELAY FOR PEN UP/DOWN

```

```

:

```

```

:***
:***

```

```

:***
:***

```

```

: CLEARS MODEM
: CYBER RNH COMMAND

```

```

: XMIT 'RETURN'
: IGNORE CR,LF;WAIT FOR PROMPT
:***
: INIT PLOTTER PORT

```

```

:***

```

```

: RESET PNTER

```

```

:***

```

```

: CLFAR CURPX, CURRY

```

```

:***

```

```

: GET COMMAND
: OFFSET = 2*COMMAND
:***

```

```

:***

```

```

: GET ADDRESS OF
: COMMAND ROUTINE
:***

```

```

: INTO DE, THEN

```

```

: INTO HL, THEN
: INTO PC
:***

```

```

: MOVE W/ PEN UP

```

```

: MOVE W/ PEN DOWN
: X-AXIS GRAPH ROUTINE
: Y-AXIS GRAPH ROUTINE
: PLOT CHARACTERS
: RETURN CURR. X,Y
: RESET CURR. X,Y
: TERMINATES PLOTTING
:***

```

```

PNLFT EQU $          ; **
CALL LIFT            ; #
JMP PNMov           ; : LIFTS PEN IF NEG
; **
PNDROP EQU $         ; #
CALL DROP            ; : DROPS PEN IF NEG
;
PNMOV EQU $          ; #
CALL REGIN           ; : #
SHLD ENDX            ; : #
CALL REGIN           ; : #
SHLD ENDY            ; : READS ENDPts AND
CALL PLOTS           ; : ** MOVES PEN THERE
JMP MNITR            ; : #
; **
; **
XGRAF EQU $          ; : PLOT X-AXIS GRAPH
CALL NXCHR           ; : GET X-INCR.
MOV C, A             ; : B IS CLEAR
LHLD CURRX           ; : MOVE PEN TO 1ST POINT
SHLD ENDX
CALL REGIN
SHLD ENDY
CALL LIFT
CALL PLOTS
LOOPX EQU $          ; : PLOT STREAM
CALL REGIN           ; : GET NEXT Y POINT
MOV A, H             ; : CHECK FOR END OF STREAM
CPI NCHRR
JZ MNITR
SHLD ENDY
LHLD CURRX           ; : UPDATE X COORD
DAD B
SHLD ENDX
CALL DROP            ; : INSURE PEN DOWN
CALL PLOTS
JMP LOOPX
; **
; **
; **
YGRAF EQU $          ; : PLOT Y-AXIS GRAPH
CALL NXCHR           ; : GET Y-INCR.
MOV C, A             ; : B IS CLEAR
LHLD CURRX           ; : MOVE PEN TO 1ST POINT
SHLD ENDX
CALL REGIN
SHLD ENDY
CALL LIFT
CALL PLOTS
LOOPY EQU $          ; : PLOT STREAM
CALL REGIN           ; : GET NEXT Y POINT
MOV A, H             ; : CHECK FOR END OF STREAM
CPI NCHRR
JZ MNITR
SHLD ENDY
LHLD CURRX           ; : UPDATE X COORD
DAD B
SHLD ENDX
CALL DROP            ; : INSURE PEN DOWN
CALL PLOTS
JMP LOOPY
; **
; **
TXPLT EQU $          ; : GET SCALE
CALL NXCHR

```

