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of Laser-Supported Detonation Waves

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1.0 INTRODUCTION

When a target in air is irradiated by a high intensity laser, air breakdown waves or absorption waves are frequently observed to propagate from the target toward the laser even at laser intensities insufficient to breakdown the air in the absence of the target. Since the initial observation of these waves by Ramsden and Davies (Ref. 38) and their subsequent interpretation by Ramsden and Savic (Ref. 39) and by Raizer (Ref. 17) as laser-supported detonation waves (LSD-waves), considerable effort has been expended and large computer codes developed toward substantiating and extending the simple detonation wave ideas in order to better understand the phenomena.

A most complex and general computer program adapted to this purpose is the LASNEX computer program of the Lawrence Livermore Laboratory (Ref. 23), incorporating two-dimensional hydrodynamics and two-temperature non-equilibrium effects. Computational predictions of LASNEX agree well with experiment. The intent of the study reported here was to investigate the underlying physical mechanisms for some of the more phenomenological assumptions employed in the LASNEX code, especially those concerning radiative properties of high temperature air.

In Chapter 2 we discuss the laser absorption coefficient of air, and in Chapter 3 the basic radiative properties of air: opacities, emissivities and absorption coefficients. Chapter 4 describes a simple one-dimensional, stationary model we have developed for describing LSD waves in air in sufficient detail to assess radiative effects. In Chapter 5

we describe some electromagnetic propagation studies and calculations we have carried out to investigate the applicability of geometric optics and weak reflection corrections thereto. Some results and discussion then constitute the concluding Chapter 6. Finally, we have collected tables of air properties--thermodynamic and radiative--into the Appendices.

2.0 THE ABSORPTION COEFFICIENT FOR LASER RADIATION IN AIR

The laser radiation absorption coefficient has been derived by many authors, the results differing mainly due to the different disciplines from which the topic is approached--classical electrodynamics, quantum theory of radiation, or plasma physics. In this chapter these alternative formulations are presented and compared, and their respective domains of validity described.

In subsection 1 below, the absorption coefficient of a fully-ionized plasma is treated. Absorption on neutral air components is the topic of subsection 2, and the final approximation employed in our numerical studies comprises subsection 3.

2.1 THE RADIATION ABSORPTION COEFFICIENT OF A FULLY-IONIZED PLASMA

A. Free-free Absorption of Radiation

The absorption of visible or near infrared radiation by a plasma is predominantly due to inverse bremsstrahlung processes -- the so-called "Free-free" absorption, in which a radiation-absorbing electron undergoes a transition between two continuum states of the (electron + ion) system. Transitions between high-lying bound states are generally sufficiently well-approximated by simply lowering the ionization potential by $\sim kT$, in effect increasing the number of free electrons by a very small number at not too high densities.

The cross section for free-free absorption of a photon of energy $\hbar\omega$ by an electron of initial velocity v interacting with an ion of charge Z is conventionally written (Ref. 1, Eq. 41-42)

$$\sigma^{\text{FF}}(\omega, v) = g_{\text{FF}}(\omega, v) \sigma_{\text{K}}^{\text{FF}}(\omega, v) \quad (1)$$

in terms of the Kramers cross section.

$$\begin{aligned} \sigma_{\text{K}}^{\text{FF}}(\omega, v) &= \frac{128\pi^3}{3\sqrt{3}} Z^2 \alpha^2 \left(\frac{c}{v} \right) \left(\frac{\text{Ryd}}{\hbar\omega} \right)^3 a_0^6 \text{ (cm}^2\text{)} \\ &= \frac{128\pi^3}{3\sqrt{3}} Z^2 \alpha \left(\frac{\text{Ryd}}{\epsilon} \right)^{1/2} \left(\frac{\text{Ryd}}{\hbar\omega} \right)^3 a_0^6 \text{ (cm}^2\text{)} \end{aligned} \quad (2)$$

and the (dimensionless) "Gaunt factor" $g_{FF}(\omega, \nu)$. Here, and in the following,

ϵ = initial electron energy

α = "Fine Structure" constant

$$= e^2/\hbar c = 1/137$$

Ryd = Rydberg unit of energy

$$= 13.605 \text{ eV} = 109,737 \text{ cm}^{-1}$$

a_0 = Bohr radius = $5.30 \times 10^{-9} \text{ cm}$

Several useful approximations to the Gaunt factor are given in Ref. 1-3.

If the free electron energy distribution is thermal at a temperature T , the thermal-averaged cross section applies.

$$\begin{aligned} \sigma^{FF}(\omega, T) &= \frac{2}{\sqrt{\pi}} \int_0^\infty \frac{\epsilon^{1/2} d\epsilon}{(kT)^{3/2}} \sigma^{FF}(\omega, \nu) e^{-\epsilon/kT} \\ &= \frac{256\pi^3}{3\sqrt{3}\pi} Z^2 \alpha \left(\frac{\text{Ryd}}{kT} \right)^{1/2} \left(\frac{\text{Ryd}}{\hbar\omega} \right)^3 \langle g_{FF}(\omega, T) \rangle a_0^6 (\text{cm}^5) \\ &= 2.62 \times 10^{-41} (\text{cm}^5) \left(\frac{\text{Ryd}}{kT} \right)^{1/2} \left(\frac{\text{Ryd}}{\hbar\omega} \right)^3 Z^2 \langle g_{FF}(\omega, T) \rangle \end{aligned} \quad (3)$$

Values of the thermal-averaged Gaunt factor are presented in Fig. 1 and 2 (from Ref. 3).

Fig. 1 - Temperature-averaged free-free Gaunt factor versus $u = \hbar\nu/kT$ for various values of $\nu = Z^2 \text{ Ryd}/kT$.

Fig. 2 - Temperature-averaged free-free Gaunt factor versus $u = k\nu/kT$ for various values of $\gamma^2 = Z^2 \text{ Ry}/kT$.

For low photon energies and high temperatures, Born approximation gives

$$\langle g_{\text{FF}}(\omega, T) \rangle \approx \frac{\sqrt{3}}{\Pi} \ln \left(\frac{4kT}{\hbar\omega} \right). \quad (4)$$

The radiation absorption coefficient per unit length is

$$\mu_{\text{FF}}(\omega, T) = n_e N_i \sigma^{\text{FF}}(\omega, T) \text{ (cm}^{-1}\text{)} \quad (5)$$

in terms of the electron and ion number densities n_e and N_i (cm^{-3}). In frequency units, we obtain from Eqs. 3-5,

$$\mu_{\text{FF}}(\nu, T) = \frac{4}{3} \sqrt{\frac{2\Pi}{3kT}} \frac{Z^2 e^2 n_e N_i}{\hbar \text{cm}^{3/2} \nu^3} \langle g_{\text{FF}}(\omega, T) \rangle$$

which is the familiar result quoted in Spitzer (Ref. 4, Eq. 5-48) if the Gaunt factor is set to unity.

In most radiation transport applications consideration of the effects of induced emission results in an effective absorption coefficient $\mu'(\omega, T)$ given by

$$\begin{aligned} \mu'(\omega, T) &= \left(1 - e^{-\frac{\hbar\omega}{kT}} \right) \mu(\omega, T) \\ &\approx \frac{\hbar\omega}{kT} \mu(\omega, T), \quad (\hbar\omega \ll kT) \end{aligned}$$

(See Appendix IIA to this chapter.)

The resulting frequency-scale absorption coefficient then becomes

$$\begin{aligned}\mu'_{\text{FF}}(\nu, T) &= \frac{4}{3} \sqrt{\frac{2}{\pi}} \frac{Z^2 e^6 n_e N_I}{(kT)^{3/2} \text{cm}^{3/2} \nu^2} \ln \left(\frac{4kT}{h\nu} \right) \quad (6) \\ &= 1.7 \times 10^{-31} \frac{Z^2 n_e^2}{(T_{\text{eK}})^{3/2} (h\nu_{\text{eV}})^2} \ln \left(\frac{4kT}{h\nu} \right)\end{aligned}$$

for $h\nu \ll kT$.

The above results are for a pure hydrogen plasma. As discussed in Ref. 1, however, the coulomb interaction dominates free-free absorption for all ions if $\hbar\omega \ll kT$. If this condition isn't satisfied, detailed quantum mechanical calculations are necessary for the non-hydrogenic free-free absorption coefficient.

B. The Absorption Coefficient for Microwave Radiation

Plasma absorption of microwave radiation has been conventionally treated in a classical approximation (Ref. 5). The equation of motion of the k^{th} electron in the electric field of radiation with angular frequency ω is

$$m \ddot{\vec{r}}_k + m \nu_{\text{eff}} \dot{\vec{r}}_k = e E_0 e^{i\omega t}$$

ν_{eff} is an "effective collision frequency" for momentum transfer between the electrons and the plasma ions.

From these classical equations of motion and Maxwell's equations the plasma dielectric function is obtained.

$$\begin{aligned}\epsilon(\omega) &= \left[1 - \left(\frac{\omega_p^2}{\omega(\omega - i\nu_{\text{eff}})} \right) \right] \\ &= \left[1 - \left(\frac{\omega_p^2}{\omega^2 + \nu_{\text{eff}}^2} \right) \right] - i \left(\frac{\omega_p^2}{\omega^2 + \nu_{\text{eff}}^2} \right) \frac{\nu_{\text{eff}}}{\omega}\end{aligned}\quad (7)$$

Here ω_p is the plasma frequency

$$\begin{aligned}\omega_p &= \sqrt{\frac{4\pi n_e e^2}{m}} = 5.65 \times 10^4 \sqrt{n_e (\text{cm}^{-3})} \text{ (rad/sec)}, \\ \hbar\omega_p &= 3.72 \times 10^{-2} \sqrt{\frac{n_e (\text{cm}^{-3})}{10^{18}}} \text{ (eV)}.\end{aligned}\quad (8)$$

Writing $\epsilon(\omega) = [n(\omega) - i\kappa(\omega)]^2$ in terms of a complex index of refraction, the linear energy absorption coefficient is

$$\begin{aligned}\mu(\omega) &= 2 \frac{\omega}{c} \kappa(\omega) = -2 \frac{\omega}{c} \text{Im} [\epsilon(\omega)]^{1/2} \\ &\approx \frac{\omega_p^2 \nu_{\text{eff}}}{c \omega \sqrt{\omega^2 + \nu_{\text{eff}}^2} \sqrt{1 - \frac{\omega_p^2}{\omega^2 + \nu_{\text{eff}}^2}}}, \quad (\omega \gg \nu_{\text{eff}})\end{aligned}$$

For purely coulomb collisions (Ref. 7),

$$\begin{aligned}\nu_{\text{eff}} &= N_I v 2\pi \int_0^\pi \sin \theta d\theta (1 - \cos \theta) \frac{Z^2 e^4}{4m^2 v^4 \sin^4 \theta / 2} \\ &= \frac{4\pi N_I Z^2 e^4}{m^2 v^3} \ln \left[\frac{1}{\sin \theta_M / 2} \right]\end{aligned}$$

in terms of a minimum scattering angle θ_M . From analysis via the Boltzmann equation (Ref. 5, Eq. 6.9) the appropriate thermal average is

$$\begin{aligned}\bar{\nu}_{\text{eff}}(T) &= \frac{4}{3\sqrt{\pi}} \int_0^\infty \nu_{\text{eff}}(v) \frac{\epsilon^{3/2} d\epsilon}{(kT)^{5/2}} e^{-\epsilon/kT} \\ &= \frac{4\pi}{3} \sqrt{\frac{2}{\pi}} \frac{Z^2 e^4 N_I}{m^{1/2} (kT)^{3/2}} \ln \Lambda,\end{aligned}\tag{9}$$

where $\ln \Lambda$ is the familiar coulomb logarithm (Ref. 4, 7)

$$\Lambda = \text{smaller of } \left\{ \frac{3}{2Z} \left(\frac{kT}{\hbar \omega_p} \right) \sqrt{\frac{kT}{2 \text{ Ryd}}}, \left(\frac{\sqrt{3}}{Z} \left(\frac{kT}{\hbar \omega_p} \right) \right) \right\}$$

With these results for the coulomb collision frequency, the final result for the absorption coefficient is obtained,

$$\mu(\nu, T) = \frac{4}{3} \sqrt{\frac{2}{\pi}} \frac{Z^2 e^4 n_e N_I}{(kT)^{3/2} \text{ cm}^{3/2} \nu^2} \ln \Lambda, \quad (10)$$

differing from the quantum mechanical result (Eq. 6) only in the Gaunt factor/coulomb logarithm term. (We have assumed here $\omega \gg \omega_p$.)

C. The Absorption Coefficient of a Fully Ionized Plasma - The Results of Dawson and Oberman

The quantum mechanical calculation in A above considers one electron interacting with one ion and absorbing radiation -- all plasma interactions are ignored. The microwave absorption calculation in B above is a simple plasma calculation which ignores plasma collective effects except where necessary to avoid divergences in the coulomb logarithm.

As the radiation frequency ω approaches the plasma frequency, ω_p , plasma collective effects become of greater importance. Indeed, the simple microwave absorption coefficient diverges as $\omega \rightarrow \omega_p$. A more appropriate treatment of plasma radiation absorption in this domain was made by Dawson and Oberman (Refs. 6 and 8).

The plasma in a radiation field is described by a Vlasov equation. They obtain an expression for the impedance $Z(\omega)$ (Ref. 8, Eq. 22). In terms of the impedance the plasma dispersion relation for transverse waves determines the plasma dielectric function (in a fashion similar to the derivation of Eq. 7 above).

$$\epsilon(\omega) = 1 - \frac{4\pi i}{\omega Z(\omega)} \quad (11)$$

For small absorption ($\kappa_\omega \approx \frac{c}{\omega} \mu(\omega) = \mu(\omega) \lambda_0 \ll 1$) the plasma index of refraction is

$$n_\omega^2 = \text{Re} \left[1 - \frac{4\pi i}{\omega Z(\omega)} \right]$$

and the absorption coefficient is

$$\mu(\omega) = \frac{\omega}{n_\omega c} \text{Im} \left[\frac{4\pi i}{\omega Z(\omega)} \right]$$

Limiting approximations are:

$$\omega \ll \omega_p: \frac{\omega Z(\omega)}{4\pi i} = \frac{\omega^2}{\omega_p^2} \left\{ \left[1 - \frac{\omega}{\omega_p} \left(1 - \frac{\pi}{8} \right) \right] - i \sqrt{\frac{2}{\pi}} \left[\ln \left(\frac{k^2 m_{ax}}{K_D^2} \right) - 1 \right] \right\} \quad (12a)$$

$$\omega \gg \omega_p: \quad \approx \frac{\omega^2}{\omega_p^2} \left\{ [1 - \sqrt{2\pi}\chi] - i \sqrt{\frac{2}{\pi}} \chi \left[\ln \left(\frac{2k^2 \max u_0^2}{\omega^2} \right) - \gamma \right] \right\} \quad (12b)$$

where $\chi = \frac{2\pi}{3} \frac{Z^2 e^4 n_1}{(kT)^{3/2} m^{1/2} \omega}$, $mu_0^2 = kT$, $K_D^2 = \frac{1}{\lambda_D^2} = \frac{m\omega_p^2}{kT}$,

$$= 0.63 (\nu^{\text{eff}}/\omega) / \ln \Lambda \ll 1 \quad (\text{comparing Eq. 9 above})$$

and k_{max}^{-1} corresponds to the minimum impact parameter entering the coulomb logarithm determination (Ref. 7).

$$k_{\text{max}}^{-1} = r_{\text{min}} = \text{Max} \left\{ \frac{Ze^2}{kT}, \frac{\hbar}{mu_0} \right\}.$$

The corresponding expressions for the index of refraction may be written

$$n_\omega^2 = 1 - \frac{\omega_p^2}{\omega^2} \left[1 + \beta(\omega)\chi \right] \quad (13)$$

where

$$\beta(\omega) = (1 - \pi/8) \frac{\omega}{\omega_p} = .607 \frac{\omega}{\omega_p} \quad (\omega \ll \omega_p)$$

$$\rightarrow \sqrt{2\pi} \quad (\omega \gg \omega_p)$$

For intermediate values of (ω/ω_p) the quantity $(-\Pi\beta/2\sqrt{2})$ is plotted in Fig. 3 (from Ref. 8).

Fig. 3 — The quantity $\left(-\frac{\Pi}{2\sqrt{2}}\beta\right)$ of Eq. 13 as a function of (ω/ω_p) — (from Ref. 8).

The absorption coefficient is similarly obtained.

$$\mu(\omega) = \frac{4}{3n_{\omega}} \sqrt{\frac{2}{\pi}} \frac{Z^2 e^2 n_e n_I}{(kT)^{3/2} cm^{3/2} \nu^2} G(\omega) \quad (14)$$

where the effective Gaunt factor $G(\omega)$ is obtained

$$\begin{aligned} G(\omega) &\rightarrow \left[\ln \Lambda' - \frac{1}{2} \right] \quad (\omega \ll \omega_p) \\ &\rightarrow \left[\ln \left(\sqrt{2} \frac{kT}{\hbar \omega} \right) - \gamma/2 \right] \quad (\omega \gg \omega_p \text{ and } kT \geq 2Z^2 \text{ Ryd}) \\ &\rightarrow \left[\ln \left(\frac{1}{Z} \frac{kT}{\hbar \omega} \sqrt{\frac{kT}{2 \text{ Ryd}}} - \gamma/2 \right) \right] \quad (\omega \gg \omega_p \text{ and } kT < 2Z^2 \text{ Ryd}) \end{aligned} \quad (15)$$

In the low frequency limit,

$$\Lambda' = \frac{k_{\max}}{k_D} = \frac{kT}{\hbar \omega_p} \cdot \text{Min} \left\{ 1, \sqrt{\frac{kT}{2Z^2 \text{ Ryd}}} \right\}$$

corresponding to the coulomb logarithm in the microwave result.

Furthermore, the high frequency limit approaches our Born approximation result Eq. 6.

For intermediate values of (ω/ω_p) the quantity $\Pi^{1/2} G$ is plotted in Fig. 4 along with the above asymptotic representations (from Ref. 8).

Fig. 4 — The quantity $(\sqrt{\pi G})$ of Eq. 14 as a function of (ω/ω_p) — (from Ref. 8).

Note: Numerical values in Fig. 4 correspond to

$k_{\max} = 2^{-1/2} 10^{-7} \omega_p / u_0$. For different temperatures and densities the quantity

$$\sqrt{2\pi} (2Ze^2 / 3mu_0^3) \ln (2k_{\max}^2 / 10^{14} K_D^2).$$

is to be added to the graphed results.

In terms of β and G defined above, the plasma dielectric function may be written

$$\epsilon(\omega) = 1 - \frac{\omega_p^2}{\omega \left[\omega \left(1 - \frac{\beta}{2} \frac{\pi}{\sqrt{2}} \frac{\nu_{\text{eff}}}{\omega \ln \Lambda} \right) - i \nu_{\text{eff}} \left(\frac{G}{\ln \Lambda} \right) \right]} \quad (16)$$

to be compared with the Appleton-Hartree result (Eq. 7). Here ν_{eff} is the effective collision frequency of Eq. 9.

2.2 THE ABSORPTION COEFFICIENT OF NEUTRAL AIR COMPONENTS

At high temperatures free-free absorption on ions dominates, for which the absorption cross section is described above. At lower temperatures free-free absorption on neutral species dominates. In the limit $\omega \ll kT$ the Low theorem applies (Ref. 1, Eq. 35), according to which the free-free absorption cross section is related to the electron momentum transfer cross section $Q_d(\epsilon)$ as

$$\sigma^{FF}(\omega, \epsilon) = \frac{32\pi}{3} \alpha a_0^5 \left[\frac{(\epsilon + \frac{\omega}{2}) \sqrt{\epsilon + \omega}}{Ryd^{3/2}} \right] \left(\frac{Ryd}{\omega} \right)^3 Q_d(\epsilon + \frac{\omega}{2}) / a_0^2 \quad (17)$$

for free electrons of energy ϵ . (a_0 is the Bohr radius and α the fine structure constant.) For a thermal distribution of electrons at a temperature T , we obtain

$$\begin{aligned} \sigma^{FF}(\omega, T) &= \frac{32\pi}{3} \alpha a_0^5 \left(\frac{Ryd}{\omega} \right)^{3/2} S(\omega, T) \\ &= 1.02 \times 10^{-42} (\text{cm}^5) \left(\frac{Ryd}{\omega} \right)^{3/2} S(\omega, T), \end{aligned} \quad (18)$$

where $S(\omega, T)$ is the appropriate thermal average,

$$S(\omega, T) = \frac{2}{\sqrt{\pi}} \int_0^\infty du u^{1/2} e^{-u} \left[\left(u + \frac{1}{2} \frac{\omega}{kT} \right) \left(u + \frac{\omega}{kT} \right)^{1/2} Q_d \left(ukT + \frac{\omega}{2} \right) / a_0^2 \right] \quad (19)$$

Although the above approximations are only expected to be valid if $\omega \ll kT$, we have evaluated Eq. 18, 19 for three laser wavelengths and a range of temperatures of interest. We have considered individually the contributions O, N, O₂, and N₂, momentum transfer cross sections for which we obtained from the compilation of Kieffer (Ref 9). Our results are displayed in Figures 5 and 6.

To our knowledge, the most complete quantum mechanical calculation of free-free absorption on a neutral atom is that carried out by Mjolsness and Ruppel (Ref. 10) for oxygen and nitrogen. They solved the continuum Hartree-Fock equations for the free electron, including the important polarization potential. Their results for the elastic and momentum transfer cross sections agree well with experiment. To compare with our results we have employed their analytic fit - quoted to reproduce their results to ~ twenty percent. The comparison for oxygen is included in Fig. 5 for $\omega = .117\text{eV}$ and in Fig. 6 for $\omega = 1.17\text{eV}$. It is seen that even for $\omega \sim kT$ the results of our simple approximations are in reasonable agreement with the results of the detailed quantum mechanical results. We have also included in Fig. 5 some results of Thomas-Fermi calculations for atomic oxygen - as quoted in Ref. 11.

The laser absorption coefficient is then given in terms of the above cross sections, neutral and ions, by

$$\mu_{\text{FF}}(\omega, T) = n_e \sum_i N_i \sigma_i^{\text{FF}}(\omega, T) \text{ (cm}^{-1}\text{)}, \quad (20)$$

$$\omega = .117\text{eV}$$

$$\lambda = 10.6\mu$$

Figure 5 Electron-neutral free-free cross sections (cm⁵)
(from Eq. 18-19)

Figure 6 Electron-neutral free-free cross sections (cm^5)
(from Eq. 18-19)

summed over the species i , n_e (cm^{-3}) and N_i (cm^{-3}) being the concentration of free electrons and particles of the i^{th} species, respectively. The results are presented in Table I, for densities normal ($1.29 \times 10^{-3} \text{ gm/cm}^3$) and ten times normal and temperatures 4000°K to $kT = 5.0 \text{ eV}$. (We have indicated by asterisks* in Table I the temperature-density-wavelength combinations for which the neutral and ion free-free contributions are roughly equal.) Values in parenthesis indicate the critical electron density has been exceeded.

Mjolsness and Ruppel have similarly evaluated the free-free absorption coefficient (Ref. 10), using results of their atomic calculations and a molecular approximation similarly related to the momentum transfer cross section. A comparison of our results with theirs is possible at normal density.

<u>T = 6000°K:</u>	<u>This work</u>	<u>Ref. 10</u>
($\omega = 1.17\text{eV}$)	$\mu = 2.7^{-4} \text{ cm}^{-1}$	($\omega = 1.2\text{eV}$) $\mu = 2.5^{-4} \text{ cm}^{-1}$
($= 1.79$)	$= 1.1^{-4}$	($= 1.8$) 1.1^{-4}
<u>T = 8000°K:</u>		
($\omega = 1.17\text{eV}$)	$\mu = 3.1^{-3} \text{ cm}^{-1}$	($\omega = 1.2\text{eV}$) $\mu = 2.7^{-3} \text{ cm}^{-1}$
$= 1.79$)	$= 1.2^{-3}$	($= 1.8$) 1.1^{-3}

Further in Ref. 10 a comparison is made of the plasma emission predicted using these absorption coefficients with the experiments of Taylor (Ref. 12), covering temperature $6000\text{--}8000^\circ\text{K}$. The agreement is good. On these several grounds the results in Table I are accepted as sufficiently reliable for our application here.

Table I - Free-free Absorption Coefficient of Air (cm^{-1})

kT	$\rho/\rho_0 = 1$			$\rho/\rho_0 = 10$		
	$\omega = .117\text{eV}$	1.17eV	1.79eV	$\omega = .117\text{eV}$	1.17eV	1.79eV
.345eV (4000°K)	5.2^{-4}	1.6^{-6}	7.8^{-7}	1.2^{-2}	3.7^{-5}	1.8^{-5}
.517eV (6000°K)	1.1^{-1}	2.7^{-4}	1.1^{-4}	4.7	1.1^{-2}	4.7^{-3}
.690eV (8000°K)	1.7	3.2^{-3}	1.2^{-3}	7.9^{+1}	1.5^{-1}	5.7^{-2}
.862eV (10,000°K)	1.5^{+1} (*)	2.1^{-2}	7.2	5.2^{+2}	8.2^{-1}	2.9^{-1}
1.034eV (12,000°K)	1.4^{+2}	1.5^{-1} (*)	4.7^{-2} (*)	2.9^{+3} (*)	3.7	1.2
1.293eV (15,000°K)	1.9^{+3}	1.7	4.8^{-1}	2.8^{+4}	2.8^{+1} (*)	8.7 (*)
1.5eV	1.1^{+4}	8.6	2.4	(1.6^{+5})	1.4^{+2}	4.1^{+1}
2.0eV	(1.1^{+5})	8.3^{+1}	2.2^{+1}	--	1.1^{+3}	3.0^{+2}
3.0eV	--	2.9^{+2}	7.7^{+1}	--	8.1^{+3}	2.3^{+3}
5.0eV	--	7.7^{+2}	2.0^{+2}	--	2.8^{+4}	7.4^{+3}

(* indicates roughly equal coulomb and neutral contributions)

2.3 THE AIR ABSORPTION COEFFICIENT

The absorption coefficient for air--as a mixture of neutral and ionized species--is synthesized in our numerical studies as in Eq. 20,

$$\mu_{FF}(\omega, T) = \mu_{FF}^{\text{coul}}(\omega, T) + n_e \sum_i N_i \alpha_i^{FF}(\omega, T), \quad (20)$$

explicitly separating the neutral and ionized components.

The neutral cross sections were evaluated from Eq. 18, 19 and are listed in Table II as functions of temperature (4,000 - 58,000 °K) for the indicated species at three wavelengths each, $\lambda = 10.6$, 1.06 and 0.69 μ (from left to right). The cross sections listed are in units (10^{-36} cm^2).

To appropriately treat plasma collective effects--especially near the critical frequency--we approximate the dielectric function (Eq. 16) as

$$\epsilon_{\omega} = 1 - \frac{\omega_p^2}{\omega[\omega - i\nu'_{\text{eff}} G_{\omega}]} \equiv \epsilon_R(\omega) - i\epsilon_I(\omega) \quad (21)$$

$$\equiv (n_{\omega} - i\nu_{\omega})^2$$

to first order in $\nu'_{\text{eff}}/\omega \ll 1$. From Eq. 9 above

$$\nu'_{\text{eff}} = \frac{16\pi^2}{3} N_I \left\langle v \left(\frac{Ze^2}{mv^2} \right)^2 \right\rangle$$

$$= \frac{4\pi}{3} \sqrt{\frac{2}{\pi}} \frac{Z^2 e^4 N_I}{m^{1/2} (kT)^{3/2}} = 3.64 \frac{Z^2 N_I}{T_K^{3/2}} (\text{sec}^{-1}) \quad (22)$$

Table II

FREE-FREE ABSORPTION CROSS SECTION

TEMP	N2			O2		
4.0	1.16E-01	5.54E-04	2.22E-04	2.21E-01	6.87E-04	3.06E-04
6.0	5.33E-01	7.53E-04	3.24E-04	4.53E-01	1.04E-03	4.21E-04
8.0	5.52E-01	1.05E-03	5.99E-04	7.00E-01	1.46E-03	5.54E-04
10.0	6.16E-01	1.34E-03	5.34E-04	1.13E+00	1.93E-03	7.01E-04
12.0	1.12E+00	1.70E-03	6.19E-04	1.55E+00	2.47E-03	8.60E-04
15.0	1.64E+00	2.37E-03	8.04E-04	2.27E+00	3.26E-03	1.13E-03
17.4	2.12E+00	2.72E-03	9.53E-04	2.92E+00	4.03E-03	1.34E-03
23.2	3.41E+00	4.36E-03	1.34E-03	4.67E+00	5.97E-03	1.91E-03
34.8	6.85E+00	7.52E-03	2.31E-03	8.56E+00	1.01E-02	3.11E-03
58.0	1.16E+01	1.36E-02	5.84E-03	1.54E+01	1.72E-02	5.12E-03

N			O		
4.04E-01	1.22E-03	5.13E-04	7.08E-01	2.24E-03	1.07E-03
7.22E-01	1.60E-03	6.14E-04	1.59E+00	3.74E-03	1.60E-03
1.06E+00	1.98E-03	7.20E-04	2.69E+00	5.25E-03	2.07E-03
1.43E+00	2.36E-03	8.36E-04	3.83E+00	6.60E-03	2.44E-03
1.82E+00	2.82E-03	9.66E-04	4.93E+00	7.78E-03	2.76E-03
2.49E+00	3.58E-03	1.19E-03	6.45E+00	9.35E-03	3.17E-03
3.13E+00	4.29E-03	1.40E-03	7.62E+00	1.05E-02	3.48E-03
4.98E+00	6.35E-03	2.01E-03	1.03E+01	1.32E-02	4.20E-03
1.01E+01	1.19E-02	3.63E-03	1.62E+01	1.93E-02	5.91E-03
2.37E+01	2.62E-02	7.75E-03	3.22E+01	3.58E-02	1.06E-02

From Figure 4 we approximate

$$G_{\omega} = \text{Min} \left\{ \sqrt{\frac{\pi}{3}} \left\langle g_{FF}(\omega, T) \right\rangle \left| \ln \left(\frac{kT}{3\omega_p} \right) - \frac{1}{2} \right| \right\} \quad (23)$$

where $\langle g_{FF}(\omega, T) \rangle$ is the thermal-averaged Gaunt factor of Eq. 3 and Fig. 1, 2 above. We approximate this (Ref. 11)

$$\begin{aligned} \langle g_{FF}(\omega, T) \rangle &= 1.08 (1 + ay^b) \\ a &= 0.25 - .07716x \\ b &= 1.198/a^{0.27} \\ x &= \log_{10}(10\gamma^2), \quad y = \log_{10}(10/u) \\ u &= \frac{\hbar\omega}{kT}, \quad \gamma^2 = \overline{Z^2} \left(\frac{\text{Ryd}}{kT} \right) \end{aligned}$$

[Note - the $\overline{Z^2}$ in γ^2 and in Eq. 22 is that obtained from averaging over the ions only, $\overline{Z^2} \approx 1.0$]

From the dielectric function Eq. (21) and its elements defined above, the index of refraction, n_{ω} , is

$$n_{\omega} = \left\{ \frac{\epsilon_R + \sqrt{\epsilon_R^2 + \epsilon_I^2}}{2} \right\}^{1/2}$$

and the absorption coefficient is

$$\mu_{\omega} = 2 \frac{\omega}{c} \kappa_{\omega} = 2 \frac{\omega}{c} \left\{ \frac{-\epsilon_R + \sqrt{\epsilon_R^2 + \epsilon_I^2}}{2} \right\}^{1/2} \quad (24)$$

For $\omega \gg \omega_p$ the familiar result is obtained,

$$\mu_{\omega} = \frac{\omega_p^2}{c\omega} \frac{\nu'_{\text{eff}} G_{\omega}}{2\sqrt{1 - \omega_p^2/\omega^2}} \quad (24')$$

and μ_{ω} remains finite as $\omega \rightarrow \omega_p$.

Comparing Eq's 5 and 6 it is evident that the absorption coefficient (Eq. 24') includes the induced emission correction for $\hbar\omega \ll kT$. To extend this classical result into the quantum domain, we arbitrarily multiply ν'_{eff} (Eq. 22) by $\frac{kT}{\hbar\omega} (1 - e^{-\hbar\omega/kT})$ and only the neutral term of Eq. 20' is multiplied by $(1 - e^{-\hbar\omega/kT})$ --the resulting absorption coefficient then possessing the proper limits. Only for $\omega \sim \omega_p$ and $\hbar\omega \sim kT$ is our arbitrary correction significant, but

$$\frac{\hbar\omega_p}{kT} = 2.73 \times 10^{-3} \left(\frac{\text{Ryd}}{kT} \right) \sqrt{\frac{n_e}{10^{18}}} \ll 1$$

for densities of interest to us here.

APPENDIX II A - On The Correction For Induced Emission

In most applications the absorption coefficient must be corrected for the induced emission according to

$$\mu'(\omega) = \mu(\omega) \left(1 - \frac{R_E}{R_A} \right),$$

where R_E and R_A are the rates of induced emission and absorption, respectively. For electrons of energy, ϵ , these ratios are related (Ref. 13, Appendix)

$$R_E(\epsilon) = \left(1 - \frac{\omega}{\epsilon} \right)^{1/2} R_A(\epsilon - \omega)$$

and, for a thermal distribution of electrons,

$$\begin{aligned} \bar{R}_E(T) &= \frac{2}{\sqrt{\pi}} \int_{\omega}^{\infty} \frac{E^{1/2} dE}{T^{3/2}} e^{-E/T} R_E(E) \\ &= \frac{2}{\sqrt{\pi}} \int_{\omega}^{\infty} \frac{E^{1/2} dE}{T^{3/2}} e^{-E/T} \sqrt{\frac{E - \omega}{E}} R_A(E - \omega) \\ &= e^{-\omega/T} \frac{2}{\sqrt{\pi}} \int_0^{\infty} \frac{E^{1/2} dE}{T^{3/2}} e^{-E/T} R_A(E) \\ &= e^{-\omega/T} R_A(T). \end{aligned}$$

This is the familiar result,

$$\mu'(\omega, T) = \mu(\omega, T) (1 - e^{-\omega/T})$$

(The results in Table I do not include this induced emission correction).

3.0 RADIATIVE PROPERTIES OF AIR

For the study of radiative effects on the propagation of Laser-Supported-Detonation (LSD) waves, three air opacity parameters are useful:

- (i) The air absorption coefficient for the laser radiation.
- (ii) The air emissivity coefficient - in various spectral bands - for the range of plasma temperatures, densities, and dimensions of interest.
- (iii) The absorption coefficient of low temperature air for the plasma thermal radiation of (ii).

The laser absorption coefficient is the topic of Chapter 2.0. We address the remaining two topics in turn.

3.1 The Emissivity Coefficient of High Temperature Air

The radiant energy emitted into a direction $\hat{\Omega}$ from unit surface area of a convex body per unit time and per unit photon energy interval is the radiation intensity (Ref. 14).

$$I_{\omega}(\hat{\Omega}) \text{ (Watts cm}^{-2} \text{ sterad}^{-1} \text{ eV}^{-1}\text{)},$$

a solution of the radiative transfer equation which may be expressed as

$$I_{\omega}(\hat{\Omega}) = \int_0^S ds \mu'_{\omega}(s) B_{\omega}(s) \exp \left[- \int_0^s ds' \mu'_{\omega}(s') \right]. \quad (25)$$

Here s measures distance along the $(-\hat{\Omega})$ direction from the surface element of interest to a distance S at which the ray $(-\hat{\Omega})$ emerges from the radiating body. (In writing the solution, Eq. 25, we have assumed no external radiation sources and have ignored scattering, as its contribution is negligible at the temperatures of interest here.) $\mu'_\omega(s)$ is the absorption coefficient for frequency ω at location s - corrected for induced emission (Eq. 6) - and $B_\omega(s)$ is the blackbody function at s for frequency ω ,

$$B_\omega d\omega = \frac{15}{\pi^4} \left(\frac{\sigma T^4}{\pi} \right) \frac{u^3 du}{(e^u - 1)} \quad (\text{Watts/cm}^2 \text{ sterad}).$$

$u = \omega/T$, $T = T(s)$, and $\sigma = 1.03 \times 10^5 \text{ Watts/cm}^2 \text{ eV}^4$. (In practice one usually assumes a geometry stratified into isothermal, homogeneous regions within which T and μ_ω are constant, and we shall do so in what follows.)

The total energy emission J_ω results from integrating Eq. 25 over directions $\hat{\Omega}$ satisfying $(\hat{\Omega} \cdot \hat{n}) > 0$. Only for plane parallel slab geometry are the results simple - with $\hat{\Omega} \cdot \hat{n} = \cos \theta$ and $s = x/\cos \theta$, we obtain

$$\begin{aligned} J_\omega &= 2\pi \mu'_\omega B(\omega) \int_0^1 (d \cos \theta) \cos \theta \int_0^L \frac{dx}{\cos \theta} e^{-\mu'_\omega x / \cos \theta} \\ &= 2\pi B(\omega) \left[\frac{1}{2} - E_3(\mu'_\omega L) \right], \end{aligned}$$

where L is the thickness of the plasma slab and $E_3(t)$ is the usual exponential integral,

$$E_3(t) = \int_0^1 e^{-t/x} x dx = \frac{1}{2} e^{-2t} + O(t^2 e^{-2t}), \quad (t \ll 1).$$

With this approximation and upon integration over photon energy ω the particularly simple result is obtained

$$\bar{J} \approx \pi \int_0^\infty B(\omega) [1 - e^{-2\mu'(\omega)L}] d\omega \quad (\text{watts/cm}^2). \quad (26)$$

If $\mu'L \gg 1$ for all ω , $\bar{J} = \sigma T^4$, the black body result obtains. It is convenient to describe the energy emitted as a fraction of the blackbody emission at the same temperature. We thus define a dimensionless emissivity $\epsilon_0(T, \rho, L)$ depending on temperature T , density ρ , and geometric parameter L , according to

$$\bar{J}(T, \rho, L) = \epsilon_0(T, \rho, 2L) (\sigma T^4) \quad (27)$$

That is, in this case,

$$\epsilon_0(T, \rho, L) = \frac{15}{\pi^4 T^4} \int_0^\infty \omega^3 d\omega \frac{e^{-\omega/T}}{(1 - e^{-\omega/T})} [1 - e^{-\mu'(\omega)L}]. \quad (28)$$

If $\mu_\omega L \ll 1$ for most ω the Planck mean opacity is a convenient result,

$$\bar{\mu}_P = \frac{15}{\pi^4 T^4} \int_0^\infty \omega^3 e^{-\omega/T} \mu(\omega) d\omega \quad (\text{cm}^{-1}) \quad (29)$$

in terms of which

$$\epsilon_0(T, \rho, L \rightarrow 0) = \bar{\mu}_P L. \quad (30)$$

The physics approximations and computational techniques we have employed to calculate Planck mean opacities and emissivities of high temperature air are described elsewhere (Ref. 15, 16). We wish to present here only those results from our earlier work which we expect to be of importance to the present problem.

A. Planck Mean Opacities for High Temperature Air

In Table C-I of Appendix C we list values of the Planck mean opacity, as defined by equation 29 - multiplied by (ρ/ρ_0) for densities $\rho/\rho_0 = 10, 1, 0.1$.

For the purpose of assessing effects of the plasma thermal radiation on the propagation of LSD waves, we have combined the very detailed spectral opacities of our earlier work into five broad photon energy intervals. These were chosen somewhat arbitrarily as follows:

- (1) $\omega = 0$ to 7 eV: The ambient atmosphere is reasonably transparent to such photons, so radiation emitted in this band is essentially lost to the plasma interaction region.
- (2) $\omega = 7$ to 10 eV: The mean free path of such photons in the ambient atmosphere is less than 0.1 cm, being absorbed mostly by the O_2 Schumann-Runge bands. Their energy is less than the principal ionization

thresholds, although in collaboration with the laser radiation they can provide a non-thermal source of ionization. Such radiation is expected, however, to be important mainly due to preheating the ambient air ahead of the main LSD wave.

- (3) $\omega = 10$ to 13 eV: Photons in this energy interval will play the same role as those in the second band although with greater effect. As the preshocked air is heated, however, formation of NO will allow photons in this interval to produce direct ionization - the NO ionization threshold being 9.15 eV. at low temperatures.
- (4) $\omega = 13$ to 16 eV: The photoionization threshold for O being 12.06 eV, radiation in this spectral band is a primary ionization source.
- (5) $\omega > 16$ eV: N_2 is photoionized by 15.6 eV photons. Thus essentially all photons above 16 eV in energy result in ionization near the advancing shock front.

Partial Planck mean opacities $\overline{\mu}_p(\Delta\omega)$ - corresponding to (Eq. 29) integrated over the finite, above designated photon energy limits - are also included in Appendix C, Table C-I. Thus, to estimate the optically

thin emission in one of our specified energy intervals from a plasma of given temperature and density and thickness L , we write, from Eq. 27-30,

$$J_{\Delta\omega} = 2 \sigma T^4 \bar{\mu}_p(\Delta\omega) L \quad (31)$$

where $\bar{\mu}_p(\Delta\omega)$ is from our tabulated values. For air specie concentrations not in thermal equilibrium, we estimate the radiant emission by assuming the molecular states are populated according to some "temperature"--usually the electron "temperature". Tables of Planck mean opacities per molecule for each principal air specie as functions of temperature are included in our complete air data tables (though not in this report) from which Planck Means of arbitrarily composed air may be simply synthesized.

The special role played by NO due to its much lower ionization potential was mentioned with regard to the second spectral interval above. In addition to its thermal population, its generation by non-thermal processes may play an important role. For example, the photo dissociation thresholds of oxygen (5.08 eV) and nitrogen (9.76 eV) allow photons of insufficient energy to directly ionize O_2 or N_2 to photodissociate the molecules, producing NO by chemistry and thus resulting in ionization by a second photon of similar energy. It has been shown that soft ionizing radiation at intensity sufficient to raise the air temperature from ambient to 500°K results in an NO population 10-100 times thermal in less than 1 μ sec (Ref. 18). A suitable treatment of such combined chemical-radiation processes is outside the scope of the present effort, however.

B. The Spectral Emissivity of High Temperature Air

For finite thickness of the radiating plasma the Planck mean opacity no longer determines the emissivity. From our earlier work (Ref. 16) we have available detailed spectral evaluations of the air emissivity (Eq. 28) at most temperatures and densities of interest to us here.

