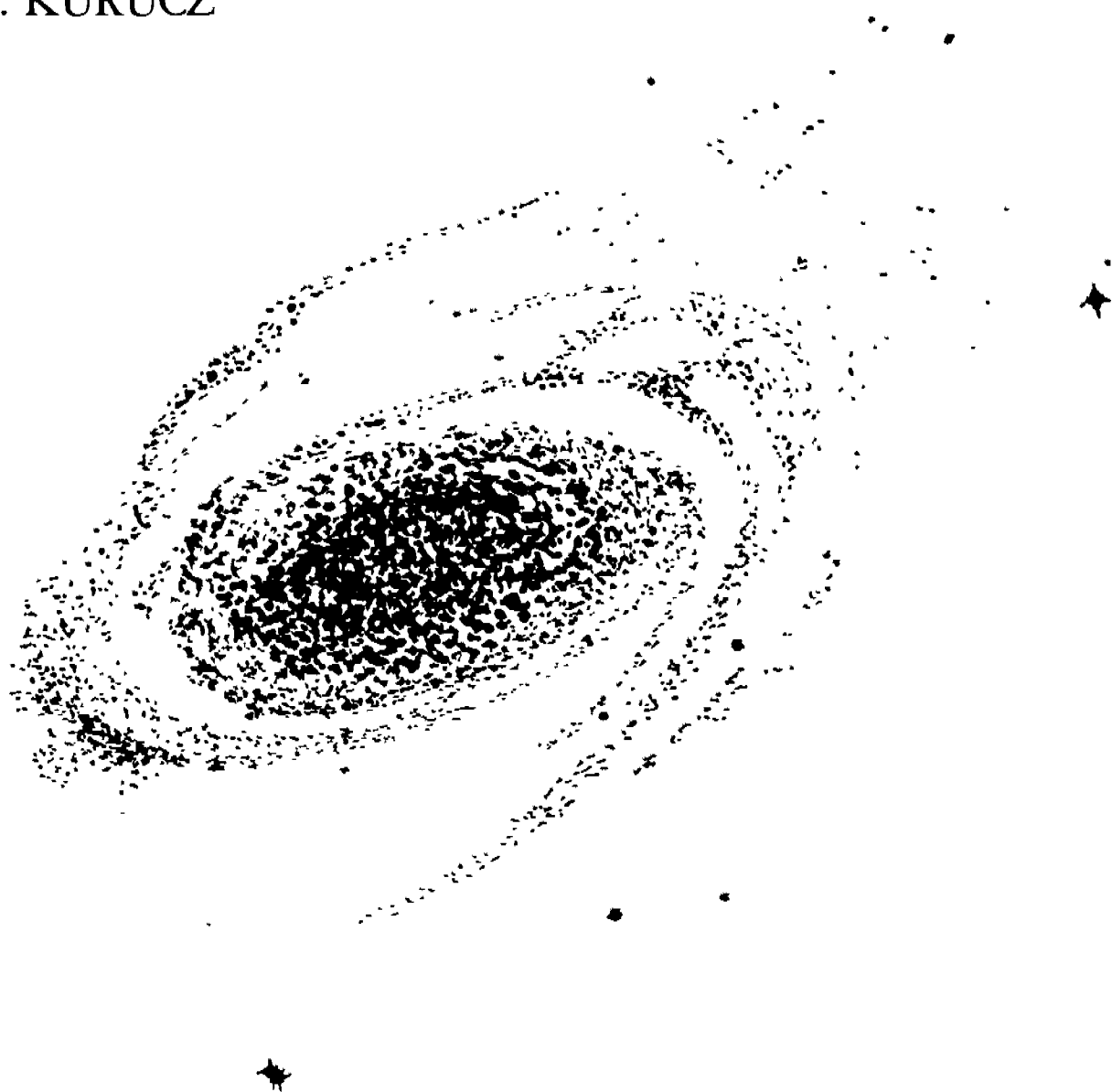


ATLAS: A COMPUTER PROGRAM FOR CALCULATING MODEL STELLAR ATMOSPHERES

R. L. KURUCZ



Smithsonian Astrophysical Observatory
SPECIAL REPORT 309

Research in Space Science
SAO Special Report No. 309

ATLAS:
A COMPUTER PROGRAM FOR CALCULATING
MODEL STELLAR ATMOSPHERES

Robert L. Kurucz

March 3, 1970

Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138

TABLE OF CONTENTS

	ABSTRACT.	vii
	MAGNETIC TAPE LISTING.	xi
	WARNING.	xiii
	PREFACE AND ACKNOWLEDGMENTS	xv
1	INTRODUCTION	1
2	RADIATIVE ENERGY TRANSPORT	3
	2.1 The Transfer Equation	3
	2.2 The Source Function.	6
	2.3 Mass Absorption Coefficients, Optical Depth, and the Plane-Parallel Approximation.	10
	2.4 Properties of the Radiation Field	11
	2.5 Computing the Optical Depth	15
	2.6 Computing the Mean Intensity and Flux	17
	2.7 Computing the Source Function.	22
	2.8 Pretabulation of the Matrices and Treatment of Large Depths	24
	2.9 Computing Specific Intensity	28
	2.10 Frequency Integrations	29
	2.11 Radiation Pressure	30
	2.12 Rosseland Optical Depth and Opacity	30
3	STATISTICAL EQUILIBRIUM	33
	3.1 Rates.	33
	3.2 Irrelevant Levels.	39
	3.3 When Are Detailed Calculations Necessary?	40
	3.4 Statistical Equilibrium in ATLAS	44
	3.5 Computing Statistical Equilibrium for Hydrogen	44
	3.6 The Negative Hydrogen Ion	46
	3.7 Computational Note	48

TABLE OF CONTENTS (Cont.)

4	THERMODYNAMIC QUANTITIES	49
4.1	Gas and Turbulent Pressures.	49
4.2	Calculation of the Pressure When $T(\tau)$ or $T(x)$ is Prescribed. .	50
4.3	Ionization and Molecular Equilibrium Equations	54
4.4	Evaluating Saha Equations	58
4.5	Mass Density and Height.	66
4.6	Thermodynamic Derivatives	67
5	OPACITY	73
5.1	H I Bound-Free and Free-Free	75
5.2	H_2^+ Bound-Free and Free-Free.	78
5.3	H^- Bound-Free and Free-Free.	79
5.4	H I Rayleigh Scattering.	80
5.5	He I Bound-Free and Free-Free.	80
5.6	He II Bound-Free and Free-Free	81
5.7	He^- Free-Free	81
5.8	He I Rayleigh Scattering	82
5.9	Low-Temperature Absorbers.	82
5.10	Intermediate-Temperature Absorbers	84
5.11	High-Temperature Absorbers	86
5.12	Electron Scattering	86
5.13	H_2 Rayleigh Scattering	86
5.14	H I Lines	88
5.15	Line-Absorption Distribution Functions.	92
5.16	Line-Scattering Distribution Functions	96
5.17	Other or Experimental Absorption Lines	97
5.18	Other or Experimental Scattering Lines.	97
5.19	Other or Experimental Continuous Absorbers	97
5.20	Other or Experimental Continuous Scatterings	97
6	CONVECTIVE ENERGY TRANSPORT	99

TABLE OF CONTENTS (Cont.)

7	THE TEMPERATURE CORRECTION.	105
	7.1 Introduction	105
	7.2 The Flux Correction	106
	7.3 The Λ Correction	111
	7.4 The Surface Correction	114
	7.5 Other Fudges	114
8	ATLAS.	117
	8.1 A Sample Model Calculation	117
	8.2 Control Cards for ATLAS5	139
	8.3 Options	145
	8.4 Programing Details of ATLAS5	161
	8.5 Subroutines	163
	8.6 Listing of ATLAS5	171
9	UTILITY PROGRAMS.	271
	9.1 FRESET	271
	9.2 PRETAB	272
	9.3 ATLAS5 for TTAUP	272
	9.4 REDIME	272
	9.5 Listing of Programs	273
10	REFERENCES	289

ABSTRACT

The computer program ATLAS calculates model stellar atmospheres in radiative and convective equilibrium for the complete range of stellar temperatures. The approximations used limit the program to plane-parallel, horizontally homogeneous, steady-state, nonmoving atmospheres with energy and abundances constant with depth. The program has been written to allow detailed statistical equilibrium calculations, but only hydrogen continua and H^- are coded at present. Most of the published continuous opacities and hydrogen lines have been included, and provision is made for adding others easily. There is also provision for treating line opacity as line-absorption distribution functions.

In Sections 2 through 7, we discuss all aspects of model atmosphere calculations in considerable detail. These include the radiation field, statistical equilibrium, thermodynamic properties, opacity, convection, and the temperature correction. In Sections 8 and 9, we discuss the computer program itself, by going first through a sample calculation and second through a technical discussion of the program coding and operation.

The program was written in FORTRAN IV and is essentially machine independent. A listing is available on magnetic tape.

RÉSUMÉ

Le programme ATLAS pour ordinateur calcule les modèles des atmosphères stellaires dans un équilibre radiatif et convectif pour toute l'étendue des températures stellaires. Les approximations utilisées limitent le programme à des atmosphères en plans parallèles, homogènes horizontalement, en état stable, immobiles, et ayant une énergie et des abondances constantes avec la profondeur. Le programme a été écrit pour permettre des calculs détaillés de l'équilibre statistique, mais seulement les spectres continus de l'hydrogène et de H^- sont programmés pour l'instant. La plupart des opacités du spectre continu qui ont été publiées et la plupart des raies de l'hydrogène ont été incluses et on peut en ajouter d'autres facilement. On peut aussi traiter l'opacité des raies comme fonctions de distribution des raies d'absorption.

Dans les Sections de 2 à 7 nous discutons de tous les aspects des calculs des modèles d'atmosphères avec beaucoup de détails. Ceux-ci comprennent le champ de radiation, l'équilibre statistique, les propriétés thermodynamiques, l'opacité, les convections et la correction de températures. Dans les Sections 8 et 9 nous discutons du programme lui-même, en faisant d'abord un calcul simple puis une discussion technique de la séquence d'instructions du programme et de la marche de ce dernier.

Le programme a été écrit en FORTRAN IV et est essentiellement indépendant de l'ordinateur. Un listing sur bande magnétique peut en être obtenu.

КОНСПЕКТ

Программа АТЛАС для электронной счетно-решающей машины вычисляет модельные звездные атмосферы в излучающем и конвективном равновесии для полного диапазона звездных температур. Употребляемые приближения ограничивают программу в рамках плоско-параллельных, горизонтально-однородных, установившегося состояния, недвижущихся атмосфер с энергией и распространениями постоянными с глубиной. Программа была составлена чтобы позволить подробные вычисления статистического равновесия, но только водородные непрерывные спектры и H^- кодированы в настоящее время. Было включено большинство опубликованных непрерывных непрозрачностей и водородных линий, и предусматривания были сделаны для добавления других. Имеется также предусматривание для рассматривания непрозрачности линий как функций распределения поглощения линий.

В отделах 2 до 7 мы обсуждаем значительно детально все виды вычисления модельной атмосферы. Эти включают поле излучения, статистическое равновесие, термодинамические свойства, непрозрачность, конвекцию и температурную поправку. В отделах 8 и 9 мы обсуждаем саму программу для электронной счетно-решающей машины сперва рассматривая простые вычисления а затем производя техническое обсуждение кодирования и действия программы.

Программа была написана по ФОРТРАН'у IV и является по существу независимой от машины. Имеется список на магнитной ленте.

MAGNETIC TAPE LISTING

The programs listed in this report can be obtained on magnetic tape by sending a tape at least 600 feet long to

Robert L. Kurucz
Smithsonian Astrophysical Observatory
60 Garden Street
Cambridge, Massachusetts 02138

The tape will be written in BCD card images at 800 bpi.

WARNING

There is no way to guarantee that ATLAS5 does not contain errors. In fact, it is almost certain that it does, since the code is so long. There also may be truncation or underflow problems on computers like an IBM 360, even though all those known at present have been allowed for. We also point out that the computation of a model atmosphere should be considered a physical experiment. The program may not be able to calculate a model for conditions that do not occur in real stars or for conditions that violate the initial assumptions on which the program is based.

PREFACE AND ACKNOWLEDGMENTS

The programing described here was started in 1966 as the first step in a project with Dr. Stephen E. Strom for calculating realistic line-blanketed model atmospheres for the whole range of stellar spectral types. Although ATLAS can now calculate models by using distribution functions for the line opacities, I have not yet completed work on the distribution functions themselves. As of now, I have written a program to calculate the distribution functions given a list of lines, but I have atomic data for only about two-thirds of the lines (36,000) in stars that do not have strong molecular bands. I expect to complete collecting and calculating atomic line data (and molecular data for the sun) in the near future, after which I will publish the line distribution functions for early and middle spectral types in a form that can easily be used in ATLAS.

Almost all the people with whom I have had contact over the last 5 years have contributed to this effort. Dr. Strom, Karen M. Strom, Dr. Owen J. Gingerich, and Dr. David W. Latham taught me programing. I had the benefit of learning about stellar atmospheres through working with programs written by the Stroms. Dr. Wolfgang Kalkofen suggested the use of integration matrices for the radiation field. Thomas Swithenbank took part in the early efforts with partition functions and Saha equations. Conversations and work with Judith G. Cohen are indirectly responsible for the way I have treated molecular equilibrium. Ruth C. Peterson has helped me on several occasions by pointing out errors in my algebra. I. Gene Campbell has often helped me with programing problems. Duane F. Carbon has listened to my ideas and helped me with a number of problems, especially those concerning molecules. Dr. Theodore Simon has worked with the program and suggested many improvements. Over the years, Dr. Deane Peterson has been most helpful. He has worked with the program and made several improvements himself; many of the details of the program have arisen from long arguments (and discussions) with him. Drs. Eric Peytremann, Eugene H. Avrett, and Peterson have kindly read the manuscript and suggested improvements.

ATLAS:
A COMPUTER PROGRAM FOR CALCULATING
MODEL STELLAR ATMOSPHERES

Robert L. Kurucz

1. INTRODUCTION

The calculation of a model atmosphere is a straightforward process once several assumptions and approximations have been made to simplify the problem physically and computationally. We simplify the problem as follows:

A. The atmosphere is in a steady state.

B. The flux of energy is constant with depth in the atmosphere since the energy source for the star lies far below the atmosphere and since no energy comes into the atmosphere from above. The flux is usually specified by an effective temperature such that $\text{flux} = \sigma T_{\text{eff}}^4$ $\sigma = 5.6697\text{E-}5$.

C. The atmosphere is homogeneous except in the normal direction. We ignore granules, spicules, cells, spots, magnetic fields, etc.

D. The atmosphere is thin relative to the radius of the star, so we can consider plane layers instead of concentric shells.

E. There is no relative motion of the layers in the normal direction and no net acceleration of the atmosphere, so the pressure balances the gravitational attraction,

$$\rho \frac{d^2 r}{dt^2} = -\rho g + \frac{dP}{dr} = 0 \quad . \quad (1.1)$$

Here ρ is the density and g is the gravitational acceleration, which is approximately constant because the atmosphere is thin,

This work was supported in part by the Smithsonian Research Foundation.

$$g = \frac{GM_*}{R_*^2} ,$$

with M_* and R_* the mass and radius of the star.

F. The atomic abundances are specified and constant throughout the atmosphere.

Given these assumptions, we go through an iteration process to find the parameters that describe the model atmosphere. We guess the temperature at a set of depth points in the atmosphere and calculate the pressure, number densities, and opacity at each point. From these quantities we determine the radiation field and convective flux at each point. The total flux does not, in general, equal the prescribed constant flux, so we change the temperature at each point according to a "temperature correction" scheme. We repeat the whole process with successive temperature distributions until the total flux is constant to within a small error.

Since the number densities and pressure also depend on the radiation field, we must carry several quantities from iteration to iteration. However, the radiation field often has only a negligible effect on these quantities, in which case only the temperature need be carried from iteration to iteration.

We describe this iteration process in considerable detail as follows: Section 2 is concerned with the radiative energy-transport equations and the computation techniques required to find the radiation field, given the atomic number densities. In Section 3 we consider the effects of the radiation field on the number densities and the means for carrying this information from iteration to iteration. We discuss the computation of the various thermodynamic properties of the gas in Section 4. Section 5 contains expressions for each of the opacity sources included in ATLAS. We consider convective energy transport and the temperature correction scheme in Sections 6 and 7, respectively. In Section 8 we describe the calculation of a model atmosphere by examining sample input and output; programing details of ATLAS, including the listing, are given. In the last section, we describe and list various utility programs.

2. RADIATIVE ENERGY TRANSPORT

2.1 The Transfer Equation

Our approach will be to follow a beam of photons of frequency ν as it passes through the atmosphere. The number density of photons per unit solid angle and frequency $N_\nu(\omega)$ will change with time owing to the presence of absorbing, emitting, and scattering atoms. (By "atom" we actually mean any atomic system, such as an atom, molecule, electron, negative ion, or ion plus electron.) In the absorption process an atom subtracts a photon of energy $h\nu$ from the beam or adds one to the beam in proportion to the number of photons in the beam. The "adding" process, when considered separately, is called negative absorption or stimulated emission. In the emitting process an atom adds a photon of energy $h\nu$ to the beam independent of the number of photons in the beam. In the scattering process an atom takes a photon from the beam and immediately gives up another, generally of slightly different energy and in a different direction.

If we consider all such atomic processes occurring at frequency ν and let ℓ and u denote lower and upper energy levels of any transition, we can add the absorption, emission, and scattering rates to obtain a differential equation of the form

$$\begin{aligned} \frac{dN_\nu(\omega)}{dt} = & -N_\nu(\omega) \sum [\text{absorption coefficient } (\ell \rightarrow u)] n(\ell) \\ & + N_\nu(\omega) \sum [\text{absorption coefficient } (u \rightarrow \ell)] n(u) \\ & - N_\nu(\omega) \sum [\text{scattering coefficient } (\ell \rightarrow u)] n(\ell) \\ & + \sum [\text{emission coefficient } (u \rightarrow \ell)] n(u) \\ & + \sum [\text{scattering emission coefficient } (u \rightarrow \ell)] n(u) \quad . \end{aligned} \tag{2.1}$$

While $n(l)$ and $n(u)$ are number densities of atoms in the lower and upper levels, we note that if a level is not bound, $n(u)$ or $n(l)$ refers to the number density in an energy interval dE corresponding to the frequency interval $h d\nu$.

Since we are actually concerned with the structure of the atmosphere instead of with photon beams, we convert from coordinates moving with the photons to coordinates fixed in the atmosphere,

$$\frac{d}{dt} = \vec{v} \cdot \vec{\nabla} + \frac{\partial}{\partial t} \quad , \quad (2.2)$$

which reduces to

$$\frac{d}{dt} = c \frac{d}{dz} \quad , \quad (2.3)$$

because the atmosphere is time independent (Section 1). Also, the number density $N_\nu(\omega)$ corresponds to the intensity (energy area⁻¹ sec⁻¹ ster⁻¹ Hz⁻¹)

$$I_\nu(\omega) = c h\nu N_\nu(\omega) \quad , \quad (2.4)$$

where the photon-velocity factor c converts number density to number flux and the factor $h\nu$ converts to energy intensity. Substituting equations (2.3) and (2.4) into (2.1), we obtain

$$\begin{aligned} \frac{dI_\nu}{dz} = & - I_\nu \frac{\sum [\text{absorption coefficient } (l \rightarrow u)]}{c} n(l) \\ & + I_\nu \frac{\sum [\text{absorption coefficient } (u \rightarrow l)]}{c} n(u) \\ & - I_\nu \frac{\sum [\text{scattering coefficient } (l \rightarrow u)]}{c} n(l) \\ & + \sum [\text{emission coefficient } (u \rightarrow l)] n(u) \\ & + \sum [\text{scattering emission coefficient } (u \rightarrow l)] n(u) \quad . \end{aligned} \quad (2.5)$$

In model stellar atmospheres it is customary (for simplicity) to assume that the scattering emission is isotropic - i. e., that photons are scattered with equal probability in all directions. Consequently in this approximation,

$$\begin{aligned} & \int \Sigma [\text{scattering emission coefficient } (u \rightarrow l)] n(u) d\omega \\ &= 4\pi \Sigma [\text{scattering emission coefficient } (u \rightarrow l)] n(u) \quad . \end{aligned} \quad (2.6)$$

Furthermore, we assume that the scattering rates are slowly varying functions of frequency, as is the case for electron scattering or for Rayleigh scattering at frequencies away from lines. Then, if we integrate over all solid angles, we find that approximately as many photons are scattered into a frequency interval as are scattered out to other frequencies. Thus, the scattering and scattering emission rates are equal,

$$\begin{aligned} & \int I_\nu \frac{\Sigma [\text{scattering coefficient } (l \rightarrow u)]}{c} n(l) d\omega \\ &= \int \Sigma [\text{scattering emission coefficient } (u \rightarrow l)] n(u) d\omega \quad . \end{aligned} \quad (2.7)$$

Combining both scattering approximations (2.6) and (2.7), we obtain

$$\begin{aligned} & \frac{\Sigma [\text{scattering coefficient } (l \rightarrow u)]}{c} n(l) \int I_\nu \frac{d\omega}{4\pi} \\ &= \Sigma [\text{scattering emission coefficient } (u \rightarrow l)] n(u) \quad , \end{aligned} \quad (2.8)$$

which we can use to simplify equation (2.1).

We adopt a notation for the various coefficients - α for absorption, s for scattering, and ϵ for emission - to obtain the transfer equation

$$\begin{aligned} \frac{dI_\nu}{dz} = & \left[-\Sigma n(l) \alpha_\nu (l \rightarrow u) + \Sigma n(u) \alpha_\nu (u \rightarrow l) - \Sigma n(l) s_\nu (l \rightarrow u) \right] I_\nu \\ & + \left[\Sigma n(u) \epsilon_\nu (u \rightarrow l) + \Sigma n(l) s_\nu (l \rightarrow u) \int I_\nu \frac{d\omega}{4\pi} \right] \quad . \end{aligned} \quad (2.9)$$

2.2 The Source Function

We introduce the source function S_ν to simplify the equations describing the radiation field by adopting a notation for the emission process similar to that for the absorption process. We define

$$S_\nu = \frac{\sum n(u) \epsilon_\nu(u \rightarrow \ell) + \sum n(\ell) s_\nu(\ell \rightarrow u) \int I_\nu(d\omega/4\pi)}{\sum n(\ell) \alpha_\nu(\ell \rightarrow u) - \sum n(u) \alpha_\nu(u \rightarrow \ell) + \sum n(\ell) s_\nu(\ell \rightarrow u)} \quad (2.10)$$

The equation for the change in intensity (2.9) becomes

$$\frac{dI_\nu}{dz} = \left[\sum n(\ell) \alpha_\nu(\ell \rightarrow u) - \sum n(u) \alpha_\nu(u \rightarrow \ell) + \sum n(\ell) s_\nu(\ell \rightarrow u) \right] (-I_\nu + S_\nu) \quad (2.11)$$

To simplify further, we now proceed to relate $n(\ell)$ to $n(u)$ and $\alpha_\nu(\ell \rightarrow u)$ to $\alpha_\nu(u \rightarrow \ell)$ and to evaluate ϵ_ν . The relation between $\alpha_\nu(\ell \rightarrow u)$ and $\alpha_\nu(u \rightarrow \ell)$ can be seen if we consider the absorption of a photon from the beam by an isolated atom. By time reversal (since in one case N photons become $N - 1$, while in the other, $N - 1$ become N), the two coefficients must be equal. A complication arises if the levels are degenerate with statistical weights $g(\ell)$ and $g(u)$. The transition rates must be proportional to the number of final states available, so that

$$\frac{\alpha_\nu(\ell \rightarrow u)}{g(u)} = \frac{\alpha_\nu(u \rightarrow \ell)}{g(\ell)} \quad (2.12)$$

Further complications may arise when we consider interactions among a large number of atoms and Doppler shifts in the frequency of the transition; however, we will assume that equation (2.12) holds in any case.

Using the relation (2. 12) between the absorption coefficients, the quantity

$$\sum n(l) \alpha_{\nu}(l \rightarrow u) - \sum n(u) \alpha_{\nu}(u \rightarrow l)$$

becomes

$$\sum n(l) \alpha_{\nu}(l \rightarrow u) - \sum n(u) \frac{g(l)}{g(u)} \alpha_{\nu}(l \rightarrow u)$$

or

$$\sum n(l) \alpha_{\nu}(l \rightarrow u) \left[1 - \frac{n(u)}{n(l)} \frac{g(l)}{g(u)} \right] . \quad (2. 13)$$

The transfer equation (2. 11) becomes

$$\frac{dI_{\nu}}{dz} = \left\{ \sum n(l) \alpha_{\nu}(l \rightarrow u) \left[1 - \frac{n(u)}{n(l)} \frac{g(l)}{g(u)} \right] + \sum n(l) s_{\nu}(l \rightarrow u) \right\} (-I_{\nu} + S_{\nu}) , \quad (2. 14)$$

and the source function becomes

$$S_{\nu} = \frac{\sum n(u) \epsilon_{\nu}(u \rightarrow l) + \sum n(l) s_{\nu}(l \rightarrow u) \int I_{\nu} (d\omega/4\pi)}{\sum n(l) \alpha_{\nu}(l \rightarrow u) \left\{ 1 - [n(u)/n(l)] [g(l)/g(u)] \right\} + \sum n(l) s_{\nu}(l \rightarrow u)} . \quad (2. 15)$$

To evaluate ϵ_{ν} , we consider the special case of thermodynamic equilibrium, for which the following conditions apply:

- A. The radiation and matter are described by one temperature, T.
- B. There is no net energy transfer, so the radiation field is constant over space, implying from equation (2. 14) that $S_{\nu} = I_{\nu}$.
- C. The intensity I_{ν} is described by the Planck function,

$$B_{\nu} = \frac{2h\nu^3}{c^2} (e^{h\nu/kT} - 1)^{-1} .$$

D. The photon number density N_ν is $B_\nu/ch\nu = (2\nu^2/c^3)(e^{h\nu/kT} - 1)^{-1}$.

E. Any process



where A, B, C and 1, 2, 3 represent particles or photons, is in equilibrium (detailed balance) such that

$$n(A) n(B) n(C) \dots R(ABC \dots \rightarrow 123 \dots) = n(1) n(2) n(3) \dots R(123 \dots \rightarrow ABC \dots) ,$$

where the R's are the rate coefficients.

F. The energy-level populations are related by the Saha equation

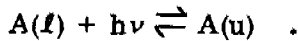
$$\frac{n_1 n_2 n_3 \dots}{n_A n_B n_C \dots} = \frac{U_1 (2\pi M_1 kT/h^2)^{3/2} U_2 (2\pi M_2 kT/h^2)^{3/2} U_3 (2\pi M_3 kT/h^2)^{3/2} \dots e^{-E_{123\dots}/kT}}{U_A (2\pi M_A kT/h^2)^{3/2} U_B (2\pi M_B kT/h^2)^{3/2} U_C (2\pi M_C kT/h^2)^{3/2} \dots e^{-E_{ABC\dots}/kT}} ,$$

where the U's are partition functions ($U_X = \sum g_i e^{-E_i/kT}$ for all i in X) or statistical weights. An example is the Boltzmann equation for two levels of the same ion:

$$\frac{n(u)}{n(l)} = \frac{g(u)}{g(l)} \frac{(2\pi M kT/h^2)^{3/2} e^{-E_u/kT}}{(2\pi M kT/h^2)^{3/2} e^{-E_l/kT}} = \frac{g(u)}{g(l)} e^{-(E_u - E_l)/kT} .$$

Further examples are given in Section 4.

We now apply the equilibrium conditions for the process



From the discussion in Section 2.1 and from E above, we know

$$n(l) a_\nu(l \rightarrow u) \frac{I_\nu}{ch\nu} = n(u) \left[a_\nu(u \rightarrow l) \frac{I_\nu}{ch\nu} + \frac{\epsilon_\nu(u \rightarrow l)}{ch\nu} \right]$$

or

$$\epsilon_{\nu}(u \rightarrow l) = \frac{n(l)}{n(u)} \alpha_{\nu}(l \rightarrow u) \left[1 - \frac{n(u)}{n(l)} \frac{g(l)}{g(u)} \right] I_{\nu} .$$

Since $I_{\nu} = B_{\nu}$ and $[n(u)/n(l)] [g(l)/g(u)] = e^{-h\nu/kT}$, we obtain

$$\epsilon_{\nu}(u \rightarrow l) = \frac{g(l)}{g(u)} e^{h\nu/kT} \alpha_{\nu}(l \rightarrow u) (1 - e^{-h\nu/kT}) \frac{2h\nu^3/c^2}{e^{h\nu/kT} - 1} ,$$

or finally

$$\epsilon_{\nu}(u \rightarrow l) = \frac{g(l)}{g(u)} \frac{2h\nu^3}{c^2} \alpha_{\nu}(l \rightarrow u) . \quad (2.16)$$

Returning to the general case, we assume that the ratio (eq. (2.16))

$$\frac{g(u)}{g(l)} \frac{\epsilon_{\nu}(u \rightarrow l)}{\alpha_{\nu}(l \rightarrow u)} = \frac{2h\nu^3}{c^2}$$

is independent of whether or not the gas is in thermal equilibrium. This is plausible, because in thermal equilibrium the ratio in no way depends on the properties of the gas. We note that for a line transition the emission coefficient (2.16) implies that the absorption and emission profiles are identical. This is, in fact, the case in a high-density, nonmoving atmosphere.