```

MOV E, A          : AND SAVE IN E
CALL NXCHR        : GE. DIRECTION
STA DIRN          :
                  :
CLOOP EQU $        :
CALL NXCHR        : GET NEXT CHAR. CODE
CPI NXCHR         : RETURN TO MONITOR
JZ MNITR          : AT END OF STRING
                  :
LHLD CURRX        : RESET ORIGINS
SHLD ORIGX        :
LHLD CURRY        :
SHLD ORIGY        :
LXI H, CHTAB      : DATA TABLE FOR CHAR GEN
ADD A             : OFFSET=CODE*2
JNC ADOFF         :
                  :
ADOFF INX H        :
EQU $            :
ADD L            : A CONTAINS OFFSET
MOV L, A         :
JNC GTSEG        : #HL POINTS INTO CHTAB
INR H           :
GTSEG EQU $       :
MOV C, M         : BC POINTS TO SEGS
INX H            :
MOV B, M         :
:
SLOOP EQU $       :
LDAX B           : GET NEXT SEGMENT CODE
MOV D, A         : SAVE SEG. CODE IN D
CALL CHGEN       : PLOT SEGMENT
INX B            : INDEX OF NEXT SEGMENT
MOV A, D         :
ANI EOCHR        : #CHECK IF LAST SEGMENT
JZ SLOOP         : CONT IF NOT LAST SEG
MVI A, NXORG     : #PEN UP, (J,6) * SCALE
MOV D, A         :
CALL CHGEN       : INTERLETTER SPACE
JMP CLOOP        : FOR NEXT CHAR
                  :
:
RETCR EQU $       :
LHLD CURRX       : SEND CURRX,CURRY
CALL RGOUT       :
LHLD CURRY       :
CALL RGOUT       :
:
CALL SNOCR       : SEND 'RET'
CALL HEXIN       : WAIT FOR PROMPT
JMP MNITR        :
:
SETCR EQU $       :
CALL REGIN       :
SHLD CURRX       :
CALL REGIN       :
SHLD CURRY       :
JMP MNITR        :
:
ENDIT EQU $       :
RST 1            : RETURN TO MONITOR
:
: I/O UTILITIES :
REGIN EQU $       : 4 HEX DIGITS INTO HL
CALL NXCHR       :
MOV H, A         :
CALL NXCHR       :
MOV L, A         :
RET              :

```

```

NXCHR EQU $           : **
      PUSH B           : GETS HEX CONSTANT FROM BUFFER
      PUSH D
      PUSH H
      LHL D PNTER      : CHECK IF BUFFER EMPTY
      LXI D, BUFR
      CALL CMPAF
      CZ LOADR         : FILL IT IF NECESSARY
                        : **
      MOV B, M         : GET CHARACTER
      INX H            : **

      PUSH H
      LXI D, BUFR
      LHL BUFLN
      DAD D
      XCHG
      POP H            : **

      CALL CMPAF
      JNZ LDONE

LDONE LXI H, BUFR      : **
      EQU $            : ELSE RESET PNTER
      SHLD PNTER
      MOV A, B
      POP H
      POP D
      POP B
      RET

LOADR EQU $           : **
      CALL LIFT         : PREVENTS INK SPOTS
      PUSH D
      PUSH H
      LXI H, BUFR
      CALL SHAKE

      CALL HEXIN        : **
      MOV D, A          : GET WORD COUNT
      CALL HEXIN
      MOV E, A
      XCHG              : **
      SHLD BUFLN        : SAVE BUFFER LENGTH
      XCHG              : **

LODNG EQU $           : **
      CALL HEXIN        : GET NEXT WORD
      MOV M, A
      INX H
      DCX D
      XRA A            : CHECK IF LAST WORD
      ORA E
      JNZ LODNG
      ORA D
      JNZ LODNG
      CALL HEXIN        : REPEAT UNTIL DONE
                        : WAIT FOR PROMPT
                        : **
      POP H
      POP D
      RET

HEXIN EQU $           : **
      PUSH B            : 2 HEX DIGITS INTO H
      CALL ASCHX        : ASCII TO HEX CONVERSION
      RLC
      RLC
      RLC
      RLC
      MOV B, A          : SAVE HIGH CHARACTER
      CALL ASCHX        : GET LOW CHARACTER

```

```

ORA      B      : THEN ADD
POP      B
RET

: **
: **
: **
ASCHX EQU $
CALL RECV
CPI 'A'
JC ARNDA
: ASCII TO HEX IN A
: GET ASCII CHAR
: JUMP IF NUMBER
: **
: **
: ADJUST A-F
ARNDA ADI 9
EQU $
ANI 0FH
RET
: CLEAR HIGH BITS
: **
: **
: **

RECEV EQU $
IN MDMCS
ANI RXRDY
JZ RECV
: TEST MODEM STATS
: WAIT FOR CHAR
: **
: READ CHAR
IN MDMDT
ORA A
JZ RECV
CPI 0AH
JZ RECV
CPI 0DH
JZ RECV
RET
: IGNORE NULL CHARS
: ...LF
: ...CR