We have fitted these in the form (compare Eq. 28)

$$\begin{aligned}\bar{\epsilon}(T, \rho, L; \omega) &= \frac{15}{\pi^4 T^4} \int_{\omega_1}^{\omega_2} \frac{\omega^3 d\omega}{(e^{\omega/T} - 1)} [1 - e^{-\mu'(T, \rho, \omega)L}] \\ &= \bar{B}(\Delta\omega, T) \left\{ 1 - \exp[-\alpha(T, \rho, L; \Delta\omega)L] \right\}\end{aligned}\quad (32)$$

where $\Delta\omega = (\omega_2 - \omega_1)$, and

$$\bar{B}(\Delta\omega, T) = \frac{15}{\pi^4 T^4} \int_{\omega_1}^{\omega_2} \frac{\omega^3 d\omega}{(e^{\omega/T} - 1)} \quad (33)$$

is the partial Planck fraction tabulated in Table C-II of Appendix C. Clearly such a representation reproduces the back body result as L becomes large (compare Eq. 27)

$$\bar{J}(T, \rho, L; \Delta\omega) \gamma_{L \gg 1} = \bar{B}(\Delta\omega, T) (\sigma T^4).$$

To reproduce the optically thin limit we write

$$\alpha(T, \rho, L; \Delta \omega) = a(T, \rho, L; \Delta \omega) \overline{\mu_p}(\Delta \omega, T) / \overline{B}(\Delta \omega, T) \quad (34)$$

and require $a \rightarrow 1$ as $L \rightarrow 0$. Values of a for $\rho/\rho_0 = 1.0$ and path lengths $L = .01$ and $.1$ cm. are listed in Table C-III-a as functions of temperature and frequency. a varies slowly with density; we write it

$$a(\rho) = a(\rho = \rho_0) (\rho/\rho_0)^b \quad (35)$$

Values of $b(T, L; \Delta \omega)$ are in Table C-III-b. Linear interpolation in b appears to be always suitable. For $L > 0.1$ cm we extrapolate a -values by log-log extrapolation. For $.01 < L < 0.1$ linear interpolation in a suffices, and for $L < .01$ cm we extrapolate a as

$$a(L) = \left[1 + 100L \left(\frac{1}{a_1^2} - 1 \right) \right]^{-1/2},$$

a form suggested by statistical band models (Ref. 15), where $a_1 = a(L = .01 \text{ cm})$.

Following these prescriptions, values of the emissivity were evaluated and are listed in Table C-IV.

3.2 The Absorption Coefficient of Low Temperature Air

In Figures 7, 8 are plotted the absorption coefficients of normal density air at ambient temperature and at 4000°K. The data are from our molecular band modelling calculations (Ref. 15) and reviews of low temperature photoionization and photodissociation data (Ref. 19-21).

The molecular band calculations evaluate the total absorption in 0.1 eV intervals and the principal temperature effects are the broadening toward lower photon energies with increasing temperature of the O₂ Shumann-Runge bands below $\omega = 7$. eV and of the N₂ Birge-Hopfield bands for $\omega = 11, -13$. eV. The continuum absorption coefficients were estimated at the higher temperature by simply renormalizing the low temperature cross sections to the higher temperature species concentrations.

It was from consideration of figures such as these that led to the choice of the photon emission energy groups described in Section A above.

Figure 7 Absorption Coefficient (cm^{-1}) of Ambient Air

Figure 8 Absorption Coefficient (cm^{-1}) of Normal Density

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4.0 THE LASER-SUPPORTED DETONATION WAVE AS A RADIATION SOURCE

In order to study the radiative effects associated with laser-supported detonation waves, a realistic representation of the thermohydrodynamic state of the radiating source is necessary. Numerous large computer codes exist for this purpose, the LASNEX code of Lawrence Livermore Laboratory being a most sophisticated and general example.

It is our intent here, however, to develop a simpler treatment of the propagating LSD wave, simple enough to allow direct incorporation of our equilibrium and possible non-equilibrium radiative interaction phenomena, yet sufficiently realistic as to allow a reasonable assessment of the considered effects on the real problem.

We follow the treatment of Raizer (Ref. 17) simply generalized for our purpose. A subsequent section extends this treatment to the case of unequal electron and ion temperatures and describes our computational implementation thereof. The concluding section of this chapter describes the radiation transport approximations we have incorporated into this model.

4.1 The Raizer Theory of LSD Waves

Raizer (Ref. 17) has presented a theory of LSD wave propagation based on a hydrodynamic mechanism which we simply extend here to suit our purpose. We consider a one-dimensional steady-state air shock moving with a velocity D (cm/sec) into the ambient atmosphere against the incident laser flux J_0 (ergs $\text{cm}^{-2} \text{sec}^{-1}$).

The shock heating at the shock front z_1 (in the moving frame) is assumed to produce enough ionization to initiate the absorption of the laser energy. The air then "breaks down" in the "Interaction" region, and relaxes into the final "Piston" state. Thus, z_2 is the point beyond which no laser energy is absorbed; the gas state is constant for $z > z_2$.

Raizer simply applied the standard conservation conditions between the ambient and "Piston" regions and deduced a relation between the shock speed D and the laser flux J_0 . His result agrees well with experiment and detailed computer simulations. As we expect most of the air radiation to be emitted by the "Interaction" region, it is necessary for our purpose to determine in further detail the thermo-hydrodynamic state of the gas in this region.

We assume a strong shock at $z = z_1$ and a gas whose internal energy equation of state at z_1 is

$$\epsilon_1 = \frac{1}{(\gamma_1 - 1)} \left(\frac{p}{\rho} \right) \text{ (ergs/gm)} \quad (36)$$

with density ρ and pressure p . Standard Hugoniot conservation relations then determine the gas state behind the shock at $z = z_1$.

$$\begin{aligned}\eta_1 &= \eta(z_1) = \frac{\gamma_1 - 1}{\gamma_1 + 1} = \rho_0 / \rho(z_1) \\ p_1 &= p(z_1) = \rho_0 (1 - \eta_1) D^2 = \left(\frac{2}{\gamma_1 + 1} \right) \rho_0 D^2 \\ c_1 &= c(z_1) = \frac{1}{(\gamma_1 + 1)} u_1 (1 - \eta_1) D^2 = 2 \left(\frac{D}{\gamma_1 + 1} \right)^2 \\ u_1 &= u(z_1) = \eta_1 D\end{aligned}\quad (37)$$

where u is the fluid velocity with respect to the moving shock surface. In the "Interaction" region the laser energy is absorbed according to geometric optics,

$$Q(z) = \frac{J_0 \mu'(z)}{\rho(z)} \exp \left[- \int_{z_1}^z \mu'(z') dz' \right] \quad (\text{ergs gm}^{-1} \text{sec}^{-1}) \quad (38)$$

where μ' is the laser absorption coefficient of Table I above (corrected for induced emission). We are ignoring for now any reflected wave contributions to $Q(z)$ as well as any energy exchange due to reradiation or conduction.

In the "Interaction" region ($z > z_1$) we then solve the gas dynamic equations in the presence of the source $Q(z)$ subject to the boundary conditions Eq. 37. We write these in the stationary frame (Ref. 22):

$$\text{Mass:} \quad \frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x} (\rho v) = 0$$

$$\text{Momentum:} \quad \left(\frac{\partial}{\partial t} + v \frac{\partial}{\partial x} \right) v = -\frac{1}{\rho} \frac{\partial p}{\partial x}$$

$$\text{Energy:} \quad \frac{\partial}{\partial t} \left(\rho \epsilon + \frac{1}{2} \rho v^2 \right) = - \frac{\partial}{\partial x} \left[\rho v \left(\epsilon + \frac{1}{2} v^2 \right) + p v \right] + \rho Q.$$

The frame moving (in $(-z)$ direction) with the shock (at velocity $-D$) is then related to the stationary frame according to

$$z = x + Dt, \quad u = v + D.$$

Therefore,

$$\frac{\partial}{\partial x} = \frac{d}{dz}, \quad \frac{\partial}{\partial t} = D \frac{d}{dz},$$

since we are considering only states which are time-stationary in the moving frame. Thus, in the moving frame, the gas is described by the conservation equations:

$$\begin{aligned} \text{Mass:} \quad u \frac{d\rho}{dz} + \rho \frac{du}{dz} &= \frac{d}{dz} (\rho u) = 0 \\ &\text{or} \\ u(z) &= D \eta(z) \end{aligned} \tag{39a}$$

$$\begin{aligned} \text{Momentum:} \quad u \frac{du}{dz} + \frac{1}{\rho} \frac{dp}{dz} &= 0 \\ &\text{or} \\ p(z) &= \rho_0 D^2 [1 - \eta(z)] \end{aligned} \tag{39b}$$

$$\begin{aligned} \text{Energy:} \quad \frac{d}{dz} \left[\rho u \left(c + \frac{v^2}{2} + pv \right) \right] &= \rho Q \\ \text{or} \\ \frac{d}{dz} \left[\epsilon - \frac{D^2}{2} (1 - \eta)^2 \right] &= \eta(z) Q / D \end{aligned}$$

Recognizing that

$$p \frac{d}{dz} \left(\frac{1}{\rho} \right) = D^2 (1 - \eta) \frac{d\eta}{dz} = - \frac{d}{dz} \left[\frac{D^2}{2} (1 - \eta)^2 \right]$$

the energy equation is obvious. Integrating,

$$\epsilon(z) - \frac{D^2}{2} [1 - \eta(z)]^2 = \frac{J_0}{\rho_0 D} \left\{ 1 - \exp[-\tau(z)] \right\}, \quad (39c)$$

where we have introduced the optical depth for the laser radiation,

$$\tau(z) = \int_{z_1}^z \mu'(z') dz',$$

and the boundary conditions (Eq. 37). In the event that the plasma frequency exceeds the laser frequency at some point z_c , the right side of (Eq. 39c) is replaced by

$$\left(\frac{J_0}{\rho_0 D} \right) \left[1 - e^{-\tau(z)} + e^{-2\tau_c} \left(e^{\tau(z)} - 1 \right) \right],$$

where $\tau_c = \tau(z_c)$, assuming total reflection at z_c .

Consistent with the stated conditions of one-dimensional stationary flow, geometric optics and neglect of radiative and conductive energy losses, the three equations (39) determine the state of the gas in the "Interaction" region in generality. It remains to determine the shock speed D .

Following Raizer (Ref. 17) we apply the Chapman-Jouget condition at $z = z_2$, according to which the gas relieves itself of the energy deposition to the maximum extent of which it is capable -- by flowing away from the deposition region at the local sound speed, $c(z)$. That is,

$$u_2 = \eta_2 D = c(z_2) = \sqrt{\tilde{\gamma}_2 \frac{p_2}{\rho_2}}$$

$$= \left[\tilde{\gamma}_2 D^2 \eta_2 (1 - \eta_2) \right]^{1/2}$$

or

$$\eta_2 = \eta(z_2) = \frac{\tilde{\gamma}_2}{\tilde{\gamma}_2 + 1} \quad (40)$$

$\tilde{\gamma}$ here is defined in terms of the speed of sound; for an ideal gas it is the familiar adiabatic exponent.

If the gas at z is not in thermodynamic equilibrium, (Eq. 39c) is our most general result. We discuss our modelling approximations for this case in the next subsection. In thermal equilibrium we can always write (Eq. 36)

$$\epsilon(z) = \frac{1}{\gamma(z) - 1} \frac{p(z)}{\rho(z)}$$

$$= \eta(z) [1 - \eta(z)] D^2 / [\gamma(z) - 1]. \quad (36')$$

Extensive tables of $(\gamma - 1)$ for air are to be found in Appendix B, Table B-II. Substituting into (Eq. 39c) an equation for the expansion $\eta(z)$ is obtained, with solution

$$\eta(z) = \frac{\gamma - \alpha}{\gamma + 1} \quad (41)$$

$$1 - \alpha^2 = \frac{2J_0}{\rho_0 D^3} (\gamma^2 - 1) [(1 - e^{-\tau}) + e^{-2\tau} c (e^\tau - 1)]$$

the quantities γ , α , and τ all being functions of z . Applying the Jouget condition (Eq. 40) at $z = z_2$ then determines the shock speed D . If we neglect the difference between $\tilde{\gamma}_2$ and $\gamma(z_2)$ --terms of order $\rho(\frac{\partial \gamma}{\partial \rho})_s$ --the simple result obtains that $\alpha(z_2) = 0$ or

$$D^3 = 2 \frac{J_0}{\rho_0} (\gamma_2^2 - 1) (1 - e^{-2\tau_c}), \quad (42)$$

which is Raizer's result for complete absorption ($e^{-\tau_c} \sim 0$), with $\gamma_2 = \gamma(z_2)$.

With this result for the shock speed, we immediately obtain from Eqs. 41 the expansion profile in the "Interaction" region

$$\alpha(z) = \left\{ 1 - \left(\frac{\gamma^2 - 1}{\gamma_2^2 - 1} \right) \left[1 - e^{-\tau} \left(\frac{1 - e^{-2(\tau_c - \tau)}}{1 - e^{-2\tau_c}} \right) \right] \right\}^{1/2}.$$

Specializing to complete absorption and constant γ , the particularly simple result obtains,

$$\eta(z) = \frac{\gamma(z) - e^{-1/2\tau(z)}}{\gamma(z) + 1} \quad (43)$$

and Eqs. 39 provide the spatial distribution of the remaining state variables.

Clearly, the simple-appearing solution, Eq. 43, involves a multitude of complications, in that the optical depth at z requires knowledge of the absorption coefficient and, hence, temperature and density at all points $z' \leq z$. In its numerical realization, in fact, it is most convenient to solve the differential equation for the optical depth

$$\frac{d\tau}{dz} = \mu'(z), \quad \tau(z_1) = 0,$$

evaluating the local density from Eq. 43, the energy from Eq. 36' and the absorption coefficient μ' -- a function of density and temperature -- as described in Chapter 2.0.

Even for the non-equilibrium models discussed in the following subsection, Eq. 42 applies, since the point z_2 is chosen such that the "Piston" region is translationally invariant, hence in equilibrium. All the non-equilibrium action is confined to the "Interaction" region. Thus, the shock speed relation is quite general. From consideration of Table B-II for densities greater than normal, it is evident that $\gamma \approx 1.18$ is a reasonable value for air for quite a range of temperatures. This value is in accord with experimental observations of the shock speed (quoted in Ref. 23).

Deviations are expected at lower laser intensities where the fundamental assumptions of this treatment no longer apply. As the intensity decreases the laser absorption length increases. A substantial portion of the deposited energy may be expected to go into lateral expansion when this absorption length becomes comparable to the beam diameter. The resulting shock speed will then be lower than predicted by (Eq. 42) -- a result again in accord with experiment. Finally, at still lower energies, the initial shock ionization may be insufficient to sustain a propagating LSD wave. Experimental results indicate a lower intensity threshold for propagation than would be predicted by equilibrium theory -- suggesting the possible importance of a non-equilibrium mechanism (Ref. 23).

4.2

Non-Equilibrium Effects in LSD Waves

As described in the preceding sections, the laser energy is assumed to be absorbed in the gas by the inverse bremsstrahlung or "free-free" mechanism. Thus, the laser energy is converted directly into kinetic energy of the free electrons. These in turn then further ionize the gas, excite internal degrees of freedom and heat the gas by collisions. Such a two-stage heating process requires time. For sufficiently high electron heating rates the mean electron energy may substantially exceed that of the gas and significantly effect is radiative characteristics.

Central to the extension of our LSD theory to include non-LTE effects is the choice of a suitable energy expression. We have limited our considerations to two-temperature models, prescribing an "Electron Temperature" T_e and a "Gas Temperature" T_A . The gas energy is then written

$$E(T_e, T_A) = \bar{E}(T_e) - \sum_i N_i \left\{ \sum_{\gamma(i)}' [\epsilon_{\gamma}^i(T_e) - \epsilon_{\gamma}^i(T_A)] \right\} \quad (44)$$

where $\bar{E}(T)$ is the equilibrium gas energy at temperature T (obtained from Tables B-I and B-II), N_i is the number density of particles of species i , and $\epsilon_{\gamma}^i(T)$ is the energy per particle of the i^{th} species associated with the γ^{th} degree of freedom at the temperature T . (Values of $\sum_{\gamma} \epsilon_{\gamma}^i(T)$ --summed over all internal degrees of freedom-- are obtained from Table B-V.)

Definition of a particular model--in the two-temperature class-- lies in the choice of those degrees of freedom to be included in the $\gamma(i)$ summation. Indeed, if the γ -sum is complete for all i , $E(T_e, T_A) = E(T_A)$.

The two particular models we have considered are described in subsections B and C below, along with some details of their computational realization.

Given a particular model for the energy, Equations 39 allow determination of the gas state by iteration. We have found it most efficient to iterate on $\eta(z)$. A temperature relaxation equation results from specification of the $\gamma(i)$ degrees of the model,

$$\frac{dT_A}{dz} = \frac{(T_e - T_A)}{Dt_c} \quad (45)$$

Given T_A and η , the pressure equation (39b) determines T_e

$$n_e k T_e + (\sum_i N_i) k T_A = \rho_0 D^2 (1 - \eta),$$

or

$$T_e = [\rho_0 D^2 (1 - \eta) + (\sum_i N_i) k (T_e - T_A)] / Z \hat{R} \quad (46)$$

where $Z(\rho, T_e)$ is obtain from Table B-I, and $\hat{R} = 2.87 \times 10^6 \text{ erg gm}^{-1} \text{ (}^\circ\text{K)}^{-1}$ is the "gas constant for air". Although (Eq. 46) requires iteration for T_e , it has the virtue of limiting exactly to the equilibrium results as $T_e \rightarrow T_A$. Then, given T_e , T_A and E - from (Eq. 44) - a revised value of η is obtained from (Eq. 39c) and an iterative procedure follows.

For estimation of the radiation emitted by the non-equilibrium plasma we assume the electronic excitation degrees of freedom to be at the electron temperature, although the specie concentrations may be arbitrary. This electron-excitation-collisional dominance model requires that the electron concentration, n_e , satisfy (Ref. 24).

$$n_e(\text{cm}^{-3}) \gtrsim 10^{14} [T_e(\text{eV})]^{1/2} \chi_{\text{eV}}^3$$

where $\chi(\text{eV})$ is the binding energy of the state in question. For the temperatures $T_e \gtrsim 10\text{eV}$ and energies $\chi \sim 10\text{eV}$, this condition requires greater than one percent ionization, satisfied in most cases of interest here.

Thus, from specified specie concentrations and our tables of spectral Planck mean opacities per molecule (at T_e), a non-equilibrium Planck mean may be easily generated. The emissivity prescriptions of Equations 32-35 are then simply assumed to apply--again at the electron temperature T_e .

In subsection A below we describe the various cooling rates we have employed for the evaluation of the thermal relaxation time t_c . Subsections B and C then describe the two non-equilibrium models we have studied. Finally, in subsection D, we describe the approximations we have employed to evaluate the radiation emitted by the plasma and its absorption by and effects upon the ambient air ahead of the shocked region.

4.2-A Electron Cooling Rates

As indicated in Eq. 45, the thermal equilibration in our two-temperature models is characterized by an electron cooling time t_c . For its evaluation we have considered several energy loss processes--the particular subset of which we employ in any case depending on our particular

model assignment of specific degrees of freedom to each of the two temperatures. That is, if our model assigns N_2 -vibrational degrees of freedom to the electron temperature T_e , electron vibrational excitations on N_2 will not change the electron temperature T_e and so will not contribute to t_e .

We consider several relaxation times in turn; numerical values are listed in Table III as functions of temperature ($10^4 K$).

1. Electron-electron self-collision time (Ref. 4)

$$\tau_{ee} = \frac{0.267 T_e^{3/2}}{n_e \ln \Lambda} \text{ (sec.)}$$

(T_e in $^{\circ}K$, n_e being electron density (cm^{-3})). For $\ln \Lambda$ we use the fit (Ref. 25),

$$\ln \Lambda = 23.1 - 0.50 \ln n_e + \frac{3}{2} \ln [T_e (\text{eV})]$$

Only for phenomena varying slowly with respect to τ_{ee} may we consider the free electrons thermalized at T_e . In the present study this is always assumed.

2. Elastic scattering on neutral atoms

These we have evaluated from

$$\frac{1}{\tau_{eA}} = \frac{4}{3} \left(\frac{m_e}{M_A} \right) \sqrt{\frac{8kT_e}{\pi m_e}} \int_0^{\infty} \frac{\epsilon^2 d\epsilon}{(kT_e)^3} e^{-\epsilon/kT_e} Q_d(\epsilon) \text{ (cm}^3/\text{sec)}$$

in terms of the momentum transfer cross sections, Q_d , of Kieffer (Ref. 9). For the lower temperatures the results are in agreement with Banks (Ref. 26).

Table III

REACTION	SPECIE	RELAXATION TIMES/SPECTRE- (SEC/CC)					
		T=	4,0	6,0	8,0	10,0	12,0
ELASTIC	N2		4,24E+11	2,67E+11	2,04E+11	1,76E+11	1,63E+11
ELASTIC	O2		5,45E+11	6,70E+11	5,90E+11	5,41E+11	5,03E+11
ELASTIC	N		5,77E+11	4,68E+11	3,62E+11	3,00E+11	2,59E+11
ELASTIC	O		1,03E+12	7,26E+11	5,69E+11	4,73E+11	4,09E+11
ROTATIONAL	N2		2,65E+11	3,49E+11	4,02E+11	4,50E+11	4,93E+11
ROTATIONAL	O2		1,23E+11	1,47E+11	1,70E+11	1,90E+11	2,08E+11
VIBRATION	N2		2,23E+09	6,52E+08	3,96E+08	3,36E+08	3,26E+08
VIBRATION	O2		1,73E+10	1,64E+10	1,87E+10	2,16E+10	2,57E+10
EXCITE 1	N2		7,74E+15	9,78E+12	3,35E+11	4,34E+10	1,10E+10
EXCITE 2	N2		1,27E+19	3,65E+15	4,59E+13	3,61E+12	6,56E+11
EXCITE 1	O2		1,63E+15	1,70E+13	1,68E+12	4,09E+11	1,58E+11
EXCITE 2	O2		1,32E+19	4,73E+15	8,67E+13	7,63E+12	1,50E+12
IONIZATION	N2		5,64E+27	1,96E+21	8,85E+17	8,36E+15	3,64E+14
IONIZATION	O2		2,67E+20	2,10E+16	1,99E+14	1,17E+13	1,72E+12

REACTION	SPECIE	T=	15,0	17,4	23,2	34,8	58,0
ELASTIC	N2		1,53E+11	1,50E+11	1,47E+11	1,39E+11	1,15E+11
ELASTIC	O2		4,54E+11	4,18E+11	3,47E+11	2,55E+11	1,79E+11
ELASTIC	N		2,18E+11	1,96E+11	1,62E+11	1,31E+11	1,21E+11
ELASTIC	O		3,46E+11	3,09E+11	2,53E+11	2,02E+11	1,83E+11
ROTATIONAL	N2		5,51E+11	5,94E+11	6,85E+11	8,39E+11	1,08E+12
ROTATIONAL	O2		2,33E+11	2,51E+11	2,89E+11	3,54E+11	4,58E+11
VIBRATION	N2		3,50E+08	3,86E+08	5,16E+08	9,22E+08	2,33E+09
VIBRATION	O2		3,32E+10	4,05E+10	6,29E+10	1,30E+11	3,65E+11
EXCITE 1	N2		2,75E+09	1,27E+09	3,80E+08	1,14E+08	4,58E+07
EXCITE 2	N2		1,17E+11	4,51E+10	1,00E+10	2,19E+09	6,69E+08
EXCITE 1	O2		6,00E+10	3,50E+10	1,50E+10	6,45E+09	3,50E+09
EXCITE 2	O2		2,90E+11	1,16E+11	2,77E+10	6,52E+09	2,12E+09
IONIZATION	N2		1,53E+13	2,61E+12	1,55E+11	8,02E+09	5,66E+08
IONIZATION	O2		2,44E+11	8,08E+10	1,35E+10	1,93E+09	2,97E+08

3. Elastic scattering on ions--following Spitzer (Ref. 4)

$$\frac{1}{\tau_{el}} = \frac{6.2 \times 10^{-3} T_e^{3/2}}{\left\{ [O^+] + 0.50 [O_2^+] + 0.53 [NO^+] \right\}} \quad (\text{sec}^{-1})$$

[...] being the respective ion number density (cm^{-3}).

4. Rotational excitation--following Dalgarno, et. al. (Ref. 27)

$$\tau_R = C T_e^{1/2} \quad (\text{sec/cm}^3)$$

where

$$\begin{aligned} C &= 4.46 \times 10^9 \text{ for } N_2 \\ &= 1.87 \times 10^9 \text{ for } O_2 \end{aligned}$$

5. Vibrational excitation

We use the fit of Kroll and Watson (Ref. 13) and write

$$\tau_v = \frac{\frac{3}{2} k T_e}{\langle Q(T_e) \rangle} \quad (\text{sec/cm}^3)$$

$$\text{where } \langle Q(T_e) \rangle_{N_2} = 2.35 \times 10^{-8} \left\langle \epsilon^{1/2} e^{-4(\epsilon - 2.6)} \right\rangle_{T_e}$$

$$\langle Q(T_e) \rangle_{O_2} = 3.92 \times 10^{-11} \left\langle \epsilon^{1/2} \left[\frac{1}{1 + 12.6 (\epsilon - 0.75)^2} + 2.6 e^{-1.4(\epsilon - 1.75)} \right] \right\rangle_{T_e}$$

The angular brackets $\langle \dots \rangle_T$ indicate thermal average at temperature T .

These results agree quite well with Dalgarno, et. al. (Ref. 30).

6. Electronic Excitation of Molecular States

Kroll and Watson (Ref. 13) parametrize the excitation rates

$$A_X(\epsilon) = C \epsilon^{1/2} (\epsilon - \epsilon_0) e^{-\alpha \epsilon}$$

where ϵ_0 is the threshold. The thermal average is

$$A_X(T) = \frac{2C\beta^{3/2}}{\pi} \frac{e^{-(\alpha+\beta)\epsilon_0}}{(\alpha+\beta)^3} [2 + (\alpha+\beta)\epsilon_0] \text{ (cm}^3/\text{sec)}$$

$$(\beta = 1/kT \text{ (eV}^{-1}\text{)})$$

The four reactions we have considered and their associated constants are

$N_2: (X + A^3\Sigma),$	$\epsilon_0 = 6.7\text{eV}$	$\alpha = .149 \text{ (eV)}^{-1}$	$C = 2.2 \times 10^{-8} \text{ (cm}^3 \text{ (eV)}^{3/2} / \text{sec)}$
$(X + a^1\Pi),$	$= 8.4$	$= .119$	$= 1.5 \times 10^{-9}$
$O_2: (X + A^3\Sigma),$	$= 4.5$	$= .167$	$= 2.0 \times 10^{-10}$
$(X + B^3\Sigma),$	$= 8.0$	$= .125$	$= 4.7 \times 10^{-10}$

The excitation time is then

$$\tau_X = \frac{1}{A_X} \text{ (sec/cm}^3\text{)}$$

Comparison may be made with the results of Ali (Ref. 28) listed in Table B-VII.

7. Ionization of molecular species

The parametrization of Kroll and Watson (Ref. 13) is employed, according to which

$$N_2: \tau_I = 1.2 \times 10^8 \left\langle \frac{e^{15.6/\theta}}{\theta^{1/2} (1 + .13\theta + .03\theta^2)} \right\rangle_T$$

$$O_2: \tau_I = 2.7 \times 10^8 \left\langle \frac{e^{9.27/\theta}}{\theta^{1/2} (1 + .17\theta + .03\theta^2)} \right\rangle_T$$

where $\theta = kT \text{ (eV)}$. The thermal averages $\langle \dots \rangle_T$ are performed numerically. Again, these representations may be compared with Table B-VII.

NO: We fit the data of (Ref. 29) by

$$\sigma(\epsilon) = 8.2 \times 10^{-18} \text{ cm}^2 [(\epsilon - 9.267) - \delta(\epsilon)]$$

where

$$\delta(\epsilon) = 1.3 [1 - .13388 (\epsilon - 12.0)^2], \quad (9.267 < \epsilon < 14.733) \\ = 0 \quad (\text{otherwise})$$

then

$$\langle \sigma v \rangle_T = 5.1 \times 10^{-9} \theta^{1/2} e^{-9.27/\theta} \{ (1 + .216\theta) - .9804(1 - .15\theta - .12\theta^2) \\ + 1.559e^{-5.466/\theta} (1 + .50\theta + .074\theta^2) \}$$

These are the values listed in Table B-VII.

From the above prescriptions the numerical results of Table III were prepared. The most striking result is the well-known fast N_2 vibrational rate. The rotational and translational times are of the same order of magnitude, being rapidly overtaken at increasing temperatures by electronic excitation. For any state of the plasma the cooling time t_c is then given by

$$\frac{1}{t_c} = \sum_i [N_i] \sum_{\nu} \frac{1}{\tau_{i,\nu}},$$

summed over the contributing species i , concentrations $[N_i] \text{ (cm}^{-3}\text{)}$, and over reactions ν .

4.2-B The LLL Two-Temperature Model

Experience at the Lawrence Livermore Laboratory in comparing theoretical predictions from their LASNEX code (Ref. 23) with experimental results suggested a particularly simple two-temperature model. Experiments (quoted in Ref. 23) with $10.6 \mu\text{m}$ laser radiation

demonstrate LSD wave propagation for laser intensity down to 10^7 w/cm². With an equilibrium air equation of state, however, the LASNEX code is unable to initiate or maintain such an LSD wave for intensities below 10^8 w/cm². The energy of the free electrons is bled off by molecular dissociation more rapidly than the laser can supply it and the wave doesn't propagate. This observation suggests the following simple model.

Two regimes are defined according to whether the electron temperature T_e is greater than or less than a prescribed transition temperature T_p .

$$T_e > T_p:$$

Only the heavy particle translational degrees of freedom are included in the γ -sum of Eq. 44,

$$\bar{E}(T_e, T_A) = E(T_e) - \frac{3}{2} Nk (T_e - T_A)$$

where N is the number density of heavy particles.

$$T_e < T_p:$$

The electron translation and ionization degrees of freedom are at T_e , all the remaining degrees of freedom being included in the γ -sum of Eq. 44.

This is implemented as follows:

- (i) The specie concentrations $\zeta(T)$ are obtained from Table B-III at both temperatures T_e and T_A , and the degrees of ionization of species $\zeta(T_A)$ are adjusted to match those of $\zeta(T_e)$ --the electron number density being at T_e .

- (ii) The pressure equation (46) is then solved for T_e , the $(\sum_i N_i)$ corresponding to $C(T_A)$. Clearly (i) and (ii) require iteration for the electron temperature.

- (iii) The energy equation is then taken to be

$$E(T_e, T_A) = \overline{E}(T_A) + \frac{3}{2} k [n_e(T_e)T_e - n_e(T_A)T_A] \\ + \sum_i [C_i(T_e) - C_i(T_A)] \epsilon_i(T_A),$$

where $n_e(T)$ is the free electron number density at temperature T , $C(T) = (C_1, \dots, C_i, \dots)$, and $\epsilon_i(T_A)$ is from Table B-V.

The transition temperature T_p is taken to be 1.3 eV, following the LASNEX example.

With this admittedly arbitrary non-equilibrium assumption, the LASNEX computational predictions are brought into excellent agreement with experiment--as discussed in Ref. 23. Radiative consequences of these assumptions are discussed below in Chapter 6.0.

4.2-C A Two-Temperature Model with Time-Dependent Chemistry

In an attempt to justify the assumptions of the LLL Two-Temperature model, we have developed a more general non-equilibrium model in which we solve a limited, simplified set of chemical reaction equations.

The simplified NRL reaction set (Ref. 28) is our starting point, neglecting radiative de-excitation and extending the set such that for every reaction present its inverse is also, where the inverse rate is evaluated by detailed balance using the concentrations of Table B-III.

Nine species are followed:

1. N_2
2. NO
3. NO^+
4. O_2
5. O_2^+
6. N
7. N^+
8. O
9. O^+

and we assume N_2^+ in Saha equilibrium with N_2 at the temperature T_e . This assumes the N_2^+ concentration is small--due to its high ionization energy (15.58eV) compared to O_2 (12.06eV) and NO (9.27eV)--until the electron temperature is high enough that the N_2^+ dissociatively recombines essentially instantaneously. Thus, we have ignored the N_4^+ route --

which may be important, however, in that it retains the dissociation energy in the molecules.

The reaction set we have considered is the following:

(i) Two dissociative recombination reactions:

(ii) The ion-molecule rearrangement reaction:

$$K_{TV} = 10^{-12} (1-x) [1.2(1+x) + 50x^2 + 120x^3 + 260x^4 + 400x^5 + 500x^6 (1+x+x^2)]$$

$$x = e^{-3482/T_e}$$

(iii) Four electron collisional ionization reactions:

Reaction rates

from Table B-VIII

at electron temperature

T_e

(iv) Ten rearrangement reactions:

All the reaction rates are in units (cm^3/sec) and are from Ref. 28 and 31.

The O_2 and NO vibrations are assumed to be at the temperature T_A (reactions (1) and (2)) and the electron ionization at T_e .

Given the species concentrations $[N_i]$ of Eq. 44, it remains to allocate the internal degrees of freedom to the two temperatures. From consideration of Table III, we have adopted the following prescriptions.

Let $\chi(T) = (\epsilon - \epsilon_0)/RT$, the quantity in Table B-V,
(ϵ_0 from Table B-IV).

N_2 - Translational and rotational degrees of freedom at T_A
vibrational and electronic at T_e :

$$\epsilon(\text{N}_2) = \epsilon_0 + [\chi(\text{N}_2, T_e) - \frac{5}{2}]kT_e + \frac{5}{2}kT_A.$$

O_2 - Translational, rotational, and vibrational degrees of
freedom at T_A ,
electronic at T_e :

$$\begin{aligned}
 \epsilon(\text{O}_2) = & \epsilon_0 + [\chi(\text{O}_2, T_e) - \frac{5}{2}]kT_e + \frac{5}{2}kT_A \\
 & - \omega_0 [(e^{\omega_0/kT_e} - 1)^{-1} - (e^{\omega_0/kT_A} - 1)^{-1}]
 \end{aligned}$$

$$\text{where } \omega_0 = .0858\text{eV} = 996^\circ\text{K}.$$

$$N_2^+ - \text{same as } O_2, \quad \epsilon_0 = .297\text{eV} = 3450^\circ\text{K}$$

$$O_2^+ - \text{same as } O_2, \quad = .232\text{eV} = 2690^\circ\text{K}$$

$$NO - \text{same as } O_2, \quad = .233\text{eV} = 2700^\circ\text{K}$$

$$NO^+ - \text{same as } O_2, \quad = .291\text{eV} = 3370^\circ\text{K}$$

N, N⁺, O, O⁺ - Translational degrees of freedom at T_A, electronic at T_e.

$$\epsilon = \epsilon_0 + [X(T_e) - \frac{3}{2}]kT_e + \frac{3}{2}kT_A.$$

From the specie concentrations determined by solution of the reaction equations and the energy per particle defined as above, the energy (Eq. 44) may be evaluated and the plasma state equations (Eq. 39, 46) solved by iteration, as described in the previous sections.

4.3 Radiation Transport

With the plasma state determined as described above-- either by local thermodynamic equilibrium (LTE) or by one of the two non-equilibrium models discussed--and the air radiation tables of Chapter 3.0, we are in a position to realistically estimate radiation from the high temperature "interaction" region into the ambient atmosphere ahead of the shock, causing preheating and preionization. In this section we describe our theoretical/computational treatment of these processes, and relegate our results to Chapter 6.0.

From our treatment of the spectral emissivity, (Eq. 32), it is evident that the quantity $\alpha(T, \rho, L; \Delta\lambda)$ is effectively the exponential mean of the absorption coefficient weighted by the Planck function. Thus,

the mean transmission through a cell of temperature T , thickness L , and density ρ may be approximated as

$$\Theta(T, \rho, L; \Delta \omega) = \exp[-\alpha(T, \rho, L; \Delta \omega) L], \quad (47)$$

for radiation temperatures not too different from T .

Within the Interaction region, the radiation flux is divided into two elements:

1. The positive flux $J_N^{(+)}(\Delta \omega)$, the radiation flowing in the (+Z) direction, evaluated according to

$$\begin{aligned} J_1^{(+)} &= 0 \\ J_{N+1}^{(+)} &= J_N^{(+)} \Theta_N + (\sigma \overline{T_N^4}) \overline{\epsilon}_N, \quad (N = 1, NMAX) \end{aligned} \quad (48a)$$

for each spectral band $\Delta \omega$. The emissivities, $\overline{\epsilon}_N$, and transmissivities, Θ_N , are evaluated for the mean density of the cell N (bounded by z_N, z_{N+1}), the corresponding mean temperature, $\overline{T_N}$, and path length $L = 2(z_{N+1} - z_N)$, corresponding to the mean cosine = $1/2$ (compare Eq. 27).

2. The negative flux $J_N^{(-)}(\Delta \omega)$, flowing toward the ambient atmosphere. Since the state of the plasma is assumed invariant for $z \geq z_2$, no net flux must cross the surface $z = z_2$:

$$J_{NMAX}^{(-)} = J_{NMAX}^{(+)} \quad (48b)$$

$$J_N^{(-)} = J_{N+1}^{(-)} \Theta_N + (\sigma \overline{T_N^4}) \epsilon_N, \quad (N = NMAX - 1, N)$$

for each spectral band $\Delta \omega$.

Solving first for $J^{(+)}$ to obtain the boundary condition for $J_{NMAX}^{(-)}$ and then iterating by (Eq. 48b) determines the flux emitted by the piston into the ambient atmosphere, $J_1^{(-)}$. The flux of plasma radiation deposited in each cell is then

$$Q_N = \sum_{(\Delta\omega)} \left[J_N^{(+)} - J_{N+1}^{(+)} + J_{N+1}^{(-)} - J_N^{(-)} \right], \quad (49)$$

and is evaluated in each cell for comparison with the energy therein deposited by the laser radiation testing the assumptions leading to Eq. 39c.

The above outlined procedure for solving the radiation transport equation is best suited to a computational mesh over which the temperature varies significantly between adjacent points--the situation complementary to that for which radiation diffusion applies, as described in Ref. 16, Vol. III. The flux subtraction of Eq. 49 results in numerical inaccuracy as the temperature becomes constant; indeed, taking Eq. 49 to the differential limit yields the familiar diffusion equation.

The radiation into the ambient air is mostly from the region near $z = z_1$, however, where the plasma temperature does vary rapidly and the above formulation should be suitable. Moreover, the necessary elements are immediately available to us from Chapter 3.0 above.

Given the radiant flux emitted by the "Interaction" region, we evaluate the heating and ionization in the ambient atmosphere on a computation mesh of specified interval increasing in the $(-)$ direction. The energy deposition rate at x due to plasma radiation is $(X = -z)$

$$\frac{d\epsilon}{dx} = - \frac{1}{\rho_0 D} \sum_{(\Delta \omega)} J_1^{(-)}(\Delta \omega) \mu_T(x) e^{-\tau'(x)} \text{ (erg/gm cm}^{-1}\text{)} \quad (50)$$

and the electron production rate at x due to ionizing plasma radiation is

$$\frac{dn_e}{dx} = - \frac{1}{D} \sum_{(\Delta \omega)} J_1^{(-)}(\Delta \omega) \mu_I(x) e^{-\tau'(x)/\bar{\omega}(\Delta \omega)} \quad (51)$$

Here $\tau'(x)$ is optical depth

$$\tau'(x) = \int_0^x \mu_T(x') dx'$$

and the total and ionization coefficients, μ_T and μ_I , respectively, and mean photon energy $\bar{\omega}$ are listed in Table IV as function of $\Delta \omega$ and temperature. The absorption coefficients are rough averages obtained from figures such as Fig. 7, 8.

The heating of the ambient atmosphere is determined iteratively. The density remains ambient; the temperature is initially chosen to be ambient (288 °K), and the absorption coefficient is known for all x . The deposition rate is evaluated, starting from $x = 0$ ($z = z_1$) and advancing into the ambient atmosphere until the contribution is small. The internal energy and the updated air temperature are then evaluated by integrating Eq. 50 back toward the shock front. With the revised temperature profile the absorption coefficients are re-evaluated and the procedure repeats until pointwise temperature convergence obtains.

Table IV. Ambient Air Absorption and Ionization
Coefficients (cm^{-1})

		T = 1000 °K		T = 2000 °K		T = 4000 °K		T = 6000 °K	
$\Delta\omega(\text{eV})$	$\omega(\text{eV})$	μ_T	μ_I	μ_T	μ_I	μ_T	μ_I	μ_T	μ_I
0-7	5.0	0	0	0	0	0	0	0	0
7-10	8.5	25.3	$1.5 \cdot 10^{-4}$	24.4	$3.3 \cdot 10^{-2}$	17.1	.35	4.65	.22
10-13	11.5	28.2	4.72	29.7	5.54	44.	14.2	34.9	7.62
13-16	14.5	198	71.	196.	71.	190.	71.	133.	46.3
> 16	18.	611	473.	606.	470.	551.	442.	474.	383.

The electron concentration n_e consists of two components, the thermal concentration $\bar{n}_e$ and a non-thermal part $\tilde{n}_e$ induced by the ionizing radiation from the plasma. We estimate the non-thermal component from

$$\frac{dn_e}{dx} = -\frac{S(x)}{D} + \frac{1}{D} (\alpha_d \tilde{n}_e n_e + A n_e). \quad (52)$$

$S(x) = -\frac{dn_e}{dx}$ is from Eq. 51, A is the electron attachment rate, and α_d the recombination coefficient, values for which we obtained from (Ref. 32)

$$A = 5.4 \times 10^{-14} T^{-5/2} e^{-540/T} + 1.3 \times 10^{-15} [O] + 2.5 \times 10^{-12} [O_3] (\text{cm}^3 \text{sec}^{-1})$$

$$\alpha_d = 9 \times 10^{-5} / T_e (\text{sec}^{-1})$$

We integrate Eq. 52 inward from large x toward the shock -- in effect, integrating the time history of a parcel of air as the shock approaches and engulfs it.

With the stationary temperature and electron profile generated ahead of the shock by plasma radiation, the laser absorption coefficient and energy deposition may be evaluated to study radiative corrections to Raizer's hydrodynamic theory. Our results are in Chapter 6.0.