We substitute our result for ϵ_{ν} (eq. (2.16)) into the source function (2.15), first making the transformation

$$\begin{aligned} \sum n(u) \epsilon_{\nu}(u \rightarrow l) &= \sum n(l) \alpha_{\nu}(l \rightarrow u) \frac{n(u)}{n(l)} \frac{g(l)}{g(u)} \frac{2h\nu^3}{c^2} \\ &= \sum n(l) \alpha_{\nu}(l \rightarrow u) \left[1 - \frac{n(u)}{n(l)} \frac{g(l)}{g(u)} \right] \frac{2h\nu^3}{c^2} \left[\frac{n(l)}{n(u)} \frac{g(u)}{g(l)} - 1 \right]^{-1} , \end{aligned}$$

to obtain

$$S_\nu = \frac{\sum n(l) \alpha_\nu(l \rightarrow u) \left[1 - \frac{n(u)}{n(l)} \frac{g(l)}{g(u)} \right] \frac{2h\nu^3}{c^2} \left[\frac{n(l)}{n(u)} \frac{g(u)}{g(l)} - 1 \right]^{-1} + \sum n(l) s_\nu(l \rightarrow u) \int I_\nu \frac{d\omega}{4\pi}}{\sum n(l) \alpha_\nu(l \rightarrow u) \left[1 - \frac{n(u)}{n(l)} \frac{g(l)}{g(u)} \right] + \sum n(l) s_\nu(l \rightarrow u)} \quad (2.17)$$

2.3 Mass Absorption Coefficients, Optical Depth, and the Plane-Parallel Approximation

We wish to change variables and make some simplifying definitions before proceeding. First, we define the following mass absorption coefficients or opacities:

$$\kappa_\nu(l \rightarrow u) = n(l) \alpha_\nu(l \rightarrow u) \left\{ \frac{1 - [n(u)/n(l)] [g(l)/g(u)]}{\rho} \right\} , \quad (2.18)$$

$$\kappa_\nu = \sum \kappa_\nu(l \rightarrow u) , \quad (2.19)$$

$$\sigma_\nu(l \rightarrow u) = \frac{n(l) s_\nu(l \rightarrow u)}{\rho} , \quad (2.20)$$

$$\sigma_\nu = \sum \sigma_\nu(l \rightarrow u) . \quad (2.21)$$

We have divided by the mass density ρ in order to remove the rapid variation caused by the change in the number densities as we pass through the atmosphere. In this notation, the transfer equation (2.14) becomes

$$\frac{dI}{\rho dz} = (\kappa_\nu + \sigma_\nu)(-I_\nu + S_\nu) , \quad (2.22)$$

and the source function (2.17) becomes

$$S_\nu = \frac{\sum \kappa_\nu(l \rightarrow u) S_\nu(u \rightarrow l) + \sigma_\nu \int I_\nu (d\omega/4\pi)}{\kappa_\nu + \sigma_\nu} , \quad (2.23)$$

where we have defined a source function for a single transition,

$$S_{\nu}(u \rightarrow l) = \frac{2h\nu^3}{c^2} \left[\frac{n(l)}{n(u)} \frac{g(u)}{g(l)} - 1 \right]^{-1}. \quad (2.24)$$

To make the derivative $dI_{\nu}/\rho dz$ in the transfer equation (2.22) of the same physical magnitude as I_{ν} , we divide it by $\kappa_{\nu} + \sigma_{\nu}$ and define the optical depth along the beam such that $d\tau_{\nu} = (\kappa_{\nu} + \sigma_{\nu}) \rho |dz|$. We note that in an optical depth τ , the number of original photons left in the beam decreases by $e^{-\tau}$ (from $dI/d\tau = -I$). Therefore, photons do not travel distances greater than a few optical depths. The density in a stellar atmosphere can be large enough so that the distance corresponding to a few optical depths is small compared to the radius of the star. In this case, the radiation field cannot "see" curvature, and we can treat the atmosphere in plane layers where distances and optical depths are measured in terms of the normal distance x . Then, $z = x/\cos \theta = x/\mu$, $dz = dx/\mu$, and the optical depth along x is determined from

$$d\tau_{\nu} = -(\kappa_{\nu} + \sigma_{\nu}) \rho dx, \quad \tau = 0 \text{ at } x = \infty. \quad (2.25)$$

The transfer equation then can be written in the simple form

$$\mu \frac{dI_{\nu}}{d\tau_{\nu}} = I_{\nu} - S_{\nu}. \quad (2.26)$$

2.4 Properties of the Radiation Field

If we assume that S_{ν} is specified, we can integrate equation (2.26) to obtain I_{ν} . The homogeneous solution is $I_{\nu} = c(\tau_{\nu}) e^{\tau_{\nu}/\mu}$. Substituting this solution into the non-homogeneous equation gives the result

$$I_{\nu} = -e^{\tau_{\nu}/\mu} \int_c^{\tau_{\nu}} S_{\nu} e^{-t/\mu} \frac{dt}{\mu},$$

where c is an arbitrary constant. There are two cases: $\mu < 0$ and $\mu > 0$. For $\mu < 0$, the boundary condition is no incident radiation at the top of the atmosphere ($\tau_\nu = 0$), with the result

$$I_\nu = - \int_0^{\tau_\nu} S_\nu e^{-(t-\tau_\nu)/\mu} \frac{dt}{\mu} , \quad \mu < 0 . \quad (2.27a)$$

For $\mu > 0$, the boundary condition is that the intensity contribution from infinity is zero because the energy source in a star is finite:

$$I_\nu = \int_{\tau_\nu}^{\infty} S_\nu e^{-(t-\tau_\nu)/\mu} \frac{dt}{\mu} , \quad \mu > 0 . \quad (2.27b)$$

We are also interested in properties of the radiation field other than the specific intensity I_ν . The radiation field that each atom sees and that governs the level populations is the integrated intensity $\int I_\nu d\omega$. Another quantity, the radiative energy that actually passes through the atmosphere in any outward direction per unit area per second, is the flux $\int \mu I_\nu d\omega$. The cosine factor μ subtracts the inward-flowing radiation from the outward-flowing radiation to yield the net outward flow. A third property is the radiation pressure $(1/c) \int \mu^2 I_\nu d\omega$. Since photons carry momentum $h\nu/c$, they exert a pressure. The pressure in the normal direction per unit frequency, or the rate of momentum transfer per unit area, is the normal component of the energy flow $\mu(\mu I_\nu)$ integrated over all angles and divided by the photon velocity c .

We can formalize this discussion by introducing the intensity moments

$$J_\nu = \int I_\nu \frac{d\omega}{4\pi} , \quad (2.28)$$

$$H_\nu = \int \mu I_\nu \frac{d\omega}{4\pi} , \quad (2.29)$$

and

$$K_\nu = \int \mu^2 I_\nu \frac{d\omega}{4\pi} ; \quad (2.30)$$

J_ν is called the mean intensity, and the integrated intensity is $4\pi J_\nu$. The flux is $4\pi H_\nu$; for confusion, H_ν is also called the flux. The monochromatic radiation pressure is $4\pi K_\nu/c$, but K_ν does not have a common name. Use of the moments keeps all the radiation quantities in the same units. Note that the source function (2.19) can be written in terms of J_ν as

$$S_\nu = \frac{\sum \kappa_\nu(l \rightarrow u) S_\nu(u \rightarrow l) + \sigma_\nu J_\nu}{\kappa_\nu + \sigma_\nu} . \quad (2.31)$$

We can also take the moments of the transfer equation (2.26)

$$\mu \frac{dI_\nu}{d\tau_\nu} = I_\nu - S_\nu ,$$

$$\frac{dH_\nu}{d\tau_\nu} = J_\nu - S_\nu , \quad (2.32)$$

$$\frac{dK_\nu}{d\tau_\nu} = H_\nu . \quad (2.33)$$

If we use the relation $d\omega = 2\pi \sin \theta d\theta = -2\pi d\mu$, the moments become

$$J_\nu = \frac{1}{2} \int_{-1}^1 I_\nu d\mu , \quad (2.34)$$

$$H_\nu = \frac{1}{2} \int_{-1}^1 \mu I_\nu d\mu . \quad (2.35)$$

$$K_\nu = \frac{1}{2} \int_{-1}^1 \mu^2 I_\nu d\mu . \quad (2.36)$$

To evaluate equations (2.34) through (2.36), we substitute the solution for I_ν (eq. (2.27a, b)) to obtain

$$J_\nu = \frac{1}{2} \int_{-1}^0 \int_0^{\tau_\nu} S_\nu e^{-(\tau_\nu - t)/\mu} \frac{dt}{\mu} d\mu + \frac{1}{2} \int_0^1 \int_{\tau_\nu}^{\infty} S_\nu e^{-(t - \tau_\nu)/\mu} \frac{dt}{\mu} d\mu , \quad (2.37)$$

$$H_\nu = -\frac{1}{2} \int_{-1}^0 \int_0^{\tau_\nu} S_\nu e^{-(\tau_\nu - t)/\mu} dt d\mu + \frac{1}{2} \int_0^1 \int_{\tau_\nu}^{\infty} S_\nu e^{-(t - \tau_\nu)/\mu} dt d\mu , \quad (2.38)$$

and

$$K_\nu = \frac{1}{2} \int_{-1}^0 \int_0^{\tau_\nu} S_\nu e^{-(\tau_\nu - t)/\mu} \mu dt d\mu + \frac{1}{2} \int_0^1 \int_{\tau_\nu}^{\infty} S_\nu e^{-(t - \tau_\nu)/\mu} \mu dt d\mu . \quad (2.39)$$

The preceding notation can be considerably simplified if we introduce the exponential integral

$$E_n(x) = \int_1^{\infty} \frac{e^{-xz}}{z^n} dz = \int_0^1 e^{-x/\mu} \mu^{n-2} d\mu , \quad (2.40)$$

so that

$$J_\nu(\tau_\nu) = \frac{1}{2} \int_0^{\tau_\nu} S_\nu E_1(\tau_\nu - t) dt + \frac{1}{2} \int_{\tau_\nu}^{\infty} S_\nu E_1(t - \tau_\nu) dt , \quad (2.41)$$

$$H_\nu(\tau_\nu) = -\frac{1}{2} \int_0^{\tau_\nu} S_\nu E_2(\tau_\nu - t) dt + \frac{1}{2} \int_{\tau_\nu}^{\infty} S_\nu E_2(t - \tau_\nu) dt , \quad (2.42)$$

and

$$K_{\nu}(\tau_{\nu}) = \frac{1}{2} \int_0^{\tau_{\nu}} S_{\nu} E_3(\tau_{\nu} - t) dt + \frac{1}{2} \int_{\tau_{\nu}}^{\infty} S_{\nu} E_3(t - \tau_{\nu}) dt \quad . \quad (2.43)$$

We see that the mean intensity is an average over τ of S_{ν} for τ near τ_{ν} . The flux is the difference between S_{ν} for τ greater than τ_{ν} and S_{ν} for τ less than τ_{ν} . We must remember that S_{ν} depends on J_{ν} (eq. (2.31)), so we actually must solve an integral equation to determine S_{ν} or J_{ν} .

2.5 Computing the Optical Depth

We define a mass variable $-\int \rho dx$, which we call *rhox* (pronounced rocks), and use it to label depth points in the atmosphere. In non-FORTRAN equations, we denote *rhox* by M and the differential $-\rho dx$ by dM .

We now consider the numerical calculation of the radiation field, assuming we know the opacity as described in Section 5. We divide the atmosphere into N layers, each labeled by depth M_j . The optical depth is easily found by integrating the opacity,

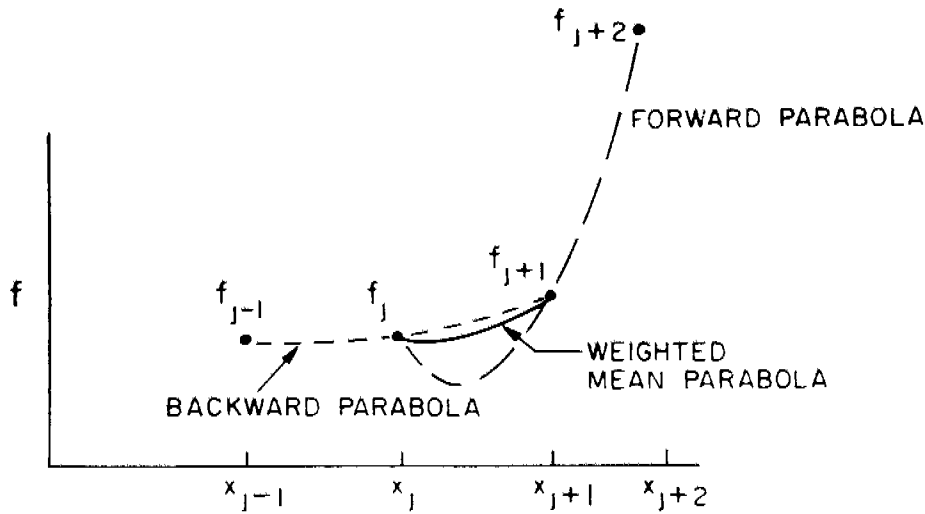
$$\tau_{\nu j} = \int_0^{M_j} (\kappa_{\nu} + \sigma_{\nu}) dM \quad . \quad (2.44)$$

Simple integrals like (2.44) are performed by fitting parabolas to the integrand for each depth interval in the atmosphere, as follows:

$$\begin{aligned} \int_0^{x_N} f(x) dx &= \sum \int_{x_j}^{x_{j+1}} f(x) dx = \sum \int_{x_j}^{x_{j+1}} (a_j + b_j x + c_j x^2) dx \\ &= \sum \left[a_j(x_{j+1} - x_j) + \frac{b_j(x_{j+1}^2 - x_j^2)}{2} + \frac{c_j(x_{j+1}^3 - x_j^3)}{3} \right] \\ &= \sum \left[a_j + \frac{b_j(x_{j+1} + x_j)}{2} + \frac{c_j(x_{j+1}^2 + x_{j+1}x_j + x_j^2)}{3} \right] (x_{j+1} - x_j) \quad . \end{aligned} \quad (2.45)$$

In ATLAS, the interpolation coefficients a_j , b_j , and c_j are determined by weighting forward and backward parabolas inversely by their second derivatives, as shown in the following diagram:

106-048



This weighting avoids large overshoots, which are a problem with simple parabolic interpolation. The unweighted parabolas are given by the expressions

$$c_j = \frac{f_{j+1}}{(x_{j+1} - x_j)(x_{j+1} - x_{j-1})} - \frac{f_j}{(x_j - x_{j-1})(x_{j+1} - x_j)} + \frac{f_{j-1}}{(x_j - x_{j-1})(x_{j+1} - x_{j-1})}, \quad (2.46c)$$

$$b_j = \frac{f_j - f_{j-1}}{x_j - x_{j-1}} - (x_j + x_{j-1}) c_j, \quad (2.46b)$$

and

$$a_j = f_{j-1} - x_{j-1} \frac{f_j - f_{j-1}}{x_j - x_{j-1}} + x_j x_{j-1} c_j. \quad (2.46a)$$

The weight is

$$w_j = \frac{|c_{j+1}|}{|c_{j+1}| + |c_j|}, \quad (2.47)$$

so the weighted mean parabola is

$$\begin{aligned}\bar{a}_j &= w_j a_j + (1 - w_j) a_{j+1} \quad , \\ \bar{b}_j &= w_j b_j + (1 - w_j) b_{j+1} \quad , \\ \bar{c}_j &= w_j c_j + (1 - w_j) c_{j+1} \quad .\end{aligned}\tag{2.48}$$

2.6 Computing the Mean Intensity and Flux

The source function, mean intensity, and flux are calculated as described by Kurucz (1969) by using integration matrices.

To derive these matrices, we consider the general moment integral of the specific intensity,

$$M_n(\tau) = \frac{1}{2} \int_0^\infty \text{sign}(t - \tau)^{n-1} S(t) E_n |t - \tau| dt \quad .\tag{2.49}$$

Then, from equations (2.41), (2.42), and (2.43),

$$J(\tau) = M_1(\tau) \quad , \quad H(\tau) = M_2(\tau) \quad , \quad \text{and} \quad K(\tau) = M_3(\tau) \quad .$$

We divide the integration range into N subintervals,

$$M_{n\ell} \equiv M_n(\tau_\ell) = \frac{1}{2} \sum_{j=1}^N \text{sign}(\tau_j - \tau_\ell)^{n-1} \int_{\tau_j}^{\tau_{j+1}} S(t) E_n |t - \tau_\ell| dt \quad .\tag{2.50}$$

We now assume that S can be represented by a parabola in the interval (τ_j, τ_{j+1}) .

Thus,

$$S(t) = \sum_{k=1}^3 t^{k-1} \sum_{i=1}^N C_{jki} S_i \quad ,\tag{2.51}$$

where the C_{jki} are interpolation coefficients. The C_{jki} can be, for example, one-half the sum of the forward-parabolic and the backward-parabolic interpolation coefficients; or they can even be linear if a large number of points is used. In the version of ATLAS described here, however, the interpolation coefficients C_{jki} were found by passing a parabola through S_j and S_{j+1} and by least-squares fitting S_{j-1} and S_{j+2} . These coefficients are listed in Table 1.

Inserting the expression for $S(t)$ (eq. (2.51)) into the j th term of the sum (eq. (2.50)), we find that

$$M_{nlj} = \frac{1}{2} \text{sign}(\tau_j - \tau_l)^{n-1} \int_{\tau_j}^{\tau_{j+1}} dt E_n |t - \tau_l| \sum_{k=1}^3 t^{k-1} \sum_{i=1}^N C_{jki} S_i . \quad (2.52)$$

This expression can be simplified to

$$M_{nlj} = \sum_{k=1}^3 \eta_{nljk} \sum_{i=1}^N C_{jki} S_i , \quad (2.53)$$

where

$$\eta_{nljk} = \frac{1}{2} \text{sign}(\tau_j - \tau_l)^{n-1} \int_{\tau_j}^{\tau_{j+1}} t^{k-1} E_n |\tau_l - t| dt \quad (2.54)$$

is an integral that can be evaluated analytically. To evaluate η_{nljk} , we use the indefinite integral

$$\int E_n(x) dx = -E_{n+1}(x) \quad (2.55)$$

Table 1. Least-squares parabolic interpolation coefficients.

$$D = \tau_{j-1}^2 + \tau_{j+2}^2 - \tau_j \tau_{j-1} - \tau_j \tau_{j+1} - \tau_{j+1} \tau_{j-1} - \tau_{j+1} \tau_{j+2} + 2 \tau_j \tau_{j+1}$$

$$C_{j1j-1} = \frac{\tau_j \tau_{j+1}}{D}$$

$$C_{j1j} = \frac{\tau_{j+1}(-\tau_{j-1}^2 - \tau_{j+2}^2 + \tau_{j+1} \tau_{j-1} + \tau_{j+1} \tau_{j+2})}{(\tau_j - \tau_{j+1}) D}$$

$$C_{j1j+1} = \frac{\tau_j(\tau_{j-1}^2 + \tau_{j+2}^2 - \tau_j \tau_{j-1} - \tau_j \tau_{j+2})}{(\tau_j - \tau_{j+1}) D}$$

$$C_{j1j+2} = \frac{\tau_j \tau_{j+1}}{D}$$

$$C_{j2j-1} = \frac{-(\tau_j + \tau_{j+1})}{D}$$

$$C_{j3j-1} = \frac{1}{D}$$

$$C_{j2j} = \frac{\tau_{j-1}^2 - 2\tau_{j+1}^2 + \tau_{j+2}^2}{(\tau_j - \tau_{j+1}) D}$$

$$C_{j3j} = \frac{-\tau_{j-1} + 2\tau_{j+1} - \tau_{j+2}}{(\tau_j - \tau_{j+1}) D}$$

$$C_{j2j+1} = \frac{-\tau_{j-1}^2 + 2\tau_j^2 - \tau_{j+2}^2}{(\tau_j - \tau_{j+1}) D}$$

$$C_{j3j+1} = \frac{\tau_{j-1} - 2\tau_j + \tau_{j+2}}{(\tau_j - \tau_{j+1}) D}$$

$$C_{j2j+2} = \frac{-(\tau_j + \tau_{j+1})}{D}$$

$$C_{j3j+2} = \frac{1}{D}$$

and integrate by parts, obtaining

$$\begin{aligned}
\eta_{n\ell jk} = & \frac{1}{2} \text{sign}(\tau_j - \tau_\ell)^{n-1} \left| \left(\tau_j^{k-1} E_{n+1}|\tau_\ell - \tau_j| - \tau_{j+1}^{k-1} E_{n+1}|\tau_\ell - \tau_{j+1}| \right) \right. \\
& + (k-1) \text{sign}(\tau_j - \tau_\ell) \left(\tau_j^{k-2} E_{n+2}|\tau_\ell - \tau_j| - \tau_{j+1}^{k-2} E_{n+2}|\tau_\ell - \tau_{j+1}| \right) \\
& \left. + (k-1)(k-2) \left(\tau_j^{k-3} E_{n+3}|\tau_\ell - \tau_j| - \tau_{j+1}^{k-3} E_{n+3}|\tau_\ell - \tau_{j+1}| \right) \right| .
\end{aligned} \tag{2.56}$$

We must evaluate $\eta_{n\ell jk}$ carefully when the τ 's are small because of two cases of numerical cancellation. First, for $|\tau_\ell - \tau_j|$ small, we write out the expression for $\eta_{n\ell jk}$ explicitly using the power-series expansion for the exponential integrals and grouping terms in such a way that no loss of accuracy occurs. The power series is

$$E_n(x) = \frac{(-x)^{n-1}}{(n-1)!} \left(-\log x - \gamma + \sum_{m=1}^{n-1} \frac{1}{m} \right) - \sum_{\substack{m=0 \\ m \neq n-1}}^{\infty} \frac{(-x)^m}{(m-n+1)m!} , \tag{2.57}$$

where $\gamma = 0.577215664901533$ is Euler's constant. Second, for τ_j/τ_ℓ small, we use the power-series expansion around τ_ℓ and evaluate only those terms that do not cancel analytically. The expansion is

$$\begin{aligned}
E_n(x-y) = & E_n(x) + y E_{n-1}(x) + \frac{1}{2} y^2 E_{n-2}(x) + \cdots + \frac{y^{n-2}}{(n-2)!} E_2(x) \\
& + \frac{y^{n-1}}{(n-1)!} E_1(x) + e^{-x} \sum_{m=0}^{\infty} \frac{y^{m+n}}{(m+n)!} \left[1 + \frac{m}{x} + \frac{m(m-1)}{x^2} + \cdots + \frac{m!}{x^{m-1}} + \frac{m!}{x^m} \right] .
\end{aligned} \tag{2.58}$$

Detailed expressions for η_{nljk} can be extracted from program PRETAB listed in Section 9.2.

We now collect terms to achieve the form of a matrix operator on S ,

$$\begin{aligned} M_{nl} &= \sum_{j=1}^N \sum_{k=1}^3 \eta_{nljk} \sum_{i=1}^N C_{jki} S_i = \sum_{j=1}^N \sum_{k=1}^3 \sum_{i=1}^N \eta_{nljk} C_{jki} S_i \\ &= \sum_{j=1}^N \sum_{k=1}^3 \sum_{i=1}^N \eta_{nljk} C_{ikj} S_j = \sum_{j=1}^N \Xi_{nlj} S_j \quad , \end{aligned} \quad (2.59)$$

where

$$\Xi_{nlj} = \sum_{k=1}^3 \sum_{i=1}^N \eta_{nljk} C_{ikj} \quad . \quad (2.60)$$

The matrix Ξ_n is the desired matrix operator

$$M_n = \Xi_n S \quad . \quad (2.61)$$

To calculate the flux or mean intensity, we simply matrix multiply

$$J = \Lambda S \quad (2.62)$$

and

$$H = \Phi S \quad , \quad (2.63)$$

where we have defined the matrices

$$\Lambda \equiv \Xi_1 \quad \text{and} \quad \Phi \equiv \Xi_2 \quad .$$

2.7 Computing the Source Function

We recall equation (2.31) for the source function

$$S_\nu = \frac{\sum \kappa_\nu(\ell \rightarrow u) S_\nu(u \rightarrow \ell) + \sigma_\nu J_\nu}{\kappa_\nu + \sigma_\nu}$$

and rewrite it as

$$S_\nu = (1 - \alpha_\nu) \bar{S}_\nu + \alpha_\nu J_\nu, \quad (2.64)$$

where

$$\bar{S}_\nu \equiv \frac{\sum \kappa_\nu(\ell \rightarrow u) S_\nu(u \rightarrow \ell)}{\kappa_\nu} \quad (2.65)$$

and

$$\alpha_\nu \equiv \frac{\sigma_\nu}{\kappa_\nu + \sigma_\nu}. \quad (2.66)$$

Equation (2.64) is an integral equation for S_ν since J_ν depends on S_ν . In matrix notation, the integral equation becomes

$$S = (I - \alpha) \bar{S} + \alpha \Lambda S$$

or

$$(I - \alpha \Lambda) S = (I - \alpha) \bar{S}, \quad (2.67)$$

where I is the identity matrix, α is now a diagonal matrix, and S and \bar{S} are now column vectors. The solution to this system of equations can be rapidly obtained by Gauss-Seidel iteration since the matrix is almost diagonal. The iteration proceeds as follows: An initial guess is made for S , such as $S = \bar{S}$. This vector is multiplied by the matrix $(I - \alpha \Lambda)$ to give a vector that differs by Δ from the required result $(I - \alpha) \bar{S}$,

$$\Delta = (I - \alpha \Lambda) S - (I - \alpha) \bar{S}. \quad (2.68)$$

We wish to find a correction ΔS so that

$$(I - \alpha \Lambda)(S + \Delta S) = (I - \alpha) \bar{S} . \quad (2.69)$$

The solution of equation (2.69) is

$$\Delta S = (I - \alpha \Lambda)^{-1} [(I - \alpha) \bar{S} - (I - \alpha \Lambda) S] = - (I - \alpha \Lambda)^{-1} \Delta . \quad (2.70)$$

Since $(I - \alpha \Lambda)$ is almost diagonal,

$$(I - \alpha \Lambda)^{-1} \simeq \frac{1}{1 - \alpha_i \Lambda_{ii}} , \quad (2.71)$$

so that

$$\Delta S \simeq - \frac{\Delta}{1 - \alpha_i \Lambda_{ii}} . \quad (2.72)$$

We iterate on the equation

$$S^{\text{new}} = S^{\text{old}} + \Delta S \quad (2.73)$$

until $\Delta S/S$ is less than some prescribed value, currently 1.E-5.

Equation (2.67) for the source function can be rewritten in a form that avoids the quantity $(1 - \alpha)$, which may lead to numerical difficulties. We have

$$\left(I - \frac{\sigma}{\kappa + \sigma} \Lambda \right) S = \left(I - \frac{\sigma}{\kappa + \sigma} \right) \bar{S} \quad (2.74)$$

or

$$\left(\frac{\kappa + \sigma - \sigma \Lambda}{\kappa + \sigma} \right) S = \frac{\kappa}{\kappa + \sigma} \bar{S} ,$$

and finally

$$\left(I + \frac{\sigma}{\kappa} - \frac{\sigma}{\kappa} \Lambda \right) S = \bar{S} \quad . \quad (2.75)$$

2.8 Pretabulation of the Matrices and Treatment of Large Depths

Since the integration matrices are rather complicated to evaluate, they have been pretabulated for a fixed τ set, where the values of τ have been chosen to give accurate integrations. The program that does this, PRETAB, is listed in Section 9.2. The 43 points currently used are the following:

1	0	12	0.01	23	0.63	34	3.65
2	0.000032	13	0.016	24	0.78	35	4.15
3	0.000056	14	0.025	25	0.95	36	4.9
4	0.0001	15	0.042	26	1.15	37	6.1
5	0.00018	16	0.065	27	1.35	38	7.7
6	0.00032	17	0.096	28	1.6	39	10.
7	0.00056	18	0.139	29	1.85	40	12.5
8	0.001	19	0.196	30	2.15	41	15.
9	0.0018	20	0.273	31	2.45	42	17.5
10	0.0032	21	0.375	32	2.75	43	20.
11	0.0056	22	0.5	33	3.15		

Note that since there are few points near the surface, integrals at monochromatic optical depths of 10^{-4} and less cannot be very reliable if the source function varies there. The abundance of points at large depths allows better treatment of these regions.

To evaluate S_ν , J_ν , and H_ν , we interpolate a_ν and \bar{S}_ν from the τ_ν set onto the fixed τ set. Then we solve for S_ν and use it to integrate for J_ν and H_ν . Finally, we interpolate S_ν , J_ν , and H_ν back onto the τ_ν set. For the interpolations we use the method described in Section 2.5.

Optical depths larger than the last value of the fixed τ set ($\tau = 20$) must be treated separately by using the asymptotic forms for the Λ and Φ operators, namely,

$$J_\nu = S_\nu + \frac{1}{3} \frac{d^2 S_\nu}{d\tau_\nu^2} \quad \text{and} \quad H_\nu = \frac{1}{3} \frac{dS_\nu}{d\tau_\nu} \quad . \quad (2.76)$$

These asymptotic relations can be derived by evaluating K_ν at large depths and then using the moment equations (2.32) and (2.33) to find J_ν and H_ν by differentiation. From equation (2.43), we have

$$K_\nu(\tau_\nu) = \frac{1}{2} \int_0^\infty S_\nu(t) E_3|t - \tau_\nu| dt \quad . \quad (2.77)$$

We expand $S(t)$ around τ_ν ,

$$S(t) = S(\tau_\nu) + (\tau_\nu - t) \left(\frac{dS_\nu}{dt} \right)_{\tau_\nu} + \frac{1}{2} (\tau_\nu - t)^2 \left(\frac{d^2 S_\nu}{dt^2} \right)_{\tau_\nu} + \dots \quad ,$$

and insert the expansion into the integral (2.77),

$$\begin{aligned} K_\nu(\tau_\nu) = & \left[S(\tau_\nu) + \tau_\nu \left(\frac{dS}{dt} \right)_{\tau_\nu} + \frac{\tau_\nu^2}{2} \left(\frac{d^2 S_\nu}{dt^2} \right)_{\tau_\nu} \right] \left[\frac{1}{2} \int_0^{\tau_\nu} E_3(\tau_\nu - t) dt + \frac{1}{2} \int_{\tau_\nu}^\infty E_3(t - \tau_\nu) dt \right] \\ & + \left[- \left(\frac{dS}{dt} \right)_{\tau_\nu} - \tau_\nu \left(\frac{d^2 S}{dt^2} \right)_{\tau_\nu} \right] \left[\frac{1}{2} \int_0^{\tau_\nu} t E_3(\tau_\nu - t) dt + \frac{1}{2} \int_{\tau_\nu}^\infty t E_3(t - \tau_\nu) dt \right] \\ & + \left[\frac{1}{2} \left(\frac{d^2 S}{dt^2} \right)_{\tau_\nu} \right] \left[\frac{1}{2} \int_0^{\tau_\nu} t^2 E_3(\tau_\nu - t) dt + \frac{1}{2} \int_{\tau_\nu}^\infty t^2 E_3(t - \tau_\nu) dt \right] \quad . \end{aligned}$$

From equations (2.54) and (2.56), we find

$$\begin{aligned}
K_\nu(\tau_\nu) = & \left[S(\tau_\nu) + \tau_\nu \left(\frac{dS}{dt} \right)_{\tau_\nu} + \frac{\tau_\nu^2}{2} \left(\frac{d^2 S_\nu}{dt^2} \right)_{\tau_\nu} \right] \left[\frac{1}{3} - \frac{1}{2} E_4(\tau_\nu) \right] \\
& + \left[- \left(\frac{dS}{dt} \right)_{\tau_\nu} - \tau_\nu \left(\frac{d^2 S}{dt^2} \right)_{\tau_\nu} \right] \left[\frac{1}{3} \tau_\nu + \frac{1}{2} E_5(\tau_\nu) \right] \\
& + \left[\frac{1}{2} \left(\frac{d^2 S}{dt^2} \right)_{\tau_\nu} \right] \left[\frac{2}{5} + \frac{1}{3} \tau_\nu^2 - E_6(\tau_\nu) \right] .
\end{aligned}$$

The asymptotic form for the exponential integral

$$E_n(x) \sim \frac{e^{-x}}{x} \left[1 - \frac{n}{x} + \frac{n(n+1)}{x^2} - \dots \right] \quad (2.78)$$

implies that we can ignore $E_n(\tau_\nu)$ terms for τ_ν large. We find

$$K_\nu(\tau_\nu) \sim \frac{1}{3} S(\tau_\nu) + \frac{1}{5} \left(\frac{d^2 S}{dt^2} \right)_{\tau_\nu} , \quad (2.79)$$

so that to second order,

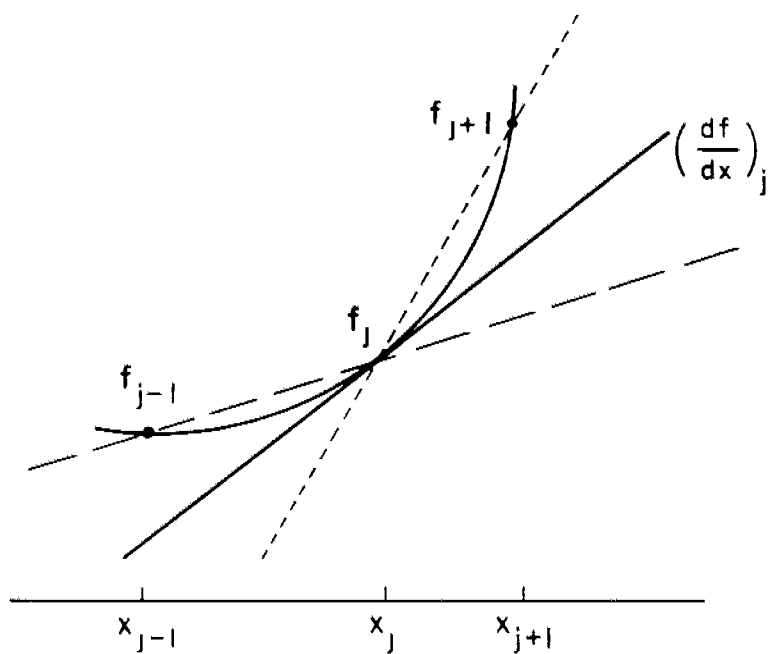
$$H_\nu = \frac{dK_\nu}{d\tau_\nu} = \frac{1}{3} \frac{dS_\nu}{d\tau_\nu}$$

and

$$J_\nu - S_\nu = \frac{dH_\nu}{d\tau_\nu} = \frac{1}{3} \frac{d^2 S_\nu}{d\tau_\nu^2} . \quad (2.80)$$

Derivatives are taken by bisecting the angles formed by the extension of the line segments as shown in the following diagram:

106-048



The result is

$$\left(\frac{df}{dx}\right)_j = \frac{S(T_{j+1} + T_j)}{1 - T_{j+1}T_j},$$

where

$$T_j = \frac{D_j}{1 + \sqrt{1 + D_j^2}},$$

with

$$D_j = \frac{1}{S} \frac{f_j - f_{j-1}}{x_j - x_{j-1}},$$

and where

$$S = \frac{\max(|f_{j-1}|, |f_j|, |f_{j+1}|)}{|x_j|} .$$

The scaling factor S converts f and x to the same magnitude

We calculate S_v by iteration on the numerical derivatives until the relative change in S_v is less than $1. E-5$.