: **
: **
: **
RGOUT EQU $
CALL HXOUT
MOV H, L
CALL HXOUT
RET
: (HL) TO 4 ASCII CHARS
: **
: **
: **

HXOUT EQU $
MOV A, H
RRC
RRC
RRC
RRC
CALL HXASC
MOV A, H
CALL HXASC
RET
: (H) TO 2 ASCII CHARS
: **
: **
: **

HXASC EQU $
ANI 0FH
CPI 0AH
JC ARNDC
: (A) TO 1 ASCII CHAR
: SEND LOW 4 BITS
: CHECK FOR AND
: **
: ADJUST A - F
ARNDC ADI 7
EQU $
ADI 00H
CALL XMIT
RET
: FOR ASCII "PREFIX"
: **
: **
: **

XMIT EQU $
PUSH B
MOV C, A
: **

XLOOP EQU $
IN MDMCS
ANI TXRDY
JZ XLOOP

```

```

MOV A, C
OUT MDMOT
CALL RECEV
POP B
RET

:***

:***

SHAKE EQU $
      PUSH H
      MVI L, CAH
      : WAIT FOR CYBER FOX
      : APPROX. 1 SEC

EWAIT EQU $
      CALL LONG
      DCR L
      JNZ EWAIT
      POP H
      MVI A, '1'
      CALL XMIT
      : HANDSHAKE CHAR
      : **

SNDCR EQU $
      IN MDMCS
      ANI TXRDY
      JZ SNDCR
      : XBITS 'CF'
      : ***
      MVI A, 0DH
      OUT MDMOT
      RET
      : RETURN
      : ECHO & LF IGNORED
      : ***
      : ***
      : PEN CONTROL UTILITIES
      : ***

LIFT EQU $
      LDA PSTAT
      ORA A
      RZ
      MVI A, LFTPN
      CALL MOVE
      JMP PWAIT
      : CONTROLS PLOTTER
      : #

DROP EQU $
      LDA PSTAT
      ORA A
      RNZ
      MVI A, DRPFN
      CALL MOVE
      INR A
      : CONTROLS PLOTTER
      : PSTAT GETS 1
      : *****

PWAIT EQU $
      STA PSTAT
      : #
LONG EQU $
      PUSH H
      MVI L, LWAIT
      : #
      : **

LLOOP EQU $
      CALL SHORT
      DCR L
      JNZ LLOOP
      : #
      POP H
      RET
      : #
      : ***

MOVE EQU $
      OUT PLOTF
      XRA A
      OUT PLOTF
      CALL SHORT
      : SEND INSTRUCTION
      : FOLLOWED BY 0
      : WAIT 1.65 MILLISEC
      : ***

```

```

SHORT EQU $          : **
PUSH  H              : #
MVI   L, SWAIT      : **

MLOOP EQU $          : **
DCR   L              : #
JNZ   MLOOP         : #
POP   H              : #
RET                               : #

: ARITHMETIC UTILITIES
: **

DPSUB EQU $          : **
MOV   A, E          : #
SUB   L, A           : #
MOV   L, A           : #
MOV   A, D           : #
SBB   H, A           : #
MOV   H, A           : #
XRA   A              : #
RET                               : #
: **

CMR   EQU $          : **
MOV   A, D           : #
CMP   H              : #
RNZ   :              : #
MOV   A, E           : #
CMP   L              : #
RET                               : #
: **

SCALR EQU $          : **
ANI   7              : #

MULT  EQU $          : **
PUSH  B              : #
PUSH  D              : #
MVI   C, 8           : #
MVI   D, 0           : #
MOV   L, D           : #
MOV   H, L           : #
: **

MLOOP EQU $          : **
RAR   :              : #
MOV   B, A           : #
JNC   ARNDM          : #
DAD   D              : #
CMC                               : #
: **

ARNDM EQU $          : **
XCHG  H              : #
DAD   H              : #
XCHG  C              : #
JNZ   MLOOP         : #
: **