5.0

RADIATION PROPAGATION IN A PLASMA

A collection of formulae useful for estimating reflection and transmission coefficients and energy deposition in a few simple cases is the content of this section. All the results are implicit in the books of Ginzburg (Ref. 5) and Brekhovskikh (Ref. 33), though the derivations there are but sketched and generally ignore absorption. Finally, we describe a computer program for one dimensional propagation and include some results therefrom.

We consider radiation propagating in the ($\pm Z$) direction in a medium whose properties vary only in the Z -direction. Let $E_x(Z)$ be the x -component of the radiation electric field; it satisfies

$$\left. \begin{aligned} E_x(Z, t) &= \operatorname{Re} E(Z) e^{i\omega t} \\ \frac{d^2 E}{dZ^2} + \frac{\omega^2}{c^2} \epsilon_\omega(Z) E &= 0. \end{aligned} \right\} \quad (53)$$

The complex magnetic field associated with E is

$$H(Z) = i \frac{c}{\omega} \frac{dE}{dZ}$$

in the y -direction, and the time-averaged Poynting vector $S(Z)$ has Z -component only

$$S(Z) = \frac{c}{8\pi} \operatorname{Re} [E(Z) H^*(Z)] = \hat{Z} \cdot \vec{S}(Z) \quad (54)$$

where $\hat{Z}$ is a unit vector in the Z -direction.

5.1 Propagation in an Homogeneous Medium and the Fresnel Formulae

A. For an homogeneous medium, the dielectric function

$\epsilon_\omega = \epsilon_\omega = \eta_\omega^2 = (n_\omega - i\kappa_\omega)^2$ is independent of Z . Then

$$\left. \begin{aligned} E(Z) &= E_0 e^{\mp i \frac{\omega}{c} \eta_\omega Z} \\ H(Z) &= \pm \eta E_0 e^{\mp i \frac{\omega}{c} \eta_\omega Z} \\ S(Z) &= \pm \frac{c}{8\pi} n_\omega |E_0|^2 e^{\mp 2 \frac{\omega}{c} \kappa_\omega Z} \text{ (watts/cm}^2\text{)} \end{aligned} \right\} \quad (55)$$

The upper sign thus corresponds to propagation in the $(+Z)$ direction, and the lower sign in the $(-Z)$ direction. $n_\omega = \text{Re} \epsilon_\omega^{1/2}$ is the index of refraction of the medium, and the energy absorption coefficient is

$$\mu_\omega = 2 \frac{\omega}{c} \kappa_\omega = -2 \frac{\omega}{c} \text{Im} [\epsilon_\omega^{1/2}], \quad (56)$$

as was stated following Eq. 8 above.

The energy deposition per unit volume is

$$\begin{aligned} Q(Z) &= - \frac{dS}{dZ} = \frac{c}{8\pi} N_\omega \mu_\omega |E|^2 \\ &= \mu_\omega I(Z) \text{ (Watts/cm}^3\text{)} \end{aligned} \quad (57)$$

B. The Fresnel formulae provide the reflection and transmission coefficients from a boundary between two homogeneous media with different dielectric functions.

Then, writing $S(Z) = I^{(+)}(Z) - I^{(-)}(Z)$ in terms of the separate directional fluxes $I^{(\pm)}(Z) > 0$,

$$I_{<}^{(-)}(Z') = \mathcal{R}_{12} I_{<}^{(+)}(Z) e^{2 \frac{\omega}{c} \kappa_1 (Z+Z')}, \quad (Z, Z' \leq 0)$$

$$I_{>}^{(+)}(Z') = \left(\frac{n_2}{n_1} \right) \sqrt{12} I_{<}^{(+)}(Z) e^{-2 \omega/c (\kappa_2 Z' - \kappa_1 Z)}$$

defines the reflection coefficient

$$\mathcal{R}_{12} = \left| \frac{\eta_1 - \eta_2}{\eta_1 + \eta_2} \right|^2 = \frac{(n_1 - n_2)^2 + (\kappa_1 - \kappa_2)^2}{(n_1 + n_2)^2 + (\kappa_1 + \kappa_2)^2} \quad (58)$$

and the transmission coefficient

$$\gamma_{12} = \left| \frac{2\eta_1}{\eta_1 + \eta_2} \right|^2 = \frac{4(n_1^2 + \kappa_1^2)}{(n_1 + n_2)^2 + (\kappa_1 + \kappa_2)^2} \quad (59)$$

5.2 Propagation in an Inhomogeneous Medium in the Geometric Optics Approximation

If the dielectric properties of the medium vary slowly in a spatial domain of the order of the local wavelength $\lambda(Z) = \frac{c}{\omega n(Z)}$, a long wavelength, WKB-like approximate solution to Eq. 53 is useful - the so-called geometric optics approximation (Ref. 5),

$$E(Z) = \frac{E_{\pm}}{[\epsilon(Z)]^{1/4}} \exp \left[\mp i \frac{\omega}{c} \int^Z \sqrt{\epsilon(Z')} dZ' \right]. \quad (60)$$

The validity condition for (Eq. 60) to be a useful approximate solution to (Eq. 53) is

$$\left| \alpha \right| \equiv \left| \frac{c}{\omega} \frac{d\eta/dZ}{\eta(Z)} \right| \ll 1$$

where, as usual, $\epsilon(Z) = \eta^2(Z) = [n(Z) - i\kappa(Z)]^2$. Further, $\kappa(Z) \ll n(Z)$ and $(d\eta/dZ)$ must be continuous. It is clear this condition can never be

satisfied near those regions where $\operatorname{Re} \zeta(Z) = 0$, the critical points,
as then $\lambda(Z) \rightarrow \infty$.

The magnetic field corresponding to (Eq. 60) is

$$H(Z) = \pm [\zeta(Z)]^{1/4} E_{\pm} \exp \left[\mp i \frac{\omega}{c} \int^Z \sqrt{\zeta(Z')} dZ' \right]$$

and

$$S(Z) = \pm \left[\frac{n(Z)}{\sqrt{n^2(Z) + \kappa^2(Z)}} \right] \left(\frac{c}{8\pi} \right) |E_{\pm}|^2 \exp \left[-2 \frac{\omega}{c} \int^Z \kappa(Z') dZ' \right].$$

Thus, the directional flux $I^{(\pm)}(Z)$ is related to that at another point Z'
according to

$$I^{(\pm)}(Z) = I^{(\pm)}(Z') \exp \left[- \int_{Z'}^Z \mu(x) dx \right] \quad (61)$$

where $n(Z) \gg \kappa(Z)$ is assumed.

It is evident from (Eqs. 60-61) that the radiant fluxes
propagating in the $(\pm Z)$ directions are independent -- there is no
reflection from a region where the geometric optics approximation

is valid. In References 5 and 33 the leading order corrections to the approximate solutions (Eq. 60) are obtained, providing a coupling between $I^{(-)}$ and $I^{(+)}$ -- a "weak" reflection. These results must be used with care, however, as in several cases they lead to incorrect results.

As derived by Ginzburg (Ref. 5, Eq. 16-30) the electric field for (+Z) propagating radiation -- to first order in α -- is

$$E(Z) = \frac{E_+}{\sqrt{\eta(Z)}} \left[e^{-i\alpha(Z)} + R_W(Z) e^{i\varphi(Z)} \right]$$

where

$$R_W(Z) = -\frac{ic}{4\omega} \int_{Z_1}^Z \frac{dZ'}{\sqrt{\eta}} \frac{d}{dZ'} \left(\eta^{-3/2} \frac{d\eta}{dZ'} \right) e^{-2i\varphi(Z')}$$

$$\varphi(Z) = \frac{\omega}{c} \int_{Z_1}^Z \eta(Z') dZ' \quad \text{and}$$

Then,

$$S(Z) = \left(\frac{c}{8\pi} \right) \left| E_+ \right|^2 \left\{ e^{-\int_{Z_1}^Z \mu(Z') dZ'} - \left| R_W(Z) \right|^2 e^{+\int_{Z_1}^Z \mu(Z') dZ'} \right\},$$

where we have omitted terms $O(n_{\omega/\kappa\omega})^2$.

$|R_W|^2$ plays the role of a reflection coefficient. Z_1 is to be chosen such that $R_W(Z_1) = 0$.

Integrating by parts, an alternative expression for R_W is obtained.

$$R_W(Z) = -\frac{ic}{4\omega} \left\{ \left[\frac{1}{\eta^2} \frac{d\eta}{dZ} e^{-2i\varphi(Z)} \right]_{Z_1}^Z + \int_{Z_1}^Z \frac{dZ'}{2\eta^3} \left(\frac{d\eta}{dZ'} \right)^2 e^{-2i\varphi(Z')} \right\} \quad (62)$$

$$+ \int_{Z_1}^Z \frac{dZ}{2\eta} \frac{d\eta}{dZ} e^{-2i\varphi(Z')}$$

In this form for the reflection amplitude one recognizes physically separate effects.

1. If the dielectric function has a finitely discontinuous derivative at Z_0 , the reflection amplitude is

$$R_D = -\frac{ic}{4\omega\eta^2(Z_0)} \left[\left(\frac{d\eta}{dZ} \right)_{Z_0+} - \left(\frac{d\eta}{dZ} \right)_{Z_0-} \right] e^{-2i\varphi(Z_0)} \quad (62a)$$

which compares to the first term in (Eq. 62).

2. If the inhomogeneous medium is replaced by a large number of homogeneous layers of infinitesimally different dielectric properties, then the Fresnel formulae apply. The reflection density $r(Z)$ is then (from Eq. 58)

$$r(Z) = \frac{1}{2\eta} \frac{d\eta}{dZ}$$

and consideration of phase results in a "Fresnel" reflection

$$R_F(Z) = \int_{Z_1}^Z \frac{dZ'}{2\eta} \frac{d\eta}{dZ'} e^{-2i\phi(Z')} \quad (62b)$$

which is the last term of (Eq. 62')

5.3 Propagation in a Medium with Dielectric Function Varying Linearly in Space

$$\underline{Z \leq 0}: \quad E_0(Z) = A \left[e^{-i\varphi_0 Z} + R e^{i\varphi_0 Z} \right], \quad \varphi_0 = \frac{\omega}{c} \eta_0$$

$$\underline{Z \geq d}: \quad E_2(Z) = T A e^{-i\varphi_2(Z-d)}, \quad \varphi_2 = \frac{\omega}{c} \eta_2$$

where the reflection and transmission coefficients are

$|R|^2$ and $|T|^2$, respectively.

Two cases must be differentiated:

A. Plasma underdense at $Z = d$. That is, $\text{Re}\epsilon_2 > 0$.

Then

$$0 \leq Z \leq d: \quad E_1(Z) = B w^{1/3} \left[H_{1/3}^{(2)}(w) + C H_{1/3}^{(1)}(w) \right]$$

$$\text{where } w(Z) = \frac{2}{3} \frac{\omega}{c} \left[\frac{1}{a} \eta^3(Z) \right]$$

and $H^{(1,2)}$ are the usual Hankel functions (Ref. 34).

Applying the continuity conditions at $Z=0$ and at $Z=d$:

$$C = - \left[\frac{H_{-2/3}^{(2)}(w_d) + iH_{1/3}^{(2)}(w_d)}{H_{-2/3}^{(1)}(w_d) + iH_{1/3}^{(1)}(w_d)} \right]$$

$$\alpha = \frac{H_{-2/3}^{(2)}(w_0) + CH_{-2/3}^{(1)}(w_0)}{H_{1/3}^{(2)}(w_0) + CH_{1/3}^{(1)}(w_0)}$$

$$R = \frac{1-i\alpha}{1+i\alpha}$$

$$T = (1+R) \left(\frac{w_d}{w_0} \right)^{1/3} \left[\frac{H_{1/3}^{(2)}(w_d) + CH_{1/3}^{(1)}(w_d)}{H_{1/3}^{(2)}(w_0) + CH_{1/3}^{(1)}(w_0)} \right]$$

in terms of the Hankel functions and $w_0 = w(Z=0)$,

$$w_d = w(Z=d) = w_0 + \frac{\omega}{c} \int_0^d \eta(Z) dZ. \quad \text{These four expressions}$$

completely determine the reflection and transmission

coefficients.

Fresnel limit:

($d \rightarrow 0$ and $a \rightarrow \infty$ such that $ad = \eta_2^2 - \eta_0^2$ is finite)

$$\alpha = -i \left(\frac{\eta_2}{\eta_0} \right) \left[1 - \frac{i}{2a} \frac{\omega}{c} \eta_2^3 \left(1 - \frac{\eta_0^2}{\eta_2^2} \right)^2 \right],$$

$$R = \left(\frac{\eta_0 - \eta_2}{\eta_0 + \eta_2} \right) \left(\frac{1 - i \frac{\omega}{c} \frac{d}{2} (\eta_0 + \eta_2)}{1 + i \frac{\omega}{c} \frac{d}{2} (\eta_0 - \eta_2)} \right)$$

$$T = 1 + R$$

to first order in d . The reflection coefficient is then

$$\mathcal{R} \equiv |R|^2 = \left| \frac{\eta_0 - \eta_2}{\eta_0 + \eta_2} \right|^2 \left(\frac{1 - \frac{\omega}{c} d (\kappa_0 + \kappa_2)}{1 - \frac{\omega}{c} d (\kappa_0 - \kappa_2)} \right),$$

to be compared with the Fresnel result (Eq. 58).

Weak Reflection limit:

($a \rightarrow 0$, $w_0 \gg 1$, $w_d \gg 1$)

$$R = \frac{i}{12} \left(\frac{1}{w_0} - \frac{1}{w_d} e^{-2i\lambda} \right) + \frac{1}{5184} \left[\frac{35}{2w_0^2} - \frac{1}{w_d} \left(\frac{47}{w_d} - \frac{12}{w_0} \right) e^{-2i\lambda} \right]$$

$$\chi = w_d - w_0 = \frac{\omega}{c} \int_0^d \eta(Z) dZ.$$

Comparing this result with the weak reflection approximations, the first term in R is due to the discontinuities in $(d\eta/dZ)$ at $Z = 0$ and $Z = d$, and only the second term is due to weak reflections from the dielectric gradient itself.

- B. Plasma overdense at $Z = d$. That is, $\text{Re}\epsilon_3 < 0$. Then at some point Z_c in $[0, d]$, $\text{Re}\epsilon(Z_c) = 0$. Writing $\eta_1^2 = \eta_0^2 - \alpha Z$ in this case, we write the solutions in $[0, d]$

$$0 \leq Z \leq Z_c: \quad E_1^{(<)}(Z) = B w_1^{1/3} [H_{1/3}^{(a)}(w_1) + C H_{1/3}^{(1)}(w_1)]$$

$$w_1 = \frac{2}{3} \frac{\omega}{\alpha c} \eta_1^3, \quad \left(-\frac{3\pi}{4} < \text{Arg}(w_1) \leq \frac{\pi}{2} \right)$$

$$Z_c \leq Z \leq d: \quad E_1^{(>)}(Z) = D_1 \text{Ai}(\xi) + D_2 \text{Bi}(\xi)$$

in terms of the Airy functions (Ref. 34, Section 10.4).

$$\text{Then } E_1^{(>)}(Z) \longrightarrow r_1 e^{-w_2} + D_2 e^{+w_2}$$

$$\text{where } w_2 = \frac{2}{3} \frac{\omega}{\alpha c} (-\eta_1^3)^{3/2} \text{ is real if } \epsilon \text{ is real,}$$

and $(-\pi \leq \text{Arg}(w_2) \leq \pi/4)$. Clearly, $D_2 = 0$ and, considering the analytic continuation of $E_1^{(>)}$ into $E_1^{(<)}$ near $Z = Z_c$, we find

$$w_2 = e^{-3\pi i/2} w_1$$

$$C = e^{i\pi/3}$$

$$= - \left[\frac{J_{1/3}(w_0) + J_{-1/3}(w_0)}{J_{2/3}(w_0) - J_{-2/3}(w_0)} \right]$$

$$R = \frac{1 - i\alpha}{1 + i\alpha}$$

Here, $w_0 = w_1(0)$ and the phases are chosen such that w_1 and w_2 are both real if there is no absorption. But if α is real, R has modulus unity and total reflection occurs. In the presence of absorption

$$R = \frac{\{J_{-2/3}(w_0) - J_{2/3}(w_0)\} - i\{J_{1/3}(w_0) + J_{-1/3}(w_0)\}}{\{J_{-2/3}(w_0) - J_{2/3}(w_0)\} + i\{J_{1/3}(w_0) + J_{-1/3}(w_0)\}}$$

In the limit that

$$\text{Re} \left[\frac{\omega}{c} \int_0^{Z_c} \eta(Z') dZ' \right] \gg 1$$

asymptotic approximations apply.

Then

$$R = -ie^{-2iw_0}$$

and

$$\mathcal{R} = |R|^2 = [\exp(4 \operatorname{Im} w_c)] e^{-2 \int_0^{Z_c} \mu(Z') dZ'} \quad (63)$$

From the definition of Z_c

$$\operatorname{Im} w_c = -\frac{4}{3} \frac{\omega}{c} (Z_c \kappa_c) \left(\frac{\kappa_c}{n(0)} \right)^2 \ll 1.$$

As noted following Eq. 60, the approximation of geometric optics cannot be valid near Z_c , because the real wavelength tends to become infinite. Nevertheless, the more rigorous result for the energy reflection coefficient (Eq. 63) is precisely what one would obtain from geometric optics.

5.4 Propagation in a "Transition Layer"

Suppose

$$\epsilon(Z) = \epsilon_a + (\epsilon_b - \epsilon_a) \left(\frac{e^{Z/L}}{1 + e^{Z/L}} \right), \quad (64)$$

$$\begin{aligned} &\longrightarrow \epsilon_a \quad \text{as } Z \ll (-L) \\ &\longrightarrow \epsilon_b \quad \text{as } Z \gg (+L) \end{aligned}$$

Such a medium is termed a "Transition Layer" and provides an exact solution worthy of study due to the absence of discontinuities in derivatives (Ref. 35).

For this dielectric function, a non-linear transformation reduces the wave equation, Eq. 53, to a hypergeometric equation, from the solutions of which the reflection and transmission amplitudes may be extracted - mathematical details are in Ref. 33, Section 14. The reflection amplitude is

$$R = \frac{\Gamma(iS\eta_a) \Gamma\left[-i\frac{S}{2}(\eta_a + \eta_b)\right] \Gamma\left[1-i\frac{S}{2}(\eta_a + \eta_b)\right]}{\Gamma(-iS\eta_a) \Gamma\left[i\frac{S}{2}(\eta_a - \eta_b)\right] \Gamma\left[1+i\frac{S}{2}(\eta_a - \eta_b)\right]} \quad (65)$$

and the transmission amplitude is

$$T = \frac{\Gamma\left[-i\frac{S}{2}(\eta_a + \eta_b)\right] \Gamma\left[1-i\frac{S}{2}(\eta_a + \eta_b)\right]}{\Gamma(-iS\eta_a) \Gamma(1-iS\eta_b)}$$

where

$$S = 2 \frac{\omega}{c} L = 4\pi \frac{L}{\lambda}$$

measures the thickness of the layer in vacuum wavelength units.

The reflection coefficient may be written $\mathcal{R} = F\rho$, where

$$F = \prod_{n=1}^{\infty} \frac{[(n+\alpha_0)^2 + \alpha_1^2] [(n-\alpha_0)^2 + \alpha_2^2]}{[(n-\alpha_0)^2 + \alpha_1^2] [(n+\alpha_0)^2 + \alpha_2^2]} \quad (66a)$$

$$\alpha_0 = -\frac{S}{2} \kappa_b, \quad \alpha_1 = \frac{S}{2} (n_a + n_b), \quad \alpha_2 = \frac{S}{2} (n_a - n_b)$$

and we have assumed ϵ_a real, and

$$\rho = \frac{\cosh \left[S \Pi (n_b - n_a) \right] - \cos \left[S \Pi (\kappa_b - \kappa_a) \right]}{\cosh \left[S \Pi (n_b + n_a) \right] - \cos \left[S \Pi (\kappa_b + \kappa_a) \right]} \quad (66b)$$

Clearly, $F=1$ if there is no absorption, and in the presence of absorption the form (Eq. 66a) is a rapidly convergent, easily computed function, to our knowledge not previously recognized (compare Ref. 35). As $S \rightarrow 0$, the Fresnel limit obtains,

$$\mathcal{R}_{S \rightarrow 0} \rightarrow \rho_0 = \left| \frac{\eta_b - \eta_a}{\eta_b + \eta_a} \right|^2$$

If $\text{Re } \epsilon_b < 0$, the plasma becomes overdense for $Z \gg L$

The above result still applies except

$$\rho = \frac{\cosh(S\Pi n_a) - \cos\left[S\Pi(\kappa_b - \nu_b - \kappa_a)\right]}{\cosh(S\Pi n_a) - \cos\left[S\Pi(\kappa_b - \nu_b + \kappa_a)\right]}$$

so total reflection obtains as $\kappa_a \rightarrow 0$. (Here, $n_b = i\nu_b$.)

From numerous computer evaluations of Eq. 65 for Radar applications (Ref. 35) the reflection coefficient decreases exceedingly rapidly for $S > 1$ in an everywhere underdense plasma. For no absorption and $n_a = 1$, $n_b = 1.1$, as the half-value thickness l varies from 0.1λ to 5.0λ , the reflection coefficient decreases 23 orders of magnitude.

5.5 EPROP - A One-Dimensional Wave Propagation Computer Program

In order to study the laser energy deposition rate $Q(z)$ (Eq. 57) in the one-dimensional compression profile $\eta(z)$ determined as in Section 4 above, we have developed a one-dimensional wave propagation code EPROP. Standard treatments of $Q(z)$ assume the validity everywhere of a geometric optics approximation to wave propagation as in Eq. 38, above, with reflection only at a critical point at which the local free electron density exceeds the critical values. Due to the possibly large electron density gradients produced by the LSD waves, it is of interest to study weak or near-Fresnel reflection corrections to this approximation.

As in Section 4, we focus our attention on propagation in the "Interaction" region $z_1 \leq z \leq z_2$, with the laser radiation incident from $z < z_1$.

The computer program EPROP numerically integrates the wave equation 53 for $E(z)$ from $z = z_2$ to $z = z_1$, with the boundary condition at $z = z_2$ of rightward propagation only,

$$E(z_2) = 1$$

$$E'(z_2) = \frac{d}{dz} E(z_2) = -i \frac{\omega}{c} \sqrt{\epsilon(z_2)} .$$

Since we assume $\epsilon(z) = 1$ for $z < z_1$, the resulting numerical solution for $z < z_1$ may be written

$$E(z) = A [E_1(z) + RE_2(z)], \quad (67)$$

in terms of the fundamental solutions to Eq. 53 which satisfy

$$E_1(z_1) = E_2(z_1) = 1.$$

$$E'_1(z_1) = -E'_2(z_1) = -i \frac{\omega}{c} = -ik_0 .$$

The reflection amplitude R of Eq. 67 is then given by

$$R = \frac{ik_0 E(z_1) + E'(z_1)}{ik_0 E(z_1) - E'(z_1)} \quad (68)$$

and the transmission amplitude T is

$$T = \frac{\sqrt{n(z_2)}}{A} = \sqrt{n(z_2)} \left[\frac{1+R}{E(z_2)} \right] \quad (69)$$

For $z = z_1$, the Poynting vector is

$$S(z_1) = \frac{c}{8\pi} |A|^2 (1 - |R|^2) \quad ,$$

allowing the identification $J_0 = \frac{c}{8\pi} |A|^2$, which then serves to normalize the solution $\tilde{E}(z) = \sqrt{\frac{8\pi}{c}} J_0 E(z)$, where $E(z)$ is the numerical solution.

Finally, the energy deposition is

$$\begin{aligned} Q(z) &= \frac{dS}{dz} = -\frac{\omega}{8\pi} \chi(z) |\tilde{E}|^2 \\ &= -\frac{\omega}{c} \chi J_0 |E|^2 \\ Q(z) &= -\mu_\omega(z) J_0 \left(\frac{1}{2} |E|^2 \right) \quad . \end{aligned}$$

The wave equation is integrated in two ways at the option of the user as a wave solution or as a phase solution. The basic equations evaluated in each case are treated separately below.

(i) Wave Solution for the Electric Field

We write

$$E(z) = a(z) + ib(z)$$

$$\epsilon(z) = \epsilon_R - i\epsilon_I = [n(z) - i\chi(z)]^2$$

a , b , ϵ_R and ϵ_I being real functions. Then the differential equations to be solved are

$$a'' + k_o^2 (\epsilon_R a + \epsilon_I b) = 0$$

$$b'' + k_o^2 (\epsilon_R b - \epsilon_I a) = 0$$

with boundary conditions

$$a(z_2) = 1, \quad a'(z_2) = -k_o n(z_2)$$

$$b(z_2) = 0, \quad b'(z_2) = -k_o n(z_2)$$

(ii) Phase Solution for the Electric Field

We write

$$E(z) = e^{ik_o S(z)}$$

$$S(z) = \int_{z_2}^z (u + iv) dz'$$

in terms of the real functions u and v which satisfy

$$u'(z) = k_o [2uv + \epsilon_I]$$

$$v'(z) = k_o [v^2 + \epsilon_R - u^2]$$

subject to the boundary conditions

$$\begin{aligned}u(z_2) &= -n(z_2) \\v(z_2) &= \kappa(z_2)\end{aligned}$$

5.5-A Results for Some Test Cases

Both the wave and the phase formulations provide adequate solutions. The results obtained from the wave formulations are numerically more stable but for short wavelengths require so fine a computing mesh ($\Delta X \ll \lambda$) as to incur roundoff accumulation. The phase solution, on the other hand, although subject to instability problems, chooses its mesh such that

$$\Delta X \ll \lambda \frac{\Delta E}{E}$$

which is much more efficient near the geometric optics domain of validity.

The weak reflection approximation (Eq. 62) has also been evaluated to compare with the more accurate numerical results. Only for a linear layer were the weak results satisfactory. For example: let $n(z) = 0.8 - .005z$, $\kappa(z) = 0$ on a computational mesh ($-40. \leq z \leq +40.$). Our results are in Table V. The results labeled $R_{\text{Weak}}^{(1)}$ are the "Fresnel" reflection results (Eq. 62b), while $R_{\text{Weak}}^{(2)}$ results from evaluation of the more complete expression (Eq. 62) which is apparently less reliable!

Table V. Comparison of Reflection Coefficients for
a "Linear Layer"

λ	R	$R_{\text{Weak}}^{(1)}$	$R_{\text{Weak}}^{(2)}$
1.0	1.25^{-7}	1.20^{-7}	1.20^{-7}
3.162	5.63^{-6}	5.71^{-6}	5.71^{-6}
10.	2.74^{-5}	2.75^{-5}	2.79^{-5}
31.62	1.35^{-4}	1.41^{-4}	1.46^{-4}
100.	3.73^{-3}	3.97^{-3}	4.78^{-3}
316.2	3.69^{-2}	3.81^{-2}	8.30^{-2}

As a further test of the code we have evaluated results for the "Transition Layer" studied in Section 4 above. Some results are presented in Table VI for $L=1$, $\epsilon_a=1$, and the indicated values of ϵ_b for a range of wavelengths. Clearly, the "Wave" and "Phase" results are essentially equivalent except at the shorter wave lengths where the noted instabilities render the results inaccurate. The Weak reflection results are not very useful, although increasing absorption improves their accuracy. The "Fresnel" result is Eq. 58, the "Theoretical" result is from Eq. 66 a, b, with the number in parenthesis being the number of factors included in Eq. 66a for convergence to better than one part in 10^6 .

5.5-B Plasma Absorption of Laser Radiation

In our LSD-wave model described in Chapter 4, laser reflection is assumed to occur only from the critical surface z_c of the plasma, where the free electron density is sufficiently large that the plasma frequency, ω_p , equals the laser frequency, ω . Furthermore, laser propagation is treated by geometric optics, which can't be strictly correct near z_c because

Table VI. Reflection Coefficient of a "Transition Layer"

ϵ_2	(λ/L)	Numerical Solutions			Theoretical	Fresnel
		Wave	Phase	Weak		
0.1	3.162	3.722^{-4}	3.728^{-4}	1.45^{-3}	3.722^{-4}	.2699
	10.	7.244^{-2}	7.244^{-2}	.263	7.244^{-2}	
	31.62	.2300	.2300	2.07	.2300	
	100.	.2655	.2655	15.6	.2655	
	316.2	.2694	.2694	150.	.2694	
(0.1-0.01i)	3.162	3.984^{-4}	3.989^{-4}	1.40^{-3}	3.983^{-4} (86)	.2695
	10.	7.320^{-2}	7.319^{-2}	.250	7.320^{-2} (28)	
	31.62	.2298	.2298	1.91	.2298 (9)	
	100.	.2651	.2651	14.9	.2651 (3)	
	316.2	.2691	.2691	146.	.2691 (1)	
(0.1-0.1i)	3.162	3.718^{-4}	3.724^{-4}	3.66^{-4}	3.718^{-4} (185)	.2432
	10.	6.512^{-2}	6.512^{-2}	7.44^{-2}	6.512^{-2} (59)	
	31.62	.2054	.2054	.2927	.2054 (19)	
	100.	.2389	.2389	2.91	.2389 (6)	
	316.2	.2427	.2427	36.8	.2427 (2)	
(0.25-0.01i)	3.162	4.077^{-6}	4.223^{-6}	2.85^{-6}	4.077^{-6} (86)	.1111
	10.	1.456^{-2}	1.456^{-2}	1.49^{-2}	1.456^{-2} (28)	
	31.62	8.642^{-2}	8.642^{-2}	.108	8.642^{-2} (9)	
	100.	.1083	.1083	.207	.1083 (3)	
	316.2	.1108	.1108	.954	.1108 (1)	

the wavelength becomes infinitely large; see (Eq. 63) however. The same assumptions are made in most laser-plasma interaction codes, including LASNEX (Ref. 23).

Near the critical surface absorption becomes large and careful estimates of the absorbed and reflected energy are necessary. Such estimates have been made by Dawson, Kaw, and Green (Ref. 36) and by Shearer (Ref. 37). These authors write the absorption coefficient in the form (see discussion following Eq. 8)

$$\mu(\omega) = \frac{\omega_p^2 \nu_{\text{eff}}}{\omega^2 c \sqrt{1 - \omega_p^2 / \omega^2}},$$

which may be expressed directly in terms of the local electron density $n(z)$ as (Eq. 8)

$$\mu(z) = \mu_0 \frac{n^2}{\sqrt{1 - n/n_c}}.$$

Assuming $n(z)$ to vary linearly near z_c , the optical depth is

$$\tau_c = \int_0^z \mu(z') dz' = \frac{16}{15} \mu_0 \left| \frac{n_c^3}{\Delta n} \right|, \quad (70)$$

which is the result of Dawson and of Shearer. (Here $z = 0$ corresponds to $n = 0$). The reflection coefficient is then

$$R \approx e^{-2\tau_c}.$$

In fact, of course, the absorption coefficient does not become infinite near z_c and geometric optics does not apply. Therefore, we have tested this result with our numerical model EPROP. We consider

the layer $0 \leq z \leq L$, assume $n(z)$ to vary linearly between zero at $z = 0$ and critical at $z = L$, and obtain for the dielectric function (Eq. 7)

$$\epsilon(z) = \left(1 - \frac{z}{L}\right) - iK \left(\frac{z}{L}\right)^2$$

where

$$K = \nu_{\text{eff}}/\omega_p \ll 1$$

Except near z_c , the absorption coefficient agrees with Dawson and Shearer, but $\sqrt{\epsilon(z_c)} = \sqrt{\frac{K}{2}}(1-i)$, so $\mu(z_c) = 2\frac{\omega}{c} \times 2\frac{\omega}{c} \sqrt{\frac{K}{2}}$ is finite. Realistic values of K may be obtained from Eq. 8, 22 above,

$$K = 6.4 \times 10^{-5} Z^2 \sqrt{\frac{n_e (\text{cm}^{-3})}{T_{eK}^3}}$$

-- Assuming coulomb interactions only --

for which we obtain for two densities at thermal equilibrium.

	$\frac{\rho/\rho_0 = 10}{K = 5.5^{-4}}$	$\frac{\rho/\rho_0 = 1}{K = 2.1^{-4}}$
$T = 3000^\circ\text{K}$		
6000 $^\circ\text{K}$	.016	7.9^{-3}
8000 $^\circ\text{K}$	.033	.015
10,000 $^\circ\text{K}$	.049	.025
1.0 eV	.072	.040
1.5 eV	.137	.075
2.0 eV	.164	.084
3.0 eV	.159	.109
5.0 eV	.126	.101
10.0 eV	.236	.174

In terms of the above parametrization, the geometric optics reflection coefficient of Dawson and Shearer becomes

$$R_D = \exp \left[-\frac{32}{15} K \left(2\pi \frac{L}{\lambda} \right) \right] .$$

In Table VII we list the ratio of our numerical evaluation of the reflection coefficient to the above R_D as functions of K and λ/L . As λ/L becomes large, geometric optics begins to fail and the ratio is observed to decrease; the Dawson Shearer approximation overestimates the reflection. At large absorption (large K) their approximation is seen to greatly underestimate the reflection and overestimate the absorption due to the finite value of $\mu(z_c)$ and the fact that the index of refraction $n(z_c) = \sqrt{K/2} \gg 0$.

Except for the smallest K values (where the Dawson Shearer result is valid) the "Fresnel Weak reflection" approximation (Eq. 62b) is found to agree with the correct reflection coefficient to better than twenty percent. Again, however, inclusion of the higher order terms of (Eq. 62) leads to a much greater error.

Table VII. Ratio of Numerical Reflection Coefficient to
the Result of Dawson and Shearer

	K = .5	K = .1	K = .05	K = .01
$\lambda/L = 0.20$	5.9^{+9}	1.51	1.06	1.00
$= 0.356$	4.4^{+3}	1.18	1.02	1.00
$= 0.6325$	70.8	1.02	.985	.995
$= 1.125$	7.60	1.01	.989	.997
$= 2.0$	4.47	1.05	1.02	1.00
$= 3.56$	2.06	1.02	1.00	1.00
$= 6.325$	1.16	.932	.961	.992
$= 11.25$	.828	.865	.925	.984

6.0 RESULTS AND DISCUSSION

In the previous chapters, we have described the various elements necessary to our study of radiative effects in the propagation of LSD waves. In this chapter we describe some results of our incorporation of these elements into a simple computer code LSD. Due to the simplicity of our model and the extensive use of tabular data, the resulting computer code is very fast and efficient, requiring but a few seconds of CDC-7600 time per case.

For comparison with real experimental data appropriate account must be taken of the one-dimensional, stationary nature of our plasma state model. The stationary assumption results from complete neglect of the presence of the target -- the existence of the wave propagating in air is assumed before our discussion begins. Limitations due to this approximation will be further discussed below. Given the existence of an LSD wave propagating in air, the principal shortcoming of a one-dimensional treatment is the neglect of plasma cooling by lateral expansion -- that is, in directions perpendicular to the direction of the laser beam. Some discussion of this approximation was given by Raizer (Ref. 17).

If a is the cross section area of the laser beam at $z = z_1$, and we recall that the speed of sound (at z_2) is $\eta_2 D$, then a time for lateral relaxation may be taken to be of the order

$$t_{\text{ex}} \sim a / \eta_2 D,$$

as seen by a parcel of air moving through the interaction region. From consideration of the variation of optical depth with z for various intensities J_0 , as presented in Figures 12 through 14, it is evident that

once optical depth one-half is achieved in the plasma, the remaining laser energy is quickly absorbed. Thus, a useful measure of the laser energy deposition time may be

$$t_{\text{abs}} \approx \frac{z(\tau = 1/2)}{D\eta(\tau = 1/2)},$$

recognizing that the fluid velocity $\mu = \eta D$. Therefore, we might reasonably expect that lateral expansion may be negligible if

$$t_{\text{abs}} \ll t_{\text{ex}}.$$

From (Eq. 43) this may be written

$$z(\tau = 1/2) \ll \left(\frac{\gamma - 1/4}{\gamma} \right) a \approx a.$$

Thus, the suitability of our one-dimensional treatment rests on the specifics of the laser beam diameter and figures such as Fig. 12 through 14.

The effects of our neglect of the target are more difficult to estimate. The picture we have regarding the initiation of LSD waves is the following. Initially, the laser energy is absorbed directly by the target. As the deposited laser energy increases, the target vaporizes and an expanding layer of target vapor develops, pushing the air away from the target and driving a weak shock into the air. This regime has been studied by Thomas (Ref. 40). He obtains a relationship between the shock speed and the laser intensity which leads to a slower shock speed than that obtained by Raizer (Eq. 42) -- in agreement with experiment (as quoted in Ref. 23).

As still more laser energy is deposited -- or as the laser intensity increases -- the target vapor layer itself may become optically thick enough to absorb the bulk of the laser energy, even though the air remains transparent. The interaction region of section 4 then is separated into two regions by a contact discontinuity. Throughout the air region the density, pressure, and fluid velocity remain constant -- the air shock is passive. The absorbing vapor now plays the part of the earlier "Interaction" region.

To attempt to delineate such an intermediate regime, the results in Table VIII may be useful. We there present the electron number densities at the shock front, n_1 , for both air and aluminum vapor as a function of laser intensity -- obtained using Eq. 37. The corresponding laser absorption coefficients (cm^{-1}) in air for the three wavelengths of interest are also included. (The aluminum vapor density is taken as $1.293 \times 10^{-2} \text{ gm/cm}^3$ in these results.)

Our calculated one-dimensional threshold for propagation of a Nd - glass laser LSD wave is $2 \times 10^7 \text{ W/cm}^2$ ($\omega = 1.17 \text{ eV}$), for which the air electron density $n_e = 1 \times 10^{17} \text{ cm}^{-3}$. Thus, the intermediate regime for an aluminum target in air might range from 8×10^6 to 2×10^7 in laser intensity. Clearly the shock speed in this intermediate regime depends on the rate at which target vapor is provided. Unless conduction in the vapor plays a role -- either electron or radiative -- the vapor layer cannot remain optically thick. In any case the resulting shock speed will be limited by the target vaporization rate and will be less than the pure LSD waves we consider.

TABLE VIII

$J_0(\text{W/cm}^2)$	$T_1(^{\circ}\text{K})$	$n(\text{cm}^{-3})$		$\mu(\text{cm}^{-1})$		
		air	alum.	$\omega=.117\text{eV}$	$\omega=1.17\text{eV}$	$\omega=1.79\text{eV}$
6×10^6	4,075	$1.92+14$	$7.+16$	$2.04-3$	-	-
8×10^6	4,501	$8.88+14$	$1.6+17$	$1.36-2$	-	-
10^7	4,869	$1.51+15$	$3.3+17$	$2.96-2$	-	-
2×10^7	6,391	$2.69+16$	$3+18$	1.10	-	-
3×10^7	7,746	$1.14+17$	...	7.20	$6.85-2$	$2.98-2$
5×10^7	9,297	$4.50+17$		18.5	.414	.175
10^8	11,433	$1.88+18$		27.9	2.89	1.18
5×10^8	25,381	$1.26+20$		30.9	$9.47+2$	$3.21+2$
10^9	36,207	$3.02+20$		20.2	$3.11+3$	$1.14+3$
5×10^9	77,498	$7.20+20$		6.38	$4.69+3$	$4.90+3$
10^{10}	107,300	$9.77+20$		4.03	$2.97+3$	$7.88+3$

Increasing the intensity further the LSD waves develop in air, for which our one-dimensional treatment may be expected to apply, above that intensity for which the laser beam radius exceeds the deposition thickness -- as described above. Thus the true threshold will be greater than our computed one-dimensional threshold.

6.1 THERMAL EQUILIBRIUM RESULTS

We have considered three laser wavelengths in this study:

$$\begin{array}{lll}
 \lambda = 10.6\mu & \omega = .117\text{eV} & n_c = 1 \times 10^{19} \text{cm}^{-3} \\
 = 1.06\mu & = 1.17\text{eV} & = 1 \times 10^{21} \text{cm}^{-3} \\
 = 0.69\mu & = 1.79\text{eV} & = 2.4 \times 10^{21} \text{cm}^{-3}
 \end{array}$$

(Here, n_c is the electron number density at which the plasma becomes overdense, $\omega = \omega_p$ (Eq. 8).) In all the cases studied, the simple result (Eq. 43) for the plasma density in the interaction region in terms of the optical depth was found to be valid to within the variations in $\gamma = 1.18$ to 1.22. Thus, the specification of the dependence of the optical depth, $\tau(z)$, on z completely determines the plasma state everywhere, from Eqs. 43 and 39 and the air equation of state tables in Appendix B.

In Figures 9 - 11 are values of the distance $z(\text{cm})$ from the shock front, z_1 , as a function of optical depth τ . Results are presented for several relevant laser intensities $J_0(\text{W/cm}^2)$ at the three laser energies ω . Similar information is presented in Figures 12 - 14, where we give the distance $z(\text{cm})$ at fixed optical depths τ ($= .5, 1.0, 2.0, 4.0$ and 8.0) as function of the laser intensity $J_0(\text{W/cm}^2)$. This representation is most useful for estimation of the validity of our one-dimen-

Figure 9: Distance z (cm) from shock front, z_1 , as a function of optical depth τ , for various laser intensities J_0 (W/cm^2). ($\omega = 1.79 \text{ eV}$)

Figure 10: Distance $z(\text{cm})$ from shock front, z_1 , as a function of optical depth τ , for various laser intensities $J_0(\text{W}/\text{cm}^2)$. ($\omega = 1.17 \text{ eV}$)

Figure 11: Distance z (cm) from shock front, z_1 , as a function of optical depth τ , for various laser intensities J_2 (W/cm²). ($\omega = .117\text{eV}$)

Figure 12: Distance $Z(\text{cm})$ from shock front, z_1 , at fixed optical depth τ as a function of laser intensity, $J_0 (\text{W/cm}^2)$. ($\omega = 1.79 \text{ eV}$)

Figure 13: Distance $z(\text{cm})$ from shock front, z_1 , at fixed optical depth τ as a function of laser intensity, $J_0 (\text{W/cm}^2)$. ($\omega = 1.79 \text{ eV}$)

Figure 14: Distance $z(\text{cm})$ from shock front, z_1 , at fixed optical depth τ as a function of laser intensity, $J_0 (\text{W/cm}^2)$. ($\omega = .117\text{eV}$)

sional treatment. Thus, for Nd - glass laser radiation ($\lambda = 1.06\mu$, $\omega = 1.17\text{eV}$) two dimensional effects are expected to be important for laser beam diameters greater than 0.1 cm if $J_0 = 10^8 \text{W/cm}^2$, and unimportant otherwise. (The convergence to $z = .02\text{cm}$ for $J_0 = 5 \times 10^7$ and $\omega = .117\text{eV}$, Fig. 14, is due to total reflection.)