2.9 Computing Specific Intensity

The specific intensity $I_v(\mu)$ at the surface for $\cos \theta = \mu$ is often required, especially for solar work,

$$I_v(\mu) = \int_0^\infty S_v e^{-\tau_v/\mu} \frac{d\tau_v}{\mu} . \quad (2.27b')$$

We evaluate this by means of parabolic interpolation coefficients for S_v , with the following result:

$$I_v(\mu) = \sum_{i=1}^N \left(e^{-\tau_i/\mu} \left\{ a_i + b_i(\tau_i + \mu) + c_i[(\tau_i + \mu)^2 + \mu^2] \right\} \right. \\ \left. - e^{-\tau_{i+1}/\mu} \left\{ a_i + b_i(\tau_{i+1} + \mu) + c_i[(\tau_{i+1} + \mu)^2 + \mu^2] \right\} \right) ,$$

or

$$I_v(\mu) = \sum_{i=1}^N \left\{ e^{-\tau_i/\mu} \left[S_i + (b_i + 2c_i \tau_i) \mu + 2c_i \mu^2 \right] \right. \\ \left. - e^{-\tau_{i+1}/\mu} \left[S_{i+1} + (b_i + 2c_i \tau_{i+1}) \mu + 2c_i \mu^2 \right] \right\} . \quad (2.81)$$

At small optical depths, we expand in $\Delta = (\tau_{i+1} - \tau_i)/\mu$ to avoid cancellation problems,

$$I_\nu(\mu) = \sum_{i=1}^N e^{-\tau_{i+1}/\mu} \left\{ S_i \Delta + \left[S_i + (b_i + 2c_i \tau_i) \mu \right] \frac{\Delta^2}{2} + \left[S_i + (b_i + 2c_i \tau_i) \mu + 2c_i \mu^2 \right] \sum_{n=3}^{\infty} \frac{\Delta^n}{n!} \right\} . \quad (2.82)$$

No allowance is made for the integral from τ_N to infinity, so the last τ_ν/μ must be large.

2.10 Frequency Integrations

Frequency integrals over flux and mean intensity are required for the temperature correction, for radiation pressure, and for photoionization rates. For the integration, we choose as many frequencies as necessary to represent the shapes of the various continua or lines. The integrations are truncated at some maximum frequency, usually an opacity discontinuity, such that inclusion of higher frequency points does not affect the model, except perhaps in the outer surface layers, where some of our assumptions break down in any case, or at such large optical depths as to be unimportant.

The integrals are evaluated by multiplying the various integrands at each frequency f_{ν_i} by a previously determined integration coefficient w_i that is a function only of the frequency spacing. The integration coefficients can be determined in any manner, but in Section 9.1 a program (FRESET) is given that uses the least-squares parabolas defined in Section 2.6.

The integral over all frequencies $f = \int f_\nu d\nu$ is the sum $\sum w_i f_{\nu_i}$. Since the monochromatic quantities are required in ATLAS only as integrands, they need not be saved once they have been added to the integral sums. Consequently, monochromatic quantities can be evaluated for any number of frequencies, one frequency at a time, with a minimum storage requirement.

2.11 Radiation Pressure

The radiation pressure is given by the integral

$$P_{\text{rad}} = \frac{4\pi}{c} \int K_{\nu} d\nu ,$$

as discussed in Section 2.4. However, to save computation we do not evaluate K_{ν} directly but use the moment

$$\frac{dK_{\nu}}{dM} = (\kappa_{\nu} + \sigma_{\nu}) H_{\nu} .$$

Then,

$$\frac{dP_{\text{rad}}}{dM} = \frac{4\pi}{c} \int (\kappa_{\nu} + \sigma_{\nu}) H_{\nu} d\nu . \quad (2.83)$$

The quantity on the right side of equation (2.83) is the acceleration the gas experiences when it absorbs photons from below. Once the radiation field is known, P_{rad} is easily evaluated by integrating over M and specifying $P_{\text{rad}} = 0$ at $M = 0$. The actual value at the surface could be found by evaluating K_{ν} (at considerable expense), but there is no current need in ATLAS to know P_{rad} accurately at the surface.

2.12 Rosseland Optical Depth and Opacity

It is sometimes convenient to describe a model atmosphere in terms of a mean optical depth. For example, a good way to get a first guess for a model temperature distribution is to take some existing $T(M)^{\text{old}}$, express it as $T(\langle\tau\rangle)^{\text{old}}$, then scale the temperature by the ratio of the effective temperatures

$$T(\langle\tau\rangle)^{\text{new}} = \frac{T_{\text{eff}}^{\text{new}}}{T_{\text{eff}}^{\text{old}}} T(\langle\tau\rangle)^{\text{old}} ,$$

and finally convert back to obtain $T(M)^{\text{new}}$. The Rosseland optical depth is well suited to this type of scaling, as we will show below.

The Rosseland optical depth τ_{Ross} and the corresponding Rosseland opacity are based on the behavior of the integrated flux at large depths,

$$\int H_{\nu} d\nu = \frac{1}{3} \int \frac{dS_{\nu}}{d\tau_{\nu}} d\nu \quad . \quad (\text{from eq. (2.76)})$$

At large (mean) optical depths, S_{ν} goes to J_{ν} ; and J_{ν} goes to B_{ν} because the gas and radiation are almost in thermal equilibrium. Photons created at one temperature are absorbed before they can travel to regions of significantly different temperature, so the mean intensity must reflect the gas temperature. The Rosseland depth is defined so that

$$\int H_{\nu} d\nu = \frac{1}{3} \frac{d}{d\tau_{\text{Ross}}} \int B_{\nu} d\nu = \frac{1}{3} \int \frac{dB_{\nu}}{d\tau_{\nu}} d\nu \quad .$$

To find κ_{Ross} , we start with

$$\frac{d}{d\tau_{\text{Ross}}} \int B_{\nu} d\nu = \int \frac{dB_{\nu}}{d\tau_{\nu}} d\nu$$

and substitute $d\tau_{\text{Ross}} = \kappa_{\text{Ross}} dM$ to obtain

$$\frac{1}{\kappa_{\text{Ross}}} \frac{d}{dM} \int B_{\nu} d\nu = \int \frac{1}{\kappa_{\nu} + \sigma_{\nu}} \frac{dB_{\nu}}{dM} d\nu$$

or

$$\frac{1}{\kappa_{\text{Ross}}} = \frac{\int [1/(\kappa_{\nu} + \sigma_{\nu})] (dB_{\nu}/dM) d\nu}{\int (dB_{\nu}/dM) d\nu} \quad .$$

We change from dM to dT to make the definition independent of stars,

$$\frac{1}{\kappa_{\text{Ross}}} = \frac{\int [1/(\kappa_\nu + \sigma_\nu)] (dB_\nu/dT) d\nu}{\int (dB_\nu/dT) d\nu} \quad (2.84)$$

Values of the various derivatives mentioned are

$$\frac{dB_\nu}{dT} = \frac{B_\nu h\nu/kT}{T(1 - e^{-h\nu/kT})} \quad (2.85)$$

$$\int \frac{dB_\nu}{dT} d\nu = \frac{4\sigma T^3}{\pi} \quad (2.86)$$

and

$$\int H_\nu d\nu = \frac{1}{3} \frac{d}{d\tau_{\text{Ross}}} \int B_\nu d\nu = \frac{1}{3} \frac{d}{d\tau_{\text{Ross}}} \frac{\sigma T^4}{\pi} = \frac{4\sigma T^3}{3\pi} \frac{dT}{d\tau_{\text{Ross}}} \quad (2.87)$$

The scaling properties of $T(\tau_{\text{Ross}})$ follow from equation (2.87) when we substitute the value of the integrated flux

$$\frac{\sigma T_{\text{eff}}^4}{4\pi} = \frac{4\sigma T^3}{3\pi} \frac{dT}{d\tau_{\text{Ross}}} \quad (2.88)$$

We have a differential equation for $T(\tau_{\text{Ross}})$ at large depths, which has the solution

$$\frac{3}{4} T_{\text{eff}}^4 \tau_{\text{Ross}} + C = T^4 \quad (2.89)$$

or

$$T(\tau_{\text{Ross}}) = T_{\text{eff}} \left(\frac{3}{4} \tau_{\text{Ross}} + C \right)^{1/4} \quad (2.90)$$

Thus, $T(\tau_{\text{Ross}})$ should scale as T_{eff} for large optical depths in radiative models.

3. STATISTICAL EQUILIBRIUM

3.1 Rates

We turn to the problem of finding the level populations $n(k)$. The rate of change of the population in level k is given by the equation

$$\frac{dn(k)}{dt} = -n(k) \sum_{k'} \left[R(k \rightarrow k') + C(k \rightarrow k') \right] + \sum_{k'} n(k') \left[R(k' \rightarrow k) + C(k' \rightarrow k) \right] , \quad (3.1)$$

which simply states that the rate of change in population of level k must be the sum of the radiative and collisional rates into level k minus the sum of those rates out of level k . We specify that the level populations be constant (statistical equilibrium), with the result that $dn(k)/dt = 0$.

We assume that electrons are always in thermal equilibrium because the electron density in a stellar atmosphere is sufficient to ensure very frequent electron-electron collisions. We therefore do not need to solve for the electron distribution, and we can simplify the consideration of any transition involving a free electron by integrating out the electron-energy dependence, assuming the Maxwell-Boltzmann distribution. For example, the rate for the recombination of a proton and an electron to a hydrogen atom is expressed in terms of the proton number density times the electron number density, not in terms of the electron density per unit energy. Consequently, we need to solve only for discrete levels.

Also, we can ignore scattering transitions since by definition they cancel from the statistical equilibrium equations.

In considering the radiative and collision rates, it is convenient to treat separately the upward and the downward transitions. We will derive the rates and then summarize the results at the end of this section.

Let us first consider an upward radiative transition, where k and k' can be in the same or in different ions,

$$A(k) + h\nu \equiv A(\ell) + h\nu \rightarrow A(u) \equiv A(k') \quad ,$$

or

$$A(k) + h\nu \equiv A(\ell) + h\nu \rightarrow A(u) \equiv A^+(k') + e \quad .$$

Atoms in level k absorb

$$\int n(\ell) \int \alpha_{\nu}(\ell \rightarrow u) I_{\nu} d\omega d\nu = \int n(\ell) \alpha_{\nu}(\ell \rightarrow u) 4\pi J_{\nu} d\nu \quad \text{ergs/sec} \quad ,$$

which corresponds to absorbing

$$\int n(\ell) \alpha_{\nu}(\ell \rightarrow u) 4\pi \frac{J_{\nu}}{h\nu} d\nu \quad \text{photons/sec} \quad .$$

Since the lower level is bound, $n(\ell) \equiv n(k)$ and the rate is

$$n(k) R_{\text{up}}(k \rightarrow k') = n(k) \int \alpha_{\nu}(\ell \rightarrow u) 4\pi \frac{J_{\nu}}{h\nu} d\nu \quad . \quad (3.2)$$

Next we consider the downward transition, where k and k' are in the same or different ions,

$$A(k) \equiv A(u) \rightarrow A(\ell) + h\nu = A(k') + h\nu \quad ,$$

or

$$A^+(k) + e \equiv A(u) \rightarrow A(\ell) + h\nu = A(k') + h\nu \quad .$$

The downward absorption rate is similar to the upward one,

$$\int n(u) \alpha_{\nu}(u \rightarrow \ell) 4\pi \frac{J_{\nu}}{h\nu} d\nu \quad ,$$

but there is also an emission rate,

$$\int n(u) \int \epsilon_v(u \rightarrow \ell) \frac{d\omega}{h\nu} d\nu$$

The total rate is thus

$$n(k) R_{\text{down}}(k \rightarrow k') = \int n(u) \left[\alpha_v(u \rightarrow \ell) 4\pi \frac{J_v}{h\nu} + \int \epsilon_v(u \rightarrow \ell) \frac{d\omega}{h\nu} \right] d\nu .$$

This expression can be simplified by using equations (2.12) and (2.16) to reexpress $\alpha_v(u \rightarrow \ell)$ and $\epsilon_v(u \rightarrow \ell)$ in terms of $\alpha_v(\ell \rightarrow u)$,

$$n(k) R_{\text{down}}(k \rightarrow k') = \int n(u) \frac{g(k')}{g(k)} \alpha_v(\ell \rightarrow u) \left(\frac{4\pi J_v}{h\nu} + \frac{8\pi\nu^2}{c^2} \right) d\nu .$$

The final step is to evaluate $n(u)$. If k and k' are in the same ion, the upper level is bound, so $n(u) \equiv n(k)$ and the rate is

$$n(k) R_{\text{down}}(k \rightarrow k') = n(k) \frac{g(k')}{g(k)} \int \alpha_v(\ell \rightarrow u) \left(\frac{4\pi J_v}{h\nu} + \frac{8\pi\nu^2}{c^2} \right) d\nu . \quad (3.3)$$

For k and k' in different ions, the upper level is a continuum state of energy $E(u) = E(k') + h\nu$. Since the electrons are in thermal equilibrium, we have from the discussion in Section 2.2.F,

$$\frac{n(u)}{n(k) n_e} = \frac{(2\pi MkT/h^2)^{3/2} g(k) e^{-E(u)/kT}}{(2\pi MkT/h^2)^{3/2} g(k) (2\pi mkT/h^2)^{3/2} 2e^{-E(k)/kT}} ,$$

or

$$n(u) = n(k) n_e \frac{1}{2} \left(\frac{h^2}{2\pi mkT} \right)^{3/2} e^{[E(k) - E(k')]/kT} e^{-h\nu/kT} . \quad (3.4)$$

Then,

$$R_{\text{down}}(k \rightarrow k') = \frac{n_e}{2} \left(\frac{h^2}{2\pi m k T} \right)^{3/2} \frac{g(k')}{g(k)} e^{[E(k) - E(k')] / kT} \\ \times \int a_\nu(\ell \rightarrow u) e^{-h\nu/kT} \left(\frac{4\pi J_\nu}{h\nu} + \frac{8\pi \nu^2}{c^2} \right) d\nu \quad . \quad (3.5)$$

For later reference, we define

$$\bar{R}(k \rightarrow k') = \int a_\nu(\ell \rightarrow u) e^{-h\nu/kT} \left(\frac{4\pi J_\nu}{h\nu} + \frac{8\pi \nu^2}{c^2} \right) d\nu \quad . \quad (3.6)$$

We note that for k and k' in the same ion, equation (3.3) becomes

$$R_{\text{down}}(k \rightarrow k') = \frac{g(k')}{g(k)} e^{[E(k) - E(k')] / kT} \bar{R}(k \rightarrow k') \quad , \quad (3.7)$$

and for k and k' in different ions, equation (3.5) becomes

$$R_{\text{down}}(k \rightarrow k') = \frac{n_e}{2} \left(\frac{h^2}{2\pi m k T} \right)^{3/2} \frac{g(k')}{g(k)} e^{[E(k) - E(k')] / kT} \bar{R}(k \rightarrow k') \quad . \quad (3.8)$$

In thermal equilibrium, equations (3.7) and (3.8) can be written

$$R_{\text{down}}(k \rightarrow k') = \frac{n(k')}{n(k)} \bar{R}(k \rightarrow k') \quad . \quad (3.9)$$

To find the upward collision rate by electrons, we integrate the cross section $Q(\ell \rightarrow u)$ over the Maxwell-Boltzmann distribution,

$$n(k) C_{\text{up}}(k \rightarrow k') = n(k) n_e \sqrt{\frac{8kT}{\pi m}} \int Q(\ell \rightarrow u) e^{-E/kT} \frac{E}{kT} \frac{dE}{kT} \quad . \quad (3.10)$$

The downward collision rate, in analogy to the downward radiative rate, is

$$n(k) C_{\text{down}}(k \rightarrow k') = n_e \sqrt{\frac{8kT}{\pi m}} \int n(u) Q(u \rightarrow \ell) e^{-E/kT} \frac{E}{kT} \frac{dE}{kT} .$$

However, it is convenient to express the rate in terms of $Q(\ell \rightarrow u)$. As was the case for the radiative cross sections, the time-reversal argument dictates that the collision cross sections $Q(\ell \rightarrow u)$ and $Q(u \rightarrow \ell)$ be related by

$$\frac{Q(u \rightarrow \ell)}{g(k)} = \frac{Q(\ell \rightarrow u)}{g(k')} , \quad (3.11)$$

but for collisions the two cross sections refer to different energies. If $Q(\ell \rightarrow u)$ is for energy E , $Q(u \rightarrow \ell)$ is for energy $E - [E(u) - E(k')]$. This energy shift results in the appearance of a Boltzmann factor $e^{[E(u) - E(k')]/kT}$ in the integral when equation (3.11) is substituted,

$$n(k) C_{\text{down}}(k \rightarrow k') = \frac{g(k')}{g(k)} n_e \sqrt{\frac{8kT}{\pi m}} \int n(u) e^{[E(u) - E(k')]/kT} Q(\ell \rightarrow u) e^{-E/kT} \frac{E}{kT} \frac{dE}{kT} .$$

If k and k' are in the same ion, then $n(u) \equiv n(k)$, so

$$C_{\text{down}}(k \rightarrow k') = \frac{g(k')}{g(k)} e^{[E(k) - E(k')]/kT} n_e \sqrt{\frac{8kT}{\pi m}} \int Q(\ell \rightarrow u) e^{-E/kT} \frac{E}{kT} \frac{dE}{kT} . \quad (3.12)$$

We thus have a simple relation between C_{up} and C_{down} ,

$$g(k) C_{\text{down}}(k \rightarrow k') e^{-E(k)/kT} = g(k') C_{\text{up}}(k' \rightarrow k) e^{-E(k')/kT} , \quad (3.13)$$

which we could have found easily by using a detailed balance argument. If k and k' are in different ions, substituting equation (3.4) for $n(u)$ (or detailed balance) yields the relation

$$g(k) C_{\text{down}}(k \rightarrow k') e^{-E(k)/kT} \left(\frac{2\pi mkT}{h^2} \right)^{3/2} \frac{2}{n_e} = g(k') C_{\text{up}}(k \rightarrow k') e^{-E(k')/kT} . \quad (3.14)$$

Summary:

Upward rates, bound-bound and bound-free,

$$R_{\text{up}}(k \rightarrow k') = \int a_{\nu}(\ell \rightarrow u) 4\pi \frac{J_{\nu}}{h\nu} d\nu , \quad (3.2')$$

$$C_{\text{up}}(k \rightarrow k') = n_e \sqrt{\frac{8kT}{\pi m}} \int Q(\ell \rightarrow u) e^{-E/kT} \frac{E}{kT} \frac{dE}{kT} . \quad (3.10')$$

Downward rates, bound-bound

$$R_{\text{down}}(k \rightarrow k') = \frac{g(k')}{g(k)} \int a_{\nu}(\ell \rightarrow u) \left(\frac{4\pi J_{\nu}}{h\nu} + \frac{8\pi \nu^2}{c^2} \right) d\nu \quad (3.3')$$

$$= \frac{g(k')}{g(k)} e^{[E(k) - E(k')]/kT} \bar{R}(k \rightarrow k') , \quad (3.7)$$

$$C_{\text{down}}(k \rightarrow k') = \frac{g(k')}{g(k)} e^{[E(k) - E(k')]/kT} C_{\text{up}}(k' \rightarrow k) . \quad (3.13')$$

Downward rates, free-bound,

$$R_{\text{down}}(k \rightarrow k') = \frac{n_e}{2} \left(\frac{h^2}{2\pi mkT} \right)^{3/2} \frac{g(k')}{g(k)} e^{[E(k) - E(k')]/kT} \\ \times \int a_{\nu}(\ell \rightarrow u) e^{-h\nu/kT} \left(\frac{4\pi J_{\nu}}{h\nu} + \frac{8\pi \nu^2}{c^2} \right) d\nu \quad (3.5)$$

$$= \frac{n_e}{2} \left(\frac{h^2}{2\pi mkT} \right)^{3/2} \frac{g(k')}{g(k)} e^{[E(k) - E(k')]/kT} \bar{R}(k \rightarrow k') , \quad (3.8)$$

$$C_{\text{down}}(k \rightarrow k') = \frac{n_e}{2} \left(\frac{h^2}{2\pi mkT} \right)^{3/2} \frac{g(k')}{g(k)} e^{[E(k) - E(k')]/kT} C_{\text{up}}(k' \rightarrow k) . \quad (3.14')$$

3.2 Irrelevant Levels

Assuming we know the rates, we can, in principle, write down the statistical equilibrium equations for all levels. However, not all levels need to be considered explicitly. Closely spaced levels near a continuum have very large collision rates with each other and with the continuum. The collision rates are so high that the radiation field has a negligible effect, and since the electrons are in thermal equilibrium, they must force the levels into thermal equilibrium. Therefore, the collision rates between higher levels cancel from the equations (they are in detailed balance), and the higher level radiative terms drop out because they are negligible. The equations for the remaining levels, together with constraint equations, form a matrix equation that can be solved for the level populations. The first constraint is that the total number density is prescribed by the gas pressure $n_{\text{total}} = P_{\text{gas}}/kT$. The second is that the total number of atoms and ions of a given element must be a prescribed fraction of the total number of atoms and ions, since the element abundances are assumed to be constant. The third constraint is charge conservation.

We can also eliminate radiative transitions that have extremely high opacity if we are interested in a region where the optical depth is very large at frequencies that contribute significantly to the rate integrals. Because the opacity is very large, the source function given by

$$S_{\nu} = \frac{\sum \kappa_{\nu}(\ell \rightarrow u) (2h\nu^3/c^2) \{ [n(\ell)/n(u)][g(u)/g(\ell)] - 1 \}^{-1} + \sigma_{\nu} J_{\nu}}{\kappa_{\nu} + \sigma_{\nu}}$$

becomes

$$S_{\nu} \cong \frac{2h\nu^3}{c^2} \left[\frac{n(\ell)}{n(u)} \frac{g(u)}{g(\ell)} - 1 \right]^{-1}.$$

Since the optical depth is large, $J_{\nu} = S_{\nu} + (1/3)(d^2 S_{\nu}/d\tau_{\nu}^2)$ (eq. (2.76)); if it is "very large," $J_{\nu} \approx S_{\nu}$, or

$$J_\nu = \frac{2h\nu^3}{c^2} \left[\frac{n(\ell) g(u)}{n(u) g(\ell)} - 1 \right]^{-1}.$$

The upward rate (eq. (3.1)) is

$$n(\ell) \int \alpha_{\nu(\ell \rightarrow u)} \frac{8\pi\nu^2}{c^2} \left[\frac{n(\ell) g(u)}{n(u) g(\ell)} - 1 \right]^{-1} d\nu,$$

and the downward rate (3.3) can be transformed as follows:

$$\begin{aligned} & \int n(u) \frac{g(\ell)}{g(u)} \alpha_{\nu(\ell \rightarrow u)} \left\{ \frac{8\pi\nu^2}{c^2} \left[\frac{n(\ell) g(u)}{n(u) g(\ell)} - 1 \right]^{-1} + \frac{8\pi\nu^2}{c^2} \right\} d\nu \\ &= n(\ell) \int \alpha_{\nu(\ell \rightarrow u)} \frac{8\pi\nu^2}{c^2} \frac{n(u) g(\ell)}{n(\ell) g(u)} \left(\frac{1 + \{ [n(\ell)/n(u)] [g(u)/g(\ell)] - 1 \}}{[n(\ell)/n(u)] [g(u)/g(\ell)] - 1} \right) d\nu \\ &= n(\ell) \int \alpha_{\nu(\ell \rightarrow u)} \frac{8\pi\nu^2}{c^2} \left[\frac{n(\ell) g(u)}{n(u) g(\ell)} - 1 \right]^{-1} d\nu. \end{aligned}$$

In this case of very high optical depths, the rates are equal, so we can drop the transition from our equations. These radiative cancellations often occur, for example, for the Lyman lines and continuum of hydrogen, and even for the Balmer lines. See Peterson (1969) for a discussion of this and for the definition of "very large" optical depths.

3.3 When Are Detailed Calculations Necessary?

For many models we can calculate the total flux accurately even if we make the approximation that the number densities are given by the Boltzmann equation. At large optical depths for a main-sequence model, the densities are often high enough for collision rates to maintain thermal equilibrium in the level populations. This

situation is called local thermodynamic equilibrium, or LTE. At small optical depths, this approximation may not, in fact, be valid. However, the total flux cannot be very much affected by conditions at small optical depths.

If the level populations are given by the Boltzmann equation, we can calculate ionization equilibria using the Saha equation without any knowledge of the radiation field, and since the source function becomes $S_\nu = [\kappa_\nu / (\kappa_\nu + \sigma_\nu)] B_\nu + [\sigma_\nu / (\kappa_\nu + \sigma_\nu)] J_\nu$, the calculation of the radiation field is decoupled from the calculation of the level populations and opacities. Therefore, in ATLAS, when pressures are calculated for a given temperature distribution, the ionization, the level populations, and the opacities are calculated at the same time. Then the radiation field is calculated and the temperature correction made. A number of iterations are performed over the whole process to get a self-consistent model.

Because LTE is usually assumed in model calculations, more elaborate statistical equilibrium calculations are introduced, when necessary, as a modification, not ab initio. At the end of each iteration, a statistical equilibrium calculation is made and fudge factors $b(k)$ (called departure coefficients) are determined. These factors can be inserted into the Boltzmann equations, Saha equations, opacities, source functions, and rates in the next iteration of the model, as follows:

The Boltzmann equation becomes

$$\frac{n(k')}{n(k)} = \frac{b(k')}{b(k)} \frac{g(k')}{g(k)} e^{-[E(k') - E(k)]/kT} ; \quad (3.15)$$

the Saha equation for ionization,

$$\frac{n(k')n_e}{n(k)} = \frac{b(k')}{b(k)} \frac{g(k')}{g(k)} 2 \left(\frac{2\pi mkT}{h^2} \right)^{3/2} e^{-[E(k') - E(k)]/kT} ; \quad (3.16)$$

the partition function,

$$U = \sum b(k) g(k) e^{-E(k)/kT} ; \quad (3.17)$$

the source function,

$$S_{\nu}(k' \rightarrow k) = \frac{2h\nu^3}{c^2} \left[\frac{b(k)}{b(k')} e^{h\nu/kT} - 1 \right]^{-1} ; \quad (3.18)$$

and the opacity,

$$\kappa_{\nu}(k \rightarrow k') = n(k) \alpha_{\nu}(l \rightarrow u) \frac{1 - [b(k')/b(k)] e^{-h\nu/kT}}{\rho} . \quad (3.19)$$

The detailed balance principle from Section 2.2 becomes

$$\frac{n(A)}{b(A)} \frac{n(B)}{b(B)} \frac{n(C)}{b(C)} \cdots R(ABC \cdots \rightarrow 123 \cdots) = \frac{n(1)}{b(1)} \frac{n(2)}{b(2)} \frac{n(3)}{b(3)} \cdots R(123 \cdots \rightarrow ABC) , \quad (3.20)$$

so that we can express any rate in terms of the opposite rate, for example,

$$C(k \rightarrow k') = \frac{b(k)}{n(k)} \frac{n(k')}{b(k')} C(k' \rightarrow k) . \quad (3.21)$$

Also, the downward radiative rate (3.9) becomes

$$R_{\text{down}}(k \rightarrow k') = \frac{b(k)}{n(k)} \frac{n(k')}{b(k')} \bar{R}(k \rightarrow k') . \quad (3.22)$$

The statistical equilibrium equations for one element can be transformed from the number density form to the "b" form as follows. Starting with

$$n(k) \sum [R(k \rightarrow k') + C(k \rightarrow k')] = \sum n(k') [R(k' \rightarrow k) + C(k' \rightarrow k)] ,$$

the equilibrium equations in terms of up and down rates are

$$\begin{aligned}
& n(k) \left\{ \sum_{k' < k} \left[R_{\text{down}}(k \rightarrow k') + C_{\text{down}}(k \rightarrow k') \right] + \sum_{k' > k} \left[R_{\text{up}}(k \rightarrow k') + C_{\text{up}}(k \rightarrow k') \right] \right\} \\
&= \sum_{k' > k} n(k') \left[R_{\text{down}}(k' \rightarrow k) + C_{\text{down}}(k' \rightarrow k) \right] + \sum_{k' < k} n(k') \left[R_{\text{up}}(k' \rightarrow k) + C_{\text{up}}(k' \rightarrow k) \right] .
\end{aligned}$$

Expressing R_{down} in terms of \bar{R} and C_{down} in terms of C_{up} and dividing through by $n(k)$, we find

$$\begin{aligned}
& \sum_{k' < k} \frac{b(k)}{b(k')} \frac{n(k')}{n(k)} \left[\bar{R}(k \rightarrow k') + C_{\text{up}}(k' \rightarrow k) \right] + \sum_{k' > k} \left[R_{\text{up}}(k \rightarrow k') + C_{\text{up}}(k \rightarrow k') \right] \\
&= \sum_{k' > k} \frac{n(k')}{n(k)} \frac{b(k')}{b(k)} \frac{n(k)}{n(k')} \left[\bar{R}(k' \rightarrow k) + C_{\text{up}}(k \rightarrow k') \right] + \sum_{k' < k} \frac{n(k')}{n(k)} \left[R_{\text{up}}(k' \rightarrow k) + C_{\text{up}}(k' \rightarrow k) \right] .
\end{aligned}$$

Then,

$$\begin{aligned}
& \sum_{k' < k} \frac{b(k)}{b(k')} \frac{n(k')}{n(k)} \left[\bar{R}(k \rightarrow k') + C_{\text{up}}(k' \rightarrow k) \right] + \sum_{k' > k} \left[R_{\text{up}}(k \rightarrow k') + C_{\text{up}}(k \rightarrow k') \right] \\
&= \sum_{k' > k} \frac{b(k')}{b(k)} \left[\bar{R}(k' \rightarrow k) + C_{\text{up}}(k \rightarrow k') \right] + \sum_{k' < k} \frac{b(k')}{b(k)} \frac{b(k)}{b(k')} \frac{n(k')}{n(k)} \left[R_{\text{up}}(k' \rightarrow k) + C_{\text{up}}(k' \rightarrow k) \right] .
\end{aligned}$$

Finally,

$$\begin{aligned}
& b(k) \left\{ \sum_{k' < k} \frac{b(k)}{b(k')} \frac{n(k')}{n(k)} \left[\bar{R}(k \rightarrow k') + C_{\text{up}}(k' \rightarrow k) \right] + \sum_{k' > k} \left[R_{\text{up}}(k \rightarrow k') + C_{\text{up}}(k \rightarrow k') \right] \right\} \\
&= \sum_{k' > k} b(k') \left[\bar{R}(k' \rightarrow k) + C_{\text{up}}(k \rightarrow k') \right] + \sum_{k' < k} b(k') \frac{b(k)}{b(k')} \frac{n(k')}{n(k)} \left[R_{\text{up}}(k' \rightarrow k) + C_{\text{up}}(k' \rightarrow k) \right] ,
\end{aligned}$$

(3.23)

where $[b(k)/b(k')] [n(k')/n(k)]$ is given by either equation (3.15) or equation (3.16), as appropriate.

The $b(k)$ factors have been defined only by ratios. For normalization we require that the highest energy level have $b(k) = 1$. For example, the proton is the highest hydrogen energy level, so $b(p) = 1$.

3.4 Statistical Equilibrium in ATLAS

The subroutine that performs the equilibrium calculations is a considerably modified version of one written by Peterson (1969). It finds the $b(k)$ factors for H and H^- but assumes that the number densities of all other species are independent of the radiation field. Detailed equilibrium calculations for other species cannot significantly affect the flux in regions where H or H^- (or Rayleigh scattering or electron scattering) is the dominant opacity. For stars of spectral types from early B through G, these are the principal opacities at frequencies where most of the flux appears. Therefore, statistical equilibrium for H and H^- should be sufficient to determine the surface flux for a large number of stars. At other frequencies, such as in a strong metal continuum in the far ultraviolet, it may be necessary to perform detailed calculations for the metal if the surface flux must be accurately determined. It is a relatively simple matter to modify ATLAS to do statistical equilibrium for any species.

3.5 Computing Statistical Equilibrium for Hydrogen

The hydrogen calculations leave out all the bound-bound radiative transitions on the assumption that the radiative rates cancel for the stronger lines and that the weaker lines have a negligible effect on the level populations compared to the effect of the collisional transition. The radiative rates for the Lyman continuum are also assumed to cancel. The levels above 6 are assumed to have $b(k) = 1$, and collision rates to and from bound levels higher than 8 are assumed to be inconsequential.

The assumptions concerning the strong lines are obviously not valid at small optical depths in the atmosphere, where the line cores are formed. The bound-bound rates must be included in the equilibrium equations in order to calculate the line cores.