POP   D              : #
POP   B              : #
RET                               : #
: **

: MAIN-LINE UTILITIES
: **

CHGEN EQU $          : **
PUSH  B              : #
PUSH  D              : #
PUSH  H              : #
: **

ANI   1000           : #
JNZ   CHKON          : #
: **

CALL  LIFT           : #
JMP   RELPT          : #
: **

CHKON EQU $          : **
CALL  DROP           : #

```

```

RELPT EQU $
MOV A, D
CALL SCALR
MOV B, H
MOV C, L
;
MOV A, D
RRC
RRC
RRC
CALL SCALR
XCHG
;
LDA DIRN
MOV H, A
ORA DIRX
JPE DIRX
;
PUSH B
MOV B, D
MOV C, E
POP D
;***
DIRX EQU $
ANI 10B
JZ DIRY
;
XRA A
SUB E
MOV E, A
MVI A, 0
SBB D
MOV D, A
;
DIRY EQU $
MOV A, H
ANI 01B
JZ SETPT
;
XRA A
SUB C
MOV C, A
MVI A, 0
SBB B
MOV B, A
;***
SETPT EQU $
LHLD ORIGX
DAD D
SHLD ENOX
;
LHLD ORIGY
DAD B
SHLD ENDY
;
CALL PLOTS
;
POP H
POP C
POP B
RET
;***
CHTAB EQU $
DW CHR26
DW CHR33
DW CHR34
DW CHR35
DW CHR36
DW CHR37
DW CHR38
DW CHR39
DW CHR40
DW CHR41
DW CHR42
;
; #
; D CONTS SEG CODE
; (A.AND.7)*SCALE (E)
; LOADS BC WITH
; RELATIVE Y
;
; #
; #
; SHIFT FOR RELATIVE X
; IGNORES HIGH BITS IN A
; STORE REL X IN DE
;
; COMPUTE DIRECTION OF TEXT
; #
; SETS FLAGS
; JUMP IF ON X-AXIS (0&3)
;
; SWAP X AND Y VALUES
; FOR VERTICAL LETTERS
; (1&2)
;
; #
; #
; #
; COMP X VALUE
; #
; #
; #
; DE GETS -DE
;
; #
; #
; #
; COMP Y VALUE
; #
; #
; #
; BC GETS -BC
;
; #
; #
; #
; #
; #
; RESTORE REGS.
;***
; #
; #
; #
; #
; DATA FOR CHAR GEN
; CHAR:
; CHAR: A
; CHAR: 9
; CHAR: 3
; CHAR: 0
; CHAR: 5
; CHAR: 7
; CHAR: G
; CHAR: H
; CHAR: I
; CHAR: J

```

```

DW CHR43
DW CHR44
DW CHR45
DW CHR46
DW CHR47
DW CHR48
DW CHR49
DW CHR50
DW CHR51
DW CHR52
DW CHR53
DW CHR54
DW CHR55
DW CHR56
DW CHR57
DW CHR58
DW CHR16
DW CHR17
DW CHR18
DW CHR19
DW CHR20
DW CHR21
DW CHR22
DW CHR23
DW CHR24
DW CHR25
DW CHR11
DW CHR13
DW CHR10
DW CHR15
DW CHR09
DW CHR04
DW CHR29
DW CHR09
DW CHR12
DW CHR14
DW CHR03
DW CHR59

```

```

: CHAR: X
: CHAR: L
: CHAR: M
: CHAR: N
: CHAR: O
: CHAR: P
: CHAR: Q
: CHAR: R
: CHAR: S
: CHAR: T
: CHAR: U
: CHAR: V
: CHAR: W
: CHAR: X
: CHAR: Y
: CHAR: Z
: CHAR: [
: CHAR: \
: CHAR: ]
: CHAR: ^
: CHAR: _
: CHAR: `
: CHAR: '
: CHAR: / SLASH
: CHAR: (
: CHAR: )
: CHAR: $
: CHAR: = BLANK
: CHAR: .
: CHAR: # POUND SIGN
: CHAR: { OPEN SQ BRKT

```

```

DW CHR61
DW CHR62
DW CHR63
DW CHR01
DW CHR06
DW CHR07
DW CHR31
DW CHR28
DW CHR30
DW CHR32
DW CHR60
DW CHR62
DW CHR27
DW CHR64
DW CHR65
DW CHR66
DW CHR67
DW CHR68

```

```

: CHAR: J
: CHAR: P PERCENT
: CHAR: " DBL. QUOTE
: CHAR: _ UNDERSCORE
: CHAR: ! EXCLAMATION
: CHAR: & AMPERSAND
: CHAR: ' APOSTROPHIE
: CHAR: ? QUESTION MARK
: CHAR: <
: CHAR: >
: CHAR: @ COMMERCIAL AT
: CHAR: \ BACK SLASH
: CHAR: ^ CIRCUMFLEX
: CHAR: :
: CHAR: ' APOSTROPHIE
: CHAR: ( OPEN PAREN
: CHAR: | VERTICAL LINE
: CHAR: ) CLOSE PAREN
: CHAR: ~ TILDE

```