The spatial distribution of temperature is given in Fig. 15, 16 as function of optical depth τ for various laser intensities $J_0 (\text{W/cm}^2)$. The results for $\omega = 1.79\text{eV}$ and 1.17eV are indistinguishable as function of τ on such a plot; the results for $\omega = .117\text{eV}$ differ principally from the others in the onset of total reflection for $J_0 = 5 \times 10^7$. In Fig. 17 - 19 we give the spatial coordinates $z(\text{cm})$ at specified temperatures as function of the laser intensity J_0 for the three wave lengths considered. The specified temperatures are taken as specific fractions of the total temperature excursion,

$$T_i = \alpha_i [T_{\max}(J_0) - T_1(J_0)]$$

$$(\alpha_i = .25, .5, .75, .9).$$

$T_1(J_0)$ is from Table VIII and $T_{\max}(J_0)$ is from Fig. 20. Included in Fig. 17 - 19 is $z(T_{\max})$ as function of J_0 .

For the photon energies $\omega = 1.79\text{eV}$ and $\omega = 1.17\text{eV}$ the results presented in the figures described above completely specify the thermohydrodynamic state of the "Interaction" region -- ignoring energy transfer effects by plasma reradiation. For CO_2 laser radiation ($\omega = .117\text{eV}$) the electron density exceeds $10^{19} (\text{cm}^{-3})$ within the "Interaction" region and the laser beam is totally reflected for $J_0 > 2 \times 10^7 \text{W/cm}^2$. For

Figure 15: Temperature $T(^{\circ}\text{K})$ vs. optical depth τ for various laser intensities $J_0(\text{W/cm}^2)$. Results for $\omega = 1.17$ and 1.79 eV are essentially indistinguishable.

Figure 16: Temperature $T(^{\circ}\text{K})$ vs. optical depth τ for various laser intensities $J_e (\text{W}/\text{cm}^2)$.

Figure 17: $z(\text{cm})$ of specified temperatures T (see text) as functions of laser intensity $J_0(\text{W/cm}^2)$. ($\omega = 1.79\text{eV}$)

Figure 18: $z(\text{cm})$ of specified temperatures T_i (see text) as functions of laser intensity $J_0 (\text{W/cm}^2)$. ($\omega = 1.17\text{eV}$)

Figure 19: $z(\text{cm})$ of specified temperatures T (see text) as functions of laser intensity $J (\text{W cm}^{-2})$. ($\omega = .117\text{eV}$)

$J_0 = 5 \times 10^7 \text{ W/cm}^2$, 5.5% of the incident J_0 is reflected at $z = 2.4 \times 10^{-2} \text{ cm}$, while for $J_0 = 10^8 \text{ W/cm}^2$, 53% of J_0 is reflected at $z = 6.3 \times 10^{-3}$ -- according to our geometric optics treatment. Finally, for $J_0 \geq 5 \times 10^8 \text{ W/cm}^2$ the air shock at $z = z_1$ is overdense and no laser energy would be absorbed, indicating the inapplicability of our treatment.

Two principal effects are expected from plasma radiation:

1. The energy deposition term (Eq. 38) of our LSD wave model must be generalized to include energy transport within the "Interaction" region by plasma thermal radiation.
2. The ambient atmosphere ahead of the shock may be strongly disturbed by plasma radiation from the "interaction" region.

To estimate the contribution of plasma radiation in the "interaction" region, we plot in Fig. 21 - 26 the quantity Q vs. $z/z(T_{\text{max}})$ for various laser intensities, $J_0 (\text{W/cm}^2)$ and $\omega = 1.79 \text{ eV}$. Q is the ratio of the energy deposited locally by the thermal radiation (Eq. 49) to the energy deposited at the same point by the laser radiation, and $z(T_{\text{max}})$ is plotted in Fig. 18. Q is positive (+) if the region is absorbing thermal radiation and negative (-) if the net thermal transport results in emission by the given region. Near the shock front there is a region of net emission due to radiation lost into the ambient air ahead of the shock. Moving inward from the shock front there is a region of net emission up to $z = z(T_{\text{max}})$ where Q may become non-negligible and tend to flatten the temperature gradient ahead of T_{max} . Finally, for larger z ($z \gg z_{T_{\text{max}}}$), net absorption generally dominates, and since the laser energy deposited goes to

Figure 21: Q vs. (z/z_{Tmax})

for $J_0 = 5 \times 10^7 \text{ W/cm}^2$,
 $\omega = 1.79 \text{ eV}$ (see text).

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Figure 22: Q vs. (z/z_{Tmax}) for

$$J_0 = 10^8 \text{ W/cm}^2,$$

$$\alpha = 1.79 \text{ eV (see text).}$$

Figure 23: Q vs. (z/z_{Tmax}) for

$$J_0 = 5 \times 10^8 \text{ W/cm}^2,$$

$$\omega = 1.79 \text{ eV (see text).}$$

Figure 24: Q vs. (z/z_{Tmax}) for

$$J_0 = 10^9 \text{ W/cm}^2,$$

$$\omega = 1.79 \text{ eV (see text).}$$

zero, Q increases in magnitude without bound. As the laser intensity increases, the "Interaction" region becomes transparent to its own thermal radiation and radiates as a whole (from all $z > z_{Tmax}$) into the ambient atmosphere. That is, the negative phase around $z = z_{Tmax}$ extends into the piston region.

To estimate the error we make by neglect of thermal radiation transport, Table IX is useful.

TABLE IX

$J_0 = 5 \times 10^7 \text{ W/cm}^2$,	$Q_{max} = 0.9\%$
10^8	1.7%
5×10^8	10%
10^9	12%
5×10^9	30%
10^{10}	100%

Thus, for laser intensities greater than $5 \times 10^8 \text{ W/cm}^2$ and $\omega = 1.79 \text{ eV}$, the thermal reradiation contributes more than ten percent to the radiation source (Eq. 38) and rapidly becomes the dominant energy source with increasing energy.

The corresponding results for $\omega = 1.17 \text{ eV}$ are essentially the same as we have given for $\omega = 1.79 \text{ eV}$. For $\omega = 0.117 \text{ eV}$ -- the CO_2 gas laser -- the corresponding results are plotted in Figs. 27 and 28, where $z_{Tmax} = 6.31 \times 10^{-3} \text{ cm}$ is the point of total reflection for $J_0 = 10^8 \text{ W/cm}^2$.

Figure 27: Q vs. (z/z_{Tmax}) for

$$J_0 = 2 \times 10^7 \text{ W/cm}^2,$$

$$\omega = .117 \text{ eV (see text).}$$

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Figure 28: Q vs. (z/z_{Tmax}) for

$$J_0 = 10^8 \text{ W/cm}^2,$$

$$\omega = .117 \text{ eV (see text).}$$

Critical Reflectivity

(1)

1.0

 (z/z_{Tmax})

0.1

 10^{-1} Q 10^{-2} 10^{-3}

Our results for the radiative precursor effects are summarized in Figure 29, in which we plot the electron number density and the optical depth to the laser radiation induced in the ambient atmosphere by the plasma radiation. Our results are for the laser energy $\omega = 1.79\text{eV}$ ($\lambda = 0.69\mu$), the results for $\omega = 1.17\text{eV}$ being similar but slightly higher. For $\omega = 1.17\text{eV}$ the total reflection by the shock front for $J_0 \geq 5 \times 10^8 \text{W/cm}^2$ limits our considerations to intensities where precursor effects are small.

In Figure 29, two curves are given for the electron density, corresponding to distances $X = .01$ and $X = .02\text{cm}$ ahead of the shock front. The non-LTE electron contribution dominates both curves except for $X = .01\text{cm}$ and $J_0 \geq 5 \times 10^9$, for which the thermal electrons dominate. If the electron concentration in the radiative precursor is sufficiently great as to absorb a significant fraction of the laser energy our postulated hydrodynamic mechanism for LSD wave propagation isn't necessary and a radiative propagation mode may arise. Two competing effects enter --

1. Energy is removed from the "Interaction" region and preheats the ambient air -- both resulting in slowing the shock speed.
2. The preionized ambient air begins to break down under the laser radiation before it encounters the shock, so there is a breakdown wave moving ahead of the hydrodynamic shock.

We have estimated all these effects only in an uncoupled approximation, in that we ignored plasma radiation in calculating the plasma state in the "Interaction" region, and then considered the radiation from

Figure 29: The Radiative Precursor -3
 electron number density n_e (cm^{-3})
 and laser optical depth τ as function
 of J (for $\omega = 1.79\text{eV}$). The
 numbers in parentheses are the
 laser intensities necessary to
 provide the same electron concen-
 tration at the shock front.

that given plasma state. A realistic estimate of radiative modifications to the Raizer shock speed relation requires a coupled calculation, including calculation of the air breakdown rate in the precursor region similar to that of Kroll and Watson (Ref. 13) but including the important role of exciting and ionizing thermal radiation from the plasma -- a calculation outside the scope of this study. In any case, our results indicate that neglect of plasma thermal radiation will lead to incorrect results for laser intensities greater than $5 \times 10^8 \text{ W/cm}^2$ at $\omega = 1.17 \text{ eV}$.

6.2 RESULTS OF NON-EQUILIBRIUM PLASMA MODEL

Deviations from the equilibrium results of the preceding section are significant only at the higher laser intensities. We list below the maximum temperature differences, $\Delta = T_e - T_A (^{\circ}\text{K})$, and the corresponding optical depth $\tau(\Delta_{\text{max}})$ for various laser intensities and $\omega = 1.79 \text{ eV}$.

TABLE X

$J_0 = 5 \times 10^7 \text{ W/cm}^2$	$\Delta_{\text{max}} \leq 1^{\circ}\text{K}$	
10^8	$= 4^{\circ}\text{K}$	$\tau(\Delta_{\text{max}}) = .56$
5×10^8	$= 139^{\circ}\text{K}$	$= .40$
10^9	$= 740^{\circ}\text{K}$	$= .09$
	$= 370^{\circ}\text{K}$	$= .43$
5×10^9	$= 6430^{\circ}\text{K}$	$= .28$
	$= 3215^{\circ}\text{K}$	$= .47$
10^{10}	$= 16,400^{\circ}\text{K}$	$= .49$

The total optical depth to laser radiation of the radiative precursor is increased slightly at the higher intensities:

	<u>Equilibrium</u>	<u>Non-Equilibrium</u>
$J_0 = 10^9$	$\tau = 1.69 \times 10^{-5}$	$\tau = 1.77 \times 10^{-5}$
5×10^9	.175	.182
10^{10}	2.32	2.34

Results for $\omega = 1.17\text{eV}$ are very similar. For $\omega = .117\text{eV}$ the onset of total reflection at the shock front for $J_0 > 5 \times 10^8 \text{W/cm}^2$ limits our theoretical model to the lower intensities at which non-equilibrium effects are of minor importance.

This result is contrary to that obtained by the LASNEX code of Lawrence Livermore Laboratory (Ref. 23). They find it is impossible to maintain an LSD wave in air with 10.6μ radiation at intensities less than 10^8W/cm^2 unless a special non-equilibrium two-temperature model is assumed -- as described in Section 4.2B above. We obtain (one-dimensional) propagation at intensities down to 10^7W/cm^2 and no dependence on two-temperature assumptions.

Our assumption of a strong shock with no precursor for determination of the hydrodynamics vs. the LLL Lagrangian hydrodynamics calculations with artificial viscosity may play a role in this discrepancy. More likely, however, the difference resides in the choice of cooling rates, our choice of which is described in detail in Section 4.2A above.

We consider in detail the case:

$$J_0 = 10^7 \text{W/cm}^2$$

$$\omega = .117\text{eV} \quad (\lambda = 10.6\mu)$$

For this case, $T_1 = 4869^\circ\text{K}$, $(\rho/p_0) = 9.1$, $n_e = 1.5 \times 10^{15} \text{ cm}^{-3}$, and $\mu(z_1) = .03 \text{ cm}^{-1}$. With equilibrium concentrations and the results of Table III, we obtain the cooling rates t_c^{-1}

Translational (neutral):	$6.18 \times 10^8 \text{ sec}^{-1}$
Translational (ions):	$1.90 \times 10^7 \text{ sec}^{-1}$
Rotational:	$8.71 \times 10^8 \text{ sec}^{-1}$
Vibrational:	$1.26 \times 10^{11} \text{ sec}^{-1}$

so the electron cooling by vibrational excitation of N_2 molecules dominates (by three orders of magnitude). The electron heating rate is

$$\frac{dU_e}{dt} = J_0 \mu e^{-\tau}.$$

If $\Delta \equiv T_e - T_A$, it varies with time as

$$\frac{d\Delta}{dt} = \frac{J_0 \mu}{c_v} e^{-\tau(t)} - \frac{\Delta}{t_c}$$

or

$$\Delta(t) = J_0 e^{-t/t_c} \int_0^t e^{t'/t_c} \frac{\mu(t')}{c_v(t')} e^{-\frac{Dt'}{2z_{1/2}}} dt',$$

where we are following an air parcel as it moves in time through the "Interaction" region. $\mu(t')$ is the laser absorption coefficient at $z(t')$, c_v the electron specific heat, D the shock speed ($3.9 \times 10^5 \text{ cm/sec}$) and we have arbitrarily assumed the optical depth, $\tau(t')$, increases linearly with time, ($z_{1/2} = 2.3$ being from Fig. 14).

An upper bound on Δ may be achieved by assuming

$$c_v = \frac{3}{2} n_e k = 0.31 \left(\frac{\text{erg}}{\text{cm}^3 \text{ } ^\circ\text{K}} \right).$$

Observing that μ increases approximately linearly with n_e , the ratio μ/c_v should be roughly constant for small optical depth. In fact, we find

$$\begin{array}{lll} \tau = .02, & T = 5000^\circ\text{K}, & \mu/n_e = 2.0 \times 10^{-17} \\ & = .17, & = 6000, & = 2.5 \times 10^{-17} \\ & = .81, & = 8000, & = 2.7 \times 10^{-17} \end{array}$$

Assuming μ/c_v constant, our result for $\Delta(t)$ becomes

$$\begin{aligned} \Delta(t) &\approx \frac{J_0 \mu t}{c_v} \left[e^{-\left(\frac{Dt}{2z_{1/2}}\right)} - e^{-t/t_c} \right] \\ &= 74.0(^{\circ}\text{K}) \left[e^{-8.5 \times 10^4 t} - e^{-1.3 \times 10^{11} t} \right] \end{aligned}$$

so the expected temperature increase appears to be negligible. In fact, as the temperature increases c_v increases more rapidly with temperature as the electrons excite internal degrees of freedom of the gas, including the important N_2 vibrational states and further ionization -- approaching thermal equilibrium values $c_v \sim 10^5 \text{ erg cm}^{-3} (^{\circ}\text{K})$. Thus, our above result for $\Delta(t)$ appears to truly overestimate the actual temperature difference, our computer code given results $\Delta(t) \lesssim 1^{\circ}\text{K}$.

7.0 ACKNOWLEDGEMENTS

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3.0 BEAM RESEARCH STUDIES

Near the conclusion of the contractual period during which the bulk of our laser studies were performed, some studies were initiated into the time for ionizational relaxation of air subject to varying energy deposition loads -- at the request of the Lawrence Livermore Laboratory. The short time spent on this additional task during the contract period herein reported allowed us only to start the program. We discuss our approach here.

The general chemistry computer code ALCHEM (Ref. 41) is being adapted to treat the problem of interest. In its original form it was a one-temperature calculation. It is being generalized to allow for differences in electron and heavy particle temperatures and for effects due to an applied electric field. These modifications are non-trivial.

The set of reaction rates we are employing for the problem of interest are from the D-region set of Scheibe (Ref. 42). We have extended this set with the fast reaction set of Ali (Ref. 28). The electron cooling rates are those of 4.2-A above. The code is particularly useful and flexible due to its particularly general input-output features and its analysis at every major time step of the principal reactions responsible for each specie.

Starting conditions are taken from Gilmore (Ref. 43) -- reproduced here as particles per ion pair --

N_2^+	.62
O_2^+	.16
N^+	.18
O^+	.04
$N(^4S)$	.45
$N(^2D+^2P)$	.61
$O(^3P)$	.2
$O(^1D)$	.1
$N_2(A^3\Sigma)$	.5
$O_2(a^1\Delta)$	.4
$O_2(b^1\Sigma)$	.1

and the number of ion pairs is obtained by dividing the energy deposited (in eV) by 33.73.

In the absence of an electric field the electrons cool rapidly to ambient temperature. Some results from the unmodified ALCHEM code -- single temperature, no electric field, and Scheibe's D-region reaction set -- are presented in Fig. 30 for two values of the instantaneous energy deposition --

1. $Q = 1.1 \times 10^7 \text{ erg/cm}^3$, $n_e(0) = 2 \times 10^{17} \text{ cm}^{-3}$, $T = 1410^\circ \text{K}$
2. $Q = 3.7 \times 10^6 \text{ erg/cm}^3$, $n_e(0) = 7 \times 10^{16} \text{ cm}^{-3}$, $T = 690^\circ \text{K}$.

At both values of Q the electron concentration is seen to have fallen by five orders of magnitude from its initial value within a microsecond.

Work toward the appropriate modifications of the code to more adequately address the problem of present interest is underway and will be reported as completed.

Figure 30: Fractional electron density as function of time(sec).

Appendix A.

An Effective "Ionization Potential" for Air

For air in thermal equilibrium, the state of ionization is obtained by solving the set of Saha relations (Ref. 18, Eq. 6-29)

$$\frac{n_e N(Z)}{N(Z-1)} = 2 \frac{P(T, Z)}{P(T, Z-1)} \left(\frac{MkT}{2\pi\hbar^2} \right)^{3/2} \exp\{-[I(Z-1) - \Delta I(n_e, T)]/kT\}. \quad (A-1)$$

This set is solved for all charge states Z subject to the constraint that the sum over Z of $N(Z)$ be the total atom number density. $P(T, Z)$ is the partition function for charge state Z at temperature T , and $I(Z)$ is the (vacuum) ionization energy of charge state Z .

The quantity ΔI represents the "lowering of the ionization potential" due to plasma interactions, a simplified discussion of which is given by Griem (Ref. 18). We employ a more general theory appropriate to high as well as low densities and temperatures (Ref. 10).

The major complication in the above set of equations is the presence of the partition functions. Extensive tabulations exist (for example, in Ref. 3), but many applications simply employ the low density approximation

$$P(T, Z) \approx g(Z), \quad (A-2)$$

where $g(Z)$ is the statistical weight of the ground state, and ΔI is ignored.

For greater accuracy and ease of interpolation we have chosen similarly to represent the Saha relations as

$$\left. \begin{aligned} \frac{n_e N(Z)}{N(Z-1)} &= 2 \frac{g(Z)}{g(Z-1)} \left(\frac{MkT}{2\pi\hbar^2} \right)^{3/2} e^{-\tilde{I}(Z-1)/kT} \\ &= 3.0 \times 10^{23} (\text{cm}^{-3}) \frac{g(Z)}{g(Z-1)} \left(\frac{T}{\text{Ryd}} \right)^{3/2} e^{-\tilde{I}/kT} \end{aligned} \right\} \quad (\text{A-3})$$

the temperature (T) and density (ρ) variations of the partition functions and ΔI 's being lumped into an effective ionization potential $\tilde{I}(Z, T, \rho/\rho_0)$.

From our detailed evaluations of Eq. A-1 we have so deduced values of $\tilde{I}$, results for which are in Table A-1. The statistical weights we employed are for atomic nitrogen.

Z = 0	g(Z) = 4
1	9
2	6
3	1
4	2
5	1
6	2

(No entries are given for temperatures, densities which result in negligible occupation. Further, these results are for (Nitrogen + Oxygen) air only; the omission of Argon results in errors at the higher temperatures and lower densities).

Table A-1 - The Effective Ionization Potential for Air.

A-3

 $\bar{I}(Z=0) \text{ (eV)}$ ($g_0 = 4$)

ρ/ρ_0 T(eV)	10	1	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	T(°K)
.3447	11.31	11.25	11.34	11.61	11.97	12.36	12.72	4000
.43085	11.60	11.69	12.05	12.51	13.02	13.55	14.08	5000
.517	12.11	12.39	12.92	13.51	14.09	14.43	14.52	6000
.6032	12.66	13.12	13.76	14.31	14.50	14.53	14.57	7000
.6894	13.27	13.84	14.38	14.56	14.58	14.58	14.62	8000
.7755	13.86	14.37	14.61	14.64	14.65	14.65	14.68	9000
.8617	14.33	14.65	14.72	14.72	14.72	14.73	14.73	10,000
.9479	14.64	14.79	14.81	14.81	14.81	14.82	14.85	11,000
1.034	14.84	14.90	14.90	14.90	14.91	14.92	14.85	12,000
1.5	15.32	15.24	15.27	15.37	15.41	15.62	15.26	
2.0	15.80	15.87	16.12	16.83	17.22	16.80	--	
3.0	17.10	18.24	19.54	21.98	22.83	--	--	
5.0	20.56	22.63	24.20	--	--	--	--	
10.0	--	--	--	--	--	--	--	

 $\bar{I}(Z=1) \text{ (eV)}$ ($g_1 = 9$)

T(eV)							
1.2					30.01	30.06	
1.5				30.20	30.23	30.19	30.19
2.		30.50	30.37	30.38	30.39	30.50	30.87
3.	30.94	30.63	30.68	30.89	31.07	31.13	31.25
5.	31.29	32.02	33.68	36.19	33.89	--	--
10.	32.12	39.81	--	--	--		
15.	--	--	--				

Table A-1 (con't)

 $\bar{I}(Z=2)$ (eV) ($g_2 = 6$)

$\rho/\rho_0 =$ T(eV)	10.	1	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}
2.0	--	--	--	--	--	--	47.54
3.0	--	--	48.36	47.04	47.15	47.23	47.43
5.0	48.32	45.22	45.37	45.76	46.02	46.23	46.45
10.0	43.46	45.16	49.19	48.35	--	--	--
15.0	42.53	46.15	27.15	--	--	--	--
20.0	26.91	31.37	--	--	--	--	--

 $\bar{I}(Z=3)$ (eV) ($g_3 = 1$)

T(eV)							
3.0	--	--	--	--	--	--	79.10
5.0	--	--	81.84	81.82	82.05	82.35	83.00
10.0	92.74	91.91	93.16	96.28	96.51	--	--
15.0	104.2	109.2	112.6	118.0	--	--	--
20.0	116.6	128.0	129.0	--	--	--	--

 $\bar{I}(Z=4)$ (eV) ($g_4 = 2$)

T(eV)							
5.0	--	--	--	--	--	122.6	118.7
10.0	--	106.2	106.5	107.2	108.1	107.4	106.1
15.0	114.2	115.0	118.6	125.4	135.6	134.9	104.3
20.0	125.7	128.9	142.2	161.0	176.8	175.4	--

 $\bar{I}(Z=5)$ (eV) ($g_5 = 1$)

T(eV)							
10.	--	--	178.9	176.0	179.2	182.3	200.6
15.	--	195.3	197.2	211.5	240.8	274.5	309.0
20.	215.2	220.7	243.4	283.5	328.8	374.6	420.6

Appendix B. Thermodynamic Properties of Air

We collect in this appendix tables of various thermodynamic properties of air useful to the study of laser interaction and propagation problems. We include

Table B-I The quantity Z (moles per mole of cold air) defined:

$$p/\rho = Z(T, \rho/\rho_0) \hat{R}T \text{ (erg/gm)}$$

where

$$\hat{R} = 2.872 \times 10^6 \text{ (erg/gm } ^\circ\text{K)} .$$

Values of the relative density (ρ/ρ_0) head each page, ρ_0 being $1.293 \times 10^{-3} \text{ gm/cm}^3$. The temperature range is $180 - 8 \times 10^6 \text{ (}^\circ\text{K)}$ and densities from 10 to 10^{-7} normal.

Table B-II The dimensionless quantity $(\gamma - 1)$ for air, defined

$$\epsilon = \frac{1}{(\gamma - 1)} p/\rho \text{ (erg/gm).}$$

(For an ideal gas, γ is the adiabatic exponent.) The independent variables T and (ρ/ρ_0) correspond exactly to those of Table BI.

Table B-III Specie concentrations at the indicated temperatures (1000-232,000 $^\circ\text{K}$) and the density ratios $(\rho/\rho_0 = 10 - 10^{-6})$ listed at the head of each column.

For each specie two quantities are listed. The first, f_i , is most useful for density interpolation, and the second, $[N_i]$ is the specie number density (particles/cm³). The two quantities are related

$$[N_i] = 5.36 \times 10^{19} (\rho/\rho_0) f_i$$

Table B-IV The heats of formation, E_0 (eV), of the various species of interest.

Table B-V The (dimensionless) specific heats, $C(T)$, of the indicated species at the listed temperatures ($1000 - 10^6$ °K). Thus the internal energy per particle, ϵ , is given by

$$\epsilon = E_0 + C(T) kT,$$

where E_0 is from Table B IV and k is the Boltzman constant.

Table B-VI The partition functions $P(T)$ of the indicated species as functions of the temperature (°K).

Table B-VII Electron impact excitation and ionization rates (sec^{-1} per molecule). The temperatures are in eV. and the reactions are numbered as follows:

1. O: ($^3P \rightarrow ^1D$)	11. N_2 : ($X^1\Sigma \rightarrow A^3\Sigma$)
2. O: ($^3P \rightarrow ^1S$)	12. N_2 : ($X^1\Sigma \rightarrow B^3\pi$)
3. O: ($^1D \rightarrow ^1S$)	13. N_2 : ($X^1\Sigma \rightarrow C^3\pi$)
4. O: $2p^4(^3P) \rightarrow 2p^3 3s(^3S)$	14. N_2 : ($X^1\Sigma \rightarrow D^3\Sigma$)
5. O: Ionization	15. NO: Ionization
6. N: ($^4S \rightarrow ^2D$)	16. N_2 : Ionization
7. N: ($^4S \rightarrow ^2P$)	17. N_2^+ : ($X^2\Sigma \rightarrow B^2\Sigma$)
8. N: ($^2D \rightarrow ^2$)	18. O_2 : ($X^2\pi \rightarrow a^1\Delta$)
9. N: $2p^3(^4S) \rightarrow 2p^2 3s(^4P)$	19. O_2 : ($X^2\pi \rightarrow b^1\Sigma$)
10. N: Ionization	20. O_2 : Ionization

The data are from the compilation of Ali (Ref. 28), except for the NO ionization rate, for which the experimental data of Rapp and Englander - Golden were employed (Ref. 29).

Table B-I

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TABLES OF AIR DATA

Z=PV/RT

TEMP	1.00E+01	5.16E+00	1.00E+00	5.16E-01	1.00E-01	5.16E-02	1.00E-02
180.	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1000.	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1277.	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1500.	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1700.	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2000.	1.000	1.000	1.000	1.000	1.000	1.000	1.001
3000.	1.002	1.005	1.007	1.013	1.022	1.037	1.061
4000.	1.023	1.045	1.068	1.096	1.134	1.167	1.190
5000.	1.073	1.108	1.145	1.176	1.199	1.217	1.237
6000.	1.127	1.162	1.198	1.230	1.267	1.320	1.400
7000.	1.176	1.222	1.270	1.336	1.431	1.562	1.716
8000.	1.239	1.317	1.400	1.526	1.679	1.826	1.926
10000.	1.451	1.597	1.757	1.888	1.966	2.008	2.042
10500.	1.517	1.675	1.827	1.934	1.992	2.031	2.073
11000.	1.584	1.746	1.882	1.967	2.015	2.057	2.115
11500.	1.650	1.807	1.924	1.993	2.038	2.088	2.165
12000.	1.711	1.858	1.957	2.015	2.064	2.127	2.228
12500.	1.767	1.900	1.983	2.038	2.093	2.174	2.305
13000.	1.815	1.933	2.007	2.062	2.128	2.231	2.395
13500.	1.857	1.962	2.029	2.088	2.169	2.296	2.497
14000.	1.893	1.986	2.050	2.118	2.215	2.371	2.609
14500.	1.923	2.008	2.073	2.151	2.269	2.454	2.727
15000.	1.950	2.029	2.096	2.188	2.328	2.543	2.850
15500.	1.973	2.050	2.125	2.230	2.393	2.639	2.972
16000.	1.995	2.071	2.154	2.275	2.463	2.738	3.092
16500.	2.015	2.093	2.186	2.325	2.537	2.836	3.204
17000.	2.035	2.116	2.220	2.378	2.615	2.938	3.307
17500.	2.054	2.140	2.257	2.434	2.694	3.035	3.400
18000.	2.073	2.166	2.296	2.492	2.774	3.128	3.481
18500.	2.092	2.193	2.337	2.553	2.854	3.215	3.551
19000.	2.111	2.221	2.380	2.615	2.933	3.295	3.611
19500.	2.131	2.251	2.425	2.678	3.009	3.368	3.662
20000.	2.151	2.282	2.471	2.740	3.082	3.433	3.704
22000.	2.238	2.414	2.660	2.941	3.331	3.627	3.815
24000.	2.329	2.552	2.845	3.186	3.509	3.742	3.883
26000.	2.422	2.666	3.011	3.348	3.630	3.821	3.957
28000.	2.513	2.810	3.154	3.473	3.720	3.898	4.075
30000.	2.600	2.923	3.274	3.572	3.802	4.003	4.261
32000.	2.682	3.023	3.376	3.654	3.895	4.151	4.507
34000.	2.756	3.113	3.467	3.748	4.014	4.344	4.779
36000.	2.829	3.196	3.555	3.847	4.161	4.564	5.040
38000.	2.897	3.275	3.643	3.962	4.333	4.790	5.265
40000.	2.962	3.353	3.736	4.093	4.517	5.002	5.446
42000.	3.025	3.433	3.837	4.236	4.701	5.188	5.591
44000.	3.090	3.516	3.947	4.385	4.875	5.345	5.713
46000.	3.157	3.603	4.063	4.534	5.033	5.480	5.810
48000.	3.225	3.695	4.181	4.678	5.175	5.601	5.957
50000.	3.296	3.789	4.301	4.813	5.302	5.716	6.101
60000.	3.673	4.269	4.847	5.377	5.882	6.422	7.002
70000.	4.057	4.712	5.323	5.923	6.551	7.172	7.717

(Table B-I con't)

B-4

74/05/10.

TABLES OF A)M DATA

Z=PV/NY

TEMP	1.00E+01	3.16E+00	1.00E+00	3.16E-01	1.00E-01	3.16E-02	1.00E-02
80000.	4.425	5.133	5.807	6.491	7.163	7.789	8.418
90000.	4.778	5.546	6.280	7.008	7.717	8.429	9.133
100000.	5.119	5.942	6.721	7.497	8.276	9.041	9.743
150000.	6.638	7.674	8.664	9.623	10.500	11.210	11.710
200000.	7.884	9.019	10.040	10.900	11.520	11.930	12.150
300000.	9.559	10.540	11.270	11.750	12.040	12.200	12.290
400000.	10.450	11.260	11.690	12.000	12.190	12.330	12.480
500000.	10.460	11.550	11.960	12.260	12.640	13.120	13.620
600000.	11.340	11.920	12.460	13.050	13.630	14.190	14.790
800000.	12.390	13.220	14.010	14.780	15.420	15.860	16.140
1000000.	13.600	14.520	15.280	15.800	16.120	16.290	16.370
1500000.	15.410	15.690	16.150	16.290	16.350	16.390	16.410
2000000.	15.900	16.140	16.270	16.350	16.380	16.410	16.420
3000000.	16.160	16.260	16.350	16.390	16.410	16.420	16.430
4000000.	16.260	16.340	16.380	16.410	16.430	16.440	16.440
5000000.	16.320	16.360	16.410	16.430	16.440	16.440	16.450
6000000.	16.350	16.400	16.420	16.430	16.440	16.450	16.450
8000000.	16.390	16.420	16.430	16.440	16.440	16.450	16.450

(Table B-I con't)

74/05/10.

TABLES OF AIR DATA

Z=11/21

TEMP	3.16E-03	1.00E-03	1.00E-04	1.00E-05	1.00E-06	1.00E-07
180.	1.000	1.000	1.000	1.000	1.000	1.000
1000.	1.000	1.000	1.000	1.000	1.000	1.000
1277.	1.000	1.000	1.000	1.000	1.000	1.000
1500.	1.000	1.000	1.000	1.000	1.000	1.001
1700.	1.000	1.000	1.000	1.001	1.004	1.012
2000.	1.001	1.002	1.005	1.017	1.049	1.117
3000.	1.095	1.134	1.191	1.207	1.211	1.215
4000.	1.202	1.211	1.228	1.272	1.388	1.641
5000.	1.265	1.306	1.483	1.775	1.954	1.990
6000.	1.516	1.664	1.914	1.986	2.005	2.039
7000.	1.857	1.936	1.997	2.029	2.111	2.346
8000.	1.976	2.001	2.049	2.170	2.501	3.181
10000.	2.087	2.160	2.477	3.135	3.773	3.956
10500.	2.138	2.245	2.662	3.417	3.880	3.970
11000.	2.205	2.354	2.915	3.634	3.932	3.976
11500.	2.289	2.487	3.144	3.777	3.956	3.979
12000.	2.392	2.642	3.365	3.862	3.967	3.981
12500.	2.512	2.811	3.544	3.911	3.973	3.982
13000.	2.646	2.986	3.680	3.938	3.977	3.986
13500.	2.769	3.157	3.775	3.953	3.979	3.994
14000.	2.937	3.315	3.840	3.963	3.982	4.013
14500.	3.083	3.453	3.883	3.969	3.988	4.055
15000.	3.221	3.568	3.911	3.973	3.998	4.135
15500.	3.346	3.660	3.930	3.978	4.019	4.266
16000.	3.456	3.731	3.942	3.984	4.058	4.452
16500.	3.550	3.785	3.952	3.993	4.123	4.678
17000.	3.627	3.826	3.959	4.008	4.223	4.916
17500.	3.690	3.856	3.966	4.034	4.360	5.141
18000.	3.740	3.880	3.974	4.074	4.531	5.337
18500.	3.780	3.898	3.984	4.135	4.722	5.502
19000.	3.812	3.912	3.994	4.218	4.919	5.636
19500.	3.838	3.924	4.019	4.320	5.108	5.740
20000.	3.859	3.935	4.048	4.457	5.280	5.817
22000.	3.918	3.990	4.293	5.076	5.745	5.951
24000.	3.985	4.118	4.744	5.568	5.917	6.023
26000.	4.113	4.374	5.225	5.822	5.994	6.261
28000.	4.338	4.734	5.579	5.934	6.136	6.802
30000.	4.641	5.144	5.764	6.028	6.486	7.369
32000.	4.963	5.409	5.901	6.205	6.986	7.726
34000.	5.250	5.624	6.005	6.526	7.431	7.896
36000.	5.474	5.770	6.156	6.937	7.718	8.002
38000.	5.639	5.863	6.343	7.316	7.800	8.174
40000.	5.766	6.002	6.704	7.601	7.999	8.509
42000.	5.881	6.155	7.031	7.788	8.166	8.960
44000.	6.008	6.356	7.323	7.925	8.439	9.372
46000.	6.163	6.595	7.553	8.065	8.802	9.671
48000.	6.351	6.869	7.728	8.257	9.172	9.880
50000.	6.562	7.092	7.871	8.517	9.481	10.070
60000.	7.519	7.922	8.863	9.862	10.580	11.490
70000.	8.234	8.810	9.856	10.820	11.670	11.970

(Table B-I con't)

B-6

74/05/10.

TABLES OF AIR DATA

Z=00/WT

TEMP	3.16E-03	1.00E-03	1.00E-04	1.00E-05	1.00E-06	1.00E-07
80000.	9.067	9.550	10.730	11.660	12.010	12.270
90000.	9.765	10.370	11.480	11.980	12.260	12.380
100000.	10.420	11.060	11.850	12.210	12.360	12.390
150000.	12.050	12.220	12.350	12.380	12.390	12.390
200000.	12.270	12.330	12.370	12.390	12.390	12.400
300000.	12.540	12.370	12.440	12.760	13.570	14.050
400000.	12.730	13.140	13.940	14.730	15.680	16.020
500000.	14.050	14.540	15.600	16.060	16.330	16.420
600000.	15.380	15.790	16.210	16.400	16.430	16.430
800000.	16.300	16.380	16.420	16.450	16.430	16.430
1000000.	16.400	16.420	16.430	16.450	16.430	16.430
1500000.	16.420	16.420	16.430	16.450	16.430	16.430
2000000.	16.430	16.430	16.430	16.450	16.430	16.430
3000000.	16.440	16.440	16.450	16.450	16.450	16.450
4000000.	16.450	16.450	16.450	16.450	16.450	16.450
5000000.	16.450	16.450	16.450	16.450	16.450	16.450
6000000.	16.450	16.450	16.450	16.450	16.450	16.450
8000000.	16.450	16.450	16.450	16.450	16.450	16.450

(Table B-II)

74/05/10.

TABLES OF AIR DATA

(GAP-A-1) FIVE

TEMP	1.00E+01	3.16E+00	1.00E+00	3.16E-01	1.00E-01	3.16E-02	1.00E-02
180.	.400	.400	.400	.400	.400	.400	.400
1000.	.380	.380	.380	.380	.380	.380	.380
1277.	.367	.367	.367	.367	.367	.367	.367
1500.	.356	.356	.356	.356	.356	.356	.356
1700.	.348	.348	.348	.348	.348	.348	.348
2000.	.338	.338	.338	.338	.338	.338	.338
3000.	.304	.300	.297	.289	.278	.261	.240
4000.	.269	.257	.245	.228	.213	.203	.197
5000.	.245	.234	.223	.215	.209	.202	.194
6000.	.235	.226	.218	.208	.194	.177	.157
7000.	.229	.216	.203	.184	.164	.144	.129
8000.	.218	.199	.181	.161	.144	.133	.127
10000.	.189	.171	.157	.148	.144	.141	.138
10500.	.184	.168	.156	.150	.146	.143	.139
11000.	.180	.166	.157	.152	.149	.145	.140
11500.	.176	.166	.158	.154	.151	.146	.140
12000.	.176	.166	.160	.156	.152	.146	.139
12500.	.175	.167	.162	.158	.153	.146	.137
13000.	.175	.168	.164	.159	.154	.146	.136
13500.	.176	.170	.165	.160	.154	.144	.134
14000.	.177	.171	.167	.161	.153	.143	.132
14500.	.178	.173	.168	.161	.152	.142	.131
15000.	.179	.174	.168	.161	.152	.141	.130
15500.	.180	.175	.168	.160	.151	.140	.130
16000.	.181	.175	.169	.160	.150	.139	.130
16500.	.181	.176	.168	.159	.149	.139	.131
17000.	.182	.176	.168	.159	.148	.139	.131
17500.	.182	.176	.168	.158	.148	.139	.133
18000.	.183	.176	.167	.157	.148	.139	.134
18500.	.183	.176	.167	.157	.146	.140	.136
19000.	.182	.175	.166	.157	.146	.141	.137
19500.	.182	.175	.166	.157	.148	.143	.139
20000.	.181	.175	.166	.157	.149	.144	.141
22000.	.179	.173	.166	.159	.154	.151	.150
24000.	.177	.173	.168	.163	.160	.159	.158
26000.	.177	.175	.171	.169	.168	.167	.164
28000.	.178	.177	.176	.175	.174	.172	.167
30000.	.180	.181	.182	.181	.180	.175	.165
32000.	.183	.186	.187	.186	.183	.174	.161
34000.	.187	.190	.192	.190	.183	.172	.159
36000.	.190	.194	.195	.191	.182	.169	.157
38000.	.194	.197	.197	.191	.180	.167	.157
40000.	.196	.200	.198	.190	.178	.167	.159
42000.	.199	.201	.198	.188	.177	.168	.161
44000.	.200	.202	.197	.187	.177	.169	.163
46000.	.201	.202	.196	.187	.178	.171	.165
48000.	.202	.202	.196	.187	.179	.173	.166
50000.	.203	.202	.195	.187	.180	.174	.166
60000.	.204	.203	.198	.192	.184	.174	.163
70000.	.207	.207	.202	.193	.183	.174	.166

(Table B-II con't)

74/05/10.

TABLES OF AIR DATA

(GAPPA-1) = PVZE

TEMP	1.00E+01	5.16E+00	1.00E+00	5.16E+01	1.00E+01	5.16E+02	1.00E+02
80000.	.210	.209	.202	.194	.185	.176	.166
90000.	.212	.210	.204	.196	.186	.176	.167
100000.	.214	.212	.206	.197	.187	.178	.169
150000.	.228	.225	.218	.210	.202	.197	.193
200000.	.248	.245	.239	.234	.231	.229	.229
300000.	.299	.296	.294	.293	.293	.293	.293
400000.	.347	.343	.341	.340	.338	.333	.321
500000.	.383	.377	.370	.356	.330	.295	.265
600000.	.401	.383	.354	.318	.287	.261	.237
800000.	.467	.332	.301	.274	.255	.244	.236
1000000.	.535	.308	.288	.276	.269	.266	.264
1500000.	.641	.535	.332	.331	.331	.331	.330
2000000.	.681	.380	.379	.378	.378	.378	.378
3000000.	.444	.443	.443	.442	.442	.441	.441
4000000.	.484	.483	.482	.481	.480	.480	.480
5000000.	.511	.510	.509	.508	.508	.508	.508
6000000.	.531	.530	.529	.529	.529	.529	.529
8000000.	.559	.558	.558	.558	.558	.558	.558

(Table B-II con't)

74/05/10.