However, line wings and the continuum are formed at depths in the atmosphere where the optical depths in the line cores are in the thousands, so the approximation is valid for computing the line wing and continuum fluxes.

The statistical equilibrium equations (3.23) for hydrogen take the form

$$\begin{aligned}
b(k) \left[R_{\text{up}}(k \rightarrow p) + C_{\text{up}}(k \rightarrow p) + \sum_{k'=1}^k \frac{b(k)}{b(k')} \frac{n(k')}{n(k)} C_{\text{up}}(k' \rightarrow k) \right. \\
\left. + \sum_{k'=k}^8 C_{\text{up}}(k \rightarrow k') \right] = b(p) \left[\bar{R}(p \rightarrow k) + C_{\text{up}}(k \rightarrow p) \right] \\
+ \sum_{k'=1}^k b(k') \frac{b(k)}{b(k')} \frac{n(k')}{n(k)} C_{\text{up}}(k' \rightarrow k) + \sum_{k'=k}^8 b(k') C_{\text{up}}(k \rightarrow k') \quad .
\end{aligned}$$

Setting $b(7)$, $b(8)$, and $b(p) = 1$ and substituting them into equation (3.15), we obtain

$$\begin{aligned}
b(k) \left[R_{\text{up}}(k \rightarrow p) + C_{\text{up}}(k \rightarrow p) + \sum_{k'=1}^k \frac{g(k')}{g(k)} e^{-[E(k') - E(k)]/kT} C_{\text{up}}(k' \rightarrow k) \right. \\
\left. + \sum_{k'=k}^8 C_{\text{up}}(k \rightarrow k') \right] - \sum_{k'=1}^k b(k') \frac{g(k')}{g(k)} e^{-[E(k') - E(k)]/kT} C_{\text{up}}(k' \rightarrow k) \\
- \sum_{k'=k}^6 b(k') C_{\text{up}}(k \rightarrow k') \\
= \bar{R}(p \rightarrow k) + C_{\text{up}}(k \rightarrow p) + C_{\text{up}}(k \rightarrow 7) + C_{\text{up}}(k \rightarrow 8) \quad .
\end{aligned} \tag{3.24}$$

This system of six equations is easily solved for the $b(k)$'s once the rates have been calculated.

We will discuss the hydrogen cross sections α_v in Section 5. The collision cross sections $Q(k \rightarrow k')$ (from Peterson, 1969) are

$$4 f_{kk'} \gamma_{kk'}^{-2} \left[\frac{\ln E/E_{kk'}}{E/E_{kk'}} + \frac{0.148}{(E/E_{kk'})^6} \right] \pi a_0^2, \quad k' > k, \quad (3.25)$$

where $f_{kk'}$ is the transition probability, $\gamma_{kk'} = k^{-2} - k'^{-2}$, $E_{kk'} = E(p) \gamma_{kk'}$, and a_0 is the atomic radius. The collision rate coefficient is

$$C_{up}(k \rightarrow k') = n_e \pi a_0^2 \sqrt{\frac{8kT}{\pi m}} 4 f_{kk'} \gamma_{kk'}^{-2} \times \frac{E_{kk'}}{kT} \left[E_1 \left(\frac{E_{kk'}}{kT} \right) + 0.148 \left(\frac{E_{kk'}}{kT} \right) E_5 \left(\frac{E_{kk'}}{kT} \right) \right], \quad (3.26)$$

and the ionization rate coefficient is

$$C_{up}(k \rightarrow p) = n_e \pi a_0^2 \sqrt{\frac{8kT}{\pi m}} k^3 e^{-[E(p) - E(k)]/kT}. \quad (3.27)$$

3.6 The Negative Hydrogen Ion

Up to this point, we have ignored the fact that there are processes affecting the level populations other than electron collisions and radiative transitions. There are various heavy-body reactions, including molecule formation. If we consider hydrogen in a stellar atmosphere at temperatures high enough so that molecules are not important, these processes have negligible effect. But for H^- , these reactions dominate the rates, especially since H^- repels electrons.

We have taken reaction rates from Lambert and Pagel (1968) for electron collisions,

$$n(H^-) C(H^- + e \rightarrow H + 2e) = n(H^-) n_e 10^{-8.7} \left(\frac{5040}{T} \right)^{3/2},$$

where H refers to the ground state of hydrogen, and for charge cancellation,

$$n(H^-) n(p) C [H^- + p \rightarrow H + H(n > 1)] = n(H^-) n(p) 10^{-7.4} \left(\frac{5040}{T} \right)^{1/3},$$

where $H(n > 1)$ refers to some excited state of hydrogen near the continuum, which we assume to be in LTE, so that $n[H(n > 1)] = n(p) n_e f(T)$. From Browne and Dalgarno (1969), we have taken the associative detachment rate

$$n(H^-) n(H) C(H^- + H \rightarrow H_2 + e) = n(H^-) n(H) 10^{-8.7}$$

and ignored atomic collisional detachment, as they recommend. We have assumed that the levels of H_2 are populated according to the Boltzmann equation, which implies that $n(H_2)$ is related to $n(H)^2$ by a Saha equation

The statistical equilibrium equation is

$$\begin{aligned} & n(H^-) R(H^- + h\nu \rightarrow H + e) + n(H^-) n(H) C(H^- + H \rightarrow H_2 + e) \\ & + n(H^-) n(p) C[H^- + p \rightarrow H + H(n > 1)] + n(H^-) C(H^- + e \rightarrow H + 2e) \\ & = n(H) R(H + e \rightarrow H^- + h\nu) + n(H)^2 C(H_2 + e \rightarrow H^- + H) \\ & + n(H) n[H(n > 1)] C[H + H(n > 1) \rightarrow H^- + p] + n(H) C(H + 2e \rightarrow H^- + e) \end{aligned}$$

Using the detailed-balance relation (3.20) to express both sides of the equation with the same rate coefficients, we find

$$\begin{aligned} & n(H^-) R(H^- + h\nu \rightarrow H + e) + n(H^-) n(H) C(H^- + H \rightarrow H_2 + e) \\ & + n(H^-) n(p) C[H^- + p \rightarrow H + H(n > 1)] + n(H^-) C(H^- + e \rightarrow H + 2e) \\ & = \frac{b(H)}{b(H^-)} n(H^-) \bar{R}(H + e \rightarrow H^- + h\nu) + \frac{b(H)}{b(H^-)} n(H^-) n(H) C(H^- + H \rightarrow H_2 + e) \\ & + \frac{b(H)}{b(H^-)} n(H^-) n(p) C[H^- + p \rightarrow H + H(n > 1)] + \frac{b(H)}{b(H^-)} n(H^-) C(H^- + e \rightarrow H + 2e) \end{aligned}$$

The solution for $b(H^-)$ is

$$\begin{aligned}
 b(H^-) = b(H) \{ & \bar{R}(H + e \rightarrow H^- + h\nu) + n(H) C(H^- + H \rightarrow H_2 + e) \\
 & + n(p) C[H^- + p \rightarrow H + H(n > 1)] + C(H^- + e \rightarrow H + 2e) \} / \\
 & \{ R(H^- + h\nu \rightarrow H + e) + n(H) C(H^- + H \rightarrow H_2 + e) \\
 & + n(p) C[H^- + p \rightarrow H + H(n > 1)] + C(H^- + e \rightarrow H + 2e) \} .
 \end{aligned}$$

Since the b factors for these reactions are defined only by ratios, $b(H)$ is taken as unity, so the Saha equation for H^- becomes

$$\frac{n(H) n_e}{n(H^-)} = \frac{g(H) g_e}{b(H^-) g(H^-)} \left(\frac{2\pi m k T}{h^2} \right)^{3/2} e^{-0.7552 \text{ eV}/kT} ,$$

where

$$g(H) = 2 , \quad g_e = 2 , \quad \text{and} \quad g(H^-) = 1 .$$

3.7 Computational Note

In the statistical equilibrium calculations for H and H^- , the integrals R , \bar{R} , and $d\bar{R}/dT$ are computed assuming that J_ν and α_ν are temperature insensitive. After the temperature correction has been made, \bar{R} is corrected by the factor $d\bar{R}/dT \Delta T$. The collision rates are calculated with the new temperature distribution, and the matrix equations are set up and solved for the b 's. These b 's are used in the next iteration of the model to calculate populations, opacities, and source functions.

4. THERMODYNAMIC QUANTITIES

4.1 Gas and Turbulent Pressures

The motion of an atmospheric mass element is described by the equation

$$\rho \frac{d^2x}{dt^2} = - \frac{dP_{\text{total}}}{dx} - \rho g \quad , \quad (4.1)$$

where the surface gravity $g = GM_*/R_*^2$ is presumed to be constant since the atmosphere is thin and contains little mass. We assume that the atmosphere is in steady state and that any motions of the gas are random. We ignore convection when discussing pressure.

Since there is no net acceleration, the pressure-balance, or hydrostatic-equilibrium, equation becomes

$$\frac{dP_{\text{total}}}{dx} = - g\rho \quad (4.2)$$

or

$$\frac{dP_{\text{total}}}{dM} = g \quad , \quad (4.3)$$

with the boundary condition $P_{\text{total}} = P_{\text{rad}} = 0$ at $M = 0$. Then,

$$P_{\text{total}} = gM \quad . \quad (4.4)$$

We identify three components of the total pressure: the gas pressure P , the radiation pressure P_{rad} discussed in Section 2.11, and a turbulent pressure P_{turb} , which is caused by random motion of small gas elements, if such motions exist. Then,

$$P = P_{\text{total}} - P_{\text{rad}} - P_{\text{turb}} \quad , \quad (4.5)$$

where P_{rad} and P_{turb} are the values found in the previous iteration of the model.

Turbulent pressure is included in ATLAS mainly to give qualitative estimates of turbulent effects, if such effects exist. We define

$$P_{\text{turb}} = \frac{1}{2} \rho v_{\text{turb}}^2 \quad , \quad (4.6)$$

where v_{turb} is a velocity describing the turbulent elements. Arbitrary velocities can be described in the form

$$v_{\text{turb}} = A + B v_{\text{sound}} + C \rho^D \quad (4.7)$$

and are computed once v_{sound} has been found as described in Section 4.6. The corresponding turbulent pressure is carried over to the next iteration.

For most models, turbulent pressure is ignored.

4.2 Calculation of the Pressure When $T(\tau)$ or $T(x)$ is Prescribed

If we have an initial $T(\tau)$, where τ is any monochromatic or mean optical depth, or an initial $T(x)$ but do not know $T(M)$, we must go through considerable calculation to find P_{total} and $T(M) = T(P_{\text{total}}/g)$. For example, we might have an initial $T(\tau)$ if we scale a temperature distribution from a previous model, as described in Section 2.12. Or we might have an observational determination of $T(\tau)$ or $T(x)$. In either case, we have to integrate the pressure-balance equation (4.2) numerically:

$$\frac{dP_{\text{total}}}{dx} = -g\rho \quad (4.8)$$

or

$$\frac{dP_{\text{total}}}{d\tau} = \frac{g}{\kappa} \quad (4.9)$$

We describe here an integration scheme for $dP_{\text{total}}/d\tau$ that is implemented in ATLAS. A similar scheme could easily be devised for dP_{total}/dx .

The integration starts by prescribing $T(\tau)$, $P_{\text{rad}}(\tau)$, and $P_{\text{turb}}(\tau)$. If either P_{rad} or P_{turb} is not known, it is ignored. A guess is made for κ at a τ near the surface. The differential equation is solved for P_{total} at that depth, and the corresponding gas pressure determined. From P and T we find a new κ , either by computing number densities and cross sections or by interpolating in a table of opacity as a function of T and P . Iteration continues on P_{total} and κ until they are consistent to some specified maximum error. Then the differential equation is used to extrapolate a guess for the pressure at a point farther into the atmosphere. The whole procedure is repeated until the pressure is known all the way through the atmosphere.

The details of the integration are as follows: Since the P 's and τ change by many orders of magnitude in going from the top to the bottom of the atmosphere, it is convenient to convert to the logarithmic derivative,

$$\frac{dP_{\text{total}}}{d\tau} = \frac{P_{\text{total}}}{\tau} \frac{d \ln P_{\text{total}}}{d \ln \tau} = \frac{g}{\kappa}$$

or

$$\frac{d \ln P_{\text{total}}}{d \ln \tau} = \frac{g\tau}{\kappa P_{\text{total}}} \quad (4.10)$$

We choose τ points at uniform intervals in $\ln \tau$ to maintain simple expressions for integration and extrapolation, and we specify T , P_{rad} , and P_{turb} at each point, by interpolation if necessary.

There are three regions where different forms of integration are used. The first is from $\tau = 0$ to the first τ . We assume that κ is constant in this region and use the simple difference equation

$$P_1^{\text{total}} - 0 = (\tau_1 - 0) \frac{g}{\kappa_1} . \quad (4.11)$$

Then,

$$P_1 = P_1^{\text{total}} - P_1^{\text{rad}} - P_1^{\text{turb}}$$

and

$$\kappa_1 = \kappa_1(P_1, T_1) .$$

We continue to iterate on κ until $|\ln P_{\text{total}}^{\text{new}} - \ln P_{\text{total}}^{\text{old}}| \leq 0.00005$.

For the next three points, we switch to the logarithmic difference equation

$$\Delta \ln P_{\text{total}} = \ln P_j^{\text{total}} - \ln P_{j-1}^{\text{total}} = \frac{g \tau_j}{\kappa_j P_j^{\text{total}}} \Delta \ln \tau . \quad (4.12)$$

Our first guess for the pressure is

$$\ln P_j^{\text{total}} = \ln P_{j-1}^{\text{total}} + \Delta \ln P_{j-1}^{\text{total}} . \quad (4.13)$$

The iteration equations are

$$P_j = P_j^{\text{total}} - P_j^{\text{rad}} - P_j^{\text{turb}} ,$$

$$\kappa_j = \kappa_j(P_j, T_j) ,$$

and

$$\Delta \ln P_j^{\text{total}} = \frac{g \tau_j}{\kappa_j P_j^{\text{total}}} \Delta \ln \tau .$$

Once we have obtained the first four points, we use a much more sophisticated scheme, called Hamming's predictor-corrector method (Carnahan, Luther, and Wilkes, 1969). If we consider a function in the interval (x_{n-3}, x_{n+1}) , we can fit interpolating functions to fourth order. Since we know the value f_n , we can predict f_{n+1} ,

$$f_{n+1} = f_{n-3} + \frac{4}{3} \Delta x (2f'_n - f'_{n-1} + 2f'_{n-2}) + \frac{14}{45} (\Delta x)^5 f^V, \quad \text{for } f^V_{in}(x_{n-3}, x_{n+1}). \quad (4.14)$$

Hamming also fitted f with the function

$$f_{n+1} = \frac{9}{8} f_n - \frac{1}{8} f_{n-2} + \frac{3}{8} \Delta x (f'_{n+1} + 2f'_n - f'_{n-1}) - \frac{1}{40} (\Delta x)^5 f^V, \quad \text{for } f^V_{in}(x_{n-2}, x_{n+1}), \quad (4.15)$$

which can be computed, after use of the prediction for f_{n+1} , to evaluate f'_{n+1} . If f^V is specified constant in the interval (x_{n-3}, x_{n+1}) , we can eliminate f^V by combining the two expressions for f_{n+1} to obtain a still better value for f_{n+1} . The result is

$$f_{n+1} = \frac{126f_n - 14f_{n-2} + 9f_{n-3} + \Delta x (42f'_{n+1} + 108f'_n - 54f'_{n-1} + 24f'_{n-2})}{121}. \quad (4.16)$$

Putting the pressure equation into these formulas yields for the guess,

$$\ln P_j^{\text{total}} = \frac{3 \ln P_{j-4}^{\text{total}} + 8 \Delta \ln P_{j-1}^{\text{total}} - 4 \Delta \ln P_{j-2}^{\text{total}} + 8 \Delta \ln P_{j-3}^{\text{total}}}{3}, \quad (4.17)$$

and for the iteration equation,

$$\begin{aligned} \ln P_j^{\text{total}} = & \left(126 \ln P_{j-1}^{\text{total}} - 14 \ln P_{j-3}^{\text{total}} + 9 \ln P_{j-4}^{\text{total}} + 42 \Delta \ln P_j^{\text{total}} \right. \\ & \left. + 108 \Delta \ln P_{j-1}^{\text{total}} - 54 \Delta \ln P_{j-2}^{\text{total}} + 24 \Delta \ln P_{j-3}^{\text{total}} \right) / 121. \quad (4.18) \end{aligned}$$

Once the pressure is known, ρ_{ox} is found from equation (4.4).

4.3 Ionization and Molecular Equilibrium Equations

Although we need explicitly only those number densities that affect opacities, others must be considered because of their indirect effects. If ionization is involved, we have to find the number densities of all species that contribute a significant number of electrons. For molecules, we have to know what other molecules compete for the atoms available.

To calculate the equilibrium number densities, we set up as many equations as there are constraints. The first constraint is abundance – the total number density of atoms of each element must be a prescribed fraction of the total number of atoms, n_A . As an example, for a hydrogen-helium atmosphere with abundances X_H and X_{He} , we might write the equations, including most of the species possible, as

$$n(\text{H I}) + n(\text{H II}) + 2n(\text{H}_2) + 2n(\text{H}_2^+) + n(\text{H}^-) = X_H n_A \quad (4.19)$$

and

$$n(\text{He I}) + n(\text{He II}) + n(\text{He III}) = X_{He} n_A \quad (4.20)$$

When other elements are included in the atmosphere, there are also cross terms linking the abundance equations. The hydrogen equation would have $n(\text{CH})$, $n(\text{NH})$, $n(\text{OH})$, etc.; the carbon equation, $n(\text{CH})$; the nitrogen equation, $n(\text{NH})$; the oxygen equation, $n(\text{OH})$, etc.

The second constraint is charge conservation. For the same example of a hydrogen-helium atmosphere, we must have

$$n(\text{H II}) + n(\text{H}_2^+) + n(\text{He II}) + 2n(\text{He III}) - n(\text{H}^-) - n_e = 0 \quad (4.21)$$

The last constraint is that the total number of particles is $n_{\text{total}} = P/kT$,

$$\begin{aligned} n(\text{H I}) + n(\text{H II}) + n(\text{H}_2) + n(\text{H}_2^+) + n(\text{H}^-) + n(\text{He I}) + n(\text{He II}) \\ + n(\text{He III}) + n_e = n_{\text{total}} \end{aligned} \quad (4.22)$$

Each term in the equilibrium equations can be written as a function of neutral atom and electron number densities by means of a Saha equation (see Sections 2.2, 3.3, and 4.4). Some examples for the abundance equation for hydrogen follow:

$$n(\text{H}_2) = n(\text{H I}) n(\text{H I}) \frac{U(\text{H}_2)[2\pi M(\text{H}_2)kT/h^2]^{3/2}}{\{U(\text{H I})[2\pi M(\text{H I})kT/h^2]^{3/2}\}^2} e^{-[E(\text{H}_2)-E(\text{H I})]/kT}, \quad (4.23)$$

$$n(\text{H II}) = \frac{n(\text{H I})}{n_e} \frac{U_e (2\pi mkT/h^2)^{3/2} U(\text{H II})[2\pi M(\text{H II})kT/h^2]^{3/2}}{U(\text{H I})[2\pi M(\text{H I})kT/h^2]^{3/2}} e^{-[E(\text{H II})-E(\text{H I})]/kT}, \quad (4.24)$$

$$n(\text{H}_2^+) = \frac{n(\text{H I}) n(\text{H I})}{n_e} \frac{U_e (2\pi mkT/h^2)^{3/2} U(\text{H II})[2\pi M(\text{H II})kT/h^2]^{3/2}}{\{U(\text{H I})[2\pi M(\text{H I})kT/h^2]^{3/2}\}^2} e^{-[E(\text{H}_2^+)-E(\text{H I})]/kT}, \quad (4.25)$$

$$n(\text{H}^-) = n(\text{H I}) n_e \frac{U(\text{H}^-)[2\pi M(\text{H}^-)kT/h^2]^{3/2}}{U(\text{H I})[2\pi M(\text{H I})kT/h^2]^{3/2} U_e (2\pi mkT/h^2)^{3/2}} e^{-[E(\text{H}^-)-E(\text{H I})]/kT}, \quad (4.26)$$

where $U(\text{H II}) = 1$, $U_e = 2$, and $M(\text{H I}) \cong M(\text{H II}) \cong M(\text{H}^-)$, and where $E(\text{H}_2) < E(\text{H}^-) < E(\text{H I}) < E(\text{H}_2^+) < E(\text{H II})$. The evaluation of such Saha equations will be discussed in Section 4.4. We solve the resulting equilibrium equations for the number densities of neutral atoms, for n_A , and for n_e . Once these values have been obtained, any other number density can be found through use of the appropriate Saha equation.

Since the equilibrium equations are not linear, their solution requires an iteration process. In ATLAS a Newton-Raphson technique is used (Carnahan *et al.*, 1969). We specify which atoms, ions, and molecules are to be considered. Then ATLAS writes the equations in the form

$$\begin{aligned}
f_{\text{total}}(n_A, n_H, n_{\text{He}}, \dots, n_e) &= 0, \\
f_H(n_A, n_H, n_{\text{He}}, \dots, n_e) &= 0, \\
f_{\text{He}}(n_A, n_H, n_{\text{He}}, \dots, n_e) &= 0, \\
&\vdots \\
&\vdots \\
&\vdots \\
f_e(n_A, n_H, n_{\text{He}}, \dots, n_e) &= 0,
\end{aligned} \tag{4.27}$$

and analytically calculates a matrix in which each element is the derivative of each equation with respect to each variable,

$$\frac{\partial f_i}{\partial n_j} = \begin{pmatrix} \frac{\partial f_{\text{total}}}{\partial n_A} & \frac{\partial f_{\text{total}}}{\partial n_H} & \dots & \frac{\partial f_{\text{total}}}{\partial n_e} \\ \frac{\partial f_H}{\partial n_A} & \frac{\partial f_H}{\partial n_H} & \dots & \frac{\partial f_H}{\partial n_e} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\partial f_e}{\partial n_A} & \frac{\partial f_e}{\partial n_H} & \dots & \frac{\partial f_e}{\partial n_e} \end{pmatrix}. \tag{4.28}$$

After making a first guess for the number densities n_i , ATLAS puts them into the equations and the matrix. In general, the guess will be off, so the equations have nonzero values. A first-order correction is obtained from the first-order matrix equation

$$\sum_j \frac{\partial f_i}{\partial n_j} \Delta_j = f_i, \tag{4.29}$$

which is solved by Gauss-Jordan elimination (Carnahan et al., 1969). The new number densities are $n_i - \Delta_i$. Iteration continues until the relative change is below 0.0001.

For two special cases, there are faster ways to solve the equilibrium equations than the matrix method just described. If the molecules to be considered and their approximate number densities can be specified in advance, the equilibrium equations can be ordered and transformed for an iterative solution that treats the equations one at a time. However, such a scheme requires considerable revision when new molecules are added or when physical conditions change, so the initial guess for the number densities is no longer valid. The matrix method described above has no such shortcomings.

The second case is when the temperatures in the models are high enough so that molecules are not important in the equation of state. Then $n_{\text{total}} = n_A + n_e$, and there are no cross terms linking the abundance equations, so a simple iterative scheme can be used to find the electron number. Once the electron number is known, any atom or ion number can be found by using the electron number to evaluate each term in the appropriate abundance equation and then solving the abundance equation for each ion.

The iteration proceeds as follows: We guess an electron number n_e and find $n_A = n_{\text{total}} - n_e$. We go through the abundance equations (in any order) one element at a time. Each equation has the form

$$n(Q) + n(Q^+) + n(Q^{++}) + \dots = X_Q n_A \quad (4.30)$$

We write the Saha equations in terms of $n(Q)$ and the provisional value of n_e ,

$$n(Q^+) = \frac{n(Q)}{n_e} \epsilon \quad (4.31)$$

and

$$n(Q^{++}) = \frac{n(Q^+)}{n_e} \epsilon' = \frac{n(Q)}{n_e} \epsilon \frac{\epsilon'}{n_e}, \quad \text{etc.}, \quad (4.32)$$

which we substitute into the abundance equation,

$$n(Q) + \frac{n(Q)}{n_e} \epsilon + \frac{n(Q)}{n_e} \epsilon \frac{\epsilon'}{n_e} + \dots = X_Q n_A \quad (4.33)$$

We solve for $n(Q)$ and use the Saha equations to find $n(Q^+)$, $n(Q^{++})$, etc. We evaluate the charge-conservation equation as we go by adding

$$1n(Q^+) + 2n(Q^{++}) + 3n(Q^{+++}) + \dots$$

electrons for each element. Once we have evaluated all the abundance equations, the charge equation yields a new value for n_e , which we use as the basis for the next iteration. Convergence can be speeded by averaging the old and the new values for n_e .

4.4 Evaluating Saha Equations

Several different methods are used to evaluate Saha equations in ATLAS. For the equilibrium equations described in Section 4.3, where every number density is written in terms of neutral atoms and electrons, the Saha equation has the general form

$$n_{123\dots m}^{k+} = \frac{n_1 n_2 n_3 \dots n_m}{n_e^k} \epsilon \quad (4.34)$$

where

$$\epsilon = \frac{U(n_{123}^{k+}) (2\pi M_{123} kT/h^2)^{3/2} [2(2\pi m kT/h^2)^{3/2}]^k}{U_1 (2\pi M_1 kT/h^2)^{3/2} \dots U_m (2\pi M_m kT/h^2)^{3/2}} e^{-[E(n_{123}^{k+}) - E_1 - E_2 \dots - E_m]/kT}$$

Here, n_{123}^{k+} has m atoms and k positive charges. In a negative molecule, the electron is counted with the atoms. The examples given in Section 4.3 illustrate the general expression. The function ϵ is evaluated either by finding each partition function as described later or by approximating all the partition functions by one polynomial, as described next.

If we assume that the partition functions are independent of the gas density and the radiation field and that the dissociation energy is independent of gas density, then \mathcal{E} is a function only of the temperature, so it can be approximated by an expression of the form

$$\mathcal{E}(T) = \exp \left[\frac{a}{kT_{\text{ev}}} - b + cT - dT^2 + eT^3 - fT^4 - \frac{3}{2} (m - 1 - k) \ln T \right], \quad (4.35)$$

where

$$a = - \left[E \left(n_{123 \dots m}^{k+} \right) - E_1 - E_2 \dots - E_m \right].$$

Note that a is positive for neutral and negatively charged molecules because they have lower energies than do free atoms. In the following pages, we tabulate coefficients for an initial set of \mathcal{E} 's, which we found by least-squares fitting the tables by McBride, Heimerl, Ehlers, and Gordon (1963). The fit is accurate to better than 1% for $1000 \text{ K} \lesssim T \lesssim 6000 \text{ K}$ and to 1 or 2% as T approaches 500 K. The accuracy of the equilibrium constant itself may be considerably worse because of a large uncertainty in the dissociation energy. Many of the molecules tabulated do not play a significant role in stellar atmospheres.

The code for identifying atoms and molecules is as follows: The atomic number for each component is treated as a base 100 digit, and the digits are ordered increasing from left to right to form a number. An electron component, as in H^- , is written 00 and ordered as 100. The positive charge is written after the decimal point, for example, $2.02 = \text{He}^{++} = \text{He III}$. An example from the table is $608. = \text{CO}$.

The alternative method for evaluating the Saha equation is to compute each partition function separately. This has the advantage that the dependence of the partition function on the gas density and on the radiation field can be treated explicitly. For this reason, Saha equations for atoms and ions are normally treated by a separate subroutine that tabulates or computes partition functions for all ions through H II, He III, Li IV to C IV, N V, O VI to S VI, Cl V to Ni V, and Cu III to Es III. This subroutine can also solve the abundance equation for an element in order to find the number density for each ion.