```

:***
: CHARACTER TABLES
:***
: CHAR:
:***
: CHAR: "
:***
: CHAR: #

```

```

:***
: CHAR: #

```

	08	1260	
	08	0360	
	08	1230	
	08	0350	
	08	1150	
	08	0140	
	08	3340	

:			
CHR04	EQU	\$	: CHAR: \$
	08	0020	
	08	1110	
	08	1310	
	08	1420	
	08	1330	
	08	1130	
	08	1040	
	08	1150	
	08	1350	
	08	1440	
	08	0260	
	08	3200	

:			
CHR05	EQU	\$	: CHAR: PERCENT
	08	1460	
	08	1160	
	08	1050	
	08	1140	
	08	1250	
	08	1160	
	08	0410	
	08	1320	
	08	1210	
	08	1300	
	08	3410	

:			
CHR06	EQU	\$	: CHAR: &
	08	0420	
	08	1200	
	08	1100	
	08	1010	
	08	1020	
	08	1350	
	08	1260	
	08	1150	
	08	3400	

:			
CHR07	EQU	\$	: CHAR: ' '
	08	0260	
	08	3240	

:			
CHR08	EQU	\$	: CHAR: (
	08	0360	
	08	1240	
	08	1220	
	08	3300	

:			
CHR09	EQU	\$	: CHAR:)
	08	0160	
	08	1240	
	08	1220	
	08	3100	

:			
CHR10	EQU	\$	: CHAR: *
	08	0130	
	08	1350	
	08	0250	
	08	1230	
	08	0150	
	08	3330	

CHR11	EQU	\$	: CHAR: +
	DB	0130	
	DB	1330	
	DB	0240	
	DB	3220	: **
CHR12	EQU	\$	: CHAR: ,
	DB	9220	
	DB	3100	: **
CHR13	EQU	\$	: CHAR: -
	DB	0130	
	DB	3330	: **
CHR14	EQU	\$	: CHAR: .
	DB	0110	
	DB	3100	: **
CHR15	EQU	\$	: CHAR:
	DB	3460	: **
CHR16	EQU	\$	: CHAR: 0
	DB	0100	
	DB	1020	
	DB	1940	
	DB	1160	
	DB	1360	
	DB	1440	
	DB	1420	
	DB	1300	
	DB	3100	: **
CHR17	EQU	\$	: CHAR: 1
	DB	0140	
	DB	1260	
	DB	3200	: **
CHR18	EQU	\$	: CHAR: 2
	DB	0050	
	DB	1160	
	DB	1360	
	DB	1450	
	DB	1440	
	DB	1120	
	DB	1000	
	DB	3400	: **
CHR19	EQU	\$	: CHAR: 3
	DB	0010	
	DB	1100	
	DB	1330	
	DB	1410	
	DB	1420	
	DB	1330	
	DB	1230	
	DB	0330	
	DB	1440	
	DB	1450	
	DB	1360	
	DB	1160	
	DB	3050	: **
CHR20	EQU	\$	: CHAR: 4
	DB	0300	
	DB	1360	
	DB	1020	
	DB	3420	

:
CHR21 EQU \$

:**
: CHAR: 5

DB 0010
DB 1100
DB 1300
DB 1410
DB 1430
DB 1340
DB 1140
DB 1030
DB 1060
DB 3460

:**

:
CHR22 EQU \$

: CHAR: 6

DB 0030
DB 1140
DB 1340
DB 1430
DB 1410
DB 1300
DB 1100
DB 1010
DB 1050
DB 1160
DB 1360
DB 3450

:**

:
CHR23 EQU \$

: CHAR: 7

DB 0060
DB 1460
DB 3100

:**

:
CHR24 EQU \$

: CHAR: 8

DB 0100
DB 1010
DB 1020
DB 1130
DB 1040
DB 1050
DB 1160
DB 1360
DB 1450
DB 1440
DB 1330
DB 1130
DB 0330
DB 1420
DB 1410
DB 1300
DB 3100

:**

:
CHR25 EQU \$

: CHAR: 9

DB 0010
DB 1100
DB 1300
DB 1410
DB 1450
DB 1360
DB 1160
DB 1050
DB 1030
DB 1120
DB 1320

DB 3430

:**

:
CHR26 EQU \$

: CHAR: 1

DB 0140
DB 1130