TABLES OF AIR DATA

(GEOMET) = P/77

TEMP	3.16E-03	1.00E-03	1.00E-04	1.00E-05	1.00E-06	1.00E-07
180.	.400	.400	.400	.400	.400	.400
1000.	.360	.360	.360	.360	.360	.360
1277.	.367	.367	.367	.363	.360	.360
1500.	.356	.356	.356	.355	.354	.350
1700.	.348	.347	.346	.343	.333	.306
2000.	.334	.333	.322	.294	.238	.174
3000.	.216	.195	.175	.168	.165	.164
4000.	.193	.190	.181	.159	.123	.100
5000.	.181	.165	.125	.096	.087	.085
6000.	.136	.120	.103	.099	.098	.095
7000.	.119	.114	.111	.108	.102	.088
8000.	.124	.122	.118	.108	.091	.075
10000.	.134	.128	.110	.091	.082	.081
10500.	.134	.126	.106	.090	.085	.084
11000.	.133	.125	.103	.091	.088	.087
11500.	.131	.121	.102	.095	.091	.091
12000.	.129	.118	.101	.095	.094	.094
12500.	.127	.116	.102	.098	.097	.097
13000.	.125	.115	.103	.101	.100	.100
13500.	.123	.114	.105	.104	.103	.103
14000.	.122	.115	.108	.107	.106	.105
14500.	.122	.115	.110	.110	.109	.106
15000.	.122	.117	.113	.113	.112	.106
15500.	.123	.118	.116	.115	.114	.104
16000.	.124	.120	.119	.118	.115	.100
16500.	.125	.123	.121	.121	.115	.097
17000.	.127	.125	.124	.123	.113	.094
17500.	.129	.128	.127	.124	.111	.092
18000.	.131	.130	.129	.125	.108	.091
18500.	.133	.133	.132	.125	.105	.090
19000.	.136	.135	.134	.124	.103	.091
19500.	.136	.136	.135	.122	.101	.091
20000.	.141	.140	.136	.120	.100	.092
22000.	.149	.148	.135	.112	.100	.096
24000.	.156	.151	.126	.111	.105	.103
26000.	.158	.147	.124	.114	.111	.104
28000.	.156	.142	.124	.118	.114	.099
30000.	.152	.139	.127	.123	.111	.096
32000.	.149	.139	.131	.124	.107	.097
34000.	.148	.141	.135	.121	.105	.099
36000.	.144	.144	.136	.118	.106	.102
38000.	.151	.147	.135	.116	.109	.103
40000.	.154	.149	.132	.117	.111	.102
42000.	.156	.150	.130	.118	.112	.099
44000.	.158	.149	.130	.120	.111	.098
46000.	.158	.147	.130	.122	.109	.098
48000.	.157	.146	.131	.122	.107	.097
50000.	.156	.145	.133	.121	.107	.100
60000.	.155	.142	.132	.119	.109	.100
70000.	.157	.148	.133	.121	.111	.108

(Table B-II con't)

74/05/10.

TABLES OF AIR DATA

(GAMMA=1)=Pv/ρ

TEMP	5.16E-03	1.00E-03	1.00E-04	1.00E-05	1.00E-06	1.00E-07
80000.	.157	.184	.135	.124	.120	.117
90000.	.154	.151	.138	.133	.129	.127
100000.	.161	.153	.145	.141	.138	.138
150000.	.190	.184	.168	.168	.168	.166
200000.	.229	.229	.229	.229	.229	.228
300000.	.292	.292	.286	.252	.196	.174
400000.	.297	.264	.218	.184	.156	.149
500000.	.243	.222	.186	.174	.167	.165
600000.	.217	.206	.194	.189	.188	.188
800000.	.232	.230	.229	.229	.229	.229
1000000.	.264	.264	.264	.264	.264	.264
1500000.	.330	.330	.330	.330	.330	.330
2000000.	.376	.378	.376	.378	.377	.375
3000000.	.440	.439	.438	.438	.438	.438
4000000.	.479	.479	.479	.479	.479	.479
5000000.	.508	.508	.508	.508	.508	.508
6000000.	.529	.529	.529	.529	.529	.529
8000000.	.558	.558	.558	.558	.558	.558

Table B-III

74/05/10.

TABLES OF AIR DATA

SPECIE CONCENTRATION FRACTIONS			TEMP= 1000. (DEG.K)			
N	SPECIE	1.000E+01	1.000E+00	3.160E-01	1.000E-01	1.000E-02
2	N2	3.922E-01	3.922E-01	3.922E-01	3.922E-01	3.922E-01
		2.10E+20	2.10E+19	6.64E+18	2.10E+18	2.10E+17
4	O2	1.740E-05	1.740E-05	1.740E-05	1.740E-05	1.740E-05
		9.33E+15	9.33E+14	2.95E+14	9.33E+13	9.33E+12
6	O2	1.052E-01	1.052E-01	1.052E-01	1.052E-01	1.052E-01
		5.64E+19	5.64E+18	1.78E+18	5.64E+17	5.64E+16
27	CO2	1.600E-04	1.600E-04	1.600E-04	1.600E-04	1.600E-04
		8.58E+16	8.58E+15	2.71E+15	8.58E+14	8.58E+13
28	NO2	5.570E-06	1.760E-06	9.901E-07	5.570E-07	1.760E-07
		2.99E+15	9.43E+13	1.68E+13	2.99E+12	9.43E+10

(Table B-III con't)

B-12

74/05/10.

TABLES OF AIR DATA

SPECIE CONCENTRATION FRACTIONS		TEMP= 1000. (DEG.K)			
N	SPECIE	1.000E-03	1.000E-04	1.000E-05	1.000E-06
2	N2	3.922E-01	3.922E-01	3.922E-01	3.922E-01
		2.10E+10	2.10E+15	2.10E+14	2.10E+13
4	NO	1.740E-05	1.740E-05	1.740E-05	1.740E-05
		9.33E+11	9.33E+10	9.33E+09	9.33E+08
6	O2	1.052E-01	1.052E-01	1.052E-01	1.052E-01
		5.64E+15	5.64E+14	5.64E+13	5.64E+12
27	CO2	1.600E-04	1.600E-04	1.600E-04	1.600E-04
		8.58E+12	8.58E+11	8.58E+10	8.58E+09
28	NO2	5.570E-08	1.760E-08	5.570E-09	1.760E-09
		2.99E+09	9.43E+07	2.99E+06	9.43E+04

(Table B-III con't)

74/05/10.

TABLES OF AIR DATA

SPECIE CONCENTRATION FRACTIONS			TEMP= 2000. (DEG.K)			
N	SPECIE	1.000E+01	1.000E+00	3.160E-01	1.000E-01	1.000E-02
2	N2	5.902E-01	5.902E-01	3.902E-01	3.902E-01	3.902E-01
		2.09E+20	2.09E+19	6.61E+18	2.09E+18	2.09E+17
4	NO	3.990E-03	3.990E-03	3.990E-03	3.990E-03	3.990E-03
		2.14E+18	2.14E+17	6.76E+16	2.14E+16	2.14E+15
6	O2	1.031E-01	1.032E-01	1.031E-01	1.031E-01	1.030E-01
		5.53E+19	5.53E+18	1.75E+18	5.53E+17	5.52E+16
10	O	1.760E-05	5.580E-05	9.410E-05	1.760E-04	5.570E-04
		9.43E+15	2.99E+15	1.68E+15	9.43E+14	2.99E+14
27	CO2	1.600E-04	1.600E-04	1.600E-04	1.600E-04	1.580E-04
		8.58E+16	8.58E+15	2.71E+15	8.58E+14	8.47E+13
28	NO2	5.860E-05	1.860E-05	1.044E-05	5.860E-06	1.850E-06
		3.14E+16	9.97E+14	1.77E+14	3.14E+13	9.92E+11
30	CO	5.410E-06	1.710E-07	3.059E-07	5.400E-07	1.700E-06
		2.90E+13	9.17E+12	5.15E+12	2.89E+12	9.11E+11

(Table B-III con't)

74/05/10.

TABLES OF AIR DATA

SPECIE CONCENTRATION FRACTIONS		TEMP= 2000. (DEG.K)			
N	SPECIE	1.000E-03	1.000E-04	1.000E-05	1.000E-06
2	N2	5.902E-01 2.09E+16	5.902E-01 2.09E+15	3.903E-01 2.09E+14	5.904E-01 2.09E+13
4	NO	5.980E-03 2.13E+14	3.940E-03 2.11E+13	3.830E-03 2.05E+12	3.500E-03 1.88E+11
6	O2	1.023E-01 5.48E+15	1.005E-01 5.39E+14	9.490E-02 5.09E+13	7.910E-02 4.24E+12
10	O	1.760E-03 9.43E+13	5.500E-03 2.95E+13	1.690E-02 9.06E+12	4.880E-02 2.62E+12
27	CO2	1.550E-04 8.31E+12	1.440E-04 7.72E+11	1.180E-04 6.32E+10	7.200E-05 3.86E+09
28	NO2	5.820E-07 3.12E+10	1.810E-07 9.70E+08	5.400E-08 2.89E+07	1.420E-08 7.61E+05
30	CO	5.260E-06 2.82E+11	1.570E-05 8.42E+10	4.170E-05 2.24E+10	8.800E-05 4.72E+09

(Table B-III con't)

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TABLES OF AIR DATA

SPECIE CONCENTRATION FRACTIONS		TEMP= 5000. (DEG.K)				
N	SPECIE	1.000E+01	1.000E+00	5.160E-01	1.000E-01	1.000E-02
1	F=	5.646E-10	3.637E-09	7.879E-09	1.363E-08	4.261E-08
		3.03E+11	1.95E+11	1.53E+11	7.41E+10	2.28E+10
2	N2	3.807E-01	3.804E-01	3.811E-01	3.813E-01	3.826E-01
		2.04E+20	2.0E+19	6.45E+18	2.04E+18	2.05E+17
4	NO	2.290E-02	2.260E-02	2.215E-02	2.170E-02	1.920E-02
		1.23E+19	1.21E+18	3.75E+17	1.16E+17	1.03E+16
5	NO+	3.850E-09	5.930E-09	9.400E-09	1.490E-08	4.310E-08
		2.06E+12	3.18E+11	1.54E+11	7.99E+10	2.31E+10
6	O2	9.250E-02	9.030E-02	8.678E-02	8.340E-02	8.510E-02
		4.96E+19	4.84E+18	1.47E+18	4.47E+17	3.49E+16
8	N	5.770E-07	1.630E-06	3.249E-06	5.770E-06	1.830E-05
		3.09E+14	9.81E+13	5.50E+13	3.04E+13	9.81E+12
10	O	2.310E-03	7.210E-03	1.257E-02	2.190E-02	6.120E-02
		1.24E+16	3.86E+17	2.13E+17	1.17E+17	3.28E+16
27	CO2	1.460E-04	1.280E-04	1.060E-04	8.770E-05	4.050E-05
		7.93E+16	6.86E+15	1.79E+15	4.70E+14	2.17E+13
28	NO2	1.290E-04	3.470E-05	2.146E-05	1.160E-05	2.870E-06
		6.91E+16	2.13E+15	3.63E+14	6.22E+13	1.54E+12
30	CO	1.160E-05	3.200E-05	4.810E-05	7.250E-05	1.200E-04
		6.22E+15	1.72E+15	8.15E+14	3.88E+14	6.43E+13

(Table B-III con't)

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TABLES OF AIR DATA

SPECIE CONCENTRATION FRACTIONS		TEMP= 3000. (DEG.K)			
N	SPECIE	1.000E-03	1.000E-04	1.000E-05	1.000E-06
1	E-	1.128E-07 6.05E+09	2.410E-07 1.29E+09	4.450E-07 2.39E+08	7.970E-07 4.27E+07
2	N2	3.855E-01 2.07E+16	3.891E-01 2.09E+15	3.909E-01 2.10E+14	3.909E-01 2.10E+13
4	NO	1.340E-02 7.18E+14	6.070E-03 5.25E+13	2.080E-03 1.11E+12	6.660E-04 5.57E+10
5	NO+	1.130E-07 6.06E+09	2.410E-07 1.29E+09	4.450E-07 2.39E+08	7.970E-07 4.27E+07
6	O2	3.140E-02 1.68E+15	6.590E-03 3.43E+13	7.450E-04 3.99E+11	7.650E-05 4.10E+09
8	N	5.810E-05 3.11E+12	1.840E-04 9.86E+11	5.840E-04 3.13E+11	1.650E-03 9.92E+10
10	O	1.344E-01 7.20E+15	1.517E-01 1.03E+15	2.070E-01 1.11E+14	2.098E-01 1.12E+13
27	CO2	1.130E-05 6.06E+11	1.680E-06 9.00E+09	1.880E-07 1.01E+08	1.860E-08 9.97E+05
28	NO2	4.400E-07 2.36E+10	2.840E-08 1.52E+08	1.050E-09 5.63E+05	3.410E-11 1.83E+03
30	CO	1.490E-04 7.99E+12	1.580E-04 8.47E+11	1.600E-04 8.58E+10	1.600E-04 8.58E+09

(Table B-III con't)
TABLES OF AIR DATA

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SPECIE CONCENTRATION FRACTIONS

TEMP= 4000. (DEG.K)

N	SPECIE	1.000E+01	1.000E+00	5.160E-01	1.000E-01	1.000E-02
1	E-	1.142E-07	6.125E-07	1.069E-06	1.728E-06	3.707E-06
		7.13E+13	3.28E+13	1.81E+13	9.26E+12	1.49E+12
2	N2	3.081E-01	3.711E-01	3.743E-01	3.776E-01	3.848E-01
		1.97E+20	1.99E+19	6.54E+16	2.02E+18	2.06E+17
4	NO	4.790E-02	4.190E-02	3.458E-02	2.850E-02	1.280E-02
		2.57E+19	2.25E+18	5.85E+17	1.53E+17	6.86E+15
5	NO+	3.58E-07	7.370E-07	1.145E-06	1.780E-06	3.720E-06
		1.92E+14	3.95E+13	1.94E+13	9.54E+12	1.99E+12
6	O2	6.970E-02	5.290E-02	3.571E-02	2.410E-02	4.750E-03
		3.74E+19	2.84E+18	6.05E+17	1.29E+17	2.55E+15
8	N	6.260E-05	1.940E-04	3.555E-04	6.350E-04	2.030E-03
		3.36E+16	1.07E+16	6.02E+15	3.40E+15	1.09E+15
10	O	2.280E-02	6.280E-02	9.170E-02	1.349E-01	1.883E-01
		1.22E+19	3.37E+18	1.55E+18	7.18E+17	1.01E+17
27	CO2	7.630E-05	3.210E-05	1.015E-05	8.130E-06	1.190E-06
		4.09E+16	1.72E+15	2.74E+14	4.36E+13	6.38E+11
28	NO2	1.580E-04	3.810E-05	1.450E-05	5.520E-06	3.480E-07
		8.47E+16	2.04E+15	2.46E+14	2.96E+13	1.87E+11
29	O3	1.190E-06	2.440E-07	7.763E-08	2.420E-08	6.720E-10
		6.36E+14	1.33E+13	1.31E+12	1.30E+11	3.60E+08
30	CO	8.370E-05	1.280E-04	1.395E-04	1.520E-04	1.590E-04
		4.49E+16	6.86E+15	2.36E+15	8.15E+14	8.52E+13
32	C	1.680E-12	9.310E-12	2.196E-11	5.180E-11	3.660E-10
		9.00E+08	4.99E+08	3.72E+08	2.78E+08	2.07E+08

(Table B-III con't)
TABLES OF AIR DATA

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SPECIE CONCENTRATION FRACTIONS		TEMP= 4000, (DEG.K)			
N	SPECIE	1.000E-03	1.000E-04	1.000E-05	1.000E-06
1	E-	6.900E-06 3.78E+11	1.231E-05 6.60E+10	2.178E-05 1.17E+10	3.723E-05 2.00E+09
2	N2	3.866E-01 2.07E+10	3.014E-01 2.04E+15	3.610E-01 1.93E+14	3.024E-01 1.62E+13
4	NO	4.420E-03 2.37E+14	1.410E-03 7.56E+12	4.370E-04 2.54E+11	1.270E-04 6.81E+09
5	NO+	6.900E-06 3.78E+11	1.230E-05 6.59E+10	2.170E-05 1.16E+10	3.670E-05 1.97E+09
6	O2	5.640E-04 3.02E+13	5.860E-05 3.14E+11	5.920E-06 3.17E+09	5.940E-07 3.18E+07
8	N	6.420E-03 3.44E+14	2.020E-02 1.08E+14	6.210E-02 3.33E+13	1.794E-01 9.62E+12
10	O	2.050E-01 1.10E+16	2.090E-01 1.12E+15	2.101E-01 1.13E+14	2.104E-01 1.13E+13
27	CO2	1.310E-07 7.02E+09	1.340E-08 7.16E+07	1.340E-09 7.18E+05	1.320E-10 7.08E+03
28	NO2	1.310E-08 7.02E+08	4.270E-10 2.29E+06	1.330E-11 7.13E+03	3.660E-13 2.07E+01
29	O3	8.670E-12 4.65E+05	9.190E-14 4.93E+02	9.330E-16 5.00E-01	9.380E-18 5.03E-04
30	CO	1.600E-04 8.58E+12	1.600E-04 8.58E+11	1.600E-04 8.58E+10	1.570E-04 8.42E+09
32	C	3.570E-09 1.91E+02	3.500E-08 1.88E+08	3.480E-07 1.87E+08	3.400E-06 1.82E+08

(Table B-III con't)

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TABLES OF AIR DATA

SPECIE CONCENTRATION FRACTIONS		TEMP= 5000, (DEG.K)				
N	SPECIE	1.000E+01	1.000E+00	3.160E-01	1.000E-01	1.000E-02
1	E=	3.383E+06 1.81E+15	1.051E+05 5.53E+14	1.571E+05 2.06E+14	2.258E+05 1.21E+14	4.192E+05 2.25E+13
2	N2	3.616E+01 1.94E+20	3.715E+01 1.99E+19	3.751E+01 6.35E+18	3.768E+01 2.03E+18	3.728E+01 2.00E+17
3	N2+	2.030E+10 1.09E+11	6.670E+10 3.56E+10	1.454E+09 2.46E+10	3.170E+09 1.70E+10	1.680E+08 9.00E+09
4	NO	6.010E+02 3.22E+19	3.690E+02 2.04E+18	2.481E+02 4.20E+17	1.620E+02 8.68E+16	5.490E+03 2.94E+15
5	NO+	5.650E+06 3.05E+15	1.150E+05 6.16E+14	1.619E+05 2.74E+14	2.280E+05 1.22E+14	4.180E+05 2.24E+13
6	O2	3.910E+02 2.10E+19	1.520E+02 8.15E+17	6.400E+03 1.09E+17	2.700E+03 1.45E+16	3.160E+04 1.69E+14
8	N	1.040E+03 5.57E+17	3.320E+03 1.78E+17	5.932E+03 1.00E+17	1.060E+02 5.68E+16	3.350E+02 1.78E+16
9	N+	4.620E+12 2.48E+09	4.760E+11 2.55E+09	1.437E+10 3.11E+09	7.090E+10 3.80E+09	1.200E+08 6.43E+09
10	O	7.190E+02 3.85E+19	1.420E+01 7.61E+18	1.638E+01 2.77E+18	1.890E+01 1.01E+18	2.044E+01 1.10E+17
11	O+	5.750E+10 3.08E+11	3.650E+09 1.90E+11	9.102E+09 1.54E+11	2.270E+08 1.22E+11	1.320E+07 7.8E+10
26	O=	1.500E+06 8.04E+14	9.180E+07 4.92E+13	4.904E+07 8.31E+12	2.620E+07 1.40E+12	5.260E+08 2.82E+10
27	CO2	2.140E+05 1.15E+10	4.730E+06 2.54E+14	1.748E+06 2.96E+13	6.460E+07 3.46E+12	7.010E+08 3.76E+10
28	NO2	1.130E+04 6.06E+16	1.420E+05 7.61E+14	3.373E+06 5.71E+13	8.010E+07 4.29E+12	2.940E+08 1.58E+10
29	O3	1.290E+06 6.91E+14	9.960E+08 5.34E+12	1.530E+08 2.59E+11	2.350E+09 1.26E+10	2.970E+11 1.59E+07
30	CO	1.390E+04 7.45E+16	1.550E+04 8.31E+15	1.570E+04 2.66E+15	1.590E+04 8.52E+14	1.600E+04 8.58E+15
32	C	5.430E+10 2.91E+11	3.080E+09 1.65E+11	6.542E+09 1.45E+11	2.370E+08 1.27E+11	2.200E+07 1.18E+11
34	C+	1.450E+15 7.77E+05	2.640E+14 1.42E+06	1.584E+13 2.68E+06	9.500E+13 5.09E+06	4.750E+11 2.55E+07

(Table B-III con't)

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TABLES OF AIR DATA

SPECIE CONCEN (RATIO)		FRACTIONS		TEMP= 5000. (DEG.K)	
N	SPECIE	1.000E-03	1.000E-04	1.000E-05	1.000E-06
1	E-	7.546E-05	1.203E-04	2.147E-04	4.706E-04
		3.06E+12	6.77E+11	1.15E+11	2.52E+10
2	N2	3.404E-01	2.544E-01	1.485E-01	1.670E-02
		1.83E+16	1.36E+15	5.86E+13	1.00E+12
3	N2+	8.710E-06	3.820E-07	9.550E-07	7.520E-07
		4.67E+04	2.15E+09	5.12E+08	4.03E+07
4	NO	1.69E-03	4.600E-04	9.620E-05	1.270E-05
		9.06E+13	2.50E+12	5.16E+10	6.81E+08
5	NO+	7.29E-05	1.160E-04	1.433E-04	8.560E-05
		3.91E+12	6.52E+11	7.66E+10	4.59E+09
6	O2	3.290E-05	3.430E-06	3.350E-07	3.350E-08
		1.76E+12	1.78E+10	1.80E+08	1.80E+06
8	N	1.007E-01	2.751E-01	5.075E-01	7.466E-01
		5.40E+15	1.47E+15	3.04E+14	4.00E+13
9	N+	2.050E-07	3.290E-06	3.490E-05	2.390E-04
		1.10E+10	1.76E+10	2.14E+10	1.28E+10
10	O	2.087E-01	2.100E-01	2.104E-01	2.105E-01
		1.12E+16	1.13E+15	1.13E+14	1.13E+13
11	O+	7.640E-07	4.510E-06	2.660E-05	1.210E-04
		4.10E+10	2.42E+10	1.43E+10	6.49E+09
26	O-	9.490E-09	1.630E-09	2.770E-10	6.090E-11
		5.09E+08	8.74E+06	1.48E+05	3.26E+03
27	CO2	7.076E-04	6.360E-10	3.020E-11	4.270E-13
		3.79E+08	3.41E+06	1.62E+04	2.29E+01
28	NO2	9.280E-10	2.570E-11	5.310E-13	6.490E-15
		4.97E+07	1.38E+05	2.85E+02	3.75E-01
29	O3	5.160E-13	3.220E-15	3.240E-17	3.240E-19
		1.69E+04	1.73E+01	1.74E-02	1.74E-05
30	CO	1.580E-04	1.410E-04	6.680E-05	9.440E-06
		8.47E+12	7.56E+11	3.58E+10	5.06E+08
32	C	2.130E-06	1.890E-05	8.940E-05	1.260E-04
		1.14E+11	1.01E+11	4.79E+10	6.75E+09
34	C+	2.600E-09	1.560E-07	3.770E-06	2.420E-05
		1.39E+08	7.29E+08	2.02E+09	1.30E+09

(Table B-III cont')

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TABLES OF AIR DATA

SPECIE CONCENTRATION FRACTIONS		TEMP= 6000. (DEG.K)				
N	SPECIE	1.000E+01	1.000E+00	3.160E-01	1.000E-01	1.000E-02
1	E-	2.440E-05	6.050E-05	6.523E-05	1.163E-04	2.066E-04
		1.31E+16	3.24E+15	1.44E+15	6.23E+14	1.11E+14
2	N2	3.609E-01	3.683E-01	3.651E-01	3.540E-01	2.939E-01
		1.93E+20	1.97E+19	6.18E+18	1.90E+18	1.58E+17
3	N2+	1.640E-08	6.740E-08	1.500E-07	3.370E-07	1.580E-06
		8.79E+12	3.61E+12	2.54E+12	1.81E+12	8.47E+11
4	NO	5.580E-02	2.610E-02	1.580E-02	9.150E-03	2.730E-03
		2.99E+19	1.40E+18	2.68E+17	4.90E+16	1.46E+15
5	NO+	3.330E-05	6.500E-05	8.580E-05	1.150E-04	1.930E-04
		1.76E+16	5.38E+15	1.45E+15	6.16E+14	1.03E+14
6	O2	1.680E-02	3.610E-03	1.540E-03	4.610E-04	4.950E-05
		9.08E+16	1.95E+17	2.27E+16	2.47E+15	2.65E+13
8	N	6.780E-03	2.170E-02	3.640E-02	6.720E-02	1.936E-01
		3.65E+18	1.16E+18	6.50E+17	3.60E+17	1.04E+17
9	N+	1.520E-09	1.970E-08	7.810E-08	5.170E-07	5.140E-06
		8.15E+11	1.06E+12	1.32E+12	1.70E+12	2.76E+12
10	O	1.210E-01	1.72E-01	1.920E-01	2.004E-01	2.076E-01
		6.49E+19	9.50E+18	3.25E+18	1.07E+18	1.11E+17
11	O+	3.390E-08	2.010E-07	4.880E-07	1.180E-06	6.880E-06
		1.82E+13	1.06E+13	8.27E+12	6.32E+12	3.69E+12
26	O-	7.820E-06	2.830E-06	1.570E-06	6.160E-07	1.130E-07
		4.19E+15	1.52E+14	2.52E+13	3.30E+12	6.06E+10
27	CO2	6.250E-06	9.450E-07	3.240E-07	1.070E-07	1.020E-08
		3.35E+15	5.07E+13	5.44E+12	5.74E+11	5.47E+09
28	NO2	5.700E-05	3.910E-06	8.120E-07	1.550E-07	4.790E-09
		3.06E+16	2.10E+14	1.58E+13	8.31E+11	2.57E+09
30	CO	1.540E-04	1.590E-04	1.590E-04	1.580E-04	1.460E-04
		8.25E+16	4.52E+15	2.69E+15	8.47E+14	7.83E+13
31	O2-	1.260E-06	6.710E-08	1.110E-08	1.650E-09	3.150E-11
		6.75E+14	5.60E+12	1.88E+11	8.64E+09	1.69E+07
32	C	2.580E-08	1.820E-07	5.320E-07	1.600E-06	1.430E-05
		1.38E+13	9.76E+12	9.01E+12	8.58E+12	7.66E+12
34	C+	6.710E-13	1.910E-11	1.260E-10	6.780E-10	4.380E-08
		3.60E+06	1.02E+09	2.13E+09	4.71E+09	2.35E+10

(Table B-III con't)

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TABLES OF AIR DATA

SPECIE CONCENTRATION FRACTIONS		TEMP= 6000. (DEG.K)			
N	SPECIE	1.00E-03	1.00E-04	1.00E-05	1.00E-06
1	E-	3.49E+04	4.31E+04	2.43E+03	7.59E+03
		1.07E+13	4.46E+12	1.50E+12	4.01E+11
2	N2	1.63E+01	3.40E+02	4.64E+03	4.75E+04
		6.76E+15	2.09E+14	2.51E+12	2.55E+10
3	N2+	4.84E+06	5.20E+06	2.13E+06	6.91E+07
		2.62E+11	2.79E+10	1.14E+09	3.70E+07
4	NO	6.50E+04	1.01E+04	1.10E+05	1.10E+06
		3.48E+13	5.41E+11	5.40E+09	5.90E+07
5	NO+	2.57E+04	1.77E+04	6.62E+05	2.12E+05
		1.38E+13	4.49E+11	3.55E+10	1.14E+09
6	O2	5.05E+06	5.18E+07	5.07E+08	5.01E+09
		2.71E+11	2.72E+09	2.72E+07	2.69E+05
8	N	4.56E+01	7.05E+01	7.73E+01	7.77E+01
		2.45E+16	3.74E+15	4.14E+14	4.17E+13
9	N+	4.77E+05	4.66E+04	1.74E+03	5.62E+03
		2.56E+12	2.50E+12	4.53E+11	3.01E+11
10	O	2.09E+01	2.10E+01	2.10E+01	2.08E+01
		1.12E+16	1.13E+15	1.13E+14	1.12E+13
11	O+	3.86E+05	1.73E+04	5.91E+04	1.66E+03
		2.08E+12	9.27E+11	3.17E+11	1.01E+11
26	O-	2.65E+06	4.62E+09	1.35E+09	4.20E+10
		1.10E+09	2.48E+07	7.24E+05	2.25E+04
27	CO2	5.68E+10	9.91E+12	9.18E+14	6.28E+16
		3.04E+07	5.51E+04	4.92E+01	3.37E+02
28	NO2	1.15E+10	1.74E+12	1.96E+14	1.95E+16
		6.16E+06	9.59E+03	1.05E+01	1.05E+02
30	CO	8.06E+05	1.40E+05	1.30E+06	8.95E+08
		4.32E+12	7.50E+10	6.97E+08	4.80E+06
31	O2+	5.75E+13	1.30E+14	3.60E+16	1.17E+17
		3.08E+04	6.97E+01	2.04E+01	6.27E+04
32	C	7.80E+05	1.36E+04	1.26E+04	8.71E+05
		4.14E+12	7.29E+11	6.75E+10	4.67E+09
34	C+	1.34E+06	1.04E+05	3.28E+05	7.28E+05
		7.16E+10	5.57E+10	1.75E+10	3.90E+09

(Table B-III cont)

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TABLES OF AIR DATA

SPECIE CORRECTION FACTORS			TEMP= 7000. (DEG.K)			
N	SPECIE	1.000E+01	1.000E+04	3.160E+01	1.000E+01	1.000E+02
1	E+	9.390E+05	2.050E+04	2.602E+04	3.802E+04	7.579E+04
		5.63E+14	1.67E+16	4.75E+15	2.04E+15	4.06E+14
2	N2	3.560E+01	3.420E+01	3.180E+01	2.753E+01	1.570E+01
		1.91E+20	1.64E+19	5.39E+18	1.48E+18	7.34E+16
3	N2+	4.300E+07	1.900E+06	4.000E+06	8.180E+06	2.040E+05
		2.50E+10	1.0E+10	6.88E+13	4.38E+13	1.09E+13
4	NO	4.650E+02	1.820E+02	1.050E+02	5.530E+03	1.260E+03
		2.48E+14	9.76E+17	1.74E+17	2.96E+16	6.75E+14
5	NO+	1.130E+04	2.020E+04	2.640E+04	3.300E+04	3.770E+04
		6.56E+16	1.88E+16	4.47E+15	1.77E+15	2.02E+14
6	O2	6.750E+03	1.080E+03	3.740E+04	1.240E+04	1.500E+05
		3.62E+14	5.79E+16	6.33E+15	6.65E+14	6.97E+12
7	O2+	4.920E+07	3.590E+07	2.870E+07	2.230E+07	1.170E+07
		2.64E+14	1.92E+13	4.86E+12	1.20E+12	6.27E+10
8	N	2.540E+02	8.740E+02	1.378E+01	2.279E+01	5.084E+01
		1.39E+19	4.31E+18	2.33E+18	1.22E+18	7.73E+17
9	N+	1.060E+07	1.560E+06	5.920E+06	2.280E+05	2.550E+04
		5.08E+13	6.04E+13	1.00E+14	1.22E+14	1.37E+14
10	O	1.560E+01	1.991E+01	1.993E+01	2.045E+01	2.089E+01
		8.07E+14	1.02E+19	3.34E+18	1.10E+18	1.12E+17
11	O+	5.950E+07	3.450E+06	8.310E+06	1.990E+05	1.020E+04
		3.19E+14	1.85E+14	1.41E+14	1.07E+14	5.47E+13
26	O-	1.950E+05	5.360E+06	2.450E+06	1.080E+06	2.020E+07
		1.05E+16	2.88E+14	4.15E+13	5.79E+12	1.08E+11
27	CO2	2.590E+06	3.250E+07	1.030E+07	2.960E+08	1.170E+09
		1.39E+15	1.74E+13	1.74E+12	1.59E+11	6.27E+08
28	NO2	2.530E+05	1.250E+08	2.350E+07	4.100E+08	9.550E+10
		1.36E+16	6.70E+13	3.98E+12	2.20E+11	5.12E+08
30	CO	1.570E+04	1.560E+04	1.500E+04	1.320E+04	5.120E+05
		8.42E+16	8.36E+15	2.54E+15	7.08E+14	2.74E+13
31	O2-	1.220E+06	4.230E+08	6.400E+09	9.150E+10	1.900E+11
		6.54E+14	2.27E+12	1.08E+11	4.90E+09	1.02E+07
32	C	4.480E+07	3.530E+06	1.020E+05	2.770E+05	1.050E+04
		2.40E+14	1.89E+14	1.73E+14	1.40E+14	5.63E+13
34	C+	1.210E+10	4.390E+04	2.920E+06	1.850E+07	3.510E+06
		6.49E+10	2.35E+11	4.95E+11	9.92E+11	1.88E+12

(Table B-III con't)

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TABLES OF AIR DATA

SPECIE CONCENTRATION, FRACTIONS		TEMP= 7000. (DEG.K)			
N	SPECIE	1.000E-03	1.000E-04	1.000E-05	1.000E-06
1	F=	2.605E-03 1.07E+14	6.153E-03 3.30E+13	1.927E-02 1.03E+13	5.954E-02 3.19E+12
2	N2	2.800E-02 1.50E+15	3.170E-03 1.70E+13	3.130E-04 1.65E+11	2.880E-05 1.54E+09
3	N2+	1.560E-05 8.47E+11	5.610E-06 3.11E+10	1.840E-06 9.86E+06	5.460E-07 2.93E+07
4	NO	1.810E-04 9.70E+12	1.920E-05 1.03E+11	1.890E-06 1.91E+09	1.740E-07 9.33E+06
5	NO+	2.050E-04 1.10E+13	7.080E-05 3.79E+11	2.220E-05 1.19E+10	6.620E-06 3.55E+08
6	O2	1.310E-06 7.02E+10	1.310E-07 7.02E+08	1.270E-08 6.81E+06	1.170E-09 6.27E+04
7	O2+	4.460E-06 2.59E+09	1.440E-06 7.72E+07	4.500E-04 2.41E+06	1.540E-04 7.18E+04
8	N	7.266E-01 3.69E+16	7.752E-01 4.14E+15	7.686E-01 4.12E+14	7.373E-01 3.95E+13
9	N+	1.580E-03 7.40E+13	4.770E-03 2.56E+13	1.520E-02 6.15E+12	4.710E-02 2.52E+12
10	O	2.100E-01 1.13E+16	2.694E-01 1.12E+15	2.068E-01 1.11E+14	1.984E-01 1.06E+13
11	O+	3.870E-04 2.07E+13	1.260E-03 6.75E+12	3.960E-03 2.12E+12	1.230E-02 6.59E+11
26	O=	5.850E-08 3.14E+09	1.790E-08 9.59E+07	5.540E-09 2.97E+06	1.640E-09 8.79E+04
27	CO2	1.530E-11 6.20E+05	1.260E-13 6.75E+02	7.530E-16 4.04E-01	3.060E-18 1.64E-04
28	NO2	1.380E-11 7.40E+05	1.460E-13 7.83E+02	1.410E-15 7.56E-01	1.250E-17 6.70E-04
30	CO	6.650E-06 3.56E+11	5.510E-07 2.95E+09	3.330E-08 1.78E+07	1.410E-09 7.56E+04
31	O2=	5.080E-13 2.72E+04	1.550E-14 6.51E+01	4.740E-16 2.54E-01	1.350E-17 7.24E-04
32	C	1.360E-04 7.29E+12	1.130E-04 6.06E+11	6.910E-05 3.70E+10	3.050E-05 1.63E+09
34	C+	1.720E-05 9.22E+11	4.640E-05 2.49E+11	9.080E-05 4.87E+10	1.300E-04 6.97E+09

(Table B-III con't)

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TABLES OF AIR DATA

SPECIE CONCENTRATION FRACTIONS		TEMP= 8000. (DEG.K)				
N	SPECIE	1.000E+01	1.000E+00	1.160E-01	1.000E-01	1.000E-02
1	E-	2.514E-04 1.35E+17	5.234E-04 2.81E+10	7.413E-04 1.26E+16	1.103E-03 5.91E+15	3.025E-03 1.62E+15
2	N2	3.396E-01 1.62E+20	2.846E-01 1.53E+19	2.274E-01 3.85E+18	1.541E-01 8.26E+17	3.500E-02 1.88E+16
3	N2+	5.090E-06 2.73E+15	2.050E-05 1.10E+15	3.060E-05 6.20E+14	5.270E-05 2.82E+14	4.340E-05 2.33E+13
4	NO	3.480E-02 1.87E+19	1.160E-02 6.32E+17	6.100E-03 1.03E+17	2.670E-03 1.54E+16	4.380E-04 2.35E+14
5	NO+	2.740E-04 1.47E+17	4.470E-04 2.40E+16	5.160E-04 8.74E+15	5.160E-04 2.77E+15	2.860E-04 1.53E+14
6	O2	3.180E-03 1.70E+18	4.330E-04 2.52E+10	1.460E-04 2.47E+15	4.760E-05 2.55E+14	4.880E-06 2.62E+12
7	O2+	1.290E-06 6.91E+14	8.460E-07 4.53E+15	6.350E-07 1.08E+13	4.400E-07 2.36E+12	1.640E-07 8.79E+10
8	N	7.010E-02 3.70E+19	2.050E-01 1.09E+19	3.227E-01 5.47E+18	4.723E-01 2.53E+18	7.115E-01 3.81E+17
9	N+	2.590E-06 1.39E+15	3.610E-05 1.93E+15	1.280E-04 2.17E+15	3.970E-04 2.13E+15	2.180E-03 1.17E+15
10	O	1.691E-01 9.06E+19	1.975E-01 1.06E+19	2.037E-01 3.45E+18	2.071E-01 1.11E+18	2.095E-01 1.12E+17
11	O+	4.880E-06 2.62E+15	2.740E-05 1.47E+15	6.310E-05 1.07E+15	1.360E-04 7.29E+14	5.020E-04 2.69E+14
26	O-	3.540E-05 1.90E+16	8.590E-06 4.60E+14	3.970E-06 6.72E+13	1.900E-06 1.02E+13	5.280E-07 2.83E+11
27	CO2	1.270E-06 6.81E+14	1.260E-07 6.75E+12	3.010E-08 5.10E+11	5.260E-09 2.79E+10	7.010E-11 3.76E+07
28	NO2	1.210E-05 6.49E+15	4.770E-07 2.56E+13	8.060E-08 1.37E+12	1.220E-08 6.54E+10	1.880E-10 1.01E+08
30	CO	1.550E-04 8.31E+16	1.320E-04 7.08E+15	9.620E-05 1.63E+15	5.170E-05 2.77E+14	6.890E-06 3.69E+12
31	O2-	1.060E-06 5.88E+14	3.020E-08 1.62E+12	4.550E-09 7.71E+10	7.000E-10 3.75E+09	1.970E-11 1.06E+07
32	C	3.870E-06 2.07E+15	2.810E-05 1.51E+15	6.280E-05 1.06E+15	1.050E-04 5.63E+14	1.390E-04 7.45E+13
34	C+	4.810E-09 2.58E+12	1.680E-07 9.00E+12	8.390E-07 1.42E+13	2.980E-06 1.60E+13	1.430E-05 7.66E+12

(Table B-III con't)

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TABLES OF AIR DATA

SPECIE CONCENTRATION FRACTIONS		TEMP= 8000. (DEG.K)			
N	SPECIE	1.000E-03	1.000E-04	1.000E-05	1.000E-06
1	E-	9.340E-03	2.932E-02	8.953E-02	2.557E-01
		5.03E+14	1.57E+14	4.80E+13	1.37E+13
2	N2	4.680E-03	3.980E-04	3.490E-05	2.290E-06
		2.19E+14	2.13E+12	1.87E+10	1.23E+08
3	N2+	1.640E-05	5.130E-06	1.470E-06	3.370E-07
		8.79E+11	2.75E+10	7.88E+08	1.81E+07
4	NO	4.710E-05	4.580E-06	4.070E-07	2.770E-08
		2.52E+12	2.45E+10	2.18E+08	1.48E+06
5	NO+	9.960E-05	3.100E-05	9.000E-06	2.150E-06
		5.34E+12	1.66E+11	4.82E+09	1.15E+08
6	O2	4.850E-07	4.700E-08	4.220E-09	2.990E-10
		2.60E+10	2.52E+08	2.26E+06	1.60E+04
7	O2+	5.280E-08	1.640E-08	4.810E-09	1.190E-09
		2.83E+09	8.79E+07	2.58E+06	6.38E+04
8	N	7.684E-01	7.595E-01	7.107E-01	5.755E-01
		4.12E+16	4.07E+15	3.81E+14	3.08E+13
9	N+	7.610E-03	2.410E-02	7.360E-02	2.089E-01
		4.08E+14	1.29E+14	3.94E+13	1.12E+13
10	O	2.090E-01	2.050E-01	1.949E-01	1.641E-01
		1.12E+16	1.10E+15	1.04E+14	8.80E+12
11	O+	1.620E-03	5.100E-03	1.580E-02	4.600E-02
		8.68E+13	2.73E+13	8.47E+12	2.50E+12
26	O-	1.630E-07	5.010E-08	1.450E-08	3.500E-09
		8.74E+09	2.69E+08	7.77E+06	1.88E+05
27	CO2	6.010E-13	3.770E-15	1.560E-17	3.750E-20
		3.22E+04	2.02E+01	8.36E-03	2.01E-06
28	NO2	2.020E-12	1.940E-14	1.630E-16	9.350E-19
		1.08E+05	1.04E+02	8.74E-02	5.01E-05
30	CO	5.920E-07	3.770E-08	1.650E-09	4.710E-11
		3.17E+10	2.02E+08	8.84E+05	2.52E+03
31	O2-	6.070E-13	1.630E-14	5.040E-16	1.020E-17
		3.25E+04	9.81E+01	2.70E-01	5.47E-04
32	C	1.200E-04	7.740E-05	3.560E-05	1.210E-05
		6.43E+12	4.15E+11	1.91E+10	6.49E+08
34	C+	3.990E-05	6.260E-05	1.240E-04	1.480E-04
		2.14E+12	4.43E+11	6.65E+10	7.93E+09

(Table B-III con't)