CODE	A	B	C	D	E	F
101.0	4.477	4.6628E+01	1.8031E-03	5.0239E-07	8.1424E-11	5.0501E-15
103.0	2.429	4.4942E+01	2.2453E-03	5.5182E-07	8.0615E-11	4.7616E-15
104.0	2.211	4.3816E+01	1.9892E-03	4.9231E-07	7.3716E-11	4.4348E-15
105.0	3.001	4.6403E+01	1.8826E-03	4.6424E-07	6.9646E-11	4.1526E-15
106.0	3.470	4.5506E+01	1.7112E-03	3.6319E-07	5.0164E-11	2.8716E-15
107.0	3.699	4.5244E+01	1.8435E-03	4.9000E-07	7.7353E-11	4.7639E-15
108.0	4.395	4.5746E+01	1.7004E-03	4.4905E-07	7.0861E-11	4.3648E-15
109.0	5.844	4.6618E+01	1.5382E-03	4.0410E-07	6.4407E-11	3.9816E-15
111.0	2.050	4.4709E+01	2.4163E-03	6.1037E-07	9.0492E-11	5.3705E-15
112.0	1.999	4.3437E+01	2.2153E-03	5.4885E-07	8.1160E-11	4.8026E-15
113.0	2.901	4.5688E+01	1.8402E-03	4.1240E-07	5.7606E-11	3.2768E-15
114.0	3.190	4.4770E+01	1.6858E-03	3.7373E-07	5.0857E-11	2.8282E-15
115.0	3.300	4.4680E+01	1.8959E-03	4.6737E-07	6.8061E-11	4.0256E-15
116.0	3.530	4.5272E+01	1.8600E-03	4.7327E-07	7.1690E-11	4.3041E-15
117.0	4.431	4.5886E+01	1.5637E-03	3.9598E-07	6.2107E-11	3.8283E-15
303.0	1.095	4.4533E+01	2.6336E-03	6.5371E-07	9.4532E-11	5.5650E-15
308.0	3.599	4.6142E+01	2.2259E-03	5.3905E-07	7.6894E-11	4.4727E-15
309.0	5.904	4.6714E+01	2.3070E-03	5.7063E-07	8.2626E-11	4.8369E-15
317.0	4.959	4.6136E+01	2.6086E-03	6.9954E-07	1.0618E-10	6.3774E-15
408.0	4.596	4.6777E+01	1.9489E-03	4.7026E-07	7.2325E-11	4.4196E-15
409.0	6.305	4.5612E+01	2.0201E-03	4.8061E-07	6.8880E-11	4.0195E-15
417.0	4.899	4.5188E+01	2.3767E-03	6.2258E-07	9.3904E-11	5.6190E-15
505.0	2.775	4.7647E+01	2.3946E-03	6.0992E-07	8.9752E-11	5.2339E-15
507.0	4.002	4.6300E+01	2.1331E-03	5.2970E-07	7.7658E-11	4.5615E-15
508.0	8.142	4.8023E+01	1.7285E-03	3.9084E-07	5.4649E-11	3.1075E-15
509.0	8.499	4.8234E+01	1.8910E-03	4.3591E-07	6.1263E-11	3.4901E-15
516.0	5.117	4.7420E+01	1.8949E-03	4.3323E-07	5.9586E-11	3.2733E-15
517.0	5.117	4.7698E+01	2.3363E-03	6.0581E-07	9.0605E-11	5.3453E-15
606.0	6.156	4.9635E+01	3.4811E-03	1.0492E-06	1.6849E-10	1.0370E-14
607.0	8.109	4.7853E+01	1.8656E-03	4.6185E-07	7.1497E-11	4.3750E-15
608.0	11.108	4.9170E+01	1.5802E-03	3.4347E-07	4.6870E-11	2.6563E-15
609.0	4.966	4.7368E+01	2.0173E-03	4.7759E-07	6.7404E-11	3.8474E-15
615.0	6.895	4.7509E+01	2.1172E-03	4.9533E-07	7.2805E-11	4.4007E-15
616.0	7.892	4.8547E+01	1.7379E-03	3.6954E-07	4.7608E-11	2.5585E-15
617.0	3.340	4.7009E+01	2.4592E-03	6.5348E-07	9.8261E-11	5.8172E-15
707.0	9.763	4.8696E+01	1.9224E-03	4.9143E-07	7.4692E-11	4.5399E-15
708.0	6.508	4.7365E+01	1.9840E-03	4.9280E-07	7.2933E-11	4.3354E-15
709.0	2.819	4.6770E+01	2.2411E-03	5.5102E-07	7.9899E-11	4.6459E-15
714.0	4.510	4.7147E+01	1.8720E-03	4.1254E-07	5.3950E-11	2.9053E-15
715.0	7.111	4.7683E+01	2.2458E-03	5.5753E-07	7.9113E-11	4.5753E-15
716.0	4.987	4.6988E+01	2.2584E-03	5.7344E-07	8.3948E-11	4.9197E-15
808.0	5.116	4.8625E+01	1.6321E-03	3.3915E-07	4.6025E-11	2.5839E-15
811.0	3.079	4.6421E+01	2.6221E-03	6.8505E-07	1.0200E-10	6.0540E-15
812.0	3.903	4.6567E+01	2.3003E-03	4.3846E-07	5.3231E-11	2.8469E-15
813.0	4.987	4.7561E+01	2.0103E-03	4.5650E-07	6.2393E-11	3.4674E-15
814.0	8.310	4.8477E+01	1.5511E-03	2.9069E-07	3.2807E-11	1.5486E-15
815.0	6.071	4.7307E+01	2.4172E-03	6.2096E-07	8.9966E-11	5.2500E-15
816.0	5.358	4.7488E+01	1.6987E-03	3.5057E-07	4.4497E-11	2.3647E-15
817.0	2.745	4.6832E+01	2.1078E-03	5.1344E-07	7.4414E-11	4.3173E-15
909.0	1.592	4.8632E+01	2.0165E-03	4.6054E-07	6.4288E-11	3.6296E-15
911.0	4.953	4.6717E+01	2.7566E-03	7.4062E-07	1.1213E-10	6.7066E-15
912.0	3.200	4.5468E+01	2.5089E-03	6.5244E-07	9.7170E-11	5.7561E-15
913.0	6.790	4.7788E+01	2.1362E-03	5.0666E-07	7.1400E-11	4.0530E-15
914.0	5.420	4.6897E+01	2.1060E-03	4.9864E-07	6.8598E-11	3.7971E-15
916.0	3.338	4.6706E+01	1.9206E-03	4.3001E-07	5.8063E-11	3.2077E-15

CODE	A	B	C	D	E	F
917.0	2.616	4.7680E+01	2.1411E-03	5.3239E-07	7.8152E-11	4.5625E-15
1111.0	.730	4.5152E+01	3.6917E-03	1.0752E-06	1.7017E-10	1.0459E-14
1117.0	4.222	4.6147E+01	3.0037E-03	8.5128E-07	1.3301E-10	8.0960E-15
1216.0	2.901	4.6082E+01	2.6137E-03	6.8845E-07	1.0253E-10	6.0759E-15
1217.0	2.701	4.4998E+01	2.8447E-03	7.9686E-07	1.2369E-10	7.4944E-15
1313.0	1.604	4.7559E+01	2.9097E-03	7.7812E-07	1.1753E-10	6.9499E-15
1317.0	5.074	4.7276E+01	2.5438E-03	6.7568E-07	1.0182E-10	6.0055E-15
1414.0	3.252	4.7179E+01	2.0256E-03	4.5186E-07	5.7418E-11	2.9577E-15
1416.0	6.418	4.7989E+01	1.7935E-03	3.7532E-07	4.5974E-11	2.3242E-15
1417.0	4.002	4.6541E+01	2.5534E-03	6.8459E-07	1.0209E-10	5.9733E-15
1515.0	5.033	4.8223E+01	2.6898E-03	7.0362E-07	1.0075E-10	5.8493E-15
1516.0	5.637	4.6919E+01	2.7644E-03	7.4350E-07	1.0948E-10	6.4205E-15
1616.0	4.380	4.7693E+01	1.9029E-03	4.2359E-07	5.5948E-11	3.0438E-15
1617.0	2.749	4.7565E+01	3.5631E-03	1.0897E-06	1.7573E-10	1.0805E-14
1717.0	2.476	4.8021E+01	2.4184E-03	6.5374E-07	1.0061E-10	6.0420E-15
10106.0	8.850	9.3457E+01	2.2374E-03	2.9465E-07	2.7708E-11	1.2186E-15
10108.0	9.511	9.3163E+01	2.6530E-03	5.6946E-07	8.3927E-11	5.0416E-15
10116.0	7.514	9.2053E+01	2.7514E-03	5.1218E-07	6.6192E-11	3.6540E-15
10308.0	8.894	9.2675E+01	3.5194E-03	7.8181E-07	1.0862E-10	6.2491E-15
10607.0	13.135	9.6088E+01	3.4106E-03	6.7378E-07	8.7666E-11	4.8365E-15
10608.0	12.311	9.4191E+01	3.0252E-03	5.9689E-07	7.7220E-11	4.2351E-15
10811.0	8.286	9.2701E+01	4.3703E-03	1.0975E-06	1.6241E-10	9.6222E-15
10812.0	6.823	9.1448E+01	3.9729E-03	9.4759E-07	1.3688E-10	8.0099E-15
30308.0	7.366	9.4344E+01	4.5560E-03	1.0617E-06	1.4668E-10	8.3566E-15
40909.0	13.202	9.7539E+01	3.8763E-03	7.4631E-07	9.0689E-11	4.6897E-15
40917.0	11.168	9.6687E+01	4.5979E-03	1.0294E-06	1.4006E-10	7.8330E-15
41717.0	9.449	9.7191E+01	5.3790E-03	1.3389E-06	1.9437E-10	1.1303E-14
50808.0	14.587	9.9071E+01	4.5233E-03	9.7552E-07	1.2807E-10	6.9373E-15
50809.0	15.397	9.9301E+01	4.0104E-03	8.2171E-07	1.0551E-10	5.6521E-15
50817.0	13.416	9.9020E+01	4.6174E-03	1.0596E-06	1.4704E-10	8.2987E-15
50909.0	13.251	9.6613E+01	4.3092E-03	9.9043E-07	1.3679E-10	7.6726E-15
50917.0	11.196	9.5496E+01	4.9555E-03	1.2437E-06	1.8095E-10	1.0483E-14
51717.0	9.141	9.5721E+01	5.5387E-03	1.4807E-06	2.2304E-10	1.3192E-14
60606.0	13.957	1.0081E+02	3.9913E-03	8.1028E-07	1.0167E-10	5.3621E-15
60717.0	12.126	9.8836E+01	4.8687E-03	1.1673E-06	1.6627E-10	9.5674E-15
60808.0	16.561	1.0097E+02	3.3659E-03	5.7770E-07	6.3873E-11	3.0525E-15
60816.0	14.210	1.0000E+02	3.9763E-03	7.8058E-07	9.5929E-11	4.9686E-15
60909.0	10.268	9.7787E+01	3.7637E-03	7.7313E-07	9.9261E-11	5.3065E-15
61616.0	11.881	1.0044E+02	4.5422E-03	9.8359E-07	1.2836E-10	6.9210E-15
70708.0	11.440	9.9172E+01	3.9917E-03	8.1117E-07	1.0518E-10	5.7309E-15
70808.0	9.621	9.7617E+01	3.6891E-03	7.5141E-07	9.6734E-11	5.2293E-15
70909.0	6.056	9.6316E+01	4.4386E-03	1.0275E-06	1.4206E-10	7.9873E-15
80814.0	13.447	1.0004E+02	3.7484E-03	6.5483E-07	6.8677E-11	3.0007E-15
80816.0	11.023	9.8405E+01	3.7855E-03	7.7032E-07	9.7481E-11	5.1594E-15
80817.0	5.244	9.7361E+01	4.3717E-03	9.9792E-07	1.3788E-10	7.7489E-15
80913.0	12.703	9.9135E+01	5.3486E-03	1.2832E-06	1.8036E-10	1.0208E-14
80916.0	7.482	9.6508E+01	4.0897E-03	8.9324E-07	1.1798E-10	6.4190E-15
81313.0	10.615	9.7475E+01	4.5545E-03	1.0557E-06	1.4532E-10	8.1253E-15
81317.0	11.108	9.8747E+01	5.9340E-03	1.5245E-06	2.2355E-10	1.3000E-14
81617.0	7.696	9.6006E+01	4.6730E-03	1.1339E-06	1.6109E-10	9.2064E-15
81717.0	4.226	9.7105E+01	4.9032E-03	1.2343E-06	1.8020E-10	1.0475E-14
90912.0	10.812	9.8160E+01	5.3328E-03	1.2759E-06	1.7933E-10	1.0193E-14
90914.0	11.835	9.7467E+01	4.3744E-03	9.9177E-07	1.3304E-10	7.2634E-15
90916.0	6.674	9.7417E+01	4.4298E-03	1.0205E-06	1.3991E-10	7.8045E-15
121717.0	8.360	9.7591E+01	6.5730E-03	1.7908E-06	2.7180E-10	1.6183E-14
141414.0	7.588	9.9755E+01	5.5188E-03	1.3275E-06	1.8099E-10	9.9184E-15

CODE	A	B	C	D	E	F
141717.0	8.902	9.6471E+01	5.5820E-03	1.4873E-06	2.2154E-10	1.2977E-14
161717.0	5.545	9.6606E+01	5.6007E-03	1.5018E-06	2.2568E-10	1.3326E-14
1010105.0	11.697	1.4035E+02	3.6309E-03	5.3929E-07	5.8765E-11	2.9271E-15
1010106.0	12.600	1.4032E+02	4.1238E-03	7.2477E-07	8.9409E-11	4.8096E-15
1010107.0	12.004	1.3972E+02	3.5646E-03	5.7053E-07	6.8977E-11	3.7564E-15
1010115.0	9.809	1.3915E+02	4.2856E-03	6.7730E-07	7.1115E-11	3.3400E-15
1010606.0	16.864	1.4492E+02	5.1010E-03	9.2490E-07	1.1306E-10	5.9293E-15
1050808.0	19.005	1.4558E+02	4.7586E-03	8.4752E-07	1.0015E-10	5.1064E-15
4040808.0	16.308	1.4586E+02	6.9613E-03	1.5378E-06	2.0635E-10	1.1460E-14
5050808.0	21.561	1.5114E+02	7.3479E-03	1.6545E-06	2.2582E-10	1.2593E-14
6060707.0	21.323	1.5074E+02	7.5974E-03	1.7755E-06	2.4835E-10	1.4136E-14
6080909.0	18.010	1.4925E+02	5.6538E-03	1.0650E-06	1.2623E-10	6.3361E-15
6080917.0	16.353	1.4834E+02	6.4946E-03	1.3929E-06	1.8326E-10	9.9610E-15
6081717.0	14.698	1.4881E+02	7.3795E-03	1.7419E-06	2.4434E-10	1.3858E-14
6090909.0	14.907	1.4924E+02	5.7370E-03	1.0835E-06	1.2821E-10	6.4057E-15
7070909.0	10.459	1.4820E+02	7.0988E-03	1.6054E-06	2.1898E-10	1.2222E-14
7090909.0	8.498	1.4891E+02	6.9578E-03	1.5265E-06	2.0284E-10	1.1073E-14
8080816.0	14.568	1.5135E+02	6.0103E-03	1.1784E-06	1.4333E-10	7.3393E-15
8081313.0	15.827	1.5047E+02	6.7434E-03	1.4313E-06	1.8513E-10	9.9056E-15
8090916.0	11.166	1.4879E+02	7.0308E-03	1.5561E-06	2.0725E-10	1.1314E-14
8161717.0	10.044	1.4792E+02	8.6715E-03	2.2202E-06	3.2508E-10	1.8894E-14
9090915.0	15.220	1.4917E+02	7.8109E-03	1.8403E-06	2.5421E-10	1.4249E-14
9091111.0	12.416	1.4619E+02	1.1031E-02	3.0793E-06	4.7040E-10	2.8095E-14
9091616.0	9.634	1.4894E+02	8.1079E-03	1.9604E-06	2.7548E-10	1.5572E-14
11111717.0	10.590	1.4537E+02	1.1630E-02	3.3523E-06	5.2149E-10	3.1482E-14
15151515.0	12.320	1.5101E+02	9.8958E-03	2.5896E-06	3.7449E-10	2.1697E-14
15171717.0	10.038	1.4827E+02	1.0007E-02	2.7339E-06	4.1313E-10	2.4484E-14
16161717.0	8.382	1.4800E+02	9.6837E-03	2.6048E-06	3.9044E-10	2.2991E-14
101010106.0	17.019	1.8859E+02	3.7864E-03	2.3978E-07	4.9693E-12	1.3678E-15
101010114.0	13.329	1.8810E+02	5.4222E-03	6.7853E-07	4.8867E-11	1.2069E-15
101040808.0	19.626	1.9304E+02	5.1031E-03	5.8373E-07	3.8644E-11	8.8439E-16
505080808.0	28.019	2.0056E+02	9.3202E-03	2.0406E-06	2.7315E-10	1.5035E-14
609090909.0	19.911	2.0282E+02	8.5497E-03	1.6244E-06	1.9675E-10	1.0002E-14
617171717.0	13.406	2.0244E+02	1.2294E-02	3.1728E-06	4.6716E-10	2.7232E-14
707080808.0	19.793	2.5222E+02	1.2135E-02	2.6460E-06	3.5206E-10	1.9324E-14
808090916.0	18.367	2.0205E+02	8.9550E-03	1.8432E-06	2.3302E-10	1.2254E-14
909090914.0	24.676	2.0238E+02	1.0223E-02	2.3178E-06	3.1296E-10	1.7196E-14
909090916.0	13.344	2.0111E+02	1.0262E-02	2.3219E-06	3.1349E-10	1.7243E-14
1417171717.0	16.323	2.0167E+02	1.3270E-02	3.5481E-06	5.3087E-10	3.1197E-14
10101010606.0	23.067	2.3815E+02	6.0074E-03	6.4283E-07	3.6092E-11	3.6357E-16
10103030808.0	20.465	2.4088E+02	1.1084E-02	2.3946E-06	3.2062E-10	1.7815E-14
10108081111.0	18.921	2.4136E+02	1.3325E-02	3.2511E-06	4.6891E-10	2.7211E-14

The density dependence of the ionization energy and the partition function arises from collisions between atoms or between atoms and ions. Levels with very high quantum numbers are no longer bound, and the ionization energy is reduced. The process is not easy to calculate, so in ATLAS we assume that there is a definite cutoff energy and that the bound levels maintain their original values. As described in Drawin and Felenbok (1965), we assume that the energy difference is inversely proportional to the Debye radius, which is a measure of the distance between charged particles in the gas,

$$\Delta E = 1.44 E^{-7} \frac{Z_{\text{eff}}}{r_{\text{Debye}}}, \quad \text{in ev}, \quad (4.36)$$

where Z_{eff} is 1 for neutral particles, 2 for those once ionized, etc., and

$$r_{\text{Debye}} = \sqrt{\frac{kT}{4\pi e^2 n_c}}, \quad (4.37)$$

with n_c the square charge density. For singly charged ions and electrons, $n_{c1} = n_1$; for doubly charged, $n_{ci} = 4n_i$, etc. If only single ionizations occur or if hydrogen is by far the dominant ion, $n_c = 2n_e$. If He III is important and if heavier elements are negligible, $n_c = n_e + n_A - (n_e - n_A) + 4(n_e - n_A)$, where the excess number of electrons ($n_e - n_A$) comes from He III.

The partition function has the form

$$U = \sum b_i g_i e^{-E_i/kT}. \quad (3.17')$$

If there were no energy cutoff, there would be an infinite number of levels and consequently an infinite partition function. Therefore, some sort of energy cutoff is always necessary. At low temperatures ($T \lesssim 800 E$ for E in ev, i. e., 4000 K for $E = 5$ ev), the upper levels are not populated, so the value of the cutoff has a negligible effect on the sum; but at higher temperatures, the cutoff determines the value of the partition function.

As an example of a partition-function calculation, we consider an atom with hydrogenic upper levels that have b's unity. The partition function is

$$U = \sum_{E=E_0}^{E=E_1} b_i g_i e^{-E_i/kT} + G \sum_{E=E_1}^{E=E_2} n^2 e^{-E_n/kT}$$

or

$$U = U_0 + U_1, \quad (4.38)$$

where

$$E_n = E_\infty - \frac{13.595 Z^2}{n^2} = E_\infty - \frac{c}{n^2} \quad \text{in ev}.$$

We can approximate U_1 by an integral over n ,

$$U_1 \simeq G \int_{n_1}^{n_2} n^2 e^{-[E_\infty - (c/n^2)]/kT} dn. \quad (4.39)$$

When the upper levels are populated, $E_\infty/kT \lesssim 10$ to 20 ; choosing $n_1^2 \gtrsim 20$ implies that $c/n_1^2 kT < 1$. Therefore, we can expand the exponential in a power series,

$$\begin{aligned} U_1 &\simeq G e^{-E_\infty/kT} \int_{n_1}^{n_2} n^2 \left[1 + \frac{c}{n^2 kT} + \frac{1}{2!} \left(\frac{c}{n^2 kT} \right)^2 + \frac{1}{3!} \left(\frac{c}{n^2 kT} \right)^3 + \dots \right] dn \\ &\simeq G e^{-E_\infty/kT} \left\{ n^3 \left[\frac{1}{3} + \left(\frac{c}{n^2 kT} \right) \frac{1}{2} \left(\frac{c}{n^2 kT} \right)^2 - \frac{1}{18} \left(\frac{c}{n^2 kT} \right)^3 - \dots \right] \right\}_{n_1}^{n_2}. \end{aligned}$$

We change variables from n to $\Delta E = 13.595 Z^2/n^2 = c/n^2$, with the result

$$U_1 \approx G e^{-E_\infty/kT} \left\{ \left(\frac{13.595 Z^2}{\Delta E} \right)^{3/2} \left[\frac{1}{3} + \frac{\Delta E}{kT} - \frac{1}{2} \left(\frac{\Delta E}{kT} \right)^2 - \frac{1}{18} \left(\frac{\Delta E}{kT} \right)^3 - \dots \right] \right\}_{\Delta E_1}^{\Delta E_2} . \quad (4.40)$$

To apply this result to hydrogen, we treat the first six levels explicitly,

$$U_0 = \sum_{n=1}^6 b_n 2n^2 e^{-[13.595 - (13.595/n^2)]/kT} ,$$

and evaluate U_1 by choosing $n_1 = 6.5$, $\Delta E_1 = 13.595/(6.5)^2$, $\Delta E_2 = \Delta E_{\text{cutoff}}$, $G = 2$, and $E_\infty = 13.595$.

For elements that do not have b 's calculated, we pretabulate the partition functions at a fixed cutoff $\Delta E = 0.1$ ev and specify a G factor. We find the partition function for $\Delta E = 0.1$ for any temperature by linear interpolation. If the actual ΔE is less than 0.1, we use the interpolated value. If ΔE is greater than 0.1, we add the integral U_1 , evaluated with $\Delta E_1 = 0.1$ and $\Delta E_2 = \Delta E_{\text{cutoff}}$ to the interpolated value.

The table of partition functions is stored in a compact form in subroutine PFSAHA, described in Section 8.5. Many of the partition functions were taken from Drawin and Felenbok (1965), who give tables of partition functions for many elements for $\Delta E = 0.1, 0.25, 0.5, 1., 2.,$ and $3.$ ev. By fitting the expression for U_1 to their tabulated U as a function of ΔE , it was possible to obtain an approximate value for G . We computed partition functions for atoms other than those Drawin and Felenbok tabulated by adding all the known energy levels and tossing in a few more for good measure. The principal source was Moore (1949), but more recent papers were used when available. The computed partition functions are lower limits since many of the higher levels have not been found, and in fact for some elements, very little is known about the spectrum. Because of this uncertainty, no effort was made to include ΔE dependence. Even so, these partition functions should be reliable at low temperatures since most of the lower energy levels are known.

Once we have the partition functions, the Saha equation for ionization takes the form

$$\frac{n^{i+1}}{n^i} = 2.4148E15 \frac{T^{3/2}}{n_e} \frac{2U(T, \Delta E, b's)^{i+1}}{U(T, \Delta E, b's)^i} e^{-(E_\infty - \Delta E)/kT} \quad (4.41)$$

There is one further complication with Saha equations: Once we have solved the equilibrium equations, we continue the model calculation and find that we need to use Boltzmann equations of the form

$$n(\ell) = n(Q) \frac{g(\ell)}{U(Q)} e^{-[E(\ell) - E(Q)]/kT} \quad (4.42)$$

in order to evaluate number densities for levels that contribute to the opacity. Thus the quantity actually required is n/U , not n . For atoms, we have just described methods for finding partition functions that can be used to obtain n/U easily. However, if the equilibrium constant $\mathfrak{E}(T)$ has been used to find n (eq. (4.35)), we evaluate n/U by rewriting the Saha equation (4.34) in the form

$$\frac{n_{123 \dots m}^{k+}}{U(n_{123 \dots m}^{k+})} = \frac{[n_1/U_1 (2\pi M_1 kT/h^2)^{3/2}] \dots [n_m/U_m (2\pi M_m kT/h^2)^{3/2}]}{[n_e/2(2\pi m kT/h^2)^{3/2}]^k [1/(2\pi M_{123} kT/h^2)^{3/2}]} \times e^{-[E(n_{123}^{k+}) - E_1 \dots E_m]/kT} \quad (4.43)$$

Since n_{123}^{k+} , n_i , and M_i are known, since U_i can be found as described above, since M_{123} is just the sum of M_i , and since the dissociation energy is tabulated (eq. (4.35)), n/U can be evaluated straightforwardly.

4.5 Mass Density and Height

The mass density ρ is simply the atomic number density n_A , found in Section 4.3, times the average mass of each atom. The average atomic weight is

$$\mu = \sum X_i M_i \quad , \quad (4.44)$$

so

$$\rho = n_A \mu M_A , \quad (4.45)$$

where $M_A = 1.660\text{E-}24$ is 1 atomic mass unit.

The height x is

$$x = - \int_0^M \frac{dM}{\rho} , \quad (4.46)$$

with x arbitrarily 0 at the first ρ_{ox} . Only the differences in height are meaningful.

The pressure scale height h from equation (4.2) is

$$h = \frac{P_{\text{total}}}{\rho g} . \quad (4.47)$$

4.6 Thermodynamic Derivatives

A number of useful partial derivatives, some of which will be needed in Section 6 to calculate the convective flux, follow:

Specific heats,

$$C_V = \left(\frac{\partial E}{\partial T} \right)_{\rho} \quad (4.48)$$

and

$$C_P = \left(\frac{\partial E}{\partial T} \right)_{P_{\text{total}}} + \left[\frac{\partial}{\partial T} \left(\frac{P_{\text{total}}}{\rho} \right) \right]_{P_{\text{total}}} = \left(\frac{\partial E}{\partial T} \right)_{P_{\text{total}}} - \frac{P_{\text{total}}}{\rho^2} \left(\frac{\partial \rho}{\partial T} \right)_{P_{\text{total}}} , \quad (4.49)$$

where E is the energy per unit mass,

$$E = \frac{3}{2} \frac{n_{\text{total}} kT}{\rho} + \frac{3P_{\text{rad}}}{\rho} + \sum \frac{n_i [E_i + (d \ln U_i / d \ln T) kT]}{\rho} , \quad (4.50)$$

with E_i the ground energy and $(d \ln U_i / d \ln T) kT$ the internal energy of atom i ; the adiabatic gradient,

$$\left(\frac{\partial \ln T}{\partial \ln P} \right)_S = - \frac{P_{\text{total}}}{T \rho C_P} \left(\frac{\partial \ln \rho}{\partial \ln T} \right)_{P_{\text{total}}} ; \quad (4.51)$$

and the sound velocity,

$$v_{\text{sound}}^2 = \frac{C_P}{C_V} \left(\frac{\partial P_{\text{total}}}{\partial \rho} \right)_T . \quad (4.52)$$

It is convenient in ATLAS to take derivatives holding P or T constant, not P_{total} nor ρ . In general, if we change variables from u, v to x, y , we have the identities

$$\left(\frac{\partial f}{\partial u} \right)_v = \left(\frac{\partial f}{\partial x} \right)_y \left(\frac{\partial x}{\partial u} \right)_v + \left(\frac{\partial f}{\partial y} \right)_x \left(\frac{\partial y}{\partial u} \right)_v \quad (4.53)$$

and

$$\left(\frac{\partial y}{\partial u} \right)_v = - \frac{(\partial v / \partial u)_y}{(\partial v / \partial y)_u} . \quad (4.54)$$

In the special case u, v to u, y , we find

$$\left(\frac{\partial f}{\partial u} \right)_v = \left(\frac{\partial f}{\partial u} \right)_y - \frac{(\partial f / \partial y)_u (\partial v / \partial u)_y}{(\partial v / \partial y)_u} . \quad (4.55)$$

We use this identity to reexpress the partial derivatives in a form for calculation:

$$C_V = \left(\frac{\partial E}{\partial T} \right)_P - \frac{(\partial E / \partial P)_T (\partial \rho / \partial T)_P}{(\partial \rho / \partial P)_T} , \quad (4.56)$$

$$C_P = \left(\frac{\partial E}{\partial T} \right)_P - \frac{(\partial E / \partial P)_T (\partial P_{\text{total}} / \partial T)_P}{(\partial P_{\text{total}} / \partial P)_T} - \frac{P_{\text{total}}}{\rho^2} \left[\left(\frac{\partial \rho}{\partial T} \right)_P - \frac{(\partial \rho / \partial P)_T (\partial P_{\text{total}} / \partial T)_P}{(\partial P_{\text{total}} / \partial P)_T} \right], \quad (4.57)$$

$$\left(\frac{\partial \ln \rho}{\partial \ln T} \right)_{P_{\text{total}}} = \frac{T}{\rho} \left(\frac{\partial \rho}{\partial T} \right)_{P_{\text{total}}} = \frac{T}{\rho} \left[\left(\frac{\partial \rho}{\partial T} \right)_P - \frac{(\partial \rho / \partial P)_T (\partial P_{\text{total}} / \partial T)_P}{(\partial P_{\text{total}} / \partial P)_T} \right], \quad (4.58)$$

and

$$v_{\text{sound}}^2 = \frac{C_P}{C_V} \frac{(\partial P_{\text{total}} / \partial P)_T}{(\partial \rho / \partial P)_T}. \quad (4.59)$$

If we ignore any turbulent pressure and assume that radiation pressure varies as T^4 , then

$$\left(\frac{\partial P_{\text{total}}}{\partial P} \right)_T = 1 \quad (4.60)$$

and

$$\left(\frac{\partial P_{\text{total}}}{\partial T} \right)_P = \frac{4P_{\text{rad}}}{T}, \quad (4.61)$$

and we are left with only four derivatives to evaluate — $(\partial E / \partial T)_P$, $(\partial E / \partial P)_T$, $(\partial \rho / \partial T)_P$, and $(\partial \rho / \partial P)_T$.

We calculate these four derivatives numerically as follows: We make up a small set of equilibrium equations, as in Section 4.3, that include only the most abundant elements. At present, these equations include only hydrogen and helium, but others can easily be added. We note that considerable approximation is allowed because our object is to find not the exact energy nor mass density but the derivatives of those quantities. We include H I, H II, H₂, He I, He II, and He III, for which the Saha equations are

$$n(\text{H II}) = \frac{n(\text{H I})}{n_e} 2.4148\text{E}15 T^{3/2} e^{-13.595/kT} , \quad (\text{cf. 4.24})$$

$$n(\text{H}_2) = n(\text{H I}) n(\text{H I}) \exp \left(\frac{4.477}{kT} - 4.6628\text{E}1 + 1.8031\text{E}-3 T \right. \\ \left. - 5.0739\text{E}-7 T^2 + 8.1424\text{E}-11 T^3 - 5.0501\text{E}-15 T^4 - 1.5 \ln T \right) , \\ (\text{cf. 4.34, 4.35}) \quad (4.62)$$

$$n(\text{He II}) = \frac{n(\text{He I})}{n_e} 4(2.4148\text{E}15) T^{3/2} e^{-24.508/kT} , \quad (\text{cf. 4.34})$$

and

$$n(\text{He III}) = \frac{n(\text{He I})}{n_e^2} 4(2.4148\text{E}15)^2 T^3 e^{-78.983/kT} , \quad (\text{cf. 4.34})$$

where we have assumed $U(\text{H I}) = 2$, $U(\text{He I}) = 1$, and $U(\text{He II}) = 2$. We solve the equations keeping either T or P constant and varying the other by ± 0.001 . For each solution we find the density

$$\rho = n_A \mu M_A \quad (4.45)$$

and the energy per unit mass

$$E = \left\{ \left[\frac{3}{2} n_{\text{total}} + \frac{13.595}{kT} n(\text{H II}) + \frac{E(\text{H}_2)}{kT} n(\text{H}_2) + \frac{24.580}{kT} n(\text{He II}) \right. \right. \\ \left. \left. + \frac{78.983}{kT} n(\text{He III}) \right] kT + 3P_{\text{rad}} \left(\frac{T}{T_0} \right)^4 \right\} / \rho , \quad (\text{cf. 4.50})$$

where

$$\frac{E(\text{H}_2)}{kT} = -\frac{4.476}{kT} + 1(1.8031\text{E}-3) T + 2(-5.0739\text{E}-7) T^2 + 3(8.1424\text{E}-11) T^3 \\ + 4(-5.0501\text{E}-15) T^4 , \quad (\text{cf. 4.50, 4.62}) \quad (4.63)$$

because for H_2 , $(d \ln U/d \ln T)$ is important. The derivatives are

$$\left(\frac{\partial E}{\partial T}\right)_P = \frac{500}{T_0} [E(1.001 T_0) - E(0.999 T_0)] \quad ,$$

$$\left(\frac{\partial E}{\partial P}\right)_T = \frac{500}{P_0} [E(1.001 P_0) - E(0.999 P_0)] \quad ,$$

$$\left(\frac{\partial \rho}{\partial T}\right)_P = \frac{500}{T_0} [\rho(1.001 T_0) - \rho(0.999 T_0)] \quad ,$$

$$\left(\frac{\partial \rho}{\partial P}\right)_T = \frac{500}{P_0} [\rho(1.001 P_0) - \rho(0.999 P_0)] \quad .$$

5. OPACITY

For computational convenience, we divide all possible absorption and scattering transitions into the following 20 groups:

1. H I bound-free and free-free transitions. It is customary for astronomers to apply the name of the bound state to both the bound-free and the free-free transitions, even if there is no bound state. Thus the proton-electron free-free is called neutral hydrogen or H I free-free.
2. H_2^+ bound-free and free-free.
3. H^- bound-free and free-free.
4. H I Rayleigh scattering.
5. He I bound-free and free-free.
6. He II bound-free and free-free.
7. He^- free-free. There is no bound state.
8. He I Rayleigh scattering.
9. Low-temperature absorbers ($T \lesssim 10000$ K): C I + Mg I + Si I + Al I bound-free and free-free.
10. Intermediate-temperature absorbers ($10000 \text{ K} \lesssim T \lesssim 20000$ K): Si II + Mg II + Ca II + N I + O I bound-free and free-free.
11. High-temperature absorbers: C II-IV + N II-V + O II-VI + Ne I-VI bound-free for frequencies greater than the Lyman limit of hydrogen.
12. Electron scattering.
13. H_2 Rayleigh scattering.
14. H I lines.
15. Line-absorption distribution functions.
16. Line-scattering distribution functions, i.e., line opacity considered as scattering because $S_\nu \approx J_\nu$.

17. Other or experimental absorption lines.
18. Other or experimental scattering lines, i.e., line opacity considered as scattering because $S_\nu \simeq J$.
19. Other or experimental continuous absorptions.
20. Other or experimental continuous scatterings.

For each group we find a total mass absorption or scattering coefficient and a source function, as discussed in a general way in Section 2. These coefficients are labeled $\kappa_\nu(i)$ and $\sigma_\nu^c(i)$ for continuous absorptions and scatterings and $\ell_\nu(i)$ and $\sigma_\nu^\ell(i)$ for lines. The line and continuous opacities are kept separate, so that in small wavelength intervals the continuous opacity can be kept constant while the line opacity is recalculated at several closely spaced wavelength points. Total-absorption coefficients are obtained by summing over groups,

$$\kappa_\nu = \sum \kappa_\nu(i) \quad ,$$

$$\ell_\nu = \sum \ell_\nu(i) \quad ,$$

$$\sigma_\nu^c = \sum \sigma_\nu^c(i) \quad ,$$

$$\sigma_\nu^\ell = \sum \sigma_\nu^\ell(i) \quad ,$$

and

$$\kappa_\nu(\text{total}) = \kappa_\nu + \ell_\nu + \sigma_\nu^c + \sigma_\nu^\ell \quad . \quad (5.1)$$

The total source function is the average over all the groups:

$$S_\nu = \frac{\sum \kappa_\nu(i) S_\nu(i) + \sum \ell_\nu(i) S_\nu(i) + \sum \sigma_\nu^c(i) J_\nu + \sum \sigma_\nu^\ell(i) J_\nu}{\kappa_\nu(\text{total})} \quad . \quad (5.2)$$

In the following, we describe each group, beginning in considerable detail with hydrogen.