```

    DB      0120
    DB      3110
;
CHR27 EQU $
DB      0240
DB      1230
DB      0220
DB      3100
;
CHR28 EQU $
DB      0460
DB      1030
DB      3400
;
CHR29 EQU $
DB      0040
DB      1440
DB      3020
DB      3420
;
CHR30 EQU $
DB      1430
DB      3060
;
CHR31 EQU $
DB      0050
DB      1160
DB      1260
DB      1350
DB      1340
DB      1130
DB      1120
DB      0110
DB      3100
;
CHR32 EQU $
DB      0330
DB      1220
DB      1130
DB      1240
DB      1340
DB      1320
DB      1430
DB      1440
DB      1350
DB      1150
DB      1040
DB      1020
DB      1110
DB      1310
DB      3420
END1 EQU $

;
ORG      GC00H

PLOTS EQU $
PUSH     3
PUSH     0
PUSH     H

;
LXI      B,   C           ; CONVIENT CONSTANTS

LHLD     CURPX            ; #
XCHG                      ; LOADS DE WITH CURPX AND RESETS CURR
LHLD     ENOX             ; #
SHLD     CUPPX
```

:	XCHG	:	COMPARES (DE) TO (HL)
:	CALL CMPAR	:	ENDX<CURRX
:	JC NEGDX	:	ENDX>CURRX
:	JNZ POSDX	:	
:	NODX: CALL YCOMP	:	COMPARES ENDY AND CURRY, LOADS ACC
:	JC QUAD4	:	# AND THEN CLEARS B
:	JNZ QUAD2	:	ENDY<CURRY
:	JMP WRAP	:	ENDY>CURRY
:		:	ENDY=CURRY
:	POSDX EQU \$	:	#
:	CALL YCOMP	:	#
:	JC QUAD4	:	ENDY<CURRY
:	JMP QUAD1	:	ENDY>=CURRY
:		:	
:	NEGDX EQU \$	:	#
:	XCHG	:	KEEPS DX POSITIVE
:	CALL YCOMP	:	#
:	JC QUAD3	:	ENDY<CURRY
:	JNZ QUAD2	:	ENDY>CURRY
:	JMP QUAD3	:	ENDY=CURRY
:		:	
:	QUAD4: RLC	:	#
:	INR B	:	#
:	QUAD3: RLC	:	#
:	INR B	:	#
:	XCHG	:	KEEPS DY POSITIVE
:	QUAD2: RLC	:	# (DE)=GTR(ENDY, CURRY)
:	INR B	:	# (HL)=LSR(CURRY, ENDY)
:	QUAD1: RLC	:	#
:	INR B	:	#
:	ANI 0FH	:	USE LOWEST 4 BITS
:	STA DIAG	:	COMPUTES DY=(DE)-(HL)
:	CALL DPSUR	:	COMPUTES DY (DE)-(HL)
:	SHLD DY	:	# AND CLEARS ACCUM.
:		:	
:	MOV D, C	:	#
:	MOV E, C	:	# (DE)=0
:	XCHG	:	#
:	SHLD TEST	:	#
:	SHLD TEST + 2	:	#
:	SHLD COMP	:	#
:	SHLD COMP + 2	:	CLEARS VARIABLES
:	STA MAJ	:	#
:	CALL CMPAR	:	COMPARES (DE)&(HL)... 0 & DY
:		:	
:	JZ SEC5	:	DY = ZERO
:	XCHG	:	#
:	LHLD DX	:	#
:	XCHG	:	#
:	CALL CMPAR	:	# ... 0 & DX
:	JZ SEC5	:	DX=ZERO
:		:	
:	LHLD DY	:	#
:	CALL CMPAR	:	#
:	JC HISEC	:	DX<DY, M>1
:		:	
:	MVI A, 1	:	DX>=DY, M<=1
:	STA MAJ	:	MAJOR = 1
:		:	
:	LDA DIAG	:	#
:	ANI 101B	:	COMPUTES HORV
:	STA HORV	:	#
:	DAD H	:	DY*2
:	CALL CMPAR	:	#
:	JC SEC2	:	DX<2*DY, .5<M<1
:	JMP SEC1	:	DX>=2*DY, 0<M<.5
:		:	
:	HISEC EQU \$	:	#
:	LDA DIAG	:	#
:	ANI 1010B	:	COMPUTES HORV
:	STA HORV	:	#
:	XCHG	:	# (DE)=DY, (HL)=DX
:	DAD H	:	DX*2
:	CALL CMPAR	:	#
:	JC SEC3	:	DY<2*DX, 1<M<2