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TABLE B-III DATA

SPECIE CONCENTRATION FRACTIONS		TEMP= 10000. (DEG.K)				
N	SPECIE	1.000E+01	1.000E+00	3.160E-01	1.000E-01	1.000E-02
1	E-	1.096E+13 5.87E+17	2.663E+03 1.53E+17	4.665E+03 7.94E+16	6.765E+03 4.71E+16	2.747E+02 1.47E+16
2	N2	2.510E+01 1.35E+20	1.130E+01 6.06E+18	4.778E-02 8.09E+17	2.020E+02 1.08E+17	2.140E+03 1.15E+15
3	N2+	1.290E+04 6.91E+16	2.210E+04 1.18E+16	1.688E+04 2.86E+15	1.290E+04 6.91E+14	4.370E+05 2.34E+13
4	NO	2.350E+02 1.26E+19	5.490E+03 2.94E+17	2.028E+03 3.43E+16	7.490E+04 4.01E+15	7.640E+05 4.10E+13
5	NO+	7.460E+04 4.00E+17	6.610E+04 3.54E+16	4.416E+04 7.08E+15	2.950E+04 1.56E+15	9.650E+05 5.17E+13
6	O2	1.010E+03 5.41E+17	1.230E+04 6.59E+15	3.968E+05 6.72E+14	1.280E+05 6.86E+13	1.260E+06 6.75E+11
7	O2+	4.360E+06 2.34E+15	2.020E+06 1.08E+14	1.179E+06 2.00E+13	6.880E+07 3.69E+12	2.170E+07 1.16E+11
8	N	2.590E+01 1.39E+20	5.490E+01 2.94E+19	6.352E+01 1.08E+19	7.350E+01 3.94E+18	7.560E+01 4.05E+17
9	N+	1.990E+04 1.07E+17	1.600E+03 8.58E+16	3.654E+03 5.68E+16	7.030E+03 3.77E+16	2.310E+02 1.24E+16
10	O	1.850E+01 9.92E+19	2.050E+01 1.10E+19	2.070E+01 3.51E+18	2.090E+01 1.12E+18	2.070E+01 1.11E+17
11	O+	9.420E+05 5.05E+16	3.560E+04 2.12E+16	7.250E+04 1.22E+16	1.320E+05 7.08E+15	4.190E+03 2.25E+15
26	O-	7.660E+05 4.11E+16	2.230E+05 1.20E+15	1.247E+05 2.11E+14	6.970E+06 3.74E+13	2.160E+06 1.16E+12
28	NO2	3.220E+06 1.73E+15	8.310E+08 4.45E+12	9.618E+09 1.66E+11	1.160E+09 6.22E+09	1.170E+11 6.27E+06
30	CO	1.030E+04 5.52E+16	2.580E+05 1.58E+15	8.575E+06 1.45E+14	2.850E+06 1.53E+13	2.290E+07 1.23E+11
32	C	5.740E+05 3.08E+16	1.290E+04 6.91E+15	1.344E+04 2.28E+15	1.400E+04 7.50E+14	1.140E+04 6.11E+13
34	C+	5.650E+07 3.14E+14	5.010E+06 2.69E+14	9.417E+06 1.59E+14	1.770E+05 9.49E+13	4.610E+05 2.47E+13

(Table B-III con't)

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TABLES LE AIR DATA

SPECIE CONCENTRATION FRACTIONS		TEMP= 10000. (DEG.K)			
N	SPECIF	1.000E-03	1.000E-04	1.000E-05	1.000E-06
1	E-	8.413E-02	2.415E-01	5.672E-01	8.912E-01
		4.51E+15	1.29E+15	3.04E+14	4.78E+13
2	N2	1.900E-04	1.270E-05	3.780E-07	2.120E-09
		1.02E+13	6.81E+10	2.03E+08	1.14E+05
3	N2+	1.260E-05	2.940E-06	3.710E-07	1.330E-08
		6.75E+11	1.58E+10	1.99E+08	7.13E+05
4	NO	6.890E-06	4.890E-07	1.660E-08	1.070E-10
		3.69E+11	2.62E+09	8.90E+06	5.74E+03
5	NO+	2.830E-05	6.590E-06	1.010E-06	4.150E-08
		1.52E+12	3.75E+10	5.41E+08	2.22E+06
6	O2	1.150E-07	8.740E-09	3.370E-10	2.510E-12
		6.16E+09	4.68E+07	1.81E+05	1.35E+02
7	O2+	6.420E-08	1.690E-08	2.780E-09	1.330E-10
		3.44E+09	9.06E+07	1.49E+06	7.13E+03
8	N	7.150E-01	5.820E-01	3.180E-01	7.520E-02
		3.82E+16	3.12E+15	1.70E+14	4.03E+12
9	N+	7.100E-02	2.020E-01	4.660E-01	7.690E-01
		3.81E+15	1.08E+15	2.50E+14	3.80E+13
10	O	1.980E-01	1.720E-01	1.070E-01	2.920E-02
		1.06E+16	9.22E+14	5.74E+13	1.57E+12
11	O+	1.300E-02	3.940E-02	1.010E-01	1.820E-01
		6.97E+14	2.11E+14	5.41E+13	9.76E+12
26	O-	6.340E-07	1.580E-07	2.320E-08	9.880E-10
		3.40E+10	8.47E+08	1.24E+07	5.30E+04
28	NO2	1.010E-13	6.220E-16	1.310E-18	2.310E-22
		5.41E+03	3.33E+00	7.62E-04	1.24E-08
30	CO	1.330E-08	4.780E-10	8.130E-12	3.630E-14
		7.13E+08	2.56E+06	4.36E+03	1.95E+00
32	C	6.910E-05	2.860E-05	7.830E-06	1.280E-06
		3.70E+12	1.53E+11	4.20E+09	6.86E+07
34	C+	9.100E-05	1.310E-04	1.520E-04	1.570E-04
		4.88E+12	7.02E+11	8.15E+10	8.42E+09

(Table B-III con't)

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TABLES OF AIR DATA

SPECIE CONCENTRATION FRACTIONS

TEMP= 12000. (DEG.K)

N	SPECIE	1.000E+01	1.000E+00	3.160E-01	1.000E-01	1.000E-02
1	E+	4.024E-03	1.242E-02	2.162E-02	3.676E-02	1.173E-01
		2.16E+16	6.00E+17	3.60E+17	2.08E+17	6.28E+16
2	N2	1.321E-01	2.686E-02	6.801E-03	2.890E-03	2.430E-04
		7.08E+19	1.44E+18	1.49E+17	1.55E+16	1.30E+14
3	N2+	5.430E-04	3.570E-04	2.045E-04	1.230E-04	3.430E-05
		2.91E+17	1.91E+16	3.45E+15	6.59E+14	1.84E+13
4	NO	1.270E-02	1.230E-03	5.805E-04	1.880E-04	1.630E-05
		6.54E+18	9.81E+16	9.93E+15	1.01E+15	8.74E+12
5	NO+	9.450E-04	4.790E-04	2.751E-04	1.560E-04	4.530E-05
		5.26E+17	2.57E+16	4.66E+15	8.47E+14	2.43E+13
6	O2	4.680E-04	5.190E-05	1.629E-05	5.110E-06	4.570E-07
		2.51E+17	2.78E+15	2.76E+14	2.74E+13	2.45E+11
7	O2+	7.870E-06	2.810E-06	1.580E-06	8.860E-07	2.620E-07
		4.19E+15	1.51E+14	2.66E+13	4.76E+12	1.40E+11
8	N	5.038E-01	7.176E-01	7.313E-01	7.451E-01	6.837E-01
		2.70E+20	3.85E+19	1.24E+19	3.99E+18	3.66E+17
9	N+	2.150E-03	9.900E-03	1.807E-02	5.300E-02	1.000E-01
		1.15E+16	5.31E+17	3.00E+17	1.77E+17	5.36E+16
10	O	1.959E-01	2.065E-01	2.057E-01	2.049E-01	1.936E-01
		1.05E+20	1.11E+19	3.48E+18	1.10E+18	1.04E+17
11	O+	5.030E-04	1.720E-03	3.065E-03	5.460E-03	1.710E-02
		2.70E+17	9.22E+16	5.19E+16	2.93E+16	9.17E+15
26	O-	1.680E-04	5.470E-05	3.040E-05	1.690E-05	4.840E-06
		9.00E+16	2.93E+15	5.15E+14	9.06E+13	2.59E+12
28	NO2	9.920E-07	1.570E-08	1.590E-09	1.610E-10	1.320E-12
		5.32E+14	8.42E+11	2.69E+10	8.63E+08	7.08E+05
30	CO	2.940E-05	5.480E-06	1.011E-06	2.940E-07	1.780E-08
		1.56E+16	1.87E+14	1.71E+13	1.58E+12	9.54E+09
31	O2-	1.030E-06	3.540E-06	6.212E-09	1.090E-09	2.930E-11
		5.52E+14	1.90E+12	1.05E+11	5.84E+09	1.57E+07
32	C	1.260E-04	1.420E-04	1.311E-04	1.210E-04	7.780E-05
		6.75E+16	7.61E+15	2.22E+15	6.49E+14	4.17E+13
34	C+	3.890E-06	1.420E-05	2.344E-05	3.870E-05	8.220E-05
		2.09E+15	7.61E+14	3.97E+14	2.07E+14	4.41E+13

(Table B-III con't)

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TABLES OF AIR DATA

SPECIE CONCENTRATION FRACTIONS

TEMP= 12000. (DEG.K)

N	SPECIE	1.000E-03	1.000E-04	1.000E-05	1.000E-06
1	E-	3.238E-01	6.867E-01	9.371E-01	9.887E-01
		1.73E+16	5.66E+15	5.02E+14	5.30E+13
2	N2	1.370E-05	2.620E-07	8.610E-10	1.050E-12
		7.34E+11	1.40E+09	4.61E+05	5.63E+01
3	N2+	6.990E-06	6.300E-07	1.520E-08	1.760E-10
		3.75E+11	5.36E+09	8.15E+06	9.43E+03
4	NO	1.010E-06	2.55E-08	8.800E-11	1.110E-13
		5.41E+10	1.25E+08	4.72E+04	5.95E+00
5	NO+	1.020E-05	1.100E-06	3.050E-08	3.650E-10
		5.47E+11	5.90E+09	1.63E+07	1.96E+04
6	O2	3.100E-08	8.640E-10	3.750E-12	4.670E-15
		1.66E+04	4.63E+06	2.01E+03	2.61E-01
7	O2+	6.460E-08	8.460E-09	2.690E-10	3.510E-12
		3.46E+04	4.53E+07	1.44E+05	1.77E+02
8	N	5.124E-01	2.244E-01	4.070E-02	4.500E-03
		2.75E+16	1.20E+15	2.18E+13	2.41E+11
9	N+	2.719E-01	5.600E-01	7.437E-01	7.798E-01
		1.46E+16	3.00E+15	3.99E+14	4.18E+13
10	O	1.596E-01	6.420E-02	1.750E-02	2.000E-03
		8.55E+15	4.51E+14	9.38E+12	1.07E+11
11	O+	5.100E-02	1.265E-01	1.932E-01	2.067E-01
		2.73E+15	6.78E+14	1.04E+14	1.12E+13
26	O-	1.100E-06	1.250E-07	3.510E-09	4.220E-11
		5.90E+10	6.59E+08	1.88E+06	2.26E+03
28	NO2	6.700E-15	8.160E-18	6.420E-22	9.240E-25
		3.59E+02	4.37E-02	3.44E-07	4.95E-11
30	CO	6.260E-10	8.390E-12	2.500E-14	3.030E-17
		3.36E+07	4.50E+04	1.34E+01	1.62E-03
31	O2-	5.500E-15	5.250E-15	1.930E-18	2.640E-22
		2.95E+04	1.74E+01	1.03E-03	1.42E-08
32	C	3.310E-05	6.410E-06	1.200E-06	1.280E-07
		1.77E+12	4.51E+10	6.43E+08	6.86E+06
34	C+	1.270E-04	1.520E-04	1.590E-04	1.600E-04
		6.81E+12	8.15E+11	8.52E+10	8.58E+09

(Table B-III con't)

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TABLES OF AIR DATA

SPECIFIC CONCENTRATION FRACTIONS			TEMP= 18000. (DEG.K)			
N	SPECIE	1.000E+01	1.000E+00	3.160E-01	1.000E-01	1.000E-02
1	E-	4.914E-02	1.474E-01	2.402E-01	5.921E-01	7.634E-01
		2.65E+19	7.90E+16	4.07E+18	2.10E+18	4.09E+17
2	N2	9.760E-04	8.136E-04	1.787E-04	3.930E-05	5.260E-07
		5.23E+15	4.36E+16	5.03E+15	2.11E+14	2.82E+11
3	N2+	9.820E-04	2.736E-04	1.164E-04	4.960E-05	3.420E-06
		5.26E+17	1.46E+16	1.47E+15	2.66E+14	1.85E+12
4	NO	2.040E-03	1.760E-04	4.091E-05	9.510E-06	1.540E-07
		1.10E+18	9.43E+15	6.93E+14	5.10E+13	8.25E+10
5	NO+	6.170E-04	1.770E-04	7.982E-05	3.600E-05	3.000E-06
		3.31E+17	9.49E+15	1.35E+15	1.43E+14	1.61E+12
6	O2	1.370E-04	1.220E-05	3.001E-06	7.380E-07	1.450E-08
		7.54E+16	6.54E+14	5.08E+13	3.96E+12	7.77E+09
7	O2+	1.960E-05	5.780E-06	2.762E-06	1.320E-06	1.330E-07
		1.05E+16	3.10E+14	4.08E+13	7.08E+12	7.13E+10
8	N	1.191E-01	6.565E-01	3.473E-01	4.502E-01	1.670E-01
		5.65E+20	5.52E+19	9.27E+18	2.45E+18	8.95E+16
9	N+	4.120E-02	1.253E-01	2.027E-01	3.279E-01	6.173E-01
		2.21E+19	6.72E+18	3.43E+18	1.76E+18	3.51E+17
10	O	2.001E-01	1.683E-01	1.662E-01	1.467E-01	6.500E-02
		1.07E+20	1.01E+19	2.82E+18	7.86E+17	3.48E+16
11	O+	6.960E-03	2.180E-02	3.735E-02	6.400E-02	1.458E-01
		3.73E+18	1.17E+18	6.33E+17	3.43E+17	7.81E+16
12	N++	5.300E-08	5.370E-07	1.685E-06	5.290E-06	5.130E-05
		2.84E+13	2.88E+13	2.85E+13	2.84E+13	2.75E+13
19	O++	8.040E-10	8.410E-09	2.794E-08	9.280E-08	1.090E-06
		4.31E+11	4.51E+11	4.73E+11	4.97E+11	5.84E+11
26	O-	6.590E-04	1.660E-04	8.462E-05	5.850E-05	3.320E-06
		3.53E+17	9.97E+15	1.43E+15	2.06E+14	1.78E+12
30	CO	1.220E-06	8.780E-08	1.753E-08	3.500E-09	4.130E-11
		6.54E+14	4.71E+12	2.97E+11	1.88E+10	2.21E+07
31	O2-	1.100E-06	2.430E-08	5.719E-09	4.720E-10	1.600E-12
		5.90E+14	1.57E+12	6.30E+10	2.53E+09	9.65E+05
32	C	1.370E-04	1.050E-04	7.502E-05	5.360E-05	1.430E-05
		7.34E+16	5.63E+15	1.27E+15	2.87E+14	7.66E+12
34	C+	2.160E-05	5.510E-05	7.642E-05	1.060E-04	1.460E-04
		1.16E+16	2.45E+15	1.29E+15	5.68E+14	7.83E+13

(Table B-III con't)

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TABLES OF AJR DATA

SPECIE CONCENTRATION FRACTIONS

TEMP= 10000. (DFG.K)

N	SPECIE	1.000E-03	1.000E-04	1.000E-05	1.000E-06
1	E-	9.589E-01 5.14E+16	9.964E-01 5.34E+15	1.041E+00 5.58E+14	1.266E+00 6.78E+13
2	N2	1.250E-09 6.70E+07	1.420E-12 7.61E+03	1.410E-15 7.50E-01	1.040E-18 5.57E-05
3	N2+	6.480E-08 3.47E+04	7.060E-10 3.78E+06	6.690E-12 3.59E+03	4.080E-14 2.19E+00
4	NO	4.090E-10 2.19E+07	4.740E-13 2.54E+03	4.940E-16 2.65E-01	4.960E-19 2.67E-05
5	NO+	6.340E-08 3.40E+09	7.080E-10 3.79E+06	7.050E-12 3.78E+03	5.850E-14 3.14E+00
6	O2	4.280E-11 2.29E+06	5.090E-14 2.73E+02	5.570E-17 2.49E-02	7.640E-20 4.10E-06
7	O2+	3.140E-04 1.68E+08	3.590E-11 1.92E+05	3.760E-13 2.02E+02	4.240E-15 2.27E-01
8	H	2.580E-02 1.58E+15	2.740E-03 1.47E+13	2.750E-04 1.47E+11	2.350E-05 1.26E+04
9	H+	7.581E-01 4.06E+16	7.767E-01 4.16E+15	7.392E-01 3.95E+14	5.230E-01 2.80E+13
10	O	1.120E-02 6.00E+14	1.220E-03 6.54E+12	1.270E-04 6.81E+10	1.490E-05 7.99E+08
11	O+	1.996E-01 1.07E+16	2.094E-01 1.12E+15	2.095E-01 1.12E+14	2.017E-01 1.08E+13
12	H++	5.010E-04 2.69E+13	4.440E-03 2.65E+13	4.500E-02 2.41E+13	2.614E-01 1.40E+13
19	O++	1.190E-05 6.38E+11	1.200E-04 6.43E+11	1.140E-03 6.11E+11	9.060E-03 4.86E+11
26	O-	7.160E-08 3.64E+09	6.110E-10 4.35E+06	8.880E-12 4.76E+03	1.270E-13 6.81E+00
30	CO	9.670E-14 5.18E+03	1.110E-16 5.95E-01	1.220E-19 6.54E-05	1.750E-22 9.27E-09
31	O2-	6.680E-16 3.58E+01	8.250E-20 4.42E+04	9.450E-24 5.07E-09	1.580E-27 8.47E-14
32	C	1.950E-06 1.05E+11	2.050E-07 1.10E+09	2.140E-08 1.15E+07	2.610E-09 1.40E+05
34	C+	1.580E-04 8.47E+12	1.60E-04 6.58E+11	1.600E-04 8.58E+10	1.600E-04 6.58E+09

(Table B-III con't)

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TABLES OF AIR DATA

SPECIE CONCENTRATION FRACTIONS

TEMP= 24000. (DEG.K)

N	SPECIE	1.000E+01	1.000E+00	3.160E-01	1.000E-01	1.000E-02
1	E-	1.678E-01	4.365E-01	5.924E-01	8.053E-01	9.770E-01
		9.00E+19	2.34E+19	5.00E+19	4.32E+18	5.24E+17
2	N2	1.530E-03	6.780E-05	7.083E-06	7.400E-07	1.500E-09
		8.20E+17	3.63E+15	1.20E+14	3.97E+12	8.04E+08
3	N2+	7.060E-04	1.210E-04	2.943E-05	7.160E-06	1.200E-07
		3.79E+17	6.49E+15	4.99E+14	3.84E+13	6.43E+10
4	NO	5.470E-04	2.670E-05	2.986E-06	3.540E-07	7.290E-10
		2.93E+17	1.43E+15	5.06E+13	1.79E+12	3.91E+08
5	NO+	4.530E-04	8.500E-05	2.217E-05	5.780E-06	1.040E-07
		2.43E+17	4.56E+15	3.75E+14	3.10E+13	5.57E+10
6	O2	6.640E-05	3.570E-06	4.284E-07	5.140E-08	1.200E-10
		3.56E+16	1.91E+14	7.26E+12	2.76E+11	6.43E+07
7	O2+	3.500E-05	6.620E-06	1.408E-06	5.340E-07	1.030E-08
		1.77E+16	3.06E+14	3.23E+13	2.66E+12	5.52E+04
8	N	6.390E-01	4.254E-01	2.445E-01	1.405E-01	2.000E-02
		3.43E+20	2.26E+19	4.14E+18	7.53E+17	1.07E+16
9	N+	1.399E-01	3.564E-01	4.600E-01	6.429E-01	7.557E-01
		7.50E+19	1.92E+19	8.13E+16	3.45E+18	4.05E+17
10	O	1.810E-01	1.326E-01	8.167E-02	5.030E-02	7.700E-03
		9.70E+19	7.11E+18	1.58E+18	2.70E+17	4.13E+15
11	O+	2.760E-02	7.780E-02	1.117E-01	1.603E-01	2.022E-01
		1.46E+19	4.17E+18	1.89E+18	8.59E+17	1.08E+17
12	N++	9.310E-06	9.190E-05	2.868E-04	8.950E-04	8.670E-03
		4.99E+15	4.93E+15	4.86E+15	4.80E+15	4.65E+15
19	O++	6.460E-07	7.020E-06	2.347E-05	7.850E-05	8.160E-04
		3.46E+14	3.76E+14	3.98E+14	4.21E+14	4.37E+14
26	O-	9.390E-04	1.790E-04	4.730E-05	1.250E-05	2.320E-07
		5.03E+17	9.59E+15	8.01E+14	6.70E+13	1.24E+11
32	C	1.160E-04	6.560E-05	3.455E-05	1.820E-05	2.450E-06
		6.22E+16	3.52E+15	5.85E+14	9.76E+13	1.31E+12
34	C+	4.340E-05	9.430E-05	1.157E-04	1.420E-04	1.580E-04
		2.33E+16	5.05E+15	1.96E+15	7.61E+14	8.47E+13

(Table B-III con't)

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TABLES OF AIR DATA

SPECIE CONCENTRATION FRACTIONS		TEMP= 24000. (DEG.K)			
N	SPECIE	1.000E+03	1.000E+04	1.000E+05	1.000E+06
1	E-	1.074E+00 5.76E+16	1.591E+00 7.46E+15	1.814E+00 4.72E+14	1.962E+00 1.05E+14
2	N2	1.000E+12 8.58E+04	1.010E+15 5.41E+00	1.030E+19 5.79E+05	1.950E+24 1.05E+10
3	N2+	1.160E+09 6.22E+07	5.650E+12 5.03E+04	4.660E+15 2.50E+00	7.700E+19 4.13E+05
4	NO	8.290E+13 4.44E+04	6.420E+16 3.71E+00	1.200E+19 6.45E+05	2.620E+24 1.40E+10
5	NO+	1.070E+09 5.74E+07	6.920E+12 3.71E+04	9.180E+15 4.92E+00	1.650E+18 9.92E+05
6	O2	1.460E+13 7.83E+05	1.610E+16 8.63E+01	4.480E+20 2.40E+05	1.200E+24 6.43E+11
7	O2+	1.140E+10 6.11E+06	9.680E+13 5.19E+03	2.060E+15 1.10E+00	5.090E+19 2.73E+05
8	N	2.070E+05 1.11E+14	1.640E+04 8.79E+11	5.580E+06 2.88E+09	7.210E+08 3.86E+06
9	N+	7.084E+01 3.80E+16	4.345E+01 2.35E+15	1.094E+01 5.86E+13	1.350E+02 7.24E+11
10	O	8.480E+04 4.55E+13	8.910E+05 4.78E+11	4.700E+06 2.52E+09	7.690E+08 4.12E+06
11	O+	2.025E+01 1.09E+16	1.642E+01 8.80E+14	6.640E+02 3.56E+13	1.000E+02 5.36E+11
12	N++	7.390E+02 3.96E+15	3.497E+01 1.67E+15	6.749E+01 3.62E+14	7.683E+01 4.12E+13
19	O++	7.430E+03 3.98E+14	4.650E+02 2.49E+14	1.443E+01 7.73E+13	2.007E+01 1.08E+13
26	O-	2.810E+09 1.51E+08	1.830E+11 2.05E+05	2.630E+13 1.41E+02	4.670E+16 2.50E+02
32	C	2.730E+07 1.46E+10	3.548E+08 1.48E+08	4.620E+09 2.48E+06	5.010E+10 2.69E+04
34	C+	1.600E+04 8.58E+12	1.600E+04 8.58E+11	1.600E+04 8.58E+10	1.600E+04 8.58E+09

(Table B-III con't)

74/05/10.

TABLES OF AIR DATA

SPECIE CONCENTRATION FRACTIONS			TEMP= 34800. (DEG.K)			
N	SPECIE	1.000E+01	1.000E+00	3.160E-01	1.000E-01	1.000E-02
1	E-	4.791E-01	8.913E-01	9.517E-01	1.113E+00	1.505E+00
		2.57E+20	4.78E+19	1.61E+19	5.97E+18	8.06E+17
8	N	3.970E-01	9.780E-02	4.196E-02	1.800E-02	1.650E-03
		2.13E+20	5.24E+18	7.11E+17	9.65E+16	8.84E+14
9	N+	3.800E-01	6.630E-01	6.509E-01	6.390E-01	3.440E-01
		2.04E+20	3.55E+19	1.10E+19	3.43E+18	1.84E+17
10	O	1.230E-01	3.230E-02	1.434E-02	6.370E-03	6.880E-04
		6.59E+19	1.74E+18	2.43E+17	3.41E+16	3.69E+14
11	O+	9.650E-02	1.850E-01	1.914E-01	1.980E-01	1.450E-01
		5.17E+19	9.92E+18	3.24E+18	1.06E+18	7.77E+16
12	N++	1.280E-03	1.950E-02	4.847E-02	1.230E-01	4.350E-01
		6.86E+17	1.05E+18	8.30E+17	6.59E+17	2.32E+17
13	N+3	1.000E-08	1.030E-06	3.962E-06	1.570E-05	5.790E-04
		5.36E+12	5.56E+13	6.71E+13	8.42E+13	3.10E+14
19	O++	1.000E-06	2.170E-03	5.743E-03	1.520E-02	7.390E-02
		5.36E+14	1.16E+17	9.73E+16	8.15E+16	3.96E+16
20	O+3	1.000E-09	1.000E-07	3.162E-07	1.000E-06	1.880E-05
		5.36E+11	5.36E+12	5.36E+12	5.36E+12	1.01E+13

(Table B-III con't)

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TABLES OF AIR DATA

SPECIE CONCENTRATION FRACTIONS

TEMP= 34800. (DEG.K)

N	SPECIE	1.000E-03	1.000E-04	1.000E-05	1.000E-06
1	E-	1.087E+00	2.052E+00	2.370E+00	2.511E+00
		1.01E+17	1.10E+16	1.27E+15	1.24E+14
8	N	1.050E-04	1.000E-06	1.000E-07	1.000E-08
		5.63E+11	5.36E+09	5.36E+07	5.36E+05
9	N+	7.500E-02	8.550E-03	6.070E-04	6.000E-04
		4.02E+15	4.58E+13	5.25E+11	5.22E+10
10	O	1.300E-05	1.000E-06	1.000E-07	1.000E-08
		6.97E+11	5.36E+09	5.36E+07	5.36E+05
11	O+	4.580E-02	6.260E-03	6.550E-04	6.000E-04
		2.45E+15	3.36E+13	3.51E+11	3.22E+10
12	N++	6.980E-01	7.090E-01	4.460E-01	4.000E-01
		3.74E+16	3.80E+15	2.39E+14	2.14E+13
13	N+3	7.02E-03	6.250E-02	3.360E-01	3.400E-01
		3.76E+14	3.55E+14	1.80E+14	1.82E+13
19	O++	1.740E-01	2.100E-01	1.900E-01	2.000E-01
		9.33E+15	1.13E+15	1.02E+14	1.07E+13
20	O+3	3.630E-04	3.870E-03	2.970E-02	3.000E-02
		1.95E+13	2.07E+13	1.59E+13	1.61E+12

(Table B-III con't)

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TABLES OF AIR DATA

SPECIE CONCENTRATION FRACTIONS

TEMP= 5000. (DEG.K)

N	SPECIE	1.000E+01	1.000E+00	5.100E-01	1.000E-01	1.000E-02
1	E=	9.636E+01	1.598E+00	1.002E+00	2.025E+00	2.503E+00
		5.16E+20	8.50E+19	2.81E+19	1.09E+19	1.54E+18
8	N	1.160E+01	5.160E+03	7.869E+04	1.200E+04	1.000E+06
		5.22E+19	2.77E+17	1.33E+16	6.43E+14	5.36E+11
9	N+	5.610E+01	2.990E+01	1.421E+01	6.750E+02	6.310E+03
		3.01E+20	1.60E+19	2.41E+18	3.62E+17	3.38E+15
10	O	3.536E+02	1.940E+03	2.679E+04	5.700E+05	1.000E+06
		1.89E+19	1.04E+17	4.54E+15	1.98E+14	5.36E+11
11	O+	1.625E+01	1.030E+01	5.274E+02	2.700E+02	5.130E+03
		8.71E+19	5.52E+18	8.93E+17	1.45E+17	1.62E+15
12	N++	9.990E+02	4.650E+01	5.279E+01	6.020E+01	3.390E+01
		5.35E+19	2.48E+19	8.94E+18	5.23E+18	1.62E+17
13	N+3	1.650E+04	1.320E+02	3.793E+02	1.090E+01	4.290E+01
		8.84E+16	7.08E+17	6.42E+17	5.84E+17	2.50E+17
14	N+4	1.000E+07	1.000E+06	1.261E+05	1.590E+04	4.470E+03
		5.36E+13	5.36E+13	2.14E+14	8.52E+14	2.40E+15
19	O++	1.990E+02	1.130E+01	1.418E+01	1.780E+01	1.370E+01
		1.07E+19	6.06E+18	2.40E+18	9.54E+17	7.54E+16
20	O+3	1.000E+06	1.430E+03	4.536E+03	1.440E+02	7.870E+02
		5.36E+14	7.66E+16	7.69E+16	7.72E+16	4.22E+16
21	O+4	1.000E+08	1.000E+07	3.162E+07	1.000E+06	2.230E+04
		5.36E+12	5.36E+12	5.36E+12	5.36E+12	1.20E+14
22	O+5	1.000E+09	1.000E+09	3.162E+09	1.000E+08	1.000E+07
		5.36E+11	5.36E+10	5.36E+10	5.36E+10	5.36E+10

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(Table B-III con't)
TABLES OF AIR DATA

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SPECIE CONCENTRATION FRACTIONS

TEMP= 50000. (DEG.K)

N	SPECIE	1.000E-03	1.000E-04	1.000E-05	1.000E-06
1	E-	2.944E+10	5.338E+00	4.048E+00	5.744E+00
8	N	1.58E+17	1.79E+10	2.19E+15	2.01E+14
		1.000E-07	1.000E-08	1.000E-09	1.000E-09
9	N+	5.36E+09	5.36E+07	5.36E+05	5.36E+04
		1.260E-04	1.000E-05	1.000E-07	1.000E-06
10	O	6.75E+12	5.36E+09	5.36E+07	5.36E+05
		1.000E-07	1.000E-08	1.000E-09	1.000E-09
11	O+	5.36E+09	5.36E+07	5.36E+05	5.36E+04
		9.650E-05	1.000E-06	1.000E-07	1.000E-08
12	N++	5.18E+12	5.36E+09	5.36E+07	5.36E+05
		6.760E-02	5.400E-03	1.430E-01	1.000E-04
13	N+3	5.62E+15	2.89E+13	7.66E+13	5.36E+09
		6.580E-01	4.580E-01	1.120E-01	1.000E-01
14	N+4	5.55E+10	2.45E+15	6.00E+13	5.36E+12
		5.380E-02	5.160E-01	6.670E-01	7.070E-01
19	O++	2.88E+15	1.69E+15	5.58E+14	3.75E+13
		3.920E-02	4.640E-03	2.700E-04	2.000E-04
20	O+3	2.10E+15	2.49E+13	1.23E+11	1.07E+10
		1.760E-01	1.790E-01	8.040E-02	8.000E-02
21	O+4	9.43E+15	9.59E+14	4.34E+13	4.29E+12
		4.140E-03	3.570E-02	1.380E-01	1.000E-01
22	O+5	2.22E+14	1.91E+14	7.40E+13	5.36E+12
		1.000E-06	1.570E-05	6.620E-04	7.000E-04
		5.36E+10	6.42E+10	3.55E+11	3.75E+10

(Table B-III con't)

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TABLES OF AIR DATA

SPECIE CONCENTRATION FRACTIONS

TEMP= 116000. (DEG,K)

N	SPECIE	1.000E+01	1.000E+00	3.100E-01	1.000E-01	1.000E-02
1	E+	1.933E+00	2.857E+00	2.690E+00	3.671E+00	4.059E+00
		1.04E+21	1.53E+20	4.57E+19	1.97E+19	2.18E+18
9	N+	9.440E-02	1.210E-02	5.747E-04	2.730E-05	1.000E-06
		5.09E+19	6.49E+17	9.73E+15	1.46E+14	5.36E+11
11	O+	1.890E-02	4.430E-03	6.656E-05	1.000E-06	1.000E-07
		1.01E+19	2.37E+17	1.13E+15	5.36E+12	5.36E+10
12	N++	4.500E-01	1.910E-01	6.196E-02	2.010E-02	3.020E-04
		2.41E+20	1.02E+19	1.05E+18	1.08E+17	1.62E+14
13	N+3	1.820E-01	4.510E-01	3.310E-01	2.430E-01	3.340E-02
		9.76E+19	2.42E+19	5.61E+18	1.30E+18	1.79E+16
14	N+4	7.650E-03	1.230E-01	2.376E-01	4.590E-01	3.740E-01
		4.04E+18	6.59E+18	4.02E+18	2.46E+18	2.00E+17
15	N+5	1.000E-06	1.990E-03	1.067E-02	5.720E-02	3.720E-01
		5.36E+14	1.07E+17	1.81E+17	3.07E+17	1.99E+17
19	O++	1.110E-01	6.470E-02	2.292E-02	8.120E-03	1.430E-04
		5.95E+19	3.47E+18	5.88E+17	4.35E+16	7.66E+13
20	O+3	4.020E-02	1.270E-01	1.054E-01	8.740E-02	1.410E-02
		2.15E+19	6.81E+18	1.78E+18	4.68E+17	7.56E+15
21	O+4	1.000E-06	2.310E-02	5.154E-02	1.150E-01	1.280E-01
		5.36E+14	1.24E+18	8.73E+17	6.16E+17	6.86E+16
22	O+5	1.000E-06	2.180E-04	1.367E-03	8.320E-03	7.550E-03
		5.36E+14	1.17E+16	2.28E+16	4.46E+16	4.05E+14
23	O+6	1.000E-07	1.000E-06	4.037E-06	2.150E-05	1.630E-03
		5.36E+13	5.36E+13	7.85E+13	1.15E+14	8.74E+14

(Table B-III con't)

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TABLES OF AIR DATA

SPECIE CONCENTRATION FRACTIONS		TEMP= 116000. (DEG.K)			
N	SPECIE	1.000E-03	1.000E-04	1.000E-05	1.000E-06
1	E-	4.910E+00	5.126E+00	5.204E+00	5.145E+00
		2.63E+17	2.75E+16	2.79E+15	2.76E+14
9	N+	1.000E-07	1.000E-08	1.000E-09	1.000E-09
		5.36E+09	5.36E+07	5.36E+05	5.36E+04
11	O+	1.000E-08	1.000E-09	1.000E-09	1.000E-09
		5.36E+08	5.36E+06	5.36E+05	5.36E+04
12	N++	1.000E-06	1.000E-07	1.000E-08	1.000E-09
		5.36E+10	5.36E+08	5.36E+06	5.36E+04
13	N+3	9.550E-04	1.000E-06	1.000E-07	1.000E-08
		5.12E+13	5.36E+09	5.36E+07	5.36E+05
14	N+4	8.590E-02	9.410E-03	9.320E-04	9.000E-05
		4.60E+15	5.31E+13	5.00E+11	4.82E+09
15	N+5	6.930E-01	7.760E-01	7.790E-01	7.790E-01
		3.71E+16	4.13E+15	4.18E+14	4.18E+13
19	O++	1.000E-06	1.000E-07	1.000E-08	1.000E-09
		5.36E+10	5.36E+08	5.36E+06	5.36E+04
20	O+3	3.100E-04	1.000E-06	1.000E-07	1.000E-08
		1.66E+13	5.36E+09	5.36E+07	5.36E+05
21	O+4	3.150E-02	1.430E-03	1.270E-05	1.000E-06
		1.69E+15	7.66E+12	6.81E+09	5.36E+07
22	O+5	1.500E-01	7.690E-02	1.140E-02	1.000E-02
		8.47E+15	4.12E+14	6.11E+12	5.36E+11
23	O+6	3.030E-02	1.410E-01	2.080E-01	2.000E-01
		1.62E+15	7.56E+14	1.11E+14	1.07E+13

(Table B-II con't)

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TABLES OF AIR DATA

SPECIE CONCENTRATION FRACTIONS			TEMP= 174000. (DEG.K)			
N	SPECIE	1.000E+01	1.000E+00	3.160E-01	1.000E-01	1.000E-02
1	E-	2.776E+00	5.934E+00	3.627E+00	4.728E+00	5.098E+00
		1.49E+21	2.11E+20	5.14E+19	2.53E+19	2.73E+18
12	N++	1.740E-01	1.440E-02	8.244E-04	4.720E-05	1.000E-06
		9.33E+19	7.72E+17	1.40E+16	2.53E+14	5.36E+11
13	N+3	3.910E-01	1.810E-01	5.141E-02	1.460E-02	5.440E-04
		2.10E+20	9.70E+18	8.71E+17	7.83E+16	2.92E+14
14	N+4	1.770E-01	4.200E-01	3.026E-01	2.180E-01	4.960E-02
		9.49E+19	2.25E+19	5.13E+18	1.17E+18	2.66E+16
15	N+5	9.910E-03	1.640E-01	2.995E-01	5.470E-01	7.300E-01
		5.31E+18	8.79E+18	5.07E+18	2.93E+18	3.91E+17
19	O++	2.840E-02	4.100E-03	6.403E-05	1.000E-06	1.000E-07
		1.52E+19	2.20E+17	1.08E+15	5.36E+12	5.36E+10
20	O+3	9.000E-02	5.360E-02	1.295E-02	3.130E-03	1.000E-06
		4.82E+19	2.87E+18	2.19E+17	1.68E+16	5.36E+11
21	O+4	3.980E-02	1.100E-01	7.508E-02	4.660E-02	3.690E-03
		2.13E+19	6.22E+18	1.27E+18	2.60E+17	1.98E+15
22	O+5	2.380E-03	4.400E-02	7.592E-02	1.310E-01	6.430E-02
		1.28E+18	2.36E+18	1.29E+18	7.02E+17	3.45E+16
23	O+6	1.000E-06	1.520E-03	7.438E-03	3.640E-02	1.520E-01
		5.36E+14	8.15E+16	1.26E+17	1.95E+17	8.15E+16

(Table B-III con't)

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TABLES OF AIR DATA

SPECIE CONCENTRATION FRACTIONS

TEMP= 174000. (DEG.K)

N	SPECIE	1.000E-03	1.000E-04	1.000E-05	1.000E-06
1	E-	5.197E+00	5.219E+00	5.220E+00	5.220E+00
		2.79E+17	2.60E+16	2.80E+15	2.80E+14
12	N++	1.000E-07	1.000E-08	1.000E-09	1.000E-09
		5.36E+04	5.36E+07	5.36E+05	5.36E+04
13	N+3	1.000E-06	1.000E-07	1.000E-08	1.000E-09
		5.36E+10	5.36E+08	5.36E+06	5.36E+04
14	N+4	1.050E-02	1.010E-03	1.310E-05	1.000E-05
		5.63E+14	5.41E+12	7.02E+09	5.36E+08
15	N+5	7.690E-01	1.790E-01	7.800E-01	7.800E-01
		4.12E+16	4.18E+15	4.18E+14	4.18E+13
19	O++	1.000E-08	1.000E-09	1.000E-09	1.000E-09
		5.36E+08	5.36E+06	5.36E+05	5.36E+04
20	O+3	1.000E-07	1.000E-08	1.000E-09	1.000E-09
		5.36E+09	5.36E+07	5.36E+05	5.36E+04
21	O+4	1.190E-05	1.000E-06	1.000E-07	1.000E-08
		6.38E+11	5.36E+09	5.36E+07	5.36E+05
22	O+5	1.120E-02	1.150E-03	8.170E-05	1.000E-05
		6.00E+14	6.16E+12	4.38E+10	5.36E+08
23	O+6	2.090E-01	2.190E-01	2.200E-01	2.200E-01
		1.12E+16	1.17E+15	1.18E+14	1.18E+13

(Table B-III con't)

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TABLES OF AIR DATA

SPECIE CONCENTRATION FRACTIONS		TEMP= 232000, (DEG.K)				
N	SPECIE	1.000E+01	1.000E+00	3.160E-01	1.000E-01	1.000E-02
1	E=	3.500E+00	4.604E+00	4.429E+00	5.057E+00	5.182E+00
		1.88E+21	2.47E+20	7.58E+19	2.71E+19	2.78E+18
12	N++	2.320E-02	6.150E-04	2.476E-05	1.000E-06	1.000E-07
		1.24E+19	5.29E+16	4.19E+14	5.36E+12	5.36E+10
13	N+3	2.470E-01	3.950E-02	7.646E-03	1.480E-03	1.000E-06
		1.32E+20	2.12E+18	1.30E+17	7.93E+15	5.36E+11
14	N+4	3.870E-01	2.790E-01	1.565E-01	8.780E-02	2.490E-02
		2.07E+20	1.50E+19	2.65E+18	4.71E+17	1.33E+16
15	N+5	9.830E-02	4.600E-01	5.638E-01	6.910E-01	7.550E-01
		5.27E+19	2.47E+19	9.55E+18	3.70E+18	4.05E+17
16	N+6	1.000E-09	1.000E-09	3.16E-09	1.000E-08	1.000E-07
		5.36E+11	5.36E+10	5.36E+10	5.36E+10	5.36E+10
20	O+3	4.120E-02	6.870E-03	8.289E-05	1.000E-06	1.000E-07
		2.21E+19	5.68E+17	1.40E+15	5.36E+12	5.36E+10
21	O+4	9.700E-02	5.500E-02	1.637E-02	4.870E-03	2.340E-05
		5.20E+19	2.95E+18	2.77E+17	2.61E+16	1.25E+13
22	O+5	3.040E-02	1.170E-01	8.420E-02	6.060E-02	1.500E-02
		1.63E+19	6.27E+18	1.43E+18	3.25E+17	6.97E+15
23	O+6	1.570E-03	4.050E-02	7.697E-02	1.540E-01	2.070E-01
		8.42E+17	2.17E+18	1.34E+18	8.25E+17	1.11E+17

(Table B-III con't)

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TABLES OF AIR DATA

SPECIE CONCENTRATION FRACTIONS		TEMP= 232000, (DFG.A)			
N	SPECIE	1.000E-03	1.000E-04	1.000E-05	1.000E-06
1	E-	5.210E+00	5.218E+00	5.220E+00	5.222E+00
		2.79E+17	2.60E+16	2.80E+15	2.80E+14
12	N++	1.000E-08	1.000E-09	1.000E-09	1.000E-09
		5.36E+00	5.36E+00	5.36E+05	5.36E+04
13	N+3	1.000E-07	1.000E-08	1.000E-09	1.000E-09
		5.36E+09	5.36E+07	5.36E+05	5.36E+04
14	N+4	5.580E-03	5.230E-04	1.000E-06	1.000E-07
		2.99E+14	2.80E+12	5.36E+08	5.36E+06
15	N+5	7.740E-01	7.740E-01	7.74E-01	7.800E-01
		4.15E+10	4.16E+15	4.18E+14	4.18E+13
16	N+6	1.000E-06	1.000E-05	3.100E-04	3.000E-04
		5.36E+10	1.66E+11	1.66E+11	1.61E+10
20	O+3	1.000E-08	1.000E-09	1.000E-09	1.000E-09
		5.36E+08	5.36E+06	5.36E+05	5.36E+04
21	O+4	1.000E-06	1.000E-07	1.000E-08	1.000E-09
		5.36E+10	5.36E+08	5.36E+06	5.36E+04
22	O+5	3.060E-03	2.580E-04	1.000E-06	1.000E-07
		1.64E+14	1.28E+12	5.36E+08	5.36E+06
23	O+6	2.170E-01	2.200E-01	2.200E-01	2.200E-01
		1.16E+16	1.18E+15	1.18E+14	1.18E+13

Table B-IV

74/05/10,

TABLES OF AIR DATA

SPECIE SPECIFICATIONS

N	SPECIE	CHARGE	MASS	EZERO
1	E-	-1	.001	0.000
2	N2	0	28.000	0.000
3	N2+	1	28.000	15.580
4	NO	0	30.000	.031
5	NO+	1	30.000	10.197
6	O2	0	32.000	0.000
7	O2+	1	32.000	12.062
8	N	0	14.000	4.880
9	N+	1	14.000	19.411
10	O	0	16.000	2.558
11	O+	1	16.000	16.175
12	V++	2	14.000	49.011
13	N+3	3	14.000	96.448
14	N+4	4	14.000	173.915
15	N+5	5	14.000	271.797
16	N+6	6	14.000	823.843
17	N+7	7	14.000	1490.851
18	N-	-1	14.000	6.400
19	O++	2	16.000	51.291
20	O+3	3	16.000	106.184
21	O+4	4	16.000	183.600
22	O+5	5	16.000	297.498
23	O+6	6	16.000	435.608
24	O+7	7	16.000	1174.884
25	O+8	8	16.000	2046.245
26	O-	-1	16.000	1.079
27	CO2	0	44.000	-4.775
28	NO2	0	46.000	.372
29	O3	0	48.000	1.506
30	CO	0	28.000	-1.179
31	O2-	-1	32.000	-.429
32	C	0	12.000	7.371
33	CO+	1	28.000	12.834
34	C+	1	12.000	18.630

Table B-V

74/05/10.