5.1 H I Bound-Free and Free-Free

The bound-free absorption coefficient has the form

$$\kappa_{\nu}(\text{bound-free}) = \sum_{n=1}^{\infty} \frac{n_n}{\rho} \alpha_n \left(1 - \frac{1}{b_n} e^{-h\nu/kT} \right), \quad (5.3)$$

as discussed in Section 3.5. Here the upper level is the proton, for which $b = 1$. The number density in each level n_n is found from the Boltzmann equation

$$n_n = b_n n(\text{H I}) \frac{g_n}{U(\text{H I})} e^{-E_n/kT}, \quad (5.4)$$

where $g_n = 2n^2$ and $E_n = 13.595 \text{ eV } Z^2[1 - (1/n^2)]$, and where $n(\text{H I})/U(\text{H I})$ was found earlier as described in Section 4. The cross sections α_n are given by polynomial approximations (Gingerich, 1969) to the Coulomb cross sections of Karsas and Latter (1961),

$$\alpha_n = \frac{2.815\text{E}29}{n^5 \nu^3} \left[A_n + \left(B_n + C_n \frac{Z^2}{\nu} \right) \frac{Z^2}{\nu} \right] \quad (5.5)$$

for

$$\nu \geq 3.28805\text{E}15 \frac{Z^2}{n^2},$$

where

$$2.815\text{E}29 = \frac{64 \pi^4 e^{10} m}{3\sqrt{3} c h^6}.$$

Note that since $3.28805\text{E}15$ is the ionization frequency and 13.595 eV is the ionization energy, $(3.28805\text{E}15) h/kT = 13.595 \text{ eV}/kT$. The polynomial coefficients are as follows:

n	A _n	B _n	C _n
1	0.9916	2.719E13	-2.268E30
2	1.105	-2.375E14	4.077E28
3	1.101	-9.863E13	1.035E28
4	1.101	-5.765E13	4.593E27
5	1.102	-3.909E13	2.371E27
6	1.0986	-2.704E13	1.229E27
7 ≤ n	1	0	0

For levels above 8, the summation of levels is treated as an integral over n:

$$\begin{aligned}
\frac{n(\text{H I})}{U(\text{H I})} \sum_{n=n'=9}^{\infty} 2n^2 e^{-13.595 Z^2 [1 - (1/n^2)]/kT} \frac{2.815\text{E}29 Z^4}{n^5 \nu^3} (1 - e^{-h\nu/kT}) \\
\approx \frac{n(\text{H I})}{U(\text{H I})} \frac{2.815\text{E}29 Z^4}{\nu^3} (1 - e^{-h\nu/kT}) 2 \int_{n'}^{\infty} e^{-13.595 Z^2 [1 - (1/n^2)]/kT} \frac{dn}{n^3} \\
= \frac{n(\text{H I})}{U(\text{H I})} \frac{2.815\text{E}29 Z^4}{\nu^3} (1 - e^{-h\nu/kT}) 2 \\
\times \frac{1}{2} \frac{kT}{13.595 Z^2} \left(e^{-13.595 Z^2 [1 - (1/n'^2)]/kT} - e^{-13.595 Z^2/kT} \right) .
\end{aligned} \tag{5.6}$$

If $\nu < 3.28805\text{E}15 Z^2/n'^2$, the lower limit of the integral must be increased, which can be accomplished approximately by replacing $13.595 Z^2/n'^2 kT$ by $h\nu/kT$.

The free-free absorption coefficient has the form

$$\kappa_{\nu}(\text{free-free}) = \frac{n(\text{H II})}{\rho} n_e \sqrt{\frac{8kT}{\pi m}} \int \alpha_{\nu}(E) e^{-E/kT} \frac{E}{kT} \frac{dE}{kT} (1 - e^{h\nu/kT}) , \tag{5.7}$$

where the integral is over the Maxwell-Boltzmann distribution for electron energies since we have assumed that electrons are in thermal equilibrium. The opacity can be rewritten as

$$\kappa_{\nu}(\text{free-free}) = n(\text{H II}) n_e F_{\nu}(T) (1 - e^{-h\nu/kT}) \quad , \quad (5.8)$$

where the function $F_{\nu}(T)$ is interpolated from a table derived from a graph in Karsas and Latter (1961). The values listed in the table below are to be multiplied by $3.6919\text{E}8 Z^2/\nu^3 T^{1/2}$, where

$$3.6919\text{E}8 = \frac{16 \pi^2}{3\sqrt{3}} \frac{e^6}{c h^4} \left(\frac{h^2}{2\pi m k} \right)^{3/2} k \quad .$$

		$\log_{10} \left(3.28805\text{E}15 \frac{Z^2 h}{kT} \right)$											
		-3.0	-2.5	-2.0	-1.5	-1.0	-0.5	0.0	0.5	1.0	1.5	2.0	
$\log_{10} \left(\frac{h\nu}{kT} \right)$	-4.0	5.53	5.49	5.46	5.43	5.40	5.25	5.00	4.69	4.48	4.16	3.85	
	-3.5	4.91	4.87	4.84	4.80	4.77	4.63	4.40	4.13	3.87	3.52	3.27	
	-3.0	4.29	4.25	4.22	4.18	4.15	4.02	3.80	3.57	3.27	2.98	2.70	
	-2.5	3.64	3.61	3.59	3.56	3.54	3.41	3.22	2.97	2.70	2.45	2.20	
	-2.0	3.00	2.98	2.97	2.95	2.94	2.81	2.65	2.44	2.21	2.01	1.81	
	-1.5	2.41	2.41	2.41	2.41	2.41	2.32	2.19	2.02	1.84	1.67	1.50	
	-1.0	1.87	1.89	1.91	1.93	1.95	1.90	1.80	1.68	1.52	1.41	1.30	
	-0.5	1.33	1.39	1.44	1.49	1.55	1.56	1.51	1.42	1.33	1.25	1.17	
	0.0	0.90	0.95	1.00	1.08	1.17	1.30	1.32	1.30	1.20	1.15	1.11	
	0.5	0.45	0.48	0.52	0.60	0.75	0.91	1.15	1.18	1.15	1.11	1.08	
	1.0	0.33	0.36	0.39	0.46	0.59	0.76	0.97	1.09	1.13	1.10	1.08	
	1.5	0.19	0.21	0.24	0.28	0.38	0.53	0.76	0.96	1.08	1.09	1.09	

The source function is

$$S_{\nu} = \frac{\sum_{n=1}^{\infty} \kappa_n S_n + \kappa_{\nu}(\text{free-free}) B_{\nu}}{\kappa_{\nu}(\text{bound-free}) + \kappa_{\nu}(\text{free-free})} \quad , \quad (5.9)$$

where

$$S_n = \frac{2 h \nu^3}{c^2} (b_n e^{h\nu/kT} - 1)^{-1} .$$

Since b_n is computed for only the first six levels, $S_n = B_\nu$ for $n > 6$. The expression for $\kappa_n S_n$,

$$\kappa_n S_n = \left[\frac{n_n}{\rho} a_n \left(1 - \frac{1}{b_n} e^{-h\nu/kT} \right) \right] \left[\frac{2 h \nu^3}{c^2} (b_n e^{h\nu/kT} - 1)^{-1} \right] ,$$

can be rewritten as

$$\kappa_n S_n = \frac{n_n a_n}{\rho} B_\nu \left(1 - \frac{1}{b_n} e^{-h\nu/kT} \right) .$$

5.2 H_2^+ Bound-Free and Free-Free

Although the H_2^+ opacity could be written in terms of the H_2^+ number density, we use the component number densities instead in order to keep the opacity calculation independent of the equilibrium calculations described in Section 4. Thus, because of its low abundance relative to the sum of H_2 , H I, and H II, we can find the H_2^+ opacity even if H_2^+ has not been included in the equation of state. Since the photodissociation of H_2^+ results in a proton and a ground-state hydrogen atom, we actually use the number density

$$n(\text{H I}, n=1) = \frac{2b_1}{U(\text{H I})} N(\text{H I}) .$$

Bates has calculated the opacity for the $1s_\sigma - 2p_\sigma$ transition of H_2^+ in several papers. His results for the sum of bound-free and free-free transitions are summarized in a table by Gingerich (1964). This table was fit with polynomials to yield the opacity

$$\kappa_{\nu} = \frac{n(\text{H I}, n=1)}{\rho} n(\text{H II}) F_{\nu}(T) (1 - e^{-h\nu/kT}) ,$$

where

$$F_{\nu}(T) = \exp\left((-E_s/kT) - 3.0233E3 + \{3.7797E2 + [-1.82496E1 + (3.9207E-1 - 3.1672E-3 \ln \nu) \ln \nu] \ln \nu\} \ln \nu\right) ,$$

with

$$E_s = -7.342E-3 + \left(-2.409E-15 + \{1.028E-30 + [-4.230E-46 + (1.224E-61 - 1.351E-77 \nu) \nu] \nu\} \nu\right) \text{ eV} .$$

The source function is assumed to be the Planck function.

5.3 H⁻ Bound-Free and Free-Free

The bound-free absorption coefficient is

$$\kappa_{\nu}(\text{bound-free}) = \frac{n(\text{H}^-)}{\rho} \alpha_{\nu} \left[1 - \frac{e^{-h\nu/kT}}{b(\text{H}^-)} \right] ,$$

where

$$n(\text{H}^-) = b(\text{H}^-) \frac{n(\text{H I}, n=1)}{2} \frac{n_e}{2} \left(\frac{h^2}{2\pi m k T} \right)^{3/2} e^{0.7552 \text{ eV}/kT} . \quad (5.10)$$

The cross section is from Gingerich (1964), who fit polynomials to Geltman's (1962) calculations. The polynomials have been reexpressed and simplified as follows:

$$\alpha_{\nu} = 6.801E-20 + \{5.358E-3 + [1.481E13 + (-5.519E27 + 4.808E41/\nu)/\nu]/\nu\} \nu$$

for $\nu \geq 2.111\text{E}14$, and

$$\alpha_{\nu} = 3.695\text{E}-16 + (-1.251\text{E}-1 + 1.052\text{E}13/\nu)/\nu$$

for $2.111\text{E}14 < \nu \leq 1.8259\text{E}14$, where $1.8259\text{E}14$ is the ionization-limit frequency.

The bound-free source function is

$$S_{\nu}(\text{bound-free}) = \frac{2h\nu^3}{c^2} \left[b(\text{H}^-) e^{h\nu/kT} - 1 \right]^{-1} = B_{\nu} \frac{1 - e^{-h\nu/kT}}{b(\text{H}^-) - e^{-h\nu/kT}} .$$

The free-free absorption coefficient is

$$\kappa_{\nu}(\text{free-free}) = \frac{n(\text{H I}, n=1)}{\rho} n_e F_{\nu}(T) ,$$

where $F_{\nu}(T)$ is given by

$$F_{\nu}(T) = [1.3727\text{E}-25 + (4.3748\text{E}-10 - 2.5993\text{E}-7 T)/\nu]/\nu ,$$

which is a fit to the dipole-length calculations by Stilly and Callaway (1970).

5.4 H I Rayleigh Scattering

The cross section is from Dalgarno (1962),

$$\sigma_{\nu} = \frac{n(\text{H I}, n=1)}{\rho} \left(\frac{5.799\text{E}-13}{\lambda^4} + \frac{1.422\text{E}-6}{\lambda^6} + \frac{2.784}{\lambda^8} \right) ,$$

where $\lambda = 2.997925\text{E}18/\text{min}(\nu, 2.922\text{E}15)$.

5.5 He I Bound-Free and Free-Free

The cross sections for the first 11 levels are listed below in the form of power laws:

Level	g_1	E_1	ν_1	$\ln a_1$
1 1^1S	1	0.0	5.9447E15	$33.32 - 2.0 \ln \nu$
2 2^3S	3	19.819	1.1526E15	$-390.026 + (21.035 - 0.318 \ln \nu) \ln \nu$
3 2^1S	1	20.615	0.96025E15	$26.83 - 1.91 \ln \nu$
4 2^3P^0	9	20.964	0.87607E15	$61.21 - 2.9 \ln \nu$
5 2^1P^0	3	21.217	0.81465E15	$81.35 - 3.5 \ln \nu$
6 3^3S	3	22.718	0.4519E15	$12.69 - 1.54 \ln \nu$
7 3^1S	1	22.920	0.4031E15	$23.85 - 1.86 \ln \nu$
8 3^3P^0	9	23.006	0.3821E15	$49.30 - 2.60 \ln \nu$
9 3^3D+3^1D	20	23.073	0.3659E15	$85.20 - 3.69 \ln \nu$
11 3^1P^0	3	23.086	0.3628E15	$58.81 - 2.89 \ln \nu$

Data for the $n=1$ and $n=2$ levels were taken with modifications from Gingerich (1964), and the data for the $n=3$ levels, from Hunger and van Blerkom (1967). The higher levels starting with $n=4$ are treated hydrogenically with $g_n = 4n^2$, with $E_n = E(\text{He II}) - E(\text{H II})/n^2 = 24.587 - 13.595/n^2$, and with $n'=4$.

The free-free opacity has been calculated by Peach (1967), but since it is approximately the same as the hydrogen value, we have used the latter.

The source function is the Planck function.

It would be straightforward to include the b factors for helium, as was done for hydrogen.

5.6 He II Bound-Free and Free-Free

The opacity is hydrogenic with $Z = 2$ and $n'=10$, but $E_n = 54.403/n^2$, not $4(13.595)/n^2$. The source function is the Planck function. Inserting b factors would be easy.

5.7 He⁻ Free-Free

Carbon, Gingerich, and Latham (1969) give a polynomial fit to the free-free calculations of John (1968). The opacity is

$$\kappa_{\nu} = \frac{n(\text{He I}, n=1)}{\rho} n_e F_{\nu}(T) \quad ,$$

where

$$F_{\nu}(T) = aT + b + \frac{c}{T}$$

with

$$a = 3.397\text{E-}46 + (-5.216\text{E-}31 + 7.039\text{E-}15/\nu)/\nu \quad ,$$

$$b = -4.116\text{E-}42 + (1.067\text{E-}26 + 8.135\text{E-}11/\nu)/\nu \quad ,$$

and

$$c = 5.081\text{E-}37 + (-8.724\text{E-}23 - 5.659\text{E-}8/\nu)/\nu \quad .$$

5.8 He I Rayleigh Scattering

The cross section is from Dalgarno (1962):

$$\sigma_{\nu} = \frac{n(\text{He I}, n=1)}{\rho} \frac{5.484\text{E-}14}{\lambda^4} \left[1 + \frac{2.44\text{E}5}{\lambda^2} + \frac{5.94\text{E-}10}{\lambda^2(\lambda^2 - 2.90\text{E}5)} \right]^2 \quad ,$$

where

$$\lambda = \frac{2.997925\text{E}18}{\min(\nu, 5.15\text{E}15)} \quad .$$

The frequency cutoff keeps the expression from blowing up in a region where it is not valid.

5.9 Low-Temperature Absorbers

Opacities are included for C I, Mg I, Al I, and Si I. This is by no means a complete list of opacity sources, but these produce almost all the opacity at temperatures

high enough so that molecules are not important, except perhaps for Fe I. A hydro-
genic calculation for Fe I was done by Travis and Matsushima (1968), but there are
large uncertainties in such an approximation, even for astronomers. For models of
stars with "evolved" abundances, other opacity sources such as C⁻ should be investi-
gated.

The opacity routines unfortunately have not been written in a form amenable to
insertion of b's for statistical equilibrium calculations. We have included either only
low terms that are strong absorbers or opacity tables that give cross sections per
atom in the ground term. To rewrite the subroutines in b form, we should find experi-
mental cross sections or calculate them one level at a time.

The best available opacity tables are the quantum-defect calculations by Peach
(1970), which give the sum of bound-free and free-free cross sections per atom in the
ground term. These tables are put into ATLAS by choosing temperatures at which
the opacities are important and choosing the minimum number of frequencies necessary
to represent the form of the opacity. These frequencies are both sides of any signifi-
cant opacity discontinuity, the lowest and the highest frequency tabulated, and, if needed,
extra points in the continuum of the ground state. The compact table that results from
this procedure is converted to logarithms. To find the opacity for any T and ν , we
linearly interpolate or extrapolate in terms of $\ln T$ and $\ln \nu$.

The C I cross sections are calculations from Henry (1970), but only the three
lowest levels are included. The data for these levels follow:

Level	g_i	E_i	ν_i	α_i
3P	9	0	2.7254E15	$1.219E-17 \left[3.317 \left(\frac{\nu_i}{\nu} \right)^2 - 2.317 \left(\frac{\nu_i}{\nu} \right)^3 \right]$
1D	5	1.264	2.4196E15	$1.030E-17 \left[2.789 \left(\frac{\nu_i}{\nu} \right)^{3/2} - 1.789 \left(\frac{\nu_i}{\nu} \right)^{5/2} \right]$
1S	1	2.683	2.0761E15	$9.59E-18 \left[3.501 \left(\frac{\nu_i}{\nu} \right)^{3/2} - 2.501 \left(\frac{\nu_i}{\nu} \right)^{5/2} \right]$

The Mg I opacity is from Peach's tables for 4000 to 10000 K. The levels that appear explicitly as discontinuities are the following:

Level	ν_1	Level	ν_i
3s ¹ S	1.8488510E15	3d ¹ D	4.5772110E14
3p ³ P	1.1925797E15	4p ³ P	4.1440977E14
3p ¹ P	7.9804046E14	3d ³ D	4.1113514E14

Al I is represented only by the ground state for which the cross section at the limit was measured by W. Parkinson and E. Reeves (private communication to O. Gingerich and J. Rich) and for which the frequency dependence was guessed:

Level	g_1	E_1	ν_1	α_1
3p ² P	6	0	1.443E15	$2.1E-17 \left(\frac{\nu_1}{\nu} \right)^3$

The levels of Si I opacity, from Peach's tables for 4000 to 12000 K, that appear explicitly as discontinuities are as follows:

Level	ν_1	Level	ν_1
3p ² ³ P	1.9723165E15	4p ³ D	5.3295914E14
3p ² ¹ D	1.7879689E15	3d ³ F	4.7886458E14
3p ² ¹ S	1.5152920E15	4p ¹ D	4.7216422E14
3d ¹ D	5.5723927E14	3d ³ P	4.6185133E14

5.10 Intermediate-Temperature Absorbers

Opacities are included for N I, O I, Mg II, Si II, and Ca II; these should be significant mainly for evolved stars with low hydrogen abundance. Many more opacities could be included.

The N I cross sections are calculated from Henry, but only the three most important levels are included:

Level	g_i	E_i	ν_i	α_i
$4S - 3P$	4	0	3.517915E15	$1.142E-17 \left[4.29 \left(\frac{\nu_i}{\nu} \right)^2 - 3.29 \left(\frac{\nu_i}{\nu} \right)^3 \right]$
$2D - 3P$	10	2.384	2.941534E15	$4.41E-18 \left[3.85 \left(\frac{\nu_i}{\nu} \right)^{3/2} - 2.85 \left(\frac{\nu_i}{\nu} \right)^{5/2} \right]$
$2P - 3P$	6	3.575	2.653317E15	$4.2E-18 \left[4.34 \left(\frac{\nu_i}{\nu} \right)^{3/2} - 3.34 \left(\frac{\nu_i}{\nu} \right)^{5/2} \right]$

The O I ground-state cross section is from Henry, but the frequency ν_i is defined equal to the hydrogen value:

Level	g_i	E_i	ν_i	α_i
$3P$	9	0	3.28805E15	$2.94E-18 \left[2.66 \left(\frac{\nu_i}{\nu} \right) - 1.66 \left(\frac{\nu_i}{\nu} \right)^2 \right]$

The Mg II cross sections are fits to Peach's tables for the two lowest levels:

Level	g_i	E_i	ν_i	α_i
$3s \ 2S$	2	0	3.635492E15	$1.40E-19 \left[6.7 \left(\frac{\nu_i}{\nu} \right)^4 - 5.7 \left(\frac{\nu_i}{\nu} \right)^5 \right]$
$3p \ 2P$	6	4.43	2.564306E15	$5.11E-19 \left(\frac{\nu_i}{\nu} \right)^3$

The Si II opacity is from Peach's tables for 10000 to 20000 K. The levels that appear explicitly as discontinuities are the following:

Level	ν_i	Level	ν_i
$3p \ 2P$	3.9466738E15	$4d \ 2D$	9.2378947E14
$3d \ 2D$	1.5736321E15	$5p \ 2P$	8.3825004E14
$4p \ 2P$	1.5171539E15		

The Ca II cross sections are fits to Peach's tables for the lowest levels:

Level	g_i	E_i	ν_i	α_i
4s 2S	2	0	2.870454E15	$5.4E-20 \left(\frac{\nu_i}{\nu}\right)^3$
3d 2D	10	1.697	2.460127E15	$1.64E-17 \left(\frac{\nu_i}{\nu}\right)^{1/2}$
4p 2P	6	3.142	2.110779E15	$4.13E-18 \left[0.69 \left(\frac{\nu_i}{\nu}\right)^3 + 0.31 \left(\frac{\nu_i}{\nu}\right)^4 \right]$

5.11 High-Temperature Absorbers

These are opacities for low-lying levels of C II-IV, N II-V, O II-VI, and Ne I-VI that all fall in the Lyman continuum of hydrogen and consequently are important only at temperatures high enough for the Lyman continuum to be somewhat transparent. The cross sections are from several sources, but mainly from Henry; some were fit to Hildago (1968, 1969), a few were taken from Peach, and one was taken from Flower (1968). All the cross sections are approximated by the expression

$$\alpha_\nu = \alpha_i \left[A_i \left(\frac{\nu_i}{\nu}\right)^{p/2} + (1 - A_i) \left(\frac{\nu_i}{\nu}\right)^{1+p/2} \right] .$$

The following page lists the transitions in order of frequency.

5.12 Electron Scattering

We assume that the scattering is independent of angle,

$$\sigma_\nu = 6.653E-24 \frac{n_e}{\rho} .$$

5.13 H₂ Rayleigh Scattering

The cross section is from Dalgarno (1962),

$$\sigma_\nu = \frac{n(H_2)}{\rho} \left(\frac{8.14E-13}{\lambda^4} + \frac{1.28E-6}{\lambda^6} + \frac{1.61}{\lambda^8} \right) ,$$

Code	Transition	g_1	E_1	v_1	a_1	A_1	p_1	Reference
6.01	2P-3P	6	13.71	4.149945E+15	6.90E-18	1.000	6	PEACH
6.01	2S-3P	2	11.96	4.574341E+15	2.50E-18	1.000	4	
6.01	2D-3P	10	9.28	5.220770E+15	1.08E-17	1.000	4	
10.00	1S-2P	1	0.00	5.222307E+15	5.35E-18	3.769	2	HENRY
6.01	2P-1S	6	0.00	5.892577E+15	4.60E-18	1.950	6	
6.01	4P-3P	12	5.33	6.177022E+15	3.50E-18	1.000	4	PEACH
7.01	1S-2P	1	4.05	6.181062E+15	6.75E-18	3.101	5	HENRY
7.01	1D-2P	5	1.90	6.701879E+15	6.65E-18	2.789	5	
7.01	3P-2P	9	0.00	7.158382E+15	6.65E-18	2.860	6	
8.01	2P-3P	6	5.02	7.284488E+15	3.43E-18	4.174	5	
8.01	2D-3P	10	3.33	7.693612E+15	3.53E-18	3.808	5	
8.01	2P-1D	6	5.02	7.885955E+15	2.32E-18	3.110	5	
8.01	2D-1D	10	3.33	8.295079E+15	3.97E-18	3.033	5	
8.01	4S-3P	4	0.00	8.497686E+15	7.32E-18	3.837	5	
6.02	1P-2S	3	12.69	8.509966E+15	2.00E-18	1.750	7	HIDALGO
8.01	2P-1S	6	5.02	8.572854E+15	1.68E-18	3.751	5	HENRY
10.01	2P-3P	6	0.00	9.906370E+15	4.16E-18	2.717	3	
6.02	3P-2S	9	6.50	1.000693E+16	2.40E-18	1.750	7	HIDALGO
7.02	2D-3P	10	12.53	1.046078E+16	4.80E-18	1.000	4	
10.01	2P-1D	6	0.00	1.067157E+16	2.71E-18	2.148	3	HENRY
7.02	2P-1S	6	0.00	1.146734E+16	2.06E-18	1.626	6	
10.01	2P-1S	6	0.00	1.156813E+16	5.20E-19	2.126	3	
6.02	1S-2S	1	0.00	1.157840E+16	9.10E-19	4.750	4	HIDALGO
7.02	4P-3P	12	7.10	1.177220E+16	5.30E-18	1.000	4	
8.02	1S-2P	1	5.35	1.198813E+16	3.97E-18	2.780	6	HENRY
8.02	1D-2P	5	2.51	1.267503E+16	3.79E-18	2.777	6	
8.02	3P-2P	9	0.00	1.327649E+16	3.65E-18	2.014	6	
8.02	5S-4P	5	7.48	1.361466E+16	7.00E-18	1.000	2	HIDALGO
6.03	2P-1S	6	8.00	1.365932E+16	9.30E-19	1.500	7	
7.03	1P-2S	3	16.20	1.481487E+16	1.10E-18	1.750	7	
10.02	1S-2P	1	6.91	1.490032E+16	5.49E-18	3.000	5	HENRY
10.02	3P-4S	9	0.00	1.533389E+16	1.80E-18	2.277	4	
6.03	2S-1S	2	0.00	1.559452E+16	8.70E-19	3.000	6	HIDALGO
10.02	1D-2D	5	3.20	1.579688E+16	4.17E-18	2.074	4	HENRY
10.02	1D-2P	5	3.20	1.643205E+16	1.39E-18	2.792	5	
10.02	3P-2D	9	0.00	1.656208E+16	2.50E-18	2.346	5	
7.03	3P-2S	9	8.35	1.671401E+16	1.30E-18	1.750	7	HIDALGO
10.02	3P-2P	9	0.00	1.719725E+16	1.48E-18	2.225	5	HENRY
8.03	2D-3P	10	15.74	1.737839E+16	2.70E-18	1.000	4	HIDALGO
6.03	2P-1S	6	0.00	1.871079E+16	1.27E-18	.831	6	HENRY
7.03	1S-2S	1	0.00	1.873298E+16	9.10E-19	3.000	4	HIDALGO
8.03	4P-3P	12	8.88	1.903597E+16	2.90E-18	1.000	4	
10.03	4P-2S	12	22.84	2.060738E+16	4.60E-18	1.000	3	
7.04	2P-1S	6	9.99	2.125492E+16	5.90E-19	1.000	6	
10.03	2P-3P	6	7.71	2.162610E+16	1.69E-18	1.937	5	HENRY
10.03	2D-3P	10	5.08	2.226127E+16	1.69E-18	1.841	5	
10.03	2P-1D	6	7.71	2.251163E+16	9.30E-19	2.455	6	
8.04	3P-2S	9	10.20	2.278001E+16	7.90E-19	1.000	6	HIDALGO
10.03	2D-1D	10	5.08	2.317678E+16	1.65E-18	2.277	6	HENRY
10.03	4S-3P	4	0.00	2.348946E+16	3.11E-18	1.963	6	
10.03	2P-1S	6	7.71	2.351911E+16	7.30E-19	1.486	5	
7.04	2S-1S	2	0.00	2.366973E+16	5.00E-19	1.000	4	HIDALGO
8.04	1P-2S	3	19.69	2.507544E+16	6.90E-19	1.000	6	
8.04	1S-2S	1	0.00	2.754065E+16	7.60E-19	1.000	2	
10.04	1S-2P	1	7.92	2.864850E+16	1.54E-18	2.104	6	HENRY
10.04	1D-2P	5	3.76	2.965598E+16	1.53E-18	2.021	6	
10.04	3P-2P	9	0.00	3.054151E+16	1.40E-18	1.471	6	
10.04	5S-4P	5	11.01	3.085141E+16	2.80E-18	1.000	4	HIDALGO
8.05	2S-1S	2	0.00	3.339687E+16	3.60E-19	1.000	6	FLOWER
10.05	2P-1S	6	0.00	3.818757E+16	4.90E-19	1.145	6	HENRY

where

$$\lambda = \frac{2.997925E18}{\min(\nu, 2.922E15)}$$

and

$$n(H_2) = [n(H I)]^2 \exp\left(\frac{4.477}{kT} - 4.6628E1 + 1.8031E-3 T - 5.0739E-7 T^2 + 8.1424E-11 T^3 - 5.0501E-15 T^4 - 1.5 \ln T\right), \quad (4.62)$$

with $n(H I) \approx [n(H I)/U(H I)] 2b_1$ at low temperatures.

5.14 H I Lines

The Stark-broadened line cross sections for $n < 5$ are calculated by a subroutine based on one by Deane Peterson. The theory comes from Griem (1960, 1967) and is strictly valid only for the wings of high-series members. Since various approximations are used for the line cores, this subroutine should be used only for calculating model atmospheres, where some error in opacity is allowable. It should not be used to calculate detailed line profiles for comparison with observation.

The cross section for each line is given by

$$\alpha_{\nu}(n \rightarrow m) = \frac{\pi e^2}{mc} f_{nm} P_{\nu}(|\nu - \nu_{nm}|) d\nu, \quad (5.11)$$

where f_{nm} is the Stark f value for the transition and P is the profile function normalized (ideally) so that

$$\int_{-\infty}^{\infty} P(|\nu - \nu_{nm}|) d\nu = 1. \quad (5.12)$$

The Stark f value f_{nm} is tabulated by Underhill and Waddell (1959). It is less than the total f value for a line when $n+m$ is odd because there is a line component that is not affected by electric fields and so is not Stark broadened. This component appears at line center with a Voigt profile, but as one of our approximations we ignore it in treating the line core. For large m , the Stark f value approaches the total f value, so the total f value is used for $(m-n) > 10$ by scaling from $f_{n, m+10}$ as

$$\left(\frac{m}{m^2 - n^2} \right)^3 ,$$

based on Menzel and Pekeris (1935, eq. (1.31)).

The profile function P for Stark broadening by ions and electrons is given by the approximate expression

$$P dv = p(\beta) \frac{d\beta}{d\nu} R dv , \quad (5.13)$$

where β is a variable chosen so that all lines have approximately the same profile $p(\beta) d\beta$:

$$\beta = \frac{1. E 8 c \Delta \nu}{F_0 K_{nm} \nu_{nm}^2} , \quad (5.14)$$

where

$$K_{nm} \approx 5.5E-5 \frac{n^4 m^4}{m^2 - n^2} \quad (5.15)$$

(if m is small, there is a correction to K_{nm}), and where F_0 is the mean field produced by heavy ions,

$$F_0 = 1.25E-9 n_i^{2/3} , \quad (5.16)$$

assuming $n_i = n_e$. Also, the derivative $d\beta/d\nu$ converts the profile to frequency units, and R is a factor that accounts approximately for broadening by electrons. There are two regions where p and R have different expressions:

$$p(\beta) \simeq \frac{8}{80 + \beta^3} \quad ,$$

$$R = Q + I \quad , \quad \text{for} \quad \beta < 20 \quad ; \quad (5.17)$$

and

$$p(\beta) \simeq 1.5 \beta^{-5/2} \quad ,$$

$$R = Q(1+D) + I \quad , \quad \text{for} \quad \beta \geq 20 \quad . \quad (5.18)$$

In the above,

$$Q = 1 + \frac{2}{\sqrt{\pi}} \int_0^{y_1} y^{1/2} e^{-y} dy \simeq 1.5 + 0.5 \frac{y_1^2 - 1.384}{y_1^2 + 1.384} \quad , \quad (5.19)$$

with

$$y_1 = m^2 \frac{h \Delta \nu}{2kT} \quad ;$$

$$I = \left(\frac{4}{\pi}\right)^{3/2} y_1^{1/2} \left[0.4 e^{-y_1} + E_1(y_1) - \frac{1}{2} E_1(y_2) \right] \left(1 - \frac{n^2}{m^2}\right)^{1/2} \quad , \quad (5.20)$$

with

$$y_2 = \frac{\pi m_e (\Delta \nu)^2}{2e^2 n_e}$$

and E_1 the exponential integral; and

$$D = 2\pi a_0^3 n_e \left(2m^2 \frac{3.28805E15}{\Delta\nu} \right) \times \left[\left(2m^2 \frac{3.28805E15}{\Delta\nu} \right)^{1/2} (1.3Q + 0.30I) - 3.9 \frac{3.28805E15 h}{kT} \right] \quad (5.21)$$

We now discuss overlapping lines. If ν is near one of the first lines in a series, we need to consider the effects of only one or two lines, but as we approach the series limit the lines overlap to such an extent that they form a pseudocontinuum with the continuum cross section. The last observable line has been estimated by Griem (1964, eq. (5.46)):

$$m_s = \frac{1100}{n_e^{2/15}} \quad (5.22)$$

To find a lower and an upper m to limit the summation over lines, we proceed as follows: We find n from the relation

$$n = \sqrt{\frac{3.28805E15}{\nu}}$$

and the nearest m (on the low-frequency side) from

$$m^* = \sqrt{\frac{3.28805E15}{(3.28805E15/n^2) - \nu}} \quad .$$

Then we take

$$\begin{aligned} m_l &= \max(m^*, n+1) \quad , \\ m_u &= m^* + 1 \quad , \end{aligned} \quad \text{for} \quad m^* \leq 6 \quad ,$$

and

$$\begin{aligned} m_l &= m^* - 1, \\ m_u &= m^* + 4, \end{aligned} \quad \text{for } 6 < m^* \leq m_s ;$$

if $m > m_s$, we use the bound-free cross section at the limit ν_n (as computed in Section 5.1). A complication arises when $n=4$ and $m=8$ or 9 because Paschen α also falls in the same region; so Paschen α is added separately.