```

:      JMP      SEC4      : DY>=2*DX,  M>2
:
SEC5   EQU      $
      XRA      A
      STC
:      #
:      A IS 0
:      **
LOOP5  EQU      $
      RAL
      DCR      B
      JNZ      LOOP5
      STA      HORV
      MVI      C, 4
      JMP      SDRIV
:
SEC4:  INR      C
SEC3:  INR      C
SEC2:  INR      C
SEC1:  LDA      DIAG
      ANI      1000B
      JNZ      QAD34
      MOV      A, C
      JMP      SDRIV
:
QAD34: MVI      A, 3
      SUB      C
:
SDRIV  EQU      $
      STA      DRIVR
:
:
:      LHL D, DY
:      XCHG
:      LHL D, DX
:      LDA      MAJ
:      DCR      A
:
:      LINSET
:      #
:      # (DE)=DY,  (HL)=DX
:      #
:
:
:      JNZ      XMAJ
:      XCHG
:      EQU      $
:      SHLD     DXI
:      SHLD     IDIFF
:      MOV      A, C
:      MOV      B, H
:      MOV      C, L
:      DAD      H
:      XCHG
:      SHLD     DXJ
:      SHLD     JDIFF
:
:      SUI      4
:      JZ       XSDRV
:      PUSH     H
:      LDA      DRIVR
:      ANI      1
:      JNZ      LNTST
:      SHLD     COMP
:      XCHG
:      SHLD     TEST
:
:      LNTST  EQU      $
:      XRA      A
:      LXI      H, DXI
:      ORA      M
:      INX      H
:      ORA      M
:      INX      H
:      ORA      M
:      INX      H
:      ORA      M
:      JNZ      LNCMP
:      POP      D
:      JMP      WRAP
:
:      LNCMP  EQU      $
:
:      PROCESS ABS(SLOPE)>1 SEPARATELY
:      #
:      #
:      #
:      #
:      #
:      #
:      # (DE)=2*DXI,  (HL)=DXJ
:      #
:      #
:      # A=OLD C (SECTOR)
:      # TRAP OUT AXES
:      # (BC)=IDIFF,  ((SP))=JDIFF
:      #
:      # PROCESS DRIVERS 1, 3 SEPARATELY
:      #
:      # COMP=JDIFF
:      #
:      # (DE)=DXJ,  (HL)=2*DXI
:      # TEST=2*IDIFF
:      #
:      #
:      # CLEAR A
:      #
:      #
:      #
:      #
:      #
:      # IF ((DXI.OR.DXJ).EQ.0)
:      # CLEARS STACK
:      #
:      # RETURNS TO MONITOR
:      #
:      #
:      #
:      #

```