TABLES OF AIR DATA

SPECIFIC INTERNAL ENERGIES (E-E(0))/RT

TEMP	°C	°F	°R	°N	°D
1000.	2,624.19	2,646.75	2,789.23	2,622.44	2,775.04
1400.	2,746.56	2,780.01	2,902.40	2,744.22	2,921.39
1800.	2,868.10	2,906.93	2,996.67	2,850.27	3,033.89
2200.	2,936.11	3,033.03	3,071.49	2,936.73	3,126.65
2600.	3,007.76	3,159.91	3,131.38	3,006.93	3,207.48
3000.	3,064.68	3,283.89	3,180.38	3,064.60	3,281.63
3400.	3,112.47	3,400.18	3,221.38	3,112.78	3,349.20
3800.	3,152.78	3,505.24	3,256.45	3,153.70	3,411.41
4200.	3,187.47	3,597.47	3,287.10	3,169.03	3,468.69
4600.	3,217.74	3,678.80	3,314.52	3,220.04	3,521.37
5000.	3,244.53	3,744.36	3,339.62	3,247.75	3,569.65
5400.	3,268.59	3,801.06	3,363.20	3,273.04	3,613.85
5800.	3,290.51	3,849.78	3,385.92	3,296.61	3,653.36
6200.	3,310.67	3,890.96	3,408.31	3,319.19	3,688.67
6600.	3,330.21	3,926.45	3,430.74	3,341.40	3,719.45
7000.	3,349.07	3,957.33	3,453.49	3,363.85	3,745.59
7400.	3,368.02	3,985.28	3,476.66	3,387.11	3,767.03
7800.	3,387.05	4,010.55	3,500.27	3,411.71	3,783.76
8200.	3,406.56	4,034.00	3,524.19	3,438.13	3,795.90
8600.	3,431.53	4,056.12	3,548.25	3,466.78	3,803.62
9000.	3,456.51	4,077.21	3,572.21	3,498.01	3,807.15
9400.	3,484.63	4,097.49	3,595.79	3,532.07	3,806.78
9800.	3,516.12	4,117.03	3,618.70	3,569.12	3,802.83
10000.	3,533.23	4,126.52	3,629.83	3,568.79	3,799.63
11000.	3,633.60	4,170.87	3,680.88	3,648.22	3,772.95
12000.	3,758.57	4,206.76	3,722.07	3,623.43	3,732.27
13000.	3,904.13	4,238.22	3,751.59	3,958.18	3,682.05
14000.	4,062.21	4,257.84	3,769.02	4,094.35	3,625.87
15000.	4,222.94	4,267.00	3,774.95	4,223.80	3,566.40
16000.	4,376.25	4,265.89	3,770.61	4,339.81	3,505.59
17000.	4,514.20	4,255.30	3,757.51	4,437.83	3,444.19
18000.	4,631.45	4,236.33	3,737.20	4,515.62	3,384.93
19000.	4,725.44	4,210.27	3,711.15	4,572.86	3,326.62
20000.	4,795.88	4,178.41	3,680.68	4,610.63	3,270.23
22000.	4,672.30	4,101.98	3,610.75	4,635.89	3,163.99
24000.	4,679.63	4,015.08	3,534.27	4,609.80	3,066.83
26000.	4,638.99	3,923.52	3,455.73	4,549.67	2,978.47
28000.	4,767.85	3,831.15	3,377.91	4,468.88	2,898.25
30000.	4,678.65	3,746.43	3,302.44	4,376.84	2,825.40
32000.	4,586.58	3,652.80	3,230.22	4,279.81	2,759.14
34000.	4,478.65	3,569.67	3,161.69	4,181.80	2,698.15
36000.	4,376.58	3,489.61	3,097.00	4,085.29	2,643.55
38000.	4,276.55	3,414.52	3,030.12	3,991.77	2,592.97
40000.	4,179.63	3,343.76	2,978.91	3,902.06	2,546.48
50000.	4,179.63	3,343.76	2,978.91	3,902.06	2,546.48
70000.	4,179.63	3,343.76	2,978.91	3,902.06	2,546.48
100000.	4,179.63	3,343.76	2,978.91	3,902.06	2,546.48
150000.	4,179.63	3,343.76	2,978.91	3,902.06	2,546.48
200000.	4,179.63	3,343.76	2,978.91	3,902.06	2,546.48
300000.	4,179.63	3,343.76	2,978.91	3,902.06	2,546.48
400000.	4,179.63	3,343.76	2,978.91	3,902.06	2,546.48
500000.	4,179.63	3,343.76	2,978.91	3,902.06	2,546.48
600000.	4,179.63	3,343.76	2,978.91	3,902.06	2,546.48
800000.	4,179.63	3,343.76	2,978.91	3,902.06	2,546.48
1000000.	4,179.63	3,343.76	2,978.91	3,902.06	2,546.48

(Table B-V con't)

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TABLES OF AIR DATA

SPECIFIC INTERNAL ENERGIES ($E=E(0)$)/RT

TEMP	O2+	N	N+	O	O+
1000.	2.70707	1.50000	1.62287	1.59613	1.50000
1400.	2.84745	1.50000	1.58681	1.57186	1.50000
1800.	2.95677	1.50001	1.56955	1.55752	1.50000
2200.	3.04127	1.50011	1.55737	1.54780	1.50000
2600.	3.10813	1.50064	1.54948	1.54150	1.50001
3000.	3.16255	1.50230	1.54481	1.53773	1.50006
3400.	3.20807	1.50604	1.54288	1.53622	1.50034
3800.	3.24724	1.51281	1.54334	1.53678	1.50099
4200.	3.28198	1.52357	1.54587	1.53920	1.50237
4600.	3.31368	1.53814	1.55011	1.54321	1.50483
5000.	3.34430	1.55721	1.55571	1.54852	1.50673
5400.	3.37442	1.58035	1.56232	1.55464	1.51439
5800.	3.40522	1.60713	1.56965	1.56189	1.52205
6200.	3.43741	1.63646	1.57745	1.56943	1.53185
6600.	3.47142	1.66914	1.58549	1.57724	1.54387
7000.	3.50737	1.70247	1.59363	1.58516	1.55806
7400.	3.54513	1.73778	1.60174	1.59304	1.57435
7800.	3.58431	1.77293	1.60972	1.60079	1.59256
8200.	3.62436	1.80788	1.61751	1.60831	1.61249
8600.	3.66459	1.84215	1.62507	1.61557	1.63391
9000.	3.70431	1.87537	1.63238	1.62252	1.65658
9400.	3.74280	1.90726	1.63941	1.62916	1.68022
9800.	3.77944	1.93763	1.64617	1.63547	1.70458
10000.	3.79688	1.95220	1.64945	1.63852	1.71696
11000.	3.87312	2.01867	1.66487	1.65273	1.77960
12000.	3.92217	2.07506	1.67880	1.66580	1.84127
13000.	3.96103	2.12332	1.69147	1.67875	1.89954
14000.	3.97332	2.16640	1.70310	1.69291	1.95287
15000.	3.96807	2.20766	1.70860	1.70967	2.00040
16000.	3.94870	2.25047	1.71343	1.73138	2.04188
17000.	3.91849	2.29790	1.72416	1.75922	2.07740
18000.	3.88031	2.35244	1.73397	1.79512	2.10735
19000.	3.83650	2.41593	1.75301	1.84060	2.13223
20000.	3.78895	2.48934	1.76253	1.89683	2.15261
22000.	3.68811	2.66642	1.78220	2.04409	2.18230
24000.	3.58566	2.87682	1.80351	2.23647	2.20092
26000.	3.48591	3.10574	1.82743	2.46496	2.21240
28000.	3.39099	3.35549	1.85445	2.71406	2.22004
30000.	3.30186	3.55039	1.88709	2.96582	2.22663
32000.	3.21876	3.73960	1.92489	3.20397	2.23453
34000.	3.14158	3.89768	1.96933	3.41666	2.24582
36000.	3.07062	4.02364	2.02125	3.59734	2.26224
38000.	3.00369	4.11944	2.08131	3.74410	2.28547
40000.	2.94217	4.18864	2.14986	3.85835	2.31662
50000.	2.94217	4.27135	2.60891	4.07439	2.61300
70000.	2.94217	4.27135	2.60891	4.07439	2.61300
100000.	2.94217	4.27135	2.60891	4.07439	2.61300
150000.	2.94217	4.27135	2.60891	4.07439	2.61300
200000.	2.94217	4.27135	2.60891	4.07439	2.61300
300000.	2.94217	4.27135	2.60891	4.07439	2.61300
400000.	2.94217	4.27135	2.60891	4.07439	2.61300
500000.	2.94217	4.27135	2.60891	4.07439	2.61300
600000.	2.94217	4.27135	2.60891	4.07439	2.61300
800000.	2.94217	4.27135	2.60891	4.07439	2.61300
1000000.	2.94217	4.27135	2.60891	4.07439	2.61300

(Table B-V con't)

74/05/10.

TABLES OF AIR DATA

SPECIFIC INTERNAL ENERGIES ($E-E(0)$)/RT

TEMP	M=2	M=3	M=4
1000.	1.55422	1.50000	1.50000
1400.	1.55422	1.50000	1.50000
1800.	1.55422	1.50000	1.50000
2200.	1.55422	1.50000	1.50000
2600.	1.55422	1.50000	1.50000
3000.	1.55422	1.50000	1.50000
3400.	1.54800	1.50000	1.50000
3800.	1.54307	1.50000	1.50000
4200.	1.53905	1.50000	1.50000
4600.	1.53572	1.50000	1.50000
5000.	1.53291	1.50000	1.50000
5400.	1.53052	1.50000	1.50000
5800.	1.52846	1.50001	1.50000
6200.	1.52668	1.50002	1.50000
6600.	1.52513	1.50006	1.50000
7000.	1.52381	1.50012	1.50000
7400.	1.52269	1.50025	1.50001
7800.	1.52178	1.50046	1.50002
8200.	1.52109	1.50079	1.50003
8600.	1.52062	1.50131	1.50006
9000.	1.52039	1.50207	1.50010
9400.	1.52042	1.50313	1.50016
9800.	1.52074	1.50456	1.50026
10000.	1.52101	1.50545	1.50032
11000.	1.52359	1.51193	1.50083
12000.	1.52839	1.52274	1.50183
13000.	1.53559	1.53896	1.50356
14000.	1.54525	1.56157	1.50625
15000.	1.55731	1.59039	1.51014
16000.	1.57165	1.62606	1.51540
17000.	1.58807	1.66803	1.52218
18000.	1.60633	1.71554	1.53055
19000.	1.62616	1.76803	1.54056
20000.	1.64751	1.82416	1.55216
22000.	1.69248	1.94332	1.57985
24000.	1.73990	2.06483	1.61266
26000.	1.78795	2.18193	1.64926
28000.	1.83541	2.29000	1.68627
30000.	1.88138	2.38648	1.72632
32000.	1.92533	2.47046	1.76825
34000.	1.96695	2.54214	1.80708
36000.	2.00616	2.60240	1.84410
38000.	2.04306	2.65245	1.87877
40000.	2.07786	2.69359	1.91078
50000.	2.23236	2.80575	2.02279
70000.	2.58796	2.83825	2.106
100000.	3.31150	2.91726	2.10151
150000.	3.90505	3.35239	2.19264
200000.	3.75210	3.54600	2.38824
300000.	3.23274	3.36002	2.61523
400000.	2.86550	3.05141	2.60432
500000.	2.61952	2.80002	2.51576
600000.	2.44657	2.61730	2.41726
800000.	2.22165	2.36322	2.24992
1000000.	2.04284	2.20126	2.10726

(Table B-V con't)

74/05/10.

TABLES OF AIR DATA

SPECIE INTERNAL ENERGIES (E-E(0))/RT

TEMP	0++	0+3	0+4
1000.	2.78001	2.90240	2.74424
1400.	2.90693	2.99067	2.85027
1800.	3.03303	3.07146	2.93673
2200.	3.15991	3.13158	3.00893
2600.	3.28389	3.18038	3.06460
3000.	3.40018	3.22136	3.11278
3400.	3.50524	3.25645	3.15370
3800.	3.59747	3.28710	3.18903
4200.	3.67696	3.31452	3.22004
4600.	3.74436	3.33962	3.24775
5000.	3.80146	3.36320	3.27304
5400.	3.84978	3.38592	3.29661
5800.	3.89096	3.40851	3.31419
6200.	3.92605	3.43074	3.33410
6600.	3.95753	3.45349	3.36385
7000.	3.98554	3.47666	3.38711
7400.	4.01055	3.50021	3.41171
7800.	4.03400	3.52419	3.43813
8200.	4.05612	3.54825	3.46678
8600.	4.07721	3.57221	3.49801
9000.	4.09749	3.59579	3.53207
9400.	4.11703	3.61870	3.56912
9800.	4.12652	3.62983	3.58879
10000.	4.17087	3.68088	3.69822
11000.	4.20876	3.72207	3.82343
12000.	4.23622	3.75159	3.95818
13000.	4.25784	3.76902	4.09435
14000.	4.26700	3.77495	4.22360
15000.	4.26589	3.77961	4.33981
16000.	4.25530	3.76751	4.43783
17000.	4.23633	3.73720	4.51562
18000.	4.21027	3.71115	4.57286
19000.	4.17841	3.68068	4.61063
20000.	4.10198	3.61075	4.63549
22000.	4.01508	3.53427	4.60980
24000.	3.92352	3.45573	4.54967
26000.	3.83115	3.37791	4.46888
28000.	3.74043	3.30244	4.37684
30000.	3.65280	3.23022	4.27981
32000.	3.56907	3.16169	4.18180
34000.	3.48961	3.09700	4.08329
36000.	3.41452	3.03612	3.99177
38000.	3.34376	2.97891	3.90206
40000.	3.34376	2.97891	3.90206
50000.	3.34376	2.97891	3.90206
70000.	3.34376	2.97891	3.90206
100000.	3.34376	2.97891	3.90206
150000.	3.34376	2.97891	3.90206
200000.	3.34376	2.97891	3.90206
300000.	3.34376	2.97891	3.90206
400000.	3.34376	2.97891	3.90206
500000.	3.34376	2.97891	3.90206
600000.	3.34376	2.97891	3.90206
800000.	3.34376	2.97891	3.90206
1000000.	3.34376	2.97891	3.90206

74/05/10.

Table B-VI
TABLES OF AIR DATA

SPECIE PARTITION FUNCTIONS

TEMP	N2	N2+	NO	NO+	O2
1000.	1.615E+02	5.805E+02	1.614E+03	3.625E+02	8.164E+02
1400.	2.703E+02	5.718E+02	2.537E+03	5.393E+02	1.285E+03
1800.	3.747E+02	4.310E+02	3.652E+03	7.471E+02	1.862E+03
2200.	4.957E+02	1.075E+03	4.969E+03	9.882E+02	2.557E+03
2600.	6.340E+02	1.404E+03	6.494E+03	1.264E+03	3.378E+03
3000.	7.903E+02	1.795E+03	8.250E+03	1.574E+03	4.336E+03
3400.	9.648E+02	2.261E+03	1.018E+04	1.921E+03	5.442E+03
3800.	1.156E+03	2.369E+03	1.236E+04	2.303E+03	6.708E+03
4200.	1.350E+03	3.450E+03	1.475E+04	2.723E+03	8.146E+03
4600.	1.595E+03	4.190E+03	1.738E+04	3.179E+03	9.767E+03
5000.	1.842E+03	5.039E+03	2.024E+04	3.674E+03	1.158E+04
5400.	2.149E+03	6.002E+03	2.334E+04	4.207E+03	1.361E+04
5800.	2.345E+03	7.087E+03	2.668E+04	4.779E+03	1.585E+04
6200.	2.701E+03	8.301E+03	3.028E+04	5.392E+03	1.832E+04
6600.	3.070E+03	9.651E+03	3.414E+04	6.046E+03	2.102E+04
7000.	3.372E+03	1.114E+04	3.828E+04	6.742E+03	2.397E+04
7400.	3.739E+03	1.270E+04	4.269E+04	7.462E+03	2.718E+04
7800.	4.128E+03	1.458E+04	4.741E+04	8.269E+03	3.064E+04
8200.	4.539E+03	1.654E+04	5.242E+04	9.104E+03	3.435E+04
8600.	4.973E+03	1.867E+04	5.776E+04	9.992E+03	3.833E+04
9000.	5.433E+03	2.098E+04	6.343E+04	1.093E+04	4.257E+04
9400.	5.913E+03	2.348E+04	6.945E+04	1.193E+04	4.706E+04
9800.	6.433E+03	2.617E+04	7.583E+04	1.300E+04	5.181E+04
10000.	6.702E+03	2.760E+04	7.913E+04	1.356E+04	5.427E+04
11000.	8.172E+03	3.552E+04	9.720E+04	1.663E+04	6.749E+04
12000.	9.896E+03	4.449E+04	1.177E+05	2.024E+04	8.212E+04
13000.	1.192E+04	5.585E+04	1.408E+05	2.450E+04	9.799E+04
14000.	1.452E+04	6.845E+04	1.665E+05	2.955E+04	1.150E+05
15000.	1.719E+04	8.282E+04	1.948E+05	3.550E+04	1.328E+05
16000.	2.059E+04	9.902E+04	2.256E+05	4.248E+04	1.515E+05
17000.	2.462E+04	1.171E+05	2.586E+05	5.061E+04	1.708E+05
18000.	2.934E+04	1.370E+05	2.942E+05	6.000E+04	1.905E+05
19000.	3.485E+04	1.547E+05	3.319E+05	7.075E+04	2.106E+05
20000.	4.120E+04	1.822E+05	3.714E+05	8.291E+04	2.310E+05
22000.	5.004E+04	2.344E+05	4.558E+05	1.117E+05	2.721E+05
24000.	7.601E+04	2.929E+05	5.059E+05	1.466E+05	3.131E+05
26000.	9.949E+04	3.569E+05	6.404E+05	1.877E+05	3.557E+05
28000.	1.271E+05	4.257E+05	7.382E+05	2.346E+05	3.955E+05
30000.	1.584E+05	4.944E+05	8.381E+05	2.870E+05	4.323E+05
32000.	1.943E+05	5.745E+05	9.394E+05	3.445E+05	4.699E+05
34000.	2.333E+05	6.527E+05	1.041E+06	4.065E+05	5.062E+05
36000.	2.761E+05	7.330E+05	1.143E+06	4.726E+05	5.413E+05
38000.	3.217E+05	8.146E+05	1.244E+06	5.421E+05	5.750E+05
40000.	3.700E+05	8.970E+05	1.344E+06	6.146E+05	6.074E+05
50000.	3.700E+05	8.970E+05	1.344E+06	6.146E+05	6.074E+05
60000.	3.700E+05	8.970E+05	1.344E+06	6.146E+05	6.074E+05
70000.	3.700E+05	8.970E+05	1.344E+06	6.146E+05	6.074E+05
80000.	3.700E+05	8.970E+05	1.344E+06	6.146E+05	6.074E+05
100000.	3.700E+05	8.970E+05	1.344E+06	6.146E+05	6.074E+05

(Table B-VI con't)

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TABLES OF AIR DATA

SPECIE PARTITION FUNCTIONS

TEMP	O2+	O	N+	O	O+
1000.	9.034E+02	4.010E+00	7.434E+00	8.111E+00	4.000E+00
1400.	1.364E+03	4.000E+00	8.225E+00	8.342E+00	4.000E+00
1800.	1.975E+03	4.000E+00	8.384E+00	8.478E+00	4.000E+00
2200.	2.680E+03	4.000E+00	8.486E+00	8.567E+00	4.000E+00
2600.	3.472E+03	4.000E+00	8.572E+00	8.631E+00	4.000E+00
3000.	4.387E+03	4.001E+00	8.630E+00	8.680E+00	4.000E+00
3400.	5.418E+03	4.003E+00	8.677E+00	8.720E+00	4.000E+00
3800.	6.565E+03	4.007E+00	8.719E+00	8.755E+00	4.000E+00
4200.	7.844E+03	4.014E+00	8.756E+00	8.789E+00	4.001E+00
4600.	9.226E+03	4.025E+00	8.796E+00	8.822E+00	4.002E+00
5000.	1.074E+04	4.041E+00	8.835E+00	8.855E+00	4.005E+00
5400.	1.240E+04	4.062E+00	8.875E+00	8.890E+00	4.006E+00
5800.	1.419E+04	4.089E+00	8.917E+00	8.928E+00	4.013E+00
6200.	1.613E+04	4.123E+00	8.960E+00	8.967E+00	4.020E+00
6600.	1.823E+04	4.162E+00	9.006E+00	9.006E+00	4.030E+00
7000.	2.049E+04	4.208E+00	9.054E+00	9.051E+00	4.042E+00
7400.	2.293E+04	4.260E+00	9.103E+00	9.096E+00	4.057E+00
7800.	2.556E+04	4.317E+00	9.154E+00	9.142E+00	4.075E+00
8200.	2.840E+04	4.381E+00	9.206E+00	9.190E+00	4.095E+00
8600.	3.145E+04	4.449E+00	9.259E+00	9.240E+00	4.119E+00
9000.	3.474E+04	4.522E+00	9.314E+00	9.290E+00	4.147E+00
9400.	3.826E+04	4.606E+00	9.369E+00	9.341E+00	4.177E+00
9800.	4.205E+04	4.681E+00	9.425E+00	9.392E+00	4.211E+00
10000.	4.404E+04	4.724E+00	9.453E+00	9.418E+00	4.229E+00
11000.	5.562E+04	4.946E+00	9.596E+00	9.550E+00	4.330E+00
12000.	6.761E+04	5.189E+00	9.740E+00	9.663E+00	4.448E+00
13000.	8.247E+04	5.446E+00	9.885E+00	9.817E+00	4.582E+00
14000.	9.903E+04	5.710E+00	1.003E+01	9.954E+00	4.729E+00
15000.	1.174E+05	5.986E+00	1.010E+01	1.009E+01	4.887E+00
16000.	1.376E+05	6.276E+00	1.018E+01	1.024E+01	5.055E+00
17000.	1.595E+05	6.577E+00	1.032E+01	1.039E+01	5.224E+00
18000.	1.830E+05	6.894E+00	1.047E+01	1.056E+01	5.409E+00
19000.	2.079E+05	7.222E+00	1.075E+01	1.074E+01	5.594E+00
20000.	2.341E+05	7.593E+00	1.090E+01	1.094E+01	5.781E+00
22000.	2.898E+05	8.411E+00	1.118E+01	1.144E+01	6.161E+00
24000.	3.490E+05	9.592E+00	1.147E+01	1.209E+01	6.544E+00
26000.	4.108E+05	1.058E+01	1.176E+01	1.294E+01	6.925E+00
28000.	4.743E+05	1.202E+01	1.206E+01	1.402E+01	7.303E+00
30000.	5.387E+05	1.374E+01	1.238E+01	1.538E+01	7.676E+00
32000.	6.035E+05	1.579E+01	1.270E+01	1.703E+01	8.047E+00
34000.	6.682E+05	1.817E+01	1.305E+01	1.901E+01	8.416E+00
36000.	7.324E+05	2.092E+01	1.343E+01	2.133E+01	8.786E+00
38000.	7.959E+05	2.404E+01	1.383E+01	2.398E+01	9.161E+00
40000.	8.584E+05	2.755E+01	1.428E+01	2.699E+01	9.545E+00
50000.	8.564E+05	5.096E+01	1.728E+01	4.717E+01	1.177E+01
70000.	8.584E+05	5.096E+01	1.728E+01	4.717E+01	1.177E+01
100000.	8.584E+05	5.096E+01	1.728E+01	4.717E+01	1.177E+01
150000.	8.584E+05	5.096E+01	1.728E+01	4.717E+01	1.177E+01
200000.	8.584E+05	5.096E+01	1.728E+01	4.717E+01	1.177E+01
300000.	8.584E+05	5.096E+01	1.728E+01	4.717E+01	1.177E+01
400000.	8.584E+05	5.096E+01	1.728E+01	4.717E+01	1.177E+01
500000.	8.584E+05	5.096E+01	1.728E+01	4.717E+01	1.177E+01
600000.	8.584E+05	5.096E+01	1.728E+01	4.717E+01	1.177E+01
800000.	8.584E+05	5.096E+01	1.728E+01	4.717E+01	1.177E+01
1000000.	8.584E+05	5.096E+01	1.728E+01	4.717E+01	1.177E+01

(Table B-VI cont)

7/4/65/10.

TABLES OF AIR DATA

SPECIE PARTITION FUNCTIONS

TEMP	N+2	N+3	N+4
1000.	5.679E+00	1.000E+00	2.000E+00
1400.	5.679E+00	1.000E+00	2.000E+00
1800.	5.679E+00	1.000E+00	2.000E+00
2200.	5.679E+00	1.000E+00	2.000E+00
2600.	5.679E+00	1.000E+00	2.000E+00
3000.	5.679E+00	1.000E+00	2.000E+00
3400.	5.715E+00	1.000E+00	2.000E+00
3800.	5.744E+00	1.000E+00	2.000E+00
4200.	5.768E+00	1.000E+00	2.000E+00
4600.	5.787E+00	1.000E+00	2.000E+00
5000.	5.804E+00	1.000E+00	2.000E+00
5400.	5.818E+00	1.000E+00	2.000E+00
5800.	5.831E+00	1.000E+00	2.000E+00
6200.	5.841E+00	1.000E+00	2.000E+00
6600.	5.851E+00	1.000E+00	2.000E+00
7000.	5.859E+00	1.000E+00	2.000E+00
7400.	5.867E+00	1.000E+00	2.000E+00
7800.	5.874E+00	1.000E+00	2.000E+00
8200.	5.880E+00	1.000E+00	2.000E+00
8600.	5.886E+00	1.000E+00	2.000E+00
9000.	5.891E+00	1.000E+00	2.000E+00
9400.	5.896E+00	1.000E+00	2.000E+00
9800.	5.901E+00	1.001E+00	2.000E+00
10000.	5.904E+00	1.001E+00	2.000E+00
11000.	5.916E+00	1.001E+00	2.000E+00
12000.	5.930E+00	1.003E+00	2.000E+00
13000.	5.945E+00	1.005E+00	2.001E+00
14000.	5.963E+00	1.009E+00	2.001E+00
15000.	5.983E+00	1.014E+00	2.003E+00
16000.	6.006E+00	1.021E+00	2.004E+00
17000.	6.031E+00	1.030E+00	2.007E+00
18000.	6.071E+00	1.042E+00	2.010E+00
19000.	6.109E+00	1.055E+00	2.013E+00
20000.	6.152E+00	1.072E+00	2.018E+00
22000.	6.252E+00	1.111E+00	2.031E+00
24000.	6.371E+00	1.161E+00	2.048E+00
26000.	6.507E+00	1.220E+00	2.069E+00
28000.	6.659E+00	1.289E+00	2.095E+00
30000.	6.825E+00	1.366E+00	2.126E+00
32000.	7.005E+00	1.450E+00	2.160E+00
34000.	7.197E+00	1.541E+00	2.196E+00
36000.	7.400E+00	1.639E+00	2.239E+00
38000.	7.613E+00	1.742E+00	2.283E+00
40000.	7.835E+00	1.850E+00	2.330E+00
50000.	9.066E+00	2.449E+00	2.569E+00
70000.	1.222E+01	3.852E+00	3.145E+00
100000.	2.142E+01	5.224E+00	3.903E+00
150000.	4.945E+01	1.183E+01	5.837E+00
200000.	9.821E+01	2.097E+01	6.312E+00
300000.	2.211E+02	4.706E+01	9.548E+00
400000.	3.449E+02	7.646E+01	1.319E+01
500000.	4.546E+02	1.055E+02	1.672E+01
600000.	5.489E+02	1.319E+02	1.945E+01
800000.	6.666E+02	1.752E+02	2.535E+01

(Table B-VI con't)

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TABLES OF AIR DATA

SPECIE PARTITION FUNCTIONS

TEMP	O++	O+3	O+4
1000.	5.718E+02	2.537E+03	5.393E+02
1400.	8.010E+02	3.652E+03	7.471E+02
1800.	1.075E+03	4.969E+03	9.882E+02
2200.	1.404E+03	6.494E+03	1.264E+03
2600.	1.795E+03	8.230E+03	1.576E+03
3000.	2.251E+03	1.018E+04	1.921E+03
3400.	2.609E+03	1.236E+04	2.303E+03
3800.	3.450E+03	1.475E+04	2.723E+03
4200.	4.190E+03	1.736E+04	3.179E+03
4600.	5.034E+03	2.024E+04	3.674E+03
5000.	6.002E+03	2.334E+04	4.207E+03
5400.	7.067E+03	2.666E+04	4.779E+03
5800.	8.301E+03	3.028E+04	5.392E+03
6200.	9.651E+03	3.414E+04	6.046E+03
6600.	1.114E+04	3.828E+04	6.742E+03
7000.	1.278E+04	4.269E+04	7.482E+03
7400.	1.458E+04	4.741E+04	8.269E+03
7800.	1.654E+04	5.242E+04	9.104E+03
8200.	1.867E+04	5.776E+04	9.992E+03
8600.	2.098E+04	6.343E+04	1.093E+04
9000.	2.348E+04	6.945E+04	1.193E+04
9400.	2.617E+04	7.583E+04	1.300E+04
9800.	2.760E+04	7.915E+04	1.356E+04
10000.	3.552E+04	9.720E+04	1.663E+04
11000.	4.469E+04	1.177E+05	2.024E+04
12000.	5.583E+04	1.408E+05	2.450E+04
13000.	6.845E+04	1.665E+05	2.955E+04
14000.	8.262E+04	1.946E+05	3.550E+04
15000.	9.902E+04	2.256E+05	4.248E+04
16000.	1.171E+05	2.586E+05	5.061E+04
17000.	1.370E+05	2.942E+05	6.000E+04
18000.	1.587E+05	3.319E+05	7.075E+04
19000.	1.822E+05	3.714E+05	8.291E+04
20000.	2.344E+05	4.558E+05	1.117E+05
22000.	2.929E+05	5.459E+05	1.466E+05
24000.	3.569E+05	6.404E+05	1.877E+05
26000.	4.257E+05	7.382E+05	2.346E+05
28000.	4.984E+05	8.381E+05	2.870E+05
30000.	5.743E+05	9.394E+05	3.445E+05
32000.	6.527E+05	1.041E+06	4.065E+05
34000.	7.330E+05	1.143E+06	4.726E+05
36000.	8.146E+05	1.244E+06	5.421E+05
38000.	8.970E+05	1.344E+06	6.146E+05
40000.	8.970E+05	1.344E+06	6.146E+05
50000.	8.970E+05	1.344E+06	6.146E+05
70000.	8.970E+05	1.344E+06	6.146E+05
100000.	8.970E+05	1.344E+06	6.146E+05
150000.	8.970E+05	1.344E+06	6.146E+05
200000.	8.970E+05	1.344E+06	6.146E+05
300000.	8.970E+05	1.344E+06	6.146E+05
400000.	8.970E+05	1.344E+06	6.146E+05
500000.	8.970E+05	1.344E+06	6.146E+05
600000.	8.970E+05	1.344E+06	6.146E+05
800000.	8.970E+05	1.344E+06	6.146E+05
1000000.	8.970E+05	1.344E+06	6.146E+05

Table B-VII

74/05/10.

TABLES OF AIR DATA

ALIGNMENT EXCITATION/IONIZATION RATES (1/SEC)

TEMP	1	2	3	4	5
.1	1.73E-18	1.78E-29	1.53E-19	6.19E-49	1.10E-67
.2	5.58E-14	1.96E-19	1.44E-14	8.17E-29	3.14E-38
.3	2.01E-12	2.10E-16	6.99E-13	4.60E-22	2.08E-28
.4	1.26E-11	7.13E-15	4.95E-12	1.15E-18	1.71E-23
.5	4.00E-11	6.04E-14	1.61E-11	1.30E-16	1.55E-20
.6	8.66E-11	2.55E-13	3.53E-11	5.11E-15	1.46E-18
.7	1.52E-10	7.25E-13	6.17E-11	3.05E-14	3.81E-17
.8	2.52E-10	1.60E-12	9.40E-11	1.71E-13	4.43E-16
.9	3.24E-10	2.98E-12	1.30E-10	6.59E-13	3.01E-15
1.0	4.24E-10	4.43E-12	1.64E-10	1.45E-12	1.40E-14
1.1	5.30E-10	7.48E-12	2.09E-10	4.17E-12	4.95E-14
1.2	6.36E-10	1.06E-11	2.49E-10	1.01E-11	1.42E-13
1.3	7.47E-10	1.43E-11	2.90E-10	1.90E-11	3.50E-13
1.4	8.56E-10	1.85E-11	3.29E-10	3.28E-11	7.58E-13
1.5	9.63E-10	2.32E-11	3.66E-10	5.26E-11	1.49E-12
1.6	1.07E-09	2.82E-11	4.05E-10	7.96E-11	2.69E-12
1.7	1.17E-09	3.37E-11	4.41E-10	1.15E-10	4.54E-12
1.8	1.27E-09	3.94E-11	4.76E-10	1.59E-10	7.26E-12
1.9	1.36E-09	4.53E-11	5.09E-10	2.13E-10	1.11E-11
2.0	1.46E-09	5.15E-11	5.41E-10	2.76E-10	1.62E-11
2.1	1.54E-09	5.78E-11	5.72E-10	3.50E-10	2.29E-11
2.2	1.63E-09	6.42E-11	6.01E-10	4.34E-10	3.14E-11
2.3	1.71E-09	7.07E-11	6.30E-10	5.26E-10	4.20E-11
2.4	1.79E-09	7.72E-11	6.57E-10	6.31E-10	5.49E-11
2.5	1.87E-09	8.37E-11	6.82E-10	7.44E-10	7.03E-11
2.6	1.94E-09	9.02E-11	7.07E-10	8.65E-10	8.84E-11
2.7	2.01E-09	9.67E-11	7.31E-10	9.94E-10	1.09E-10
2.8	2.07E-09	1.08E-10	7.53E-10	1.13E-09	1.34E-10
2.9	2.13E-09	1.10E-10	7.75E-10	1.27E-09	1.61E-10
3.0	2.20E-09	1.16E-10	7.96E-10	1.42E-09	1.92E-10
3.1	2.25E-09	1.22E-10	8.10E-10	1.58E-09	2.26E-10
3.2	2.31E-09	1.26E-10	8.35E-10	1.74E-09	2.64E-10
3.3	2.36E-09	1.34E-10	8.53E-10	1.90E-09	3.05E-10
3.4	2.41E-09	1.40E-10	8.71E-10	2.07E-09	3.51E-10
3.5	2.46E-09	1.45E-10	8.88E-10	2.24E-09	4.00E-10
3.6	2.51E-09	1.52E-10	9.04E-10	2.42E-09	4.53E-10
3.7	2.55E-09	1.58E-10	9.20E-10	2.59E-09	5.09E-10
3.8	2.60E-09	1.63E-10	9.35E-10	2.77E-09	5.70E-10
3.9	2.64E-09	1.69E-10	9.49E-10	2.95E-09	6.34E-10
4.0	2.68E-09	1.74E-10	9.63E-10	3.12E-09	7.03E-10
4.1	2.71E-09	1.79E-10	9.77E-10	3.30E-09	7.75E-10
4.2	2.75E-09	1.84E-10	9.89E-10	3.48E-09	8.51E-10
4.3	2.78E-09	1.89E-10	1.00E-09	3.66E-09	9.30E-10
4.4	2.82E-09	1.94E-10	1.01E-09	3.84E-09	1.01E-09
4.5	2.85E-09	1.99E-10	1.03E-09	4.01E-09	1.10E-09
4.6	2.88E-09	2.04E-10	1.04E-09	4.19E-09	1.17E-09
4.7	2.91E-09	2.09E-10	1.05E-09	4.36E-09	1.24E-09
4.8	2.94E-09	2.13E-10	1.06E-09	4.53E-09	1.33E-09
4.9	2.96E-09	2.17E-10	1.07E-09	4.70E-09	1.44E-09
5.0	2.99E-09	2.21E-10	1.08E-09	4.87E-09	1.54E-09

(Table B-VII con't)

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TABLES OF AFW DATA

ALF/ARL EXCITATION/IONIZATION RATES (1/SEC)

TEMP	6	7	8	9	10
.1	3.44E-19	3.80E-25	2.57E-14	2.57E-50	0.
.2	6.26E-14	5.37E-17	1.16E-11	2.63E-29	0.
.3	3.92E-12	1.67E-14	9.59E-11	5.01E-22	0.
.4	3.19E-11	5.90E-15	2.67E-10	1.07E-18	0.
.5	1.13E-10	2.63E-12	5.04E-10	1.50E-16	7.24E-23
.6	2.64E-10	9.46E-12	7.73E-10	4.12E-15	5.14E-20
.7	4.84E-10	2.37E-11	1.05E-09	4.48E-14	1.61E-18
.8	7.61E-10	4.75E-11	1.53E-09	2.71E-13	2.88E-17
.9	1.08E-09	8.10E-11	1.60E-09	1.11E-12	2.66E-16
1.0	1.43E-09	1.25E-10	1.85E-09	3.46E-12	1.57E-15
1.1	1.79E-09	1.77E-10	2.09E-09	8.89E-12	6.09E-15
1.2	2.16E-09	2.57E-10	2.32E-09	1.96E-11	2.24E-14
1.3	2.53E-09	3.04E-10	2.53E-09	3.83E-11	6.26E-14
1.4	2.89E-09	3.75E-10	2.73E-09	6.85E-11	1.51E-13
1.5	3.24E-09	4.50E-10	2.91E-09	1.14E-10	5.25E-13
1.6	3.58E-09	5.26E-10	3.09E-09	1.76E-10	8.56E-13
1.7	3.91E-09	6.07E-10	3.25E-09	2.84E-10	1.15E-12
1.8	4.23E-09	6.87E-10	3.47E-09	3.77E-10	1.96E-12
1.9	4.55E-09	7.68E-10	3.64E-09	5.18E-10	3.16E-12
2.0	4.82E-09	8.43E-10	3.67E-09	6.92E-10	4.86E-12
2.1	5.09E-09	9.27E-10	3.79E-09	9.01E-10	7.20E-12
2.2	5.35E-09	1.01E-09	3.91E-09	1.15E-09	1.03E-11
2.3	5.59E-09	1.08E-09	4.01E-09	1.43E-09	1.45E-11
2.4	5.83E-09	1.16E-09	4.11E-09	1.75E-09	1.93E-11
2.5	6.05E-09	1.23E-09	4.21E-09	2.12E-09	2.55E-11
2.6	6.26E-09	1.30E-09	4.29E-09	2.52E-09	3.50E-11
2.7	6.46E-09	1.37E-09	4.36E-09	2.96E-09	4.20E-11
2.8	6.65E-09	1.44E-09	4.45E-09	3.45E-09	5.26E-11
2.9	6.83E-09	1.50E-09	4.53E-09	3.97E-09	6.48E-11
3.0	7.00E-09	1.57E-09	4.60E-09	4.53E-09	7.89E-11
3.1	7.16E-09	1.63E-09	4.66E-09	5.13E-09	9.49E-11
3.2	7.31E-09	1.67E-09	4.72E-09	5.77E-09	1.13E-10
3.3	7.45E-09	1.75E-09	4.78E-09	6.44E-09	1.33E-10
3.4	7.59E-09	1.80E-09	4.83E-09	7.15E-09	1.55E-10
3.5	7.72E-09	1.86E-09	4.88E-09	7.89E-09	1.80E-10
3.6	7.84E-09	1.91E-09	4.93E-09	8.66E-09	2.07E-10
3.7	7.96E-09	1.96E-09	4.97E-09	9.46E-09	2.36E-10
3.8	8.07E-09	2.01E-09	5.01E-09	1.03E-08	2.68E-10
3.9	8.18E-09	2.05E-09	5.05E-09	1.11E-08	3.02E-10
4.0	8.28E-09	2.10E-09	5.09E-09	1.20E-08	3.39E-10
4.1	8.37E-09	2.14E-09	5.12E-09	1.29E-08	3.78E-10
4.2	8.46E-09	2.18E-09	5.15E-09	1.38E-08	4.20E-10
4.3	8.55E-09	2.22E-09	5.18E-09	1.48E-08	4.64E-10
4.4	8.63E-09	2.26E-09	5.21E-09	1.58E-08	5.11E-10
4.5	8.71E-09	2.30E-09	5.24E-09	1.67E-08	5.60E-10
4.6	8.78E-09	2.33E-09	5.26E-09	1.77E-08	6.12E-10
4.7	8.85E-09	2.37E-09	5.28E-09	1.87E-08	6.67E-10
4.8	8.92E-09	2.40E-09	5.31E-09	1.97E-08	7.24E-10
4.9	8.98E-09	2.43E-09	5.33E-09	2.06E-08	7.83E-10
5.0	9.04E-09	2.46E-09	5.34E-09	2.16E-08	8.45E-10