The absorption coefficient (in a simple case) is finally

$$\kappa_\nu = \frac{n(H\text{ I})}{\rho} \frac{2n^2 b_n}{U(H\text{ I})} e^{-E_n/kT} \sum_{m=m_l}^{m_u} \alpha_{\nu(n \rightarrow m)} \left[1 - \left(\frac{b_m}{b_n} \right) e^{-(E_m - E_n)/kT} \right],$$

and the source function is

$$S_\nu = \frac{1}{\kappa_\nu} \sum \kappa_{\nu(n \rightarrow m)} \left[1 - \frac{b_m}{b_n} e^{-(E_m - E_n)/kT} \right] \frac{2h\nu^3/c^2}{(b_n/b_m) e^{h\nu/kT} - 1}.$$

5.15 Line-Absorption Distribution Functions

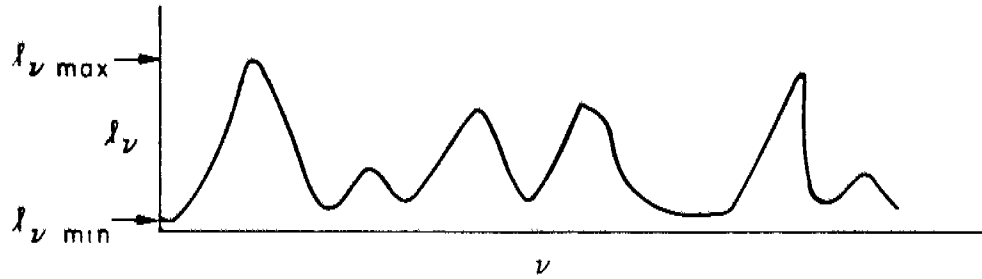
The remaining opacities are included in ATLAS only as dummy subroutines either because the work has not yet been completed (for distribution functions, helium lines, etc.) or because these opacities are designed to be experimental or to satisfy some objective other than computing a model atmosphere.

We do not need to know the opacity explicitly at every frequency in order to calculate a model atmosphere, because the structure of the atmosphere is determined by integrals that depend not so much on the details of the spectrum but more on its average properties. If only continuum opacities are considered, the integrals can be evaluated

accurately by sampling at relatively few frequency points. By adopting a line-absorption distribution function, we obtain the same simplification when line opacities are included.

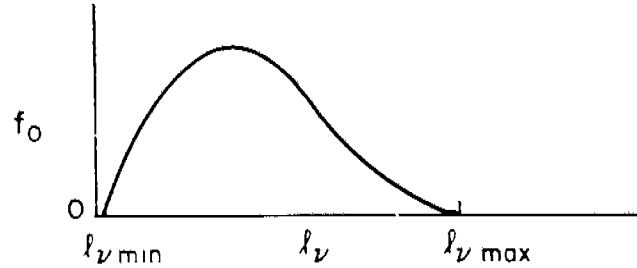
A distribution function can be found and then presented to ATLAS in a subroutine. We choose an interval (not necessarily related to the integration frequencies) for which we want an "average" opacity and compute the line opacity for the whole region as a function of temperature, pressure, electron number, and microturbulence,

106-048



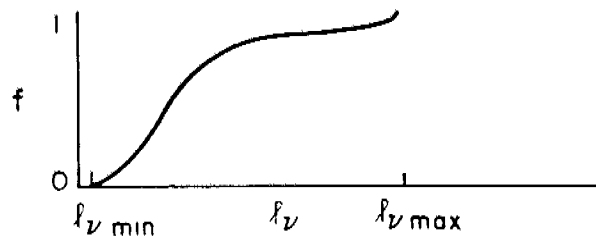
We could take a distribution function f_0 for the fraction of the interval that has ℓ_ν between $\ell_{\nu \min}$ and $\ell_{\nu \min} + \Delta \ell_\nu$,

106-048



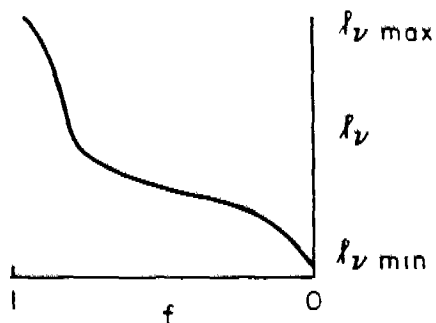
but for our purposes, we take the distribution function in the form where f is the fraction of the interval with opacity ℓ_ν or less,

106-048



because we can invert this to get something that looks like a line profile:

106-048



We can describe these last two figures more mathematically. We have

$$f(l_v) = \int_0^{l_v} f_0(\ell) d\ell \quad (5.23)$$

so that

$$f(0) = f(l_{v \min}) = 0$$

and

$$f(\infty) = f(l_{v \max}) = 1$$

Since the distribution function $f(l_v)$ is monotonic, the inverse relation $l_v(f)$ is well defined. The end points are then

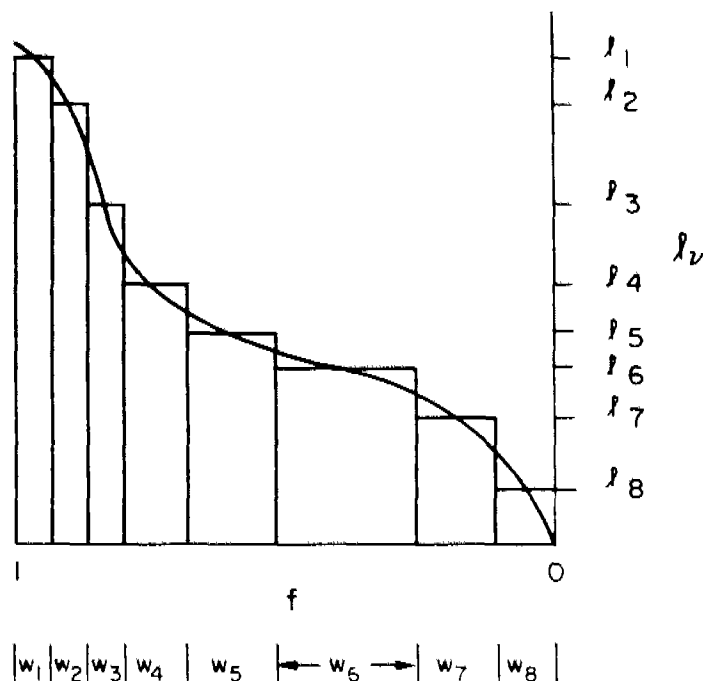
$$l_v(1) = l_{v \max}$$

and

$$l_v(0) = l_{v \min}$$

For computation, we represent the distribution function f by n steps, the number and width of which must be empirically determined,

106-048

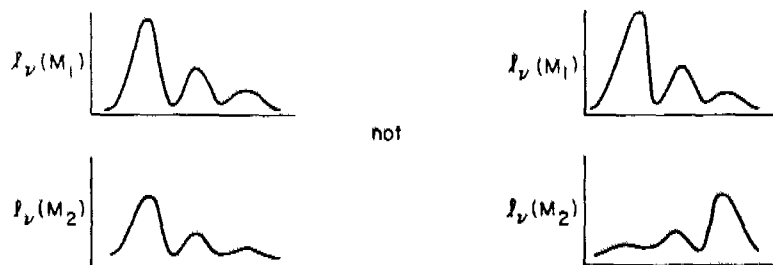


If ATLAS requests line opacity for a frequency in the interval covered by the distribution function, we tell ATLAS the number of steps n and the values of w_i and ℓ_i . Then ATLAS calculates $\tau_\nu(\ell_i)$, $S_\nu(\ell_i)$, $J_\nu(\ell_i)$, and $H_\nu(\ell_i)$ and includes w_i in frequency integrals

$$I = \int \sum_{i=1}^n w_i I_\nu(\ell_i) d\nu, \quad (5.24)$$

assuming the line source function is B_ν . The w_i 's must be constant with depth at any given frequency in order for ATLAS to be able to calculate the radiation field.

In representing lines by distribution functions, we make two implicit physical assumptions. The first is that the absorption-coefficient spectrum has the same relative shape at all depths M_j where line opacity is important:



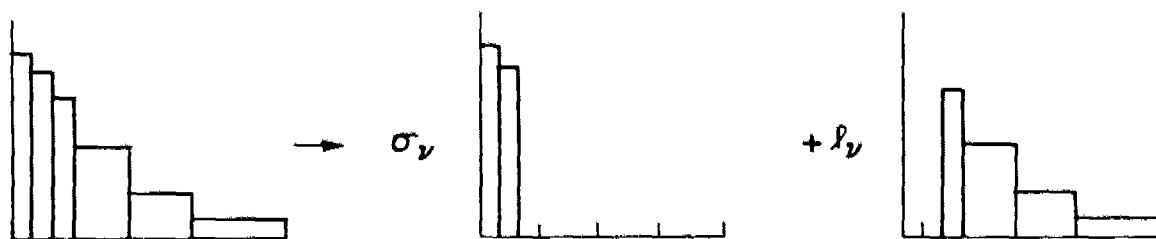
These two cases have identical distribution functions. In the second case, the distribution function predicts the wrong optical depths. The only way to investigate this effect is to compare distribution-function calculations to explicit line calculations.

The second assumption is either that lines of different strengths are uniformly distributed throughout the interval or that the continuum source function and opacity do not vary radically over the frequency interval to which the distribution function applies, so that it makes no difference where in the interval the lines appear. If the interval for the distribution function is chosen such that strong opacity discontinuities are avoided and if the width of the interval is chosen such that $\Delta\nu/\nu \lesssim 5$ to 10%, this assumption should be no problem.

5.16 Line-Scattering Distribution Functions

If we desire that high-opacity regions have $S_\nu \approx J_\nu$, we can take our previous distribution function and replace the first step or steps l_1 by σ_1 :

106-048



This approach might be used, for example, to get a qualitative estimate of the effect of detailed line-transfer calculations for strong lines.

5.17 Other or Experimental Absorption Lines

Lines can be calculated explicitly. For example, we can put in several metal lines with Voigt profiles or helium lines with Stark broadening. The source function is arbitrary.

5.18 Other or Experimental Scattering Lines

We might experiment to see what happens if we treat the cores of several strong lines as scattering.

5.19 Other or Experimental Continuous Absorbers

We might want to test the importance of C^- , etc. The source function is arbitrary.

5.20 Other or Experimental Continuous Scatterings

We might want to test the importance of C Rayleigh scattering, etc.

6. CONVECTIVE ENERGY TRANSPORT

Radiation is not the only means available for transporting energy through the atmosphere. If the gradient $(-dT/dx)$ is greater than the adiabatic gradient $(-dT/dx)_A$, the gas is convectively unstable and convection can carry energy by moving hot gas elements into cooler regions. Unfortunately, convection is not well understood, so most researchers resort to an elaborate but essentially dimensional analysis called the mixing-length theory. We present here only a crude dimensional analysis and the relevant results (see Cox and Guili, 1968, for details). The constants are traditional.

The mixing-length theory assumes that the convective elements are rising and falling bubbles. The bubbles, of diameter ℓ , rise a distance ℓ while radiating part of their energy and finally merge into the background. Since ℓ varies through the atmosphere, the ratio ℓ/h is usually specified, where $h = P_{\text{total}}/\rho g$ is the pressure scale height (eq. (4.47)). The ratio of mixing length to scale height, ℓ/h , is generally prescribed as a constant such as 1 or 2.

Gradients are usually expressed as logarithmic derivatives $d \ln T / d \ln P \equiv \nabla$ such that

$$-\frac{dT}{dx} = \rho g T \frac{d \ln T}{dP} = \frac{T}{h} \nabla . \quad (6.1)$$

The convective bubbles would follow the adiabatic gradient ∇_A , but radiative losses force a value nearer the average gradient ∇ , so

$$\nabla > \nabla_B > \nabla_A . \quad (6.2)$$

The convective flux is obtained through the following argument: In rising a distance ℓ , the bubble (of fixed mass) becomes hotter than its surroundings by an amount ΔT ,

$$\Delta T = \left[\left(\frac{-dT}{dx} \right) - \left(\frac{-dT}{dx} \right)_B \right] \ell = (\nabla - \nabla_B) \left(\frac{\ell}{h} \right) T \quad . \quad (6.3)$$

If we multiply by the specific heat at constant pressure, we find the excess energy per unit mass ΔE ,

$$\Delta E = \Delta T C_P = (\nabla - \nabla_B) \left(\frac{\ell}{h} \right) T C_P \quad . \quad (6.4)$$

This energy is converted to a flux by multiplying by ρv_{conv} , where v_{conv} is the bubble velocity,

$$\text{flux} \sim (\nabla - \nabla_B) \left(\frac{\ell}{h} \right) T C_P \rho v_{\text{conv}} \quad .$$

The "exact" expression is

$$4\pi H_{\text{conv}} = \frac{1}{2} \left(\frac{\ell}{h} \right) \rho C_P T v_{\text{conv}} (\nabla - \nabla_B) \quad , \quad (6.5)$$

but we still need to evaluate v_{conv} and $(\nabla - \nabla_B)$.

An expression for the convective velocity is found by considering the force on a bubble when its density is slightly changed. The equation of motion is

$$\frac{d^2 x}{dt^2} = -g - \frac{1}{\rho} \frac{dP}{dx} \quad . \quad (4.1')$$

If there were no density change, $d^2 x/dt^2$ would equal 0, but with $\rho \rightarrow \rho[1 + (\Delta\rho/\rho)]$, the acceleration is

$$\frac{d^2 x}{dt^2} = -g - \frac{1}{\rho} \frac{dP}{dx} + \frac{\Delta\rho}{\rho^2} \frac{dP}{dx} = \frac{-\Delta\rho}{\rho} g \quad . \quad (6.6)$$

This acceleration corresponds to a force $-g \Delta\rho$ that acts for an average distance ℓ to produce an average kinetic energy for the bubble of $-g\ell \Delta\rho$. Then,

$$\rho v_{\text{conv}}^2 \sim -g\ell \Delta\rho \quad . \quad (6.7)$$

To "evaluate" $\Delta\rho$, we relate it to ΔT and finally to $(\nabla - \nabla_B)$ through equation (6.3),

$$\frac{\Delta\rho}{\rho} = \left(\frac{\partial \ln \rho}{\partial \ln T} \right)_P \frac{\Delta T}{T} = \left(\frac{\partial \ln \rho}{\partial \ln T} \right)_P (\nabla - \nabla_B) \left(\frac{l}{h} \right). \quad (6.8)$$

Then from equations (6.7) and (6.8),

$$v_{\text{conv}}^2 \sim -gl \left(\frac{\partial \ln \rho}{\partial \ln T} \right)_P (\nabla - \nabla_B) \left(\frac{l}{h} \right). \quad (6.9)$$

The "exact" value for the convective velocity is

$$v_{\text{conv}} = \sqrt{-\frac{1}{8} gh \left(\frac{l}{h} \right)^2 \left(\frac{\partial \ln \rho}{\partial \ln T} \right)_P (\nabla - \nabla_B)}. \quad (6.10)$$

An elaborate argument is required to find $(\nabla - \nabla_B)$. We evaluate the ratio of the radiative loss while the bubble rises to the excess bubble energy when the bubble merges. We know that the excess bubble energy is proportional to $(\nabla - \nabla_B)$. If there were no radiative losses, ∇_B would equal ∇_A and the excess energy would be proportional to $(\nabla - \nabla_A)$. Then, $[(\nabla - \nabla_A) - (\nabla - \nabla_B)]/(\nabla - \nabla_B)$ must equal the ratio of radiative loss to excess bubble energy. We can also "calculate" the radiative loss directly. We make the approximation that the bubbles are optically thick. Then from equation (2.87), the radiative flux satisfies the relation

$$4\pi \int H_\nu dv \simeq 4\pi \frac{4\sigma T^3}{3\pi} \frac{dT}{d\tau_{\text{Ross}}} = \frac{16}{3} \frac{\sigma T^3}{\kappa_{\text{Ross}} \rho} \frac{dT}{dx}.$$

The radiative loss is the flux times the area times the lifetime of each bubble:

$$\sim \frac{16}{3} \frac{\sigma T^3}{\kappa_{\text{Ross}} \rho} \frac{\Delta T}{l/2} A \frac{l}{v_{\text{conv}}}, \quad (6.11)$$

where $l/2$ is the "radius," and A the "area," and l/v_{conv} the lifetime of the bubble. The excess bubble energy is the excess energy per unit mass (eq. (6.4)) times the mass of each bubble,

$$(\Delta T C_p)(\rho V), \quad (6.12)$$

where V is the bubble "volume." The ratio of the two energies (6.11) and (6.12) is

$$\begin{aligned} \frac{(\nabla - \nabla_A) - (\nabla - \nabla_B)}{(\nabla - \nabla_B)} &= \frac{[(16\sigma T^3/3)/\kappa_{\text{Ross}} \rho] (\Delta T/\ell) A (\ell/v_{\text{conv}})}{\Delta T C_P \rho V} \\ &= \frac{16\sigma T^3/3}{\kappa_{\text{Ross}} \rho C_P \rho v_{\text{conv}}} \frac{A}{V} . \end{aligned}$$

Since $A/V \sim 1/\ell$ and we know v_{conv} from equation (6.10), we find

$$\frac{(\nabla - \nabla_A) - (\nabla - \nabla_B)}{(\nabla - \nabla_B)} = \frac{32\sqrt{2} \sigma T^3}{\kappa_{\text{Ross}} \rho \ell C_P \rho \sqrt{-(1/8) gh (\ell/h)^2 (\partial \ln \rho / \partial \ln T)_P (\nabla - \nabla_B)}} , \quad (6.13)$$

where we have inserted the "exact" constant $32\sqrt{2}$. To simplify this equation, we define

$$D = \frac{1}{2} \left[\frac{32\sqrt{2} \sigma T^3}{\kappa_{\text{Ross}} \rho h C_P (\ell/h) \rho \sqrt{-(1/8) gh (\ell/h)^2 (\partial \ln \rho / \partial \ln T)_P}} \right]^2 \quad (6.14)$$

so that

$$[(\nabla - \nabla_B) - (\nabla - \nabla_A)]^2 = 2D(\nabla - \nabla_B) .$$

The solution is

$$(\nabla - \nabla_B) = D + (\nabla - \nabla_A) - \sqrt{[D + (\nabla - \nabla_A)]^2 - (\nabla - \nabla_A)^2} \quad (6.15)$$

or, expressed as a power series to avoid truncation problems,

$$\begin{aligned}
 (\nabla - \nabla_B) = [D + (\nabla - \nabla_A)] & \left[\frac{(\nabla - \nabla_A)}{D + (\nabla - \nabla_A)} \right]^2 \left\{ \frac{1}{2} + \frac{1 \cdot 1}{2 \cdot 4} \left[\frac{(\nabla - \nabla_A)}{D + (\nabla - \nabla_A)} \right]^2 \right. \\
 & \left. + \frac{1 \cdot 1 \cdot 3}{2 \cdot 4 \cdot 6} \left[\frac{(\nabla - \nabla_A)}{D + (\nabla - \nabla_A)} \right]^4 + \dots \right\} .
 \end{aligned} \quad (6.16)$$

In summary:

Convective flux,

$$4\pi H_c = \frac{1}{2} \left(\frac{\ell}{h} \right) \rho C_P T v_{\text{conv}} (\nabla - \nabla_B) . \quad (6.5)$$

Convective velocity,

$$v_{\text{conv}} = \sqrt{-\frac{1}{8} gh \left(\frac{\ell}{h} \right)^2 \left(\frac{\partial \ln \rho}{\partial \ln T} \right)_P (\nabla - \nabla_B)} . \quad (6.10)$$

Bubble gradient,

$$(\nabla - \nabla_B) = D + (\nabla - \nabla_A) - \sqrt{[D + (\nabla - \nabla_A)]^2 - (\nabla - \nabla_A)^2} , \quad (6.15)$$

with

$$D = \frac{1}{2} \left[\frac{32\sqrt{2} \sigma T^3}{\kappa_{\text{Ross}} \rho h C_P (\ell/h) \rho \sqrt{-(1/8) gh (\ell/h)^2 (\partial \ln \rho / \partial \ln T)_P}} \right]^2 . \quad (6.14)$$

The derivatives C_P , ∇_A , and $(\partial \ln \rho / \partial \ln T)_P$ are discussed in Section 4.6.

7. THE TEMPERATURE CORRECTION

7.1 Introduction

In general, the trial temperature distribution that we have used to calculate the radiation field will not have produced the desired total flux

$$\mathcal{H} = \frac{\sigma T_{\text{eff}}^4}{4\pi} \quad . \quad (7.1)$$

There will be a flux error

$$\Delta H = \mathcal{H} - \int H_{\nu} d\nu - H_{\text{conv}} \quad (7.2)$$

that we must attempt to reduce by modifying the temperature distribution.

We begin by considering the case where there is no convective flux (so the algebra is simple). Since most of the flux we see at the surface comes from the region where the atmosphere is just becoming optically thick, roughly $0.1 \leq \tau \leq 2.0$, the temperature at shallow layers cannot greatly affect the flux. Consequently, it is very difficult to use the flux errors near the surface to derive temperature changes. The flux derivative

$$\frac{dH_{\nu}}{d\tau_{\nu}} = J_{\nu} - S_{\nu} \quad (2.32)$$

is, however, sensitive to the temperature in the optically thin region and can be used to obtain temperature corrections near the surface by forcing the proper flux derivative up from the optically thick region where the temperature is known. A correction based on the flux derivative is called a Λ correction from the operator used to calculate J_{ν} .

A temperature correction can be derived by perturbing or expanding a moment of the transfer equation to get a first-order equation. Then a workable temperature correction is found by making some approximation to simplify the first-order equation. The temperature correction need not be very accurate, because successive iterations of the model remove small errors. It should be emphasized that the criterion for judging the effectiveness of a temperature correction is the total amount of computer time needed to calculate a model. Mathematical rigor is irrelevant. Any empirically derived tricks for speeding convergence are completely justified.

In ATLAS we use a flux correction related to one derived by Avrett and Krook (1963) and a Λ correction that is an approximation to an integral-equation temperature correction derived by Böhm-Vitense (1964). We also include a term to smooth out the region where the two operations overlap.

7.2 The Flux Correction

To derive the flux correction, we start with the second moment of the transfer equation

$$\frac{dK_{\nu}}{d\tau_{\nu}} = H_{\nu} \quad (2.33)$$

and rewrite it in terms of ρ_{ν}

$$\frac{dK_{\nu}}{dM} = (\kappa_{\nu} + \sigma_{\nu}) H_{\nu} \quad (7.3)$$

Then we perturb with the substitutions

$$K_{\nu} \rightarrow K_{\nu} + \Delta K_{\nu} \quad ,$$

$$M \rightarrow M + \Delta M \quad ,$$

$$(\kappa_{\nu} + \sigma_{\nu}) \rightarrow (\kappa_{\nu} + \sigma_{\nu}) + \Delta(\kappa_{\nu} + \sigma_{\nu}) \quad ,$$

and

$$H_\nu \rightarrow H_\nu + \Delta H_\nu$$

to obtain the first-order equation

$$\frac{d\Delta K_\nu}{dM} = (\kappa_\nu + \sigma_\nu) \Delta H_\nu + \Delta(\kappa_\nu + \sigma_\nu) H_\nu + (\kappa_\nu + \sigma_\nu) H_\nu \frac{d\Delta M}{dM} \quad (7.4)$$

If we can solve equation (7.4) for ΔM , we can find ΔT through

$$\Delta T = -\frac{dT}{dM} \Delta M \quad .$$

We know H_ν , $(\kappa_\nu + \sigma_\nu)$, and $\Delta H = H - \mathcal{H}$, but we do not know ΔH_ν , $\Delta(\kappa_\nu + \sigma_\nu)$, or ΔK_ν , so we must eliminate reference to them. We divide equation (7.4) by $(\kappa_\nu + \sigma_\nu)$ to isolate ΔH_ν , then integrate over frequency to obtain ΔH , and finally assume that

$$\int \frac{1}{(\kappa_\nu + \sigma_\nu)} \frac{d\Delta K_\nu}{dM} d\nu = \int \frac{\Delta(\kappa_\nu + \sigma_\nu)}{(\kappa_\nu + \sigma_\nu)} H_\nu d\nu \quad (7.5)$$

We are left with a differential equation for ΔM

$$H \frac{d\Delta M}{dM} = H - \mathcal{H} \quad , \quad (7.6)$$

for which the solution, setting $\Delta M(0) = 0$, is

$$\Delta M = \int_0^M \frac{H(y) - \mathcal{H}(y)}{H(y)} dy \quad . \quad (7.7)$$

The final flux correction is

$$\Delta T_{\text{flux}} = - \frac{dT}{dM} \Delta M \quad . \quad (7.8)$$

We now consider the flux correction when convection is included. We rewrite the expressions for the convective flux given in Section 6 so that the dependence on T and ∇ is obvious,

$$H_{\text{conv}} = A T \frac{(\nabla - \nabla_A)^3}{[BT^6 + (\nabla - \nabla_A)]^{3/2}} \Sigma^{3/2} \quad , \quad (7.9)$$

where

$$A = \frac{1}{4\pi} \frac{1}{2} \rho C_P T \left(\frac{\ell}{h}\right) \sqrt{\frac{1}{8} gh \left(\frac{\ell}{h}\right)^2 \left(\frac{d \ln \rho}{d \ln T}\right)_P} \quad ,$$

$$B = \frac{D}{T^6} = \frac{1}{2} \left[\frac{32\sqrt{2} \sigma}{\kappa_{\text{Ross}} \rho h C_P (\ell/h) \rho \sqrt{(1/8) gh (\ell/h)^2 (d \ln \rho / d \ln T)_P}} \right]^2 \quad ,$$

and

$$\Sigma = \frac{1}{2} + \frac{1 \cdot 1}{2 \cdot 4} \left[\frac{(\nabla - \nabla_A)}{BT^6 + (\nabla - \nabla_A)} \right]^2 + \frac{1 \cdot 1 \cdot 3}{2 \cdot 4 \cdot 6} \left[\frac{(\nabla - \nabla_A)}{BT^6 + (\nabla - \nabla_A)} \right]^4 + \dots \quad .$$

We obtain a temperature correction by expanding T and ∇ to first order in ΔT and by assuming that the ΔT dependence of Σ is negligible and that all other quantities are independent of ΔT .

The expansion for the flux is

$$\begin{aligned} H_{\text{conv}} + \Delta H_{\text{conv}} &= A (T + \Delta T) \left[(\nabla - \nabla_A) + \frac{d\Delta T/T}{d \ln P} \right]^3 \\ &\times \left[BT^6 + 6 BT^5 \Delta T + (\nabla - \nabla_A) + \frac{d\Delta T/T}{d \ln P} \right]^{-3/2} \Sigma^{3/2} \quad , \quad (7.10) \end{aligned}$$

where for ∇ we have simplified

$$\nabla = \frac{d \ln T}{d \ln P} \rightarrow \frac{d \ln (T + \Delta T)}{d \ln P} = \frac{d \ln T [1 + (\Delta T/T)]}{d \ln P} = \nabla + \frac{d\Delta T/T}{d \ln P} .$$

Continuing the algebra,

$$\begin{aligned} H_{\text{conv}} + \Delta H_{\text{conv}} &= A T \left(1 + \frac{\Delta T}{T}\right) \frac{(\nabla - \nabla_A)^3}{[BT^6 + (\nabla - \nabla_A)]^{3/2}} \left(1 + \frac{d\Delta T/T}{d \ln P}\right) \\ &\times \left\{1 + \frac{(BT^6 \Delta T/T) + [(d\Delta T/T)/d \ln P]}{BT^6 + (\nabla - \nabla_A)}\right\}^{-3/2} \Sigma^{3/2} , \end{aligned}$$

and to first order,

$$\Delta H_{\text{conv}} = H_{\text{conv}} \frac{\Delta T}{T} + H_{\text{conv}} \left\{ \frac{(3/2) [(d\Delta T/T)/d \ln P]}{(\nabla - \nabla_A)} - \frac{(3/2) [(d\Delta T/T)/d \ln P]}{D + (\nabla - \nabla_A)} - \frac{9D \Delta T/T}{D + (\nabla - \nabla_A)} \right\} .$$

This differential equation can be written more clearly as

$$\Delta H_{\text{conv}} = H_{\text{conv}} \frac{\Delta T}{T} \left[1 - \frac{9D}{D + (\nabla - \nabla_A)}\right] + H_{\text{conv}} \frac{(3/2) [(d\Delta T/T)/d \ln P]}{(\nabla - \nabla_A)} \left[1 + \frac{D}{D + (\nabla - \nabla_A)}\right] . \quad (7.11)$$

We have found that when H_{conv} is large, the terms containing D can be ignored because $D \ll (\nabla - \nabla_A)$.