```

;                                     (TEST-COMP)
LHLD TEST + 2                      : #
XCHG                                : #
LHLD COMP + 2                      : #
CALL CMPAR                         : #
JC PHORV                          : #
JNZ PDIAG                         : #
;                                     : #
LHLD TEST                         : #
XCHG                                : #
LHLD COMP                         : #
CALL CMPAR                         : #
JC PHORV                          : #
JZ EQTST                          : #
;                                     : #
PDIAG EQU $                        : #
LDA DIAG                          : #
CALL MOVE                         : # SEND TO PLOTTER
LHLD DXI                          : #
DCX H                             : # DXI=DXI-1
SHLD DXI                          : #
LHLD COMP                         : #
POP D                             : #
;                                     : #
PUSH D                            : # BUT LEAVE ON STACK
DAD D                             : #
SHLD COMP                         : #
JNC PWRAP                         : #
;                                     : #
LHLD COMP + 2                      : #
INX H                             : #
SHLD COMP + 2                      : #
JMP PWRAP                         : #
EQTST EQU $                       : #
LDA DRIVR                         : #
DCR A                             : #
JZ PDIAG                          : #
POP D                             : #
PUSH D                            : # BUT LEAVE ON STACK
MOV H, B                          : #
;                                     : #
MOV L, C                          : #
DAD B                             : #
CALL CMPAR                        : # (DE)=JDIFF, (HL)=2*IDIF
LDA DRIVR                         : #
JNZ TSTD1                         : #
CPI 3                             : #
JZ PDIAG                          : #
JMP PHORV                         : #
TSTD1 EQU $                       : #
DCR A                             : #
JM PDIAG                         : #
;                                     : #
PHORV EQU $                       : #
LDA HORV                         : #
CALL MOVE                         : # SEND TO PLOTTER
PWRAP EQU $                       : #
LHLD DXJ                          : #
DCX H                             : #
SHLD DXJ                          : #
LHLD TEST                         : #
DAD 9                             : # CALC. TEST
SHLD TEST                         : #
JNC LNTST                        : #
LHLD TEST + 2                     : #
INX H                             : #
SHLD TEST + 2                     : #
JMP LNTST                        : #
;                                     : #
XSDRV EQU $                       : #
DAD B                             : # ADD (BC)=IDIFF TO (HL)=JDIFF
LDA HORV                         : #
MOV C, A                          : # LOAD C WITH HORV
PAXIS EQU $                       : #
MOV A, C                          : #
CALL MOVE                         : # SEND TO PLOTTER
DCX H                             : #
ORA L                             : # A WAS CLEAR

```


	DB	0000	
	DB	3400	: **
:			
CHR38	EQU	\$	: CHAR: F
	DB	1060	
	DB	1460	
	DB	0230	
	DB	3030	: **
:			
CHR39	EQU	\$	: CHAR: G
	DB	0230	
	DB	1430	
	DB	1410	
	DB	1300	
	DB	1100	
	DB	1010	
	DB	1050	
	DB	1160	
	DB	1360	
	DB	3450	: **
:			
CHR40	EQU	\$	: CHAR: H
	DB	1060	
	DB	0030	
	DB	1430	
	DB	0460	
	DB	3400	: **
:			
CHR41	EQU	\$	: CHAR: I
	DB	1400	
	DB	0460	
	DB	1060	
	DB	0260	
	DB	3200	: **
:			
CHR42	EQU	\$	: CHAR: J
	DB	0020	
	DB	1010	
	DB	1100	
	DB	1300	
	DB	1410	
	DB	3460	: **
:			
CHR43	EQU	\$	: CHAR: K
	DB	1060	
	DB	0020	
	DB	1460	
	DB	0130	
	DB	3400	: **
:			
CHR44	EQU	\$	: CHAR: L
	DB	0060	
	DB	1000	
	DB	3400	: **
:			
CHR45	EQU	\$	: CHAR: M
	DB	1060	
	DB	1230	
	DB	1460	
	DB	3400	: **
:			
CHR46	EQU	\$	: CHAR: N
	DB	1060	
	DB	1400	
	DB	3460	: **

```

:
CHR47 EQU $
      08 0010
      08 1050
      08 1160
      08 1360
      03 1450
      03 1410
      08 1300
      08 1100
      08 3010

```

```

: CHAR: O

```

```

: **

```

```

:
CHR48 EQU $
      08 1060
      08 1360
      08 1450
      09 1440
      09 1330
      08 3030

```

```

: CHAR: P

```

```

: **

```

```

:
CHR49 EQU $
      08 0010
      08 1050
      08 1160
      09 1360
      08 1450
      08 1410
      08 1300
      03 1100
      09 1010
      08 3310
      08 3400

```

```

: CHAR: Q

```

```

: **

```

```

:
CHR50 EQU $
      08 1060
      08 1360
      09 1450
      08 1440
      08 1330
      08 1030
      08 0130
      08 3400

```

```

: CHAR: R

```

```

: **

```

```

:
CHR51 EQU $
      08 0010
      08 1100
      03 1300
      08 1410
      09 1420
      08 1330
      08 1130

```

```

: CHAR: S

```

```

      08 1040
      08 1050
      08 1160
      08 1360
      08 3450

```

```

: **

```

```

:
CHR52 EQU $
      09 0060
      08 1460
      08 0260
      09 3200

```

```

: CHAR: T

```

```

: **

```

```

: **

```

```

:
CHR53 EQU $
      08 0060
      08 1010
      08 1100
      08 1300
      08 1410

```

```

: CHAR: U

```

	DB	3460	;	**
CHR54	EQU	\$	:	CHAR: V
	DB	0060		
	DB	1200		
	DB	3460		
				**
CHR55	EQU	\$	:	CHAR: W
	DB	0060		
	DB	1060		
	DB	1230		
	DB	1400		
	DB	3460		
				**
CHR56	EQU	\$	:	CHAR: X
	DB	1460		
	DB	0060		
	DB	3400		
				**
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