(Table B-VII cont)

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TABLES OF AIR DATA

ALIGNMENT EXCITATION/RELAXATION RATES (1/SEC)

TEMP	11	12	13	14	15
.1	7.49E-30	3.90E-41	2.43E-57	5.09E-65	4.17E-49
.2	5.29E-23	4.14E-25	9.65E-33	3.50E-37	4.53E-29
.3	5.23E-18	1.02E-19	1.59E-24	7.10E-28	2.16E-22
.4	1.73E-15	5.27E-17	2.11E-20	3.24E-23	4.88E-19
.5	5.80E-14	2.30E-15	6.31E-16	2.04E-20	5.17E-17
.6	6.12E-13	2.02E-14	2.32E-16	1.49E-18	1.16E-15
.7	3.33E-12	1.21E-13	4.26E-15	3.21E-17	1.10E-14
.8	1.14E-11	7.21E-13	3.20E-14	3.20E-16	6.00E-14
.9	3.23E-11	2.13E-12	1.50E-13	1.91E-15	2.27E-13
1.0	7.16E-11	5.07E-12	5.60E-13	7.96E-15	6.66E-13
1.1	1.56E-10	1.04E-11	1.57E-12	2.57E-14	1.62E-12
1.2	2.59E-10	1.91E-11	3.71E-12	6.76E-14	3.41E-12
1.3	3.79E-10	3.17E-11	7.67E-12	1.54E-13	6.46E-12
1.4	5.63E-10	4.94E-11	1.43E-11	3.12E-13	1.12E-11
1.5	7.94E-10	7.34E-11	2.44E-11	5.72E-13	1.82E-11
1.6	1.07E-09	1.23E-10	3.49E-11	9.74E-13	2.79E-11
1.7	1.59E-09	1.59E-10	5.48E-11	1.55E-12	4.06E-11
1.8	1.76E-09	1.81E-10	4.47E-11	2.35E-12	5.74E-11
1.9	2.17E-09	2.31E-10	1.17E-10	3.41E-12	7.81E-11
2.0	2.62E-09	2.67E-10	1.57E-10	4.75E-12	1.03E-10
2.1	3.10E-09	3.50E-10	2.00E-10	6.42E-12	1.34E-10
2.2	3.61E-09	4.20E-10	2.60E-10	8.43E-12	1.69E-10
2.3	4.15E-09	4.95E-10	3.23E-10	1.08E-11	2.10E-10
2.4	4.71E-09	5.77E-10	3.94E-10	1.35E-11	2.57E-10
2.5	5.24E-09	6.64E-10	4.73E-10	1.67E-11	3.10E-10
2.6	5.84E-09	7.55E-10	5.54E-10	2.02E-11	3.69E-10
2.7	6.44E-09	8.52E-10	6.52E-10	2.41E-11	4.35E-10
2.8	7.11E-09	9.53E-10	7.53E-10	2.83E-11	5.06E-10
2.9	7.73E-09	1.06E-09	8.59E-10	3.30E-11	5.85E-10
3.0	8.35E-09	1.17E-09	9.71E-10	3.80E-11	6.70E-10
3.1	8.98E-09	1.28E-09	1.09E-09	4.33E-11	7.61E-10
3.2	9.60E-09	1.39E-09	1.21E-09	4.90E-11	8.59E-10
3.3	1.02E-08	1.51E-09	1.34E-09	5.49E-11	9.64E-10
3.4	1.08E-08	1.62E-09	1.47E-09	6.12E-11	1.08E-09
3.5	1.14E-08	1.74E-09	1.61E-09	6.77E-11	1.19E-09
3.6	1.20E-08	1.86E-09	1.74E-09	7.47E-11	1.32E-09
3.7	1.26E-08	1.99E-09	1.86E-09	8.14E-11	1.45E-09
3.8	1.32E-08	2.11E-09	2.03E-09	8.80E-11	1.59E-09
3.9	1.38E-08	2.23E-09	2.17E-09	9.50E-11	1.73E-09
4.0	1.43E-08	2.36E-09	2.32E-09	1.04E-10	1.88E-09
4.1	1.49E-08	2.46E-09	2.47E-09	1.11E-10	2.04E-09
4.2	1.54E-08	2.60E-09	2.61E-09	1.19E-10	2.20E-09
4.3	1.60E-08	2.73E-09	2.76E-09	1.27E-10	2.37E-09
4.4	1.65E-08	2.85E-09	2.91E-09	1.35E-10	2.54E-09
4.5	1.70E-08	2.97E-09	3.06E-09	1.43E-10	2.73E-09
4.6	1.74E-08	3.09E-09	3.21E-09	1.51E-10	2.91E-09
4.7	1.79E-08	3.21E-09	3.36E-09	1.59E-10	3.11E-09
4.8	1.84E-08	3.33E-09	3.50E-09	1.67E-10	3.30E-09
4.9	1.88E-08	3.45E-09	3.65E-09	1.76E-10	3.51E-09
5.0	1.92E-08	3.56E-09	3.77E-09	1.84E-10	3.72E-09

(Table B-VII con't)

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TABLES OF AIR DATA

ALIGNMENT EXCITATION/IONIZATION RATES (1/SEC)

TEMP	16	17	18	19	20
.1	1.79E-78	0.	3.42E-14	1.27E-17	1.37E-15
.2	1.92E-43	6.84E-50	1.61E-12	2.76E-14	1.99E-12
.3	6.14E-32	2.16E-36	8.20E-12	4.15E-13	2.62E-11
.4	3.65E-26	1.18E-29	1.94E-11	1.74E-12	1.04E-10
.5	1.09E-20	1.29E-25	3.45E-11	4.31E-12	2.51E-10
.6	2.32E-20	6.30E-23	5.31E-11	8.10E-12	4.69E-10
.7	1.08E-18	5.23E-21	7.46E-11	1.30E-11	7.56E-10
.8	1.96E-17	1.44E-19	9.55E-11	1.66E-11	1.10E-09
.9	1.88E-16	1.69E-18	1.24E-10	2.30E-11	1.51E-09
1.0	1.15E-15	1.49E-17	1.52E-10	3.17E-11	1.96E-09
1.1	5.13E-14	8.04E-17	1.80E-10	3.88E-11	2.46E-09
1.2	1.79E-14	3.28E-16	2.09E-10	4.60E-11	2.99E-09
1.3	5.17E-14	1.08E-15	2.39E-10	5.32E-11	3.56E-09
1.4	1.29E-13	3.01E-15	2.66E-10	6.05E-11	4.15E-09
1.5	2.36E-13	7.30E-15	2.98E-10	6.76E-11	4.77E-09
1.6	5.76E-13	1.54E-14	3.27E-10	7.46E-11	5.40E-09
1.7	1.07E-12	3.16E-14	3.55E-10	8.15E-11	6.06E-09
1.8	1.86E-12	5.82E-14	3.83E-10	8.82E-11	6.72E-09
1.9	3.07E-12	1.01E-13	4.10E-10	9.46E-11	7.40E-09
2.0	4.81E-12	1.65E-13	4.35E-10	1.01E-10	8.09E-09
2.1	7.25E-12	2.59E-13	4.62E-10	1.07E-10	8.76E-09
2.2	1.05E-11	3.90E-13	4.86E-10	1.13E-10	9.48E-09
2.3	1.49E-11	5.67E-13	5.09E-10	1.18E-10	1.02E-08
2.4	2.04E-11	7.99E-13	5.35E-10	1.24E-10	1.09E-08
2.5	2.74E-11	1.10E-12	5.53E-10	1.29E-10	1.16E-08
2.6	3.59E-11	1.47E-12	5.73E-10	1.34E-10	1.23E-08
2.7	4.62E-11	1.93E-12	5.93E-10	1.38E-10	1.30E-08
2.8	5.86E-11	2.49E-12	6.11E-10	1.43E-10	1.37E-08
2.9	7.30E-11	3.16E-12	6.29E-10	1.47E-10	1.44E-08
3.0	8.99E-11	3.95E-12	6.46E-10	1.51E-10	1.51E-08
3.1	1.09E-10	4.87E-12	6.62E-10	1.55E-10	1.58E-08
3.2	1.31E-10	5.92E-12	6.77E-10	1.59E-10	1.65E-08
3.3	1.56E-10	7.12E-12	6.92E-10	1.62E-10	1.72E-08
3.4	1.84E-10	8.46E-12	7.06E-10	1.65E-10	1.79E-08
3.5	2.15E-10	1.00E-11	7.19E-10	1.69E-10	1.85E-08
3.6	2.49E-10	1.17E-11	7.31E-10	1.72E-10	1.92E-08
3.7	2.87E-10	1.36E-11	7.43E-10	1.75E-10	1.99E-08
3.8	3.28E-10	1.57E-11	7.54E-10	1.77E-10	2.06E-08
3.9	3.73E-10	1.79E-11	7.64E-10	1.80E-10	2.12E-08
4.0	4.21E-10	2.04E-11	7.74E-10	1.82E-10	2.19E-08
4.1	4.73E-10	2.30E-11	7.84E-10	1.84E-10	2.25E-08
4.2	5.29E-10	2.59E-11	7.92E-10	1.87E-10	2.32E-08
4.3	5.89E-10	2.90E-11	8.01E-10	1.89E-10	2.38E-08
4.4	6.53E-10	3.23E-11	8.04E-10	1.91E-10	2.44E-08
4.5	7.21E-10	3.58E-11	8.10E-10	1.93E-10	2.51E-08
4.6	7.93E-10	3.95E-11	8.23E-10	1.95E-10	2.57E-08
4.7	8.69E-10	4.34E-11	8.30E-10	1.97E-10	2.63E-08
4.8	9.49E-10	4.76E-11	8.36E-10	1.98E-10	2.69E-08
4.9	1.03E-09	5.20E-11	8.42E-10	2.00E-10	2.75E-08
5.0	1.12E-09	5.66E-11	8.46E-10	2.01E-10	2.81E-08

Appendix C. Radiation Properties of Air

This appendix consists of tables of the various air radiation properties described in Chapter 3.0 and employed in our computer modelling studies. The numerical values are from our earlier work (Ref. 15, 16), although not published there in this form.

Table C-I Planck Mean opacities (cm^{-1}) for High Temperature Air.

$$\bar{\kappa}_p(\Delta\omega) = \frac{15}{\pi^4 T^4} \int_{\Delta\omega} \omega^3 e^{-\omega/T} \mu(\omega) d\omega$$

as functions of temperature ($2000^\circ\text{K} - 5.0\text{eV}$), density ratio (ρ/ρ_0) and photon energy interval.

Table C-II Partial Planck Fractions (see Eq. 33)

$$\bar{B}(\Delta\omega, T)$$

Table C-III The Emissivity coefficients a and b of Equations 32, 34 and 35.

Table C-IV The Emissivity (Eq. 32) as function of density ratio, path length, temperature, and spectral band.

74/06/75.

Table C-I
AIR RADIATION DATA

PLANCK MEAN OPACITIES (1/CM)

PHOTON ENERGIES 0-100 EV.

TEMP (EV)	RHOD=	1.00E+01	1.00E+00	1.00E-01
1 .172		3.37E-10	3.37E-10	3.37E-10
2 .345		1.34E-03	1.07E-03	5.79E-04
3 .517		5.12E-02	2.13E-02	6.44E-03
4 .689		2.43E-01	2.42E-01	4.61E-01
5 .862		2.20E+00	3.79E+00	4.86E+00
6 1.000		1.29E+01	1.81E+01	1.95E+01
7 1.200		3.47E+01	4.09E+01	3.89E+01
8 1.500		1.04E+02	1.01E+02	8.14E+01
9 2.000		2.45E+02	1.91E+02	1.17E+02
10 3.000		3.50E+02	2.79E+02	1.86E+02
11 5.000		3.35E+02	2.38E+02	1.78E+02
12 10.000		4.34E+02	6.64E+02	3.25E+02

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AIR RADIATION DATA

C-3

PLANCK MEAN OPACITIES (1/CM)

PHOTON ENERGIES 0-7 EV.

TEMP (EV)	RHO=	1.00E+01	1.00E+00	1.00E-01
1 .172		3.36E-10	3.36E-10	3.36E-10
2 .345		4.85E-04	7.81E-04	4.14E-04
3 .517		3.04E-02	1.17E-02	3.74E-03
4 .689		8.32E-02	2.96E-02	1.05E-02
5 .862		1.44E-01	4.98E-02	1.36E-02
6 1.000		3.60E-01	2.95E-01	2.70E-01
7 1.200		1.17E+00	1.22E+00	1.11E+00
8 1.500		3.74E+00	3.48E+00	2.56E+00
9 2.000		4.97E+00	4.07E+00	1.61E+00
10 3.000		6.86E+00	3.60E+00	1.32E+00
11 5.000		7.54E+00	3.07E+00	7.17E-01
12 10.000		3.78E+00	1.12E+00	2.38E-01

PHOTON ENERGIES 7-10 EV.

TEMP (EV)	RHO=	1.00E+01	1.00E+00	1.00E-01
1 .172		8.86E-13	8.86E-13	8.86E-13
2 .345		3.51E-04	2.86E-04	1.65E-04
3 .517		2.06E-02	9.16E-03	3.73E-03
4 .689		1.03E-01	7.77E-02	1.00E-01
5 .862		4.89E-01	6.66E-01	8.08E-01
6 1.000		3.43E+00	4.68E+00	5.00E+00
7 1.200		8.84E+00	1.03E+01	9.56E+00
8 1.500		2.01E+01	1.97E+01	1.40E+01
9 2.000		3.36E+01	2.27E+01	8.11E+00
10 3.000		2.01E+01	5.59E+00	9.78E-01
11 5.000		3.79E+00	1.06E+00	3.24E-01
12 10.000		1.53E+00	1.54E+00	2.07E-01

(Table C-I con't)

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AIR RADIATION DATA

C-4

PLANCK MEAN OPACITIES (1/CM)

PHOTON ENERGIES 10-13 EV.

TEMP (EV)	RHO=	1.00E+01	1.00E+00	1.00E-01
1 .172		6.22E-24	8.22E-24	8.22E-24
2 .345		3.45E-09	3.45E-09	3.54E-09
3 .517		2.16E-04	4.04E-03	9.61E-04
4 .689		5.66E-02	1.33E-01	2.67E-01
5 .862		1.53E+00	3.00E+00	3.94E+00
6 1.000		7.99E+00	1.15E+01	1.25E+01
7 1.200		2.05E+01	2.42E+01	2.31E+01
8 1.500		6.32E+01	6.12E+01	4.90E+01
9 2.000		1.21E+02	9.15E+01	5.15E+01
10 3.000		1.03E+02	5.31E+01	3.74E+01
11 5.000		2.59E+01	2.01E+01	1.65E+01
12 10.000		3.33E+00	1.67E+00	5.75E-01

PHOTON ENERGIES 13-16 EV.

TEMP (EV)	RHO=	1.00E+01	1.00E+00	1.00E-01
1 .172		2.67E-39	2.67E-39	2.67E-39
2 .345		2.73E-39	2.64E-39	3.03E-39
3 .517		2.13E-06	4.00E-06	7.73E-06
4 .689		7.38E-04	1.73E-03	3.69E-03
5 .862		3.77E-02	7.04E-02	9.27E-02
6 1.000		1.13E+00	1.55E+00	1.71E+00
7 1.200		4.04E+00	4.97E+00	4.89E+00
8 1.500		1.49E+01	1.52E+01	1.41E+01
9 2.000		5.83E+01	5.04E+01	3.92E+01
10 3.000		1.04E+02	7.37E+01	5.90E+01
11 5.000		5.26E+01	2.93E+01	1.83E+01
12 10.000		7.46E+00	5.47E+00	2.03E+00

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Table C-II
X-RAY RADIATION DATA

C-5

PARTIAL PLUCK FRACTIONS

TEMP(°C)	OMEGA#	(0-7)	(7-10.)	(10-13)	(13-16)	(>16.)
.172		1.00E+00	2.40E+14	1.30E+21	1.00E+28	5.10E+35
.345		1.00E+00	2.50E+16	1.10E+24	3.90E+33	1.20E+42
.517		9.99E+01	6.25E+04	5.17E+06	3.26E+08	1.40E+10
.690		9.91E+01	8.31E+03	2.42E+04	7.12E+06	1.40E+07
.862		9.64E+01	3.51E+02	2.72E+03	1.70E+04	1.00E+05
1.000		9.24E+01	6.40E+02	1.06E+02	1.27E+03	1.30E+04
1.200		8.50E+01	1.19E+01	2.56E+02	4.44E+03	7.50E+04
1.500		7.10E+01	1.97E+01	6.40E+02	1.92E+02	5.80E+03
2.000		5.00E+01	2.70E+01	1.40E+01	6.10E+02	3.90E+02
3.000		2.50E+01	2.20E+01	1.70E+01	1.40E+01	2.00E+01
5.000		8.00E+02	1.10E+01	1.20E+01	1.50E+01	5.60E+01
10.000		1.40E+02	2.10E+02	3.30E+02	4.20E+02	8.90E+01
15.000		5.00E+03	4.00E+03	1.10E+02	1.70E+02	4.59E+01
20.000		2.00E+03	4.00E+03	5.00E+03	8.00E+03	9.81E+01

74/06/25. Table C-III-a. Emissivity "a" Coefficient (Eq. 34)
AIR RADIATION DATA

EMISSIVITY COEFFICIENTS

PATH= 1.0E-01

TEMP(EV)	OMEGA=	(0 - 7)	(7. - 10.)	(10 - 13)	(13 - 16)	(>16.)
.172		1.01E+00	9.98E-01	9.85E-01	1.00E+00	1.00E+00
.345		1.34E+00	9.96E-02	1.01E+00	1.00E+00	1.00E+00
.517		1.13E+00	1.45E-01	2.23E-01	5.01E-01	1.01E+00
.689		1.28E+00	1.83E-01	8.69E-02	3.55E-01	6.54E+00
.862		3.21E+00	1.22E-01	4.75E-02	1.67E-01	2.42E+00
1.000		1.15E+00	4.27E-02	8.05E-02	1.75E-01	1.33E+00
1.200		7.77E-01	1.21E-01	1.57E-01	2.28E-01	6.09E-01
1.500		1.09E+00	2.37E-01	2.05E-01	3.56E-01	9.63E-01
2.000		1.83E+00	4.46E-01	5.58E-01	5.10E-01	5.59E-01
3.000		1.48E+00	1.09E+00	4.01E-01	3.20E-01	4.65E-01
5.000		1.35E+00	1.97E+00	5.06E-01	3.56E-01	5.17E-01

EMISSIVITY COEFFICIENTS

PATH= 1.0E-01

TEMP(EV)	OMEGA=	(0 - 7)	(7. - 10.)	(10 - 13)	(13 - 16)	(>16.)
.172		1.01E+00	9.99E-01	9.86E-01	1.00E+00	1.00E+00
.345		1.35E+00	9.92E-02	1.01E+00	1.00E+00	1.00E+00
.517		1.08E+00	1.41E-01	1.16E-01	1.00E+00	1.00E+00
.689		1.25E+00	1.31E-01	3.71E-02	1.00E-01	1.00E+00
.862		2.63E+00	7.45E-02	9.63E-03	2.54E-02	1.05E+00
1.000		1.05E+00	3.93E-02	2.27E-02	2.17E-02	1.33E-01
1.200		6.56E-01	4.49E-02	3.27E-02	2.58E-02	8.09E-02
1.500		8.03E-01	1.01E-01	3.81E-02	3.58E-02	9.63E-02
2.000		1.34E+00	2.09E-01	6.64E-02	6.92E-02	9.23E-02
3.000		1.12E+00	7.24E-01	1.63E-01	8.07E-02	9.91E-02
5.000		9.61E-01	1.72E+00	2.21E-01	1.67E-01	1.59E-01

Table C-III-b. Emissivity "b" Coefficients (Eq. 35)

C-7

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AIR RADIATION DATA

EMISSION COEFFICIENTS

PATH= 1.0E-02

TEMP (EV)	OMEGA=	(0-7)	(7.-10.)	(10-13)	(13-16)	(>16.)
.172		-2.10E-04	-6.80E-04	6.74E-06	1.00E+00	1.00E+00
.345		-7.80E-03	1.45E-02	1.01E-02	1.00E+00	1.00E+00
.517		3.77E-02	-9.91E-02	2.14E-01	2.73E-01	1.00E+00
.689		4.98E-02	5.84E-02	2.38E-01	9.15E-02	-1.37E-01
.862		-2.05E-01	-6.64E-03	2.30E-02	-2.67E-01	-3.52E-01
1.000		2.15E-01	-5.41E-02	-5.21E-02	-2.50E-01	-1.73E-01
1.200		1.48E-01	-1.45E-01	-1.34E-01	-3.26E-01	-2.01E-01
1.500		1.27E-01	-1.47E-01	-1.53E-01	-2.99E-01	-1.82E-01
2.000		8.73E-02	-1.62E-01	-6.29E-03	1.20E-01	1.82E-02
3.000		5.66E-02	-5.43E-02	3.35E-01	3.30E-01	1.36E-01
5.000		-1.70E-01	2.65E-02	1.66E-01	3.67E-02	1.36E-01

EMISSION COEFFICIENTS

PATH= 1.0E-01

TEMP (EV)	OMEGA=	(0-7)	(7.-10.)	(10-13)	(13-16)	(>16.)
.172		2.70E-04	2.79E-04	8.80E-05	1.00E+00	1.00E+00
.345		-6.58E-03	1.33E-01	2.64E-03	1.00E+00	1.00E+00
.517		1.02E-02	5.21E-02	1.50E-01	8.66E-01	1.00E+00
.689		4.21E-03	3.39E-01	1.55E-01	-2.47E-01	-6.01E-01
.862		-1.47E-01	-1.30E-01	-3.34E-02	2.23E-01	-3.77E-01
1.000		1.96E-01	-4.58E-01	4.78E-01	-8.13E-01	-9.54E-01
1.200		1.11E-01	-1.41E-01	-4.31E-01	-9.57E-01	-9.42E-01
1.500		4.13E-02	-1.41E-01	-9.75E-01	1.04E+00	-9.85E-01
2.000		1.38E-02	-1.92E-01	-5.26E-01	-6.82E-01	-6.25E-01
3.000		-2.10E-02	-1.13E-01	1.32E-01	-5.75E-02	-2.17E-01
5.000		-2.75E-01	3.79E-02	3.04E-01	-4.54E-02	-1.11E-01

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Table C-IV
AIR RADIATION DATA

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EMISSION AT DENSITY RATIO= $1.0E-01$ PATH(CM)= .01

TEMP(°F)	OMEGA=	(0-7)	(7.-10.)	(10-13)	(13-16)	(>16.)
.172		3.39E-13	8.70E-16	8.10E-27	2.67E-43	5.10E-35
.345		5.63E-07	1.58E-08	3.50E-12	3.03E-43	0.
.517		3.89E-06	6.80E-07	1.28E-07	2.00E-09	2.51E-13
.689		1.20E-05	1.60E-05	1.40E-05	9.40E-07	3.00E-08
.862		7.00E-05	1.00E-04	1.72E-04	2.64E-05	1.60E-06
1.000		1.90E-04	5.60E-04	1.12E-03	4.35E-04	4.50E-05
1.200		6.10E-04	1.60E-03	3.63E-03	1.83E-03	2.77E-04
1.500		2.10E-03	4.60E-03	1.23E-02	7.64E-03	2.07E-03
2.000		2.70E-03	5.20E-03	1.75E-02	1.34E-02	7.86E-03
3.000		1.70E-03	1.20E-03	6.80E-03	8.40E-03	2.76E-02
5.000		1.40E-03	6.00E-04	3.70E-03	5.90E-03	5.04E-02

EMISSION AT DENSITY RATIO= $1.0E-01$ PATH(CM)= .04

TEMP(°F)	OMEGA=	(0-7)	(7.-10.)	(10-13)	(13-16)	(>16.)
.172		1.36E-12	3.29E-15	3.24E-26	1.07E-42	5.10E-35
.345		2.26E-06	5.71E-08	1.40E-11	1.21E-42	0.
.517		1.57E-05	2.40E-06	4.59E-07	6.26E-09	1.00E-12
.689		4.93E-05	4.67E-05	4.55E-05	3.11E-06	9.47E-08
.862		2.51E-04	3.81E-04	4.94E-04	4.81E-05	4.38E-06
1.000		7.47E-04	2.38E-03	2.14E-03	1.07E-03	1.15E-04
1.200		2.38E-03	4.97E-03	1.17E-02	4.06E-03	6.73E-04
1.500		8.15E-03	1.44E-02	4.63E-02	7.87E-03	5.21E-03
2.000		1.03E-02	1.71E-02	6.17E-02	4.46E-02	2.56E-02
3.000		6.57E-03	4.43E-03	2.43E-02	3.11E-02	8.74E-02
5.000		5.37E-03	2.26E-03	1.18E-02	1.95E-02	1.60E-01

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(Table C-IV con't)
AIR RADIATION DATA

C-9

EMISSION AT DENSITY RATIO= 1.0E-01 PATH(CM)= .10

TEMP(°F)	OMEGA=	(0-7)	(7.-10.)	(10-13)	(13-16)	(>16.)
.172		3.39E-12	7.40E-15	4.10E-26	2.67E-42	5.10E-35
.345		5.67E-06	1.17E-07	3.50E-11	3.03E-42	0.
.517		3.96E-05	4.66E-06	7.31E-07	9.00E-09	2.50E-12
.689		1.30E-04	6.00E-05	6.55E-05	4.40E-06	1.00E-07
.862		5.00E-04	8.00E-04	3.81E-04	1.35E-05	5.50E-06
1.000		1.80E-03	5.40E-03	9.00E-04	1.08E-03	1.20E-04
1.200		5.60E-03	5.80E-03	1.41E-02	4.11E-03	6.91E-04
1.500		1.86E-02	1.86E-02	6.29E-02	4.60E-04	5.45E-03
2.000		2.30E-02	2.50E-02	7.98E-02	5.38E-02	3.14E-02
3.000		1.50E-02	9.00E-03	4.00E-02	4.50E-02	1.02E-01
5.000		1.20E-02	5.00E-03	1.90E-02	3.00E-02	2.24E-01

EMISSION AT DENSITY RATIO= 1.0E-01 PATH(CM)= .50

TEMP(°F)	OMEGA=	(0-7)	(7.-10.)	(10-13)	(13-16)	(>16.)
.172		1.70E-11	2.02E-14	4.05E-25	1.33E-41	5.10E-35
.345		2.86E-05	5.27E-07	1.64E-10	1.51E-41	0.
.517		1.92E-04	2.25E-05	1.98E-06	3.04E-08	1.21E-11
.689		6.39E-04	2.35E-04	1.46E-04	6.46E-06	1.20E-07
.862		2.17E-03	2.75E-03	5.96E-04	1.78E-05	6.92E-06
1.000		8.38E-03	1.38E-02	1.72E-03	1.13E-03	1.20E-04
1.200		2.46E-02	1.40E-02	2.00E-02	4.18E-03	6.91E-04
1.500		7.21E-02	4.76E-02	6.68E-02	4.60E-04	5.45E-03
2.000		8.64E-02	6.68E-02	1.03E-01	5.67E-02	3.52E-02
3.000		5.61E-02	3.20E-02	8.88E-02	7.32E-02	1.40E-01
5.000		3.61E-02	2.10E-02	5.96E-02	6.98E-02	3.77E-01

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(Table C-IV con't)

C-10

AIR RADIATION DATA

EMISSIONITY AT DENSITY RATIO= 1.0E+01

PATH(CM)= 1.00

TEMP(EV)	OMEGA=	(0-7)	(7.-10.)	(10-13)	(13-16)	(>16.)
.172		3.40E-11	2.54E-14	8.10E-25	2.67E-41	5.10E-55
.345		5.73E-05	9.52E-07	5.03E-10	3.03E-41	0.
.517		3.78E-04	4.39E-05	2.83E-06	3.28E-08	2.35E-11
.689		1.27E-03	4.21E-04	1.91E-04	7.10E-06	1.28E-07
.862		4.08E-03	4.60E-03	1.17E-04	2.00E-05	9.68E-06
1.000		1.62E-02	2.00E-02	2.25E-03	1.15E-03	1.20E-04
1.200		4.62E-02	2.02E-02	2.22E-02	4.21E-03	6.91E-04
1.500		1.26E-01	6.78E-02	6.75E-02	4.60E-04	5.45E-03
2.000		1.46E-01	9.79E-02	1.12E-01	5.76E-02	3.64E-02
3.000		9.33E-02	5.55E-02	1.17E-01	8.74E-02	1.56E-01
5.000		5.53E-02	3.67E-02	8.54E-02	9.18E-02	4.43E-01

EMISSIONITY AT DENSITY RATIO= 1.0E+00

PATH(CM)= .01

TEMP(EV)	OMEGA=	(0-7)	(7.-10.)	(10-13)	(13-16)	(>16.)
.172		3.59E-12	7.40E-15	8.10E-26	2.67E-41	5.10E-55
.345		1.04E-05	2.66E-07	3.47E-11	2.84E-41	0.
.517		1.33E-04	1.51E-05	6.35E-07	1.50E-08	1.36E-11
.689		3.80E-04	1.41E-04	9.40E-05	4.06E-06	1.20E-07
.862		1.60E-03	8.00E-04	1.11E-03	8.50E-05	5.00E-06
1.000		3.40E-03	4.20E-03	6.56E-03	1.12E-03	1.20E-04
1.200		9.40E-03	1.18E-02	1.83E-02	4.10E-03	7.00E-04
1.500		3.70E-02	4.03E-02	5.71E-02	1.81E-02	5.53E-03
2.000		6.90E-02	8.40E-02	1.26E-01	8.01E-02	3.74E-02
3.000		4.80E-02	5.50E-02	1.28E-01	1.14E-01	1.77E-01
5.000		3.20E-02	1.90E-02	4.60E-02	7.20E-02	4.50E-01

(Table C-IV con't)

C-11

74/06/25.

AIR RADIATION DATA

EMISSION AT DENSITY RATIO= 1.0E+00

PATH(CM)= .04

TEMP(°C)	OMEGA=	(0-7)	(7-10.)	(10-13)	(13-16)	(>16.)
.172		1.36E-11	1.85E-14	3.24E-25	1.07E-40	5.10E-35
.345		4.19E-05	8.98E-07	1.32E-13	1.13E-40	0.
.517		5.24E-04	5.05E-05	2.31E-06	3.16E-08	4.86E-11
.689		1.51E-03	5.00E-04	2.37E-04	6.95E-06	1.72E-07
.862		6.00E-03	2.70E-03	2.14E-03	1.47E-04	8.94E-06
1.000		1.31E-02	1.26E-02	9.44E-03	1.27E-03	1.50E-04
1.200		3.51E-02	3.35E-02	2.52E-02	4.45E-03	7.50E-04
1.500		1.26E-01	1.03E-01	6.77E-02	1.92E-02	5.80E-03
2.000		2.09E-01	1.88E-01	1.40E-01	6.10E-02	3.90E-02
3.000		1.36E-01	1.37E-01	1.85E-01	1.54E-01	2.00E-01
5.000		6.75E-02	5.68E-02	1.01E-01	1.21E-01	5.57E-01

EMISSION AT DENSITY RATIO= 1.0E+00

PATH(CM)= .10

TEMP(°C)	OMEGA=	(0-7)	(7-10.)	(10-13)	(13-16)	(>16.)
.172		3.40E-11	2.54E-14	8.10E-25	2.67E-40	5.10E-35
.345		1.05E-04	1.63E-06	3.01E-10	2.64E-40	0.
.517		1.27E-03	1.17E-04	5.16E-06	5.26E-08	9.80E-11
.689		3.70E-03	9.60E-04	2.33E-04	6.90E-06	1.46E-07
.862		1.30E-02	4.60E-03	1.70E-03	1.11E-04	9.50E-06
1.000		3.04E-02	1.60E-02	9.70E-03	1.18E-03	1.20E-04
1.200		7.62E-02	3.83E-02	2.46E-02	4.20E-03	7.00E-04
1.500		2.31E-01	1.23E-01	6.58E-02	1.81E-02	5.53E-03
2.000		3.32E-01	2.18E-01	1.38E-01	6.06E-02	3.88E-02
3.000		2.00E-01	1.45E-01	1.68E-01	1.36E-01	1.96E-01
5.000		7.80E-02	8.90E-02	1.17E-01	1.27E-01	5.57E-01

EMISSIONIVITY AT DENSITY RATIO= 1.0E+00 PATH(CM)= .50

TEMP(EV)	OMEGA=	(0-7)	(7.-10.)	(10-13)	(13-16)	(>16.)
.172		1.70E-10	2.00E-14	4.05E-24	1.33E-39	5.10E-55
.345		5.30E-04	2.29E-06	8.77E-10	1.42E-39	0.
.517		6.14E-03	5.99E-04	4.88E-06	3.28E-08	1.76E-10
.689		1.80E-02	5.20E-03	2.80E-04	7.66E-06	1.61E-07
.862		5.52E-02	1.30E-02	2.24E-03	1.28E-04	1.00E-05
1.000		1.34E-01	3.49E-02	1.05E-02	1.21E-03	1.20E-04
1.200		2.90E-01	7.40E-02	2.57E-02	4.26E-03	7.00E-04
1.500		5.65E-01	1.83E-01	6.77E-02	1.81E-02	5.53E-03
2.000		4.94E-01	2.59E-01	1.40E-01	6.09E-02	3.90E-02
3.000		2.50E-01	2.20E-01	1.90E-01	1.40E-01	2.00E-01
5.000		8.00E-02	1.10E-01	1.20E-01	1.30E-01	5.60E-01

EMISSIONIVITY AT DENSITY RATIO= 1.0E+00 PATH(CM)= 1.00

TEMP(EV)	OMEGA=	(0-7)	(7.-10.)	(10-13)	(13-16)	(>16.)
.172		3.00E-10	2.40E-14	8.09E-24	2.67E-39	5.10E-55
.345		1.06E-03	2.30E-06	1.05E-09	2.84E-39	0.
.517		1.21E-02	5.42E-04	5.12E-06	3.28E-08	1.80E-10
.689		3.55E-02	4.87E-03	2.82E-04	7.71E-06	1.66E-07
.862		1.01E-01	1.98E-02	2.40E-03	1.35E-04	1.00E-05
1.000		2.42E-01	4.51E-02	1.06E-02	1.22E-03	1.20E-04
1.200		4.65E-01	9.09E-02	2.54E-02	4.28E-03	7.00E-04
1.500		6.71E-01	1.94E-01	6.74E-02	1.81E-02	5.53E-03
2.000		5.00E-01	2.60E-01	1.40E-01	6.10E-02	3.90E-02
3.000		2.50E-01	2.20E-01	1.90E-01	1.40E-01	2.00E-01
5.000		8.00E-02	1.10E-01	1.20E-01	1.30E-01	5.60E-01

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(Table C-IV con't)
AIR RADIATION DATA

C-13

EMISSION AT DENSITY RATIO = 1.0E+01 PATH(CM) = .01

TEMP(EV)	OMEGA=	(0-7)	(7.-10.)	(10-13)	(13-16)	(>16.)
.172		3.39E-11	2.34E-14	8.10E-25	2.67E-39	5.10E-35
.345		1.29E-04	1.92E-04	3.06E-10	2.73E-39	2.50E-18
.517		3.75E-03	1.98E-04	4.06E-06	3.27E-08	1.78E-10
.689		1.19E-02	1.89E-03	2.68E-04	7.57E-06	1.80E-07
.862		2.83E-02	5.35E-03	2.56E-03	1.47E-04	9.07E-06
1.000		6.57E-02	2.15E-02	1.06E-02	1.27E-03	1.30E-04
1.200		1.19E-01	5.65E-02	2.58E-02	4.45E-03	1.50E-04
1.500		3.81E-01	1.62E-01	6.00E-02	1.92E-02	5.80E-03
2.000		4.46E-01	2.55E-01	1.40E-01	6.10E-02	3.90E-02
3.000		2.48E-01	2.20E-01	1.90E-01	1.40E-01	2.00E-01
5.000		8.00E-02	1.10E-01	1.20E-01	1.30E-01	5.40E-01

EMISSION AT DENSITY RATIO = 1.0E+01 PATH(CM) = .04

TEMP(EV)	OMEGA=	(0-7)	(7.-10.)	(10-13)	(13-16)	(>16.)
.172		1.36E-10	2.40E-14	5.24E-24	1.07E-38	5.10E-35
.345		5.19E-04	2.30E-06	7.98E-10	1.09E-38	9.70E-18
.517		1.44E-02	5.11E-04	5.13E-06	3.28E-08	1.80E-10
.689		4.48E-02	5.71E-03	2.82E-04	7.72E-06	1.80E-07
.862		1.07E-01	1.42E-02	2.72E-03	1.70E-04	9.99E-06
1.000		2.27E-01	4.03E-02	1.06E-02	1.27E-03	1.30E-04
1.200		3.62E-01	1.04E-01	2.58E-02	4.45E-03	7.50E-04
1.500		6.59E-01	1.96E-01	6.80E-02	1.92E-02	5.80E-03
2.000		5.00E-01	2.60E-01	1.40E-01	6.10E-02	3.90E-02
3.000		2.50E-01	2.20E-01	1.90E-01	1.40E-01	2.00E-01
5.000		8.00E-02	1.10E-01	1.20E-01	1.30E-01	5.40E-01

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(Table C-IV con't)
AIR RADIATION DATA

C-14

EMISSION AT DENSITY RATIO= 1.0E+01 PATH(CM)= .10

TEMP(EV)	OMEGA=	(0-7)	(7.-10.)	(10-13)	(13-16)	(>16.)
.172		3.40E-10	2.40E-14	8.09E-24	2.67E-38	5.10E-55
.345		1.31E-03	2.50E-06	1.05E-09	2.73E-38	2.28E-17
.517		3.31E-02	6.27E-04	5.15E-05	3.28E-08	1.80E-10
.689		9.98E-02	8.67E-03	2.82E-04	7.69E-06	1.74E-07
.862		2.55E-01	1.84E-02	2.70E-03	1.77E-04	1.00E-05
1.000		4.37E-01	3.35E-02	1.06E-02	1.21E-03	1.17E-04
1.200		5.06E-01	1.08E-01	2.58E-02	4.11E-03	6.85E-04
1.500		7.03E-01	1.97E-01	6.64E-02	1.42E-02	5.53E-03
2.000		5.00E-01	2.60E-01	1.40E-01	6.10E-02	3.90E-02
3.000		2.50E-01	2.20E-01	1.90E-01	1.40E-01	2.00E-01
5.000		8.00E-02	1.10E-01	1.20E-01	1.50E-01	5.60E-01

EMISSION AT DENSITY RATIO= 1.0E+01 PATH(CM)= .50

TEMP(EV)	OMEGA=	(0-7)	(7.-10.)	(10-13)	(13-16)	(>16.)
.172		1.70E-09	2.40E-14	4.01E-23	1.55E-37	5.10E-55
.345		6.57E-03	2.50E-06	1.10E-09	1.36E-37	7.82E-17
.517		1.51E-01	6.25E-04	5.17E-06	3.28E-08	1.80E-10
.689		4.03E-01	8.51E-03	2.82E-04	7.72E-06	1.78E-07
.862		6.77E-01	3.15E-02	2.72E-03	1.70E-04	1.00E-05
1.000		6.78E-01	5.54E-02	1.00E-02	1.23E-03	1.17E-04
1.200		8.45E-01	1.19E-01	2.58E-02	4.18E-03	6.85E-04
1.500		7.10E-01	1.97E-01	6.78E-02	1.42E-02	5.53E-03
2.000		5.00E-01	2.60E-01	1.40E-01	6.10E-02	3.90E-02
3.000		2.50E-01	2.20E-01	1.90E-01	1.40E-01	2.00E-01
5.000		8.00E-02	1.10E-01	1.20E-01	1.50E-01	5.60E-01

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(Table C-IV con't)
AIR RADIATION DATA

C-15

EMISSION AT DENSITY RATIO = $1.0E+01$ $PATN(CH) = 1.00$

TEMP(°F)	OMEGA =	(0-7)	(7-10.)	(10-13)	(13-16)	(>16.)
,172		3.40E-09	2.40E-10	7.93E-25	2.67E-37	5.10E-35
,345		1.31E-02	2.30E-06	1.10E-09	2.73E-37	1.05E-16
,517		2.75E-01	6.25E-04	5.17E-06	3.26E-08	1.50E-10
,689		6.59E-01	8.51E-03	2.52E-04	7.72E-06	1.79E-07
,862		6.65E-01	3.29E-02	2.72E-03	1.70E-04	1.00E-05
1,000		9.21E-01	6.11E-02	1.06E-02	1.24E-03	1.17E-04
1,200		8.50E-01	1.19E-01	2.55E-02	4.21E-03	8.64E-04
1,500		7.10E-01	1.97E-01	6.79E-02	1.92E-02	5.53E-03
2,000		5.00E-01	2.60E-01	1.40E-01	6.10E-02	3.90E-02
3,000		2.50E-01	2.20E-01	1.90E-01	1.40E-01	2.00E-01
5,000		8.00E-02	1.10E-01	1.20E-01	1.30E-01	5.60E-01

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NOTES

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