To obtain a single expression involving both the radiative and the convective flux, we change the variable from ΔT to ΔM and add ΔH_{conv} to the differential equation for ΔM that we found earlier. We substitute $\Delta T = -dT/dM \Delta M$ into the equation for ΔH_{conv} , while noting that

$$\frac{d}{d \ln P} \left(\frac{dT}{dM} \frac{\Delta M}{T} \right) = \Delta M \frac{d^2 \ln T}{d \ln P dM} + \frac{d \ln T}{dM} \frac{dM}{d \ln P} = \Delta M \frac{d\nabla}{dM} + \nabla \frac{d\Delta M}{dM} ,$$

to obtain

$$\begin{aligned} \Delta H_{\text{conv}} = & -H_{\text{conv}} \frac{dT}{dM} \frac{1}{T} \left\{ \left[1 - \frac{9D}{D + (\nabla - \nabla_A)} \right] + \frac{(3/2) (d\nabla/dM)}{(\nabla - \nabla_A)} \left[1 + \frac{D}{D + (\nabla - \nabla_A)} \right] \right\} \Delta M \\ & - H_{\text{conv}} \frac{(3/2)\nabla}{(\nabla - \nabla_A)} \left[1 + \frac{D}{D + (\nabla - \nabla_A)} \right] \frac{d\Delta M}{dM} . \end{aligned} \quad (7.12)$$

The combined differential equation for ΔM is

$$\begin{aligned} & \left\{ H_{\text{rad}} + H_{\text{conv}} \frac{(3/2)\nabla}{(\nabla - \nabla_A)} \left[1 + \frac{D}{D + (\nabla - \nabla_A)} \right] \right\} \frac{d\Delta M}{dM} \\ & + H_{\text{conv}} \left\{ \frac{dT}{dM} \frac{1}{T} \left[1 - \frac{9D}{D + (\nabla - \nabla_A)} \right] + \frac{(3/2) (d\nabla/dM)}{(\nabla - \nabla_A)} \left[1 + \frac{D}{D + (\nabla - \nabla_A)} \right] \right\} \Delta M \\ & = H_{\text{rad}} + H_{\text{conv}} - \mathcal{H} . \end{aligned} \quad (7.13)$$

The solution is

$$\Delta M = \int_0^M \frac{g(y)}{g(M)} \frac{H_{\text{rad}} + H_{\text{conv}} - \mathcal{H}}{H_{\text{rad}} + H_{\text{conv}} [(3/2)\nabla/(\nabla - \nabla_A)] (1 + \{D/[D + (\nabla - \nabla_A)]\})} dy , \quad (7.14)$$

where

$$g(y) = \exp \left(\int_0^y \frac{\text{coef of } \Delta M}{\text{coef of } d\Delta M/dM} dy \right) .$$

Since the derivation of ΔM was only to first order, ΔM may not be valid for large flux errors. To prevent difficulties, we establish the limits

$$-\frac{1}{2} \frac{\tau_{\text{Ross}}}{\kappa_{\text{Ross}}} \leq \Delta M \leq \frac{\tau_{\text{Ross}}}{\kappa_{\text{Ross}}} \quad . \quad (7.15)$$

7.3 The Λ Correction

To derive the Λ correction for the case of no convection, we start with the moment equation

$$\frac{dH_v}{d\tau_v} = J_v - S_v \quad , \quad (2.32)$$

or

$$\frac{dH_v}{dM} = (\kappa_v + \sigma_v) (J_v - S_v) \quad , \quad (7.16)$$

and express it in the form of an operator equation. Since S_v is given by the relation

$$S_v = (I - \alpha_v \Lambda_v)^{-1} (I - \alpha_v) B_v \quad , \quad (\text{from 2.67})$$

we have

$$\frac{dH_v}{dM} = (\kappa_v + \sigma_v) (\Lambda_v - I) (I - \alpha_v \Lambda_v)^{-1} (I - \alpha_v) B_v \quad . \quad (7.17)$$

We expand B_v in terms of ΔT ,

$$B_v \rightarrow B_v + \frac{dB_v}{dT} \Delta T \quad , \quad (7.18)$$

but we ignore any ΔT dependence in the functions $(\kappa_\nu + \sigma_\nu)$, Λ_ν , and α_ν . Consequently, we have

$$\frac{d\mathcal{H}_\nu}{dM} = (\kappa_\nu + \sigma_\nu) (\Lambda_\nu - I) (I - \alpha_\nu \Lambda_\nu)^{-1} (I - \alpha_\nu) \left(B_\nu + \frac{dB_\nu}{dT} \Delta T \right),$$

or for the error in the flux derivative,

$$\frac{d\mathcal{H}_\nu}{dM} - (\kappa_\nu + \sigma_\nu) (J_\nu - S_\nu) = (\kappa_\nu + \sigma_\nu) (\Lambda_\nu - I_\nu) (I - \alpha_\nu \Lambda_\nu)^{-1} (I - \alpha_\nu) \frac{dB_\nu}{dT} \Delta T. \quad (7.19)$$

We integrate equation (7.19) over frequency to remove the frequency dependence of ΔT ,

$$\frac{d\mathcal{H}}{dM} - \int (\kappa_\nu + \sigma_\nu) (J_\nu - S_\nu) d\nu = \int (\kappa_\nu + \sigma_\nu) (\Lambda_\nu - I_\nu) (I - \alpha_\nu \Lambda_\nu)^{-1} (I - \alpha_\nu) \frac{dB_\nu}{dT} d\nu \Delta T. \quad (7.20)$$

This equation can be solved explicitly (cf. Peterson, 1969), but it is extremely time-consuming to evaluate the Λ operator and the inverse operators. Instead, we settle for an approximation — we ignore all but the diagonal matrix elements. This is possible because the off-diagonal elements are small, at least in the upper layers of the atmosphere where the correction is relevant. The inverse $(I - \alpha_\nu \Lambda_\nu)^{-1}$ becomes $(1 - \alpha_\nu \Lambda_{\nu \text{ diag}})^{-1}$, and the temperature correction becomes

$$\Delta T_\Lambda = \frac{\left(d\mathcal{H}/dM \right) - \int (\kappa_\nu + \sigma_\nu) (J_\nu - S_\nu) d\nu}{\int (\kappa_\nu + \sigma_\nu) \left[(\Lambda_{\nu \text{ diag}} - 1) / (1 - \alpha_\nu \Lambda_{\nu \text{ diag}}) \right] (1 - \alpha_\nu) (dB_\nu/dT) d\nu}. \quad (7.21)$$

If we approximate S_ν by straight-line segments, we can evaluate the diagonal matrix element according to the discussion in Section 2.6 to obtain

41	1.100000E+15	4.989608E+13
42	1.150000E+15	5.423402E+13
43	1.192579E+15	1.569611E+13
44	1.192581E+15	2.172918E+13
45	1.250000E+15	6.475939E+13
46	1.300000E+15	4.584211E+13
47	1.350000E+15	5.007371E+13
48	1.400000E+15	5.257098E+13
49	1.442999E+15	1.597131E+13
50	1.453001E+15	3.614608E+13
51	1.515290E+15	3.614608E+13
52	1.515294E+15	1.235998E+13
53	1.530000E+15	4.714918E+13
54	1.600000E+15	3.869734E+13
55	1.650000E+15	8.654503E+13
56	1.750000E+15	8.135071E+13
57	1.787967E+15	4.195281E+12
58	1.787971E+15	1.115443E+13
59	1.820000E+15	4.069911E+13
60	1.848849E+15	9.028562E+12

7.4 The Surface Correction

The third correction term, which smooths out the region where the first two overlap, is the surface correction. One way to remove a flux error at the surface is simply to reduce or increase the temperature by a constant value all the way through the atmosphere. If we use the fact that the temperature in the region where the surface flux is formed is approximately T_{eff} , we find that $\Delta T \sim 4 T_{\text{eff}} H_0 / \mathcal{H}$, since $\mathcal{H} = \sigma T_{\text{eff}}^4 / 4\pi$. As a minimum, we take a smaller temperature, $\Delta T \sim 4 T_0 H_0 / \mathcal{H}$. Part or all of this temperature correction is produced by the flux and the Λ corrections. The average sum of the two corrections in the region forming the surface flux is approximately

$$\Delta T_{\text{av}} = \frac{1}{2} \int_{0.1}^2 (\Delta T_{\Lambda} + \Delta T_{\text{flux}}) d\tau_{\text{Ross}} \quad . \quad (7.26)$$

Then the required surface correction is

$$\Delta T_{\text{surf}} = 4 T_0 \frac{\Delta H_0}{\mathcal{H}} - \Delta T_{\text{av}} \quad . \quad (7.27)$$

The limit on this correction is $T_{\text{eff}}/25$.

7.5 Other Fudges

The total correction is

$$\Delta T = \Delta T_{\text{flux}} + \Delta T_{\Lambda} + \Delta T_{\text{surf}} \quad . \quad (7.28)$$

An empirically derived speeding-up process based on the behavior of ΔT from iteration to iteration is also used when there is no convection. If ΔT changes sign, it is multiplied by 0.5; if it has the same sign, it is multiplied by 1.25.

If the flux errors are large on the first iteration, ATLAS gives up on the old temperature distribution and calculates a new one (although it might eventually get the original one to converge). If there is no convection and the error at the last depth is outside +90% or -50%, the new temperature distribution is

$$T = T_{\text{eff}} \left\{ \frac{3}{4} \left[0.710 + \tau_{\text{Ross}} - 0.1331 \exp(-3.4488 \tau_{\text{Ross}}) \right] \right\}^{1/4} . \quad (7.29)$$

If convection is included and the error is greater than 1000% at any depth, ATLAS integrates down from the nonconvective surface region using an effective gradient $(d \ln T / d \ln P)_{\text{eff}} = (d \ln T / d \ln M)_{\text{eff}}$. The gradient is defined as the larger of

$$\left(\frac{d \ln T}{d \ln M} \right)_{\text{eff}} = \frac{H_{\text{rad}} (d \ln T / d \ln P) + H_{\text{conv}} (d \ln T / d \ln P)_A}{H_{\text{rad}} + H_{\text{conv}}} \quad (7.30a)$$

and

$$\left(\frac{d \ln T}{d \ln M} \right)_{\text{eff}} = \frac{(d \ln T / d \ln P) + 1}{3} . \quad (7.30b)$$

8. ATLAS

8.1 A Sample Model Calculation

We will describe the programing twice; first, we will follow a model computation from beginning to end with reference to input and output; the second time, in Sections 8.4 and 8.5, we will discuss the subroutines in order. In Section 8.6, we give a listing of ATLAS5. Numbers in parentheses following subroutine names refer to pages in this listing.

To start a model calculation, ATLAS5, the main program, calls READIN to get instructions. (Look at the first two pages of ATLAS5, then turn to page 19 and glance through READIN and its subroutines up through page 37.) READIN reads the data cards by using subroutines FREEFF, FREEFR, IWORDF, and DUMMYR. If necessary, it calculates a starting temperature distribution by use of TTAUP, filling in any variables for which data have not been read in from BLOCKE and BLOCKR. READIN produces a two-page printout of the data, which it passes to the rest of the program through COMMON blocks. If there are insufficient data or if the data are in the wrong format, READIN complains and quits (calls EXIT).

On the next page, we have a listing of the input deck that produced the sample model that we will discuss. The order of the cards does not matter (much) because each datum or set of data is preceded by a code word and the numbers themselves are read with a free-field format. A number can appear anywhere on the card after the code word and in any format as long as it is followed by a comma or a blank. Input cards will be discussed in detail in Section 8.3.

The input deck requests six iterations on a 10000 K, $\log g = 4$ model, starting from a T (τ_{Ross}) distribution that READIN will determine for 40 τ 's, beginning with $\log \tau_{\text{Ross}} = -4.5$, in steps of 1/6. Frequency integrals are to be performed using the 78 frequencies listed. The results are to be punched out at the end of the sixth iteration. The card BEGIN indicates the end of the input data and tells ATLAS to begin the model calculation.

READ FREQUENCIES	78	1	78	COOL				
1	3.28804671E+13		1.64402500E+13		2	3.28805329E+13		3.85635500E+12
3	4.05931694E+13		3.85635500E+12		4	4.05932506E+13		5.39128550E+12
5	5.13757296E+13		5.39128550E+12		6	5.13758324E+13		7.86364000E+12
7	6.71029939E+13		7.86364000E+12		8	6.71031281E+13		1.21158305E+13
9	9.13346307E+13		1.21158305E+13		10	9.13348133E+13		2.00936390E+13
11	1.31521868E+14		2.00936390E+13		12	1.31522132E+14		2.55333846E+13
13	1.82588587E+14		2.55333846E+13		14	1.82588952E+14		4.40620250E+12
15	1.95000000E+14		1.53829037E+13		16	2.05502919E+14		3.12524966E+12
17	2.05503331E+14		9.32490356E+12		18	2.30000000E+14		2.85685104E+13
19	2.60000000E+14		3.68109332E+13		20	3.00000000E+14		3.37166143E+13
21	3.30000000E+14		3.78116947E+13		22	3.65338525E+14		1.36031090E+13
23	3.65339255E+14		1.23397723E+13		24	4.00000000E+14		4.60720442E+13
25	4.50000000E+14		5.17916416E+13		26	5.00000000E+14		4.94576518E+13
27	5.50000000E+14		5.00000000E+13		28	6.00000000E+14		5.00000000E+13
29	6.50000000E+14		4.99377588E+13		30	7.00000000E+14		4.84600648E+13
31	7.50000000E+14		5.66913371E+13		32	7.98039662E+14		1.79512994E+13
33	7.98041258E+14		1.19860200E+13		34	8.22011678E+14		1.19860200E+13
35	8.22013322E+14		9.41926567E+12		36	8.50000000E+14		4.11449708E+13
37	9.00000000E+14		5.32404280E+13		38	9.50000000E+14		4.91828356E+13
39	1.00000000E+15		5.00000000E+13		40	1.05000000E+15		4.97535082E+13
41	1.10000000E+15		4.98960590E+13		42	1.15000000E+15		5.22340180E+13
43	1.19257851E+15		1.56961149E+13		44	1.19258089E+15		2.17291574E+13
45	1.25000000E+15		6.47593919E+13		46	1.30000000E+15		4.54821099E+13
47	1.35000000E+15		5.00073710E+13		48	1.40000000E+15		5.25709620E+13
49	1.44299856E+15		1.58713079E+13		50	1.44300144E+15		3.61460000E+13
51	1.51529048E+15		3.61460000E+13		52	1.51529352E+15		1.23599776E+13
53	1.55000000E+15		4.71491758E+13		54	1.60000000E+15		3.86973422E+13
55	1.65000000E+15		8.84560518E+13		56	1.75000000E+15		8.18550714E+13
57	1.78796711E+15		4.15928130E+12		58	1.78797069E+15		1.11544291E+13
59	1.82000000E+15		4.06991086E+13		60	1.84884915E+15		9.02856228E+12
61	1.84885285E+15		1.20617571E+13		62	1.90000000E+15		8.48029699E+13
63	1.97231453E+15		2.66007730E+13		64	1.97231847E+15		1.42441540E+13
65	2.02000000E+15		6.96470460E+13		66	2.07609792E+15		1.98923000E+13
67	2.07610208E+15		4.74367545E+13		68	2.20000000E+15		1.27770122E+14
69	2.30000000E+15		1.22435459E+14		70	2.41959758E+15		4.58576637E+13
71	2.41960242E+15		3.03310636E+13		72	2.50000000E+15		8.85358763E+13
73	2.60000000E+15		1.39757530E+14		74	2.72539727E+15		4.71755303E+13
75	2.72540273E+15		2.56441836E+13		76			

On the first page of the sample printout (p. 121), we find the following information:

Effective temperature.

Log gravity.

A title to label the printout and punchout.

An abundance scaling factor, which varies all the abundances except hydrogen and helium as a group so that, for example, a subdwarf might have a scaling factor 0.01.

The abundances for hydrogen and helium relative to the total number.

The abundances for all the other elements before the scaling factor is applied, in logs relative to the total number.

Twenty opacity switches telling which opacities are to be included (Section 5).

Whether a temperature correction is to be performed (Section 7). If we have a converged model already and, for example, want to find only the surface flux, we would not need a temperature correction.

Whether pressure is to be calculated (Section 4.1).

Whether flux or intensity is to be found only at the surface, as in an emergent spectrum calculation.

Whether scattering is to be included in the source function. In approximate calculations, there is a considerable time savings in setting α to 0 in equation (2.65).

Whether convective flux should be included in the temperature correction (convective flux is always calculated to indicate its importance).

The ratio of mixing length to scale height for convection (Section 6).

Whether molecular-equilibrium equations are to be solved for molecular number densities or only for the electron number through ionization (Section 4.3).

Whether turbulent pressure is to be included (four parameters are given for determining the turbulent velocity) (see Section 4.1).

The number of iterations for the model.

Print and punch switches for each iteration. We will discuss these as we look at the printout and punchout. Zeros mean no output.

The name of the frequency set. Frequency sets are named so that they can be easily distinguished from one another if they differ at only a few points.

The number of frequencies and the limits on the frequency integration. In this case, we are using a frequency set with 78 points, which were chosen to represent the major discontinuities in the cool opacities (Section 5.9). For example, frequencies 74 and 75 mark a C I edge. It might be possible to calculate a model with as few as 50 frequencies (to save computer time) without affecting the values of the frequency integrals, but no effort was made to do this for this sample calculation. The number following each frequency is the frequency integration weight (Section 2.10).

The second page of printout from READIN contains the starting model. Remember that on the input cards we specified 40 Rosseland depths. READIN then takes the gray temperature distribution $T(\text{TAUROS}) = \text{TEFF} * (.75 * (.710 + \text{TAUROS} - .1331 * \text{EXP}(-3.4488 * \text{TAUROS})))^{.25}$ and converts it to $T(\text{RHOX})$ by using subroutine TTAUP for the pressure integration (Section 4.2). TTAUP(34) finds the Rosseland opacity from a table as a function of $\log T$ and $\log P$. The results printed out are RHOX, T, P, and ABROSS. Only RHOX and T are used in the model calculation.

We have said nothing about statistical equilibrium calculations, so READIN assumes local thermodynamic equilibrium (LTE) and sets the b 's of hydrogen and H^- to unity (Section 3.3).

After READIN returns to the main program, ATLAS5(2) starts DO 100, which is the model iteration. At the beginning of each iteration, ATLAS increments the variable ITEMP, which is stored in COMMON /TEMP/. The subroutines test this variable to see if it changes, and when it does, they recalculate the temperature-dependent parameters.

The first procedure in each iteration is to calculate the pressure in DO 11 (Section 4.1). Then ATLAS5 calls POPS(37) to solve the equilibrium equations for the number densities. The argument CODE identifies atoms and molecules. The atomic number for each component is treated as a base 100 digit, and the digits are ordered increasing from left to right to form a number. An electron component, as in H^- , is written 00 and ordered as 100. The positive charge is written after the decimal point, for example, 2.02 = He^{++} = He III.

If IFMOL were 1, we would go to statement 200 to include molecules. If there is a new temperature distribution (which there is) and if IFPRES is 1 (which it is), POPS will call NMOLEC to solve the equilibrium equations (glance through NMOLEC(50)). NMOLEC stores its results in COMMON array XNMOL, which is available to MOLEC, and in XNE, XNATOM, and RHO. If CODE is any number greater than 0 (as later, when POPS is called by opacity routines), POPS calls MOLEC(48) to retrieve the number density/partition function for the requested atom or molecule. MOLEC and NMOLEC will be discussed in more detail in Section 8.3 because they require special input.

RMUX	T	P	XNE	ABROSS	PRAD	VTURB	BHYD	BMIN
1 8.456913E-05	8110.5	8.457E-01	0.	3.739E-01	0.	0.	1.0000	1.0000
2 1.625591E-04	8110.6	1.226E+00	0.	4.057E-01	0.	0.	1.0000	1.0000
3 1.738377E-04	8110.7	1.738E+00	0.	4.414E-01	0.	0.	1.0000	1.0000
4 2.429862E-04	8110.9	2.430E+00	0.	4.801E-01	0.	0.	1.0000	1.0000
5 3.361590E-04	8111.1	3.362E+00	0.	5.227E-01	0.	0.	1.0000	1.0000
6 4.617299E-04	8111.5	4.617E+00	0.	5.692E-01	0.	0.	1.0000	1.0000
7 6.310274E-04	8112.0	6.310E+00	0.	6.192E-01	0.	0.	1.0000	1.0000
8 8.596242E-04	8112.7	8.596E+00	0.	6.732E-01	0.	0.	1.0000	1.0000
9 1.168668E-03	8113.9	1.169E+01	0.	7.291E-01	0.	0.	1.0000	1.0000
10 1.588882E-03	8115.5	1.589E+01	0.	7.850E-01	0.	0.	1.0000	1.0000
11 2.162827E-03	8117.9	2.163E+01	0.	8.428E-01	0.	0.	1.0000	1.0000
12 2.948143E-03	8121.4	2.948E+01	0.	9.030E-01	0.	0.	1.0000	1.0000
13 4.024986E-03	8126.5	4.025E+01	0.	9.563E-01	0.	0.	1.0000	1.0000
14 5.501644E-03	8134.0	5.502E+01	0.	1.035E+00	0.	0.	1.0000	1.0000
15 7.524075E-03	8145.0	7.524E+01	0.	1.110E+00	0.	0.	1.0000	1.0000
16 1.028345E-02	8160.9	1.028E+02	0.	1.198E+00	0.	0.	1.0000	1.0000
17 1.501635E-02	8184.0	1.402E+02	0.	1.307E+00	0.	0.	1.0000	1.0000
18 1.900400E-02	8217.4	1.900E+02	0.	1.447E+00	0.	0.	1.0000	1.0000
19 2.554869E-02	8265.3	2.555E+02	0.	1.635E+00	0.	0.	1.0000	1.0000
20 3.392189E-02	8333.3	3.392E+02	0.	1.905E+00	0.	0.	1.0000	1.0000
21 4.626916E-02	8428.6	4.427E+02	0.	2.305E+00	0.	0.	1.0000	1.0000
22 5.655042E-02	8559.6	5.655E+02	0.	2.914E+00	0.	0.	1.0000	1.0000
23 7.046433E-02	8735.9	7.046E+02	0.	3.868E+00	0.	0.	1.0000	1.0000
24 8.545644E-02	8967.2	8.546E+02	0.	5.402E+00	0.	0.	1.0000	1.0000
25 1.009172E-01	9262.7	1.009E+03	0.	7.784E+00	0.	0.	1.0000	1.0000
26 1.165967E-01	9631.3	1.166E+03	0.	1.129E+01	0.	0.	1.0000	1.0000
27 1.327444E-01	10083.8	1.327E+03	0.	1.558E+01	0.	0.	1.0000	1.0000
28 1.509153E-01	10635.2	1.509E+03	0.	1.911E+01	0.	0.	1.0000	1.0000
29 1.742619E-01	11303.9	1.743E+03	0.	2.050E+01	0.	0.	1.0000	1.0000
30 2.069896E-01	12106.6	2.090E+03	0.	1.864E+01	0.	0.	1.0000	1.0000
31 2.580793E-01	13054.4	2.681E+03	0.	1.578E+01	0.	0.	1.0000	1.0000
32 3.704800E-01	14154.2	3.705E+03	0.	1.348E+01	0.	0.	1.0000	1.0000
33 5.837502E-01	15412.1	5.438E+03	0.	1.182E+01	0.	0.	1.0000	1.0000
34 8.276808E-01	16835.0	8.277E+03	0.	1.083E+01	0.	0.	1.0000	1.0000
35 1.272944E+00	18431.5	1.273E+04	0.	1.024E+01	0.	0.	1.0000	1.0000
36 1.956084E+00	20212.5	1.956E+04	0.	9.937E+00	0.	0.	1.0000	1.0000
37 2.784499E+00	22191.0	2.978E+04	0.	9.788E+00	0.	0.	1.0000	1.0000
38 4.582477E+00	24382.6	4.482E+04	0.	9.978E+00	0.	0.	1.0000	1.0000
39 6.508488E+00	26805.5	6.608E+04	0.	1.042E+01	0.	0.	1.0000	1.0000
40 9.585259E+00	29480.4	9.585E+04	0.	1.099E+01	0.	0.	1.0000	1.0000

Going back to the beginning of POPS(37), for the model we are discussing IFMOL = 0, so NELECT(39) finds the electron number XNE, the atom number XNATOM, and the density RHO. It finds these quantities by iterating on the number densities of the more abundant elements through calls to PFSAHA(39). PFSAHA is a general routine for finding partition functions, ionization fractions, ionization fractions/partition functions, or electron contributions. The main body of the routine is a large table of partition functions and ionization potentials followed by a small section (pages 46 and 47) that deciphers the table to find partition functions and then ionization fractions.

The printout from NELECT on the next page (which is printed only on the last iteration of the model in order to save paper) shows how the different elements contribute electrons. The left side gives the fraction of the total electron density contributed by each element. Note that since hydrogen is partially ionized the hydrogen contribution far exceeds all those but for He and C, so the other elements could just as well have not been included. On the right side of the page, we find the number of electrons contributed by each atom. Thus at the first point, H is .146 neutral and .854 ionized, He is all neutral, Na is all ionized, Ca is almost all doubly ionized, etc.

Going back to POPS(37), if CODE is a number greater than 0 but not a molecule, POPS calls PFSAHA to find the ion fraction/partition function. POPS then converts the ion fraction to a number density by multiplying XNATOM and the atomic abundance.

Once the equilibrium equations have been solved, any subsequent call to POPS for the same ITEMP does not have to bother with NELECT or NMOLEC.

Now ATLAS5(2) is ready to calculate opacities and the radiation field. It first calls PUTOUT(4) to initialize page headings. PUTOUT(4) handles all the output from ATLAS5 itself. Next ATLAS5 initializes frequency integrals by calling all the sub-routines that do frequency integration: TCORR(8), which does the temperature corrections; STATEQ(11), which does statistical equilibrium; ROSS(13), which calculates Rosseland opacity; and RADIAP(14), which calculates radiation pressure.

[illegible]

ATLAS5(3) does a long loop DO 25 over frequencies. There is a special option for doing equally spaced wavelengths instead, which can be brought in with a control card described in Section 8.2. FRESET and RCOSET are the frequencies and integration coefficients described above. ATLAS5 expects the opacity to be in the form of a step representation of the distribution function (Section 5.15), so there is a loop running from statement 24 to the statement IF(N.LT.NSTEPS)GO TO 24, where N is the step number. ATLAS5 does not know how many steps to expect or the weight for each step until the statement CALL KAPP(N, NSTEPS, STEPWT). Normally this option is not used, so both NSTEPS and STEPWT are 1. Backing up a few lines, the statement CALL PUTOUT(2) initializes some sums over the distribution function for surface flux or surface intensity. Then we start into the loop over the steps by calling KAPP to find the opacity.

Now we look at KAPP(55) in detail. The first thing KAPP does is check ITEMP for a new temperature distribution, in which case KAPP calls POPS to get hydrogen and helium number densities over partition functions, XNFPH and XNFPHE, which it stores in COMMON /IONS/ for use by any of the opacity routines. Subroutines that require number densities for other elements call POPS on their own so that they are self-contained for easy modification or deletion. Then KAPP initializes STEPWT and NSTEPS. If $N > 1$ (not the case in our example), all the continuous opacities have already been calculated for $N = 1$, so KAPP would skip to the section that treats distribution functions. This section would call LINOP and LINSOP and then adjust the total opacities and source functions for the change in line opacity.

For the normal case when $N = 1$, KAPP erases the opacity arrays and then calls the opacity subroutines for which the switches are on. The opacities are described in detail in Section 5. The subroutines are as follows:

1. HOP(56) uses COULX(57) for coulomb bound-free cross sections and COULFF(57) for coulomb free-free cross sections.
2. H2PLOP(58).
3. HMINOP(58).
4. HRAYOP(57).

5. HE1OP(59) uses COULFF(57).
6. HE2OP(60) uses COULX(57) and COULFF(57).
7. HEMIOP(60).
8. HERAOP(61).
9. COOLOP(61) uses C1OP(62), SEATON(62), MG2OP(63), AL1OP(62), and SI1OP(64).
10. LUKEOP(65) uses N1OP(65), O1OP(65), MG2OP(66), SI2OP(67), CA2OP(66), and SEATON(62).
11. HOTOP(68).
12. ELECOP(70).
13. H2RAOP(70).
14. HLINOP(71) uses STARK(72).
15. LINOP(73).
16. LINSOP(73).
17. XLINOP(73).
18. XLISOP(73).
19. XCONOP(73).
20. XSOP(73).

Each subroutine returns its opacity through COMMON /OPS/. Five subroutines (HOP, HMINOP, HLINOP, XLINOP, and XCONOP) also return source functions in COMMON /OPS/. The remaining subroutines have source functions BNU or JNU.

KAPP(38) finally constructs from the variables in COMMON /OPS/ the average opacities ACONT, SIGMAC, ALINE, and SIGMAL (Section 5) and the source functions SCONT and SLINE, all of which are stored in COMMON /OPTOT/.

Once the opacity is known, ATLAS5(3) calls JOSH(74) to find the radiation field (Section 2). First JOSH finds the total opacity ABTOT, the scattering fraction ALPHA, and SNUBAR, the part of the source function that is not JNU. Then it finds TAUNU by integrating ABTOT with subroutine INTEG(15). If IFSCAT = 1 (which it is for our example), JOSH solves the integral equation for the source function (Sections 2.7 and 2.8). (See statements with statement numbers in the 30's.) JOSH interpolates ALPHA and SNUBAR to the internal tau set XTAU by use of subroutine MAP1(16) and then solves the integral equation for S on XTAU. The integration matrices for J and H are stored in COMMON /MATX/ as 43 by 43 arrays, which are tabulated in BLOCKJ(77) and BLOCKH(86). The matrix multiplication in the integral equation is written out explicitly to force the compiler to give a fast, efficient code. Once the source function is found, it is interpolated back to TAUNU space.

The matrix solution is good only up to TAUNU = 20, so SNU, JNU, and HNU at large depths are found by taking first and second derivatives of SNU by using subroutine DERIV(14) (Sections 2.7 and 2.8). (See statements with statement numbers in the 40's.)

Next JOSH finds JNU and HNU at depths less than 20 in XTAU and interpolates from the XTAU scale the results to the TAUNU scale.

The special cases of surface flux only or surface intensity only (Section 2.9) come at the end of the routine.

Returning to ATLAS5(3), we now know the monochromatic opacities and the radiation field for step N, so we can compute integrands and add to integrals over frequency. The integration coefficient RCOWT is the frequency weight times the step weight. ATLAS5 calls the four subroutines with integrals, TCORR(8), STATEQ(11), ROSS(13), and RADIAP(14). Then it calls PUTOUT(5) to add to the total for the surface flux at this frequency and to print out the results for the step. Since we are not using distribution functions in this example, we get no results.

ATLAS5(3) continues through the loop over N. When the loop is completed, ATLAS5 calls PUTOUT(5) to print and punch (if IFPRNT or IFPNCH equals 1) the surface flux. The first page of printout is shown on the next page. The wavelength is in nanometers and the magnitudes are -2.5 times the logs. TAUONE is the log RHOX at which TAUNU = 1. TAUNU(NRHOX) is the log optical depth at the last depth. For the flux to be accurate, TAUNU(NRHOX) should be greater than 10 at every frequency. Both these quantities give estimates of the opacity variation with frequency.

The punch has the form

```
FLUX      3.288047E13      5.9589E-07      .
```

In ATLAS5(3), statement 25 is the end of the loop over frequency. All frequency integrals are determined once this loop is completed, so ATLAS5 can finish the iteration. First it calls ROSS(13) to find ABROSS and TAUROS. Then it calls CONVEC(96) to compute the convective flux. CONVEC first computes the derivatives $(\partial E/\partial T)_P$, $(\partial E/\partial P)_T$, $(\partial \rho/\partial T)_P$, and $(\partial \rho/\partial P)_T$ (Section 4.6), from which it finds C_V , C_P , v_{sound} , $(\partial \ln \rho/\partial \ln T)_P$, $(\partial \ln T/\partial \ln P)_S$, and $d \ln T/d \ln P$. Finally, it computes the convective velocity and flux (Section 6).

Returning to page 3, ATLAS5 calls RADIAP(14) to compute the radiation pressure (Section 2.11).

Next, ATLAS5 calls TCORR(8) to do the temperature correction (Section 7). After statement 30 comes the flux correction; after 40, the Λ correction; and after 43, the surface correction. The total correction is statement 50.

Pages 131 and 132 are samples of what TCORR produces if IFPRNT > 1. The first page is from the first iteration, and the second is from the last, in order to show the improvement. The column CONV/TOTAL is the fraction of convective flux if convection were included in the temperature correction. ERROR is the percentage flux error. DERIV is $100(dH/d\tau_{\text{Ross}})/H$. Note that the starting guess seems good in terms of flux errors. The flux-derivative errors are rather large but should be no problem. Normally, a previously computed starting model would be used as the

	RAVE	HLAMBDA	LOG H	MAG	FREQUENCY	MNU	LOG H	MAG	TAUONE	TAUUN
1	9117.647	2.2165E+03	3.34567	-8.364	3.288047E+13	6.1463E-07	-6.21139	15.529	-1.78	5.28
2	9117.629	2.2165E+03	3.34567	-8.364	3.288053E+13	6.1463E-07	-6.21139	15.528	-1.78	5.28
3	7385.234	5.0483E+03	3.70314	-9.258	4.059317E+13	9.1846E-07	-6.0364	15.092	-1.64	5.09
4	7385.219	5.0483E+03	3.70315	-9.258	4.059325E+13	9.1846E-07	-6.0364	15.092	-1.64	5.09
5	5835.293	1.2621E+04	4.10109	-10.252	5.137573E+13	1.4335E-06	-5.84403	14.609	-1.48	4.86
6	5835.284	1.2609E+04	4.10067	-10.252	5.137583E+13	1.4321E-06	-5.84403	14.610	-1.50	4.87
7	4467.647	3.5394E+04	6.54893	-11.372	6.710299E+13	2.3565E-06	-5.62773	14.048	-1.33	4.62
8	4467.638	3.5314E+04	6.54795	-11.370	6.710313E+13	2.3551E-06	-5.62872	14.048	-1.33	4.62
9	3282.393	1.1502E+05	5.06079	-12.652	9.133463E+13	4.1337E-06	-5.38367	13.459	-1.18	4.33
10	3282.346	1.1439E+05	5.05840	-12.646	9.133481E+13	4.1110E-06	-5.38606	13.465	-1.22	4.35
11	2279.412	4.8345E+05	5.65533	-14.141	1.315219E+14	7.8587E-06	-5.10465	12.742	-1.05	4.00
12	2279.407	4.8654E+05	5.64986	-14.125	1.315221E+14	7.7390E-06	-5.11131	12.778	-1.09	4.03
13	1641.902	1.5007E+06	6.17630	-15.441	1.825886E+14	1.3495E-05	-4.86982	12.175	-0.96	3.72
14	1641.898	1.5007E+06	6.17631	-15.441	1.825890E+14	1.3495E-05	-4.86982	12.175	-0.96	3.72
15	1537.397	1.9075E+06	6.28047	-15.701	1.930502E+14	1.5039E-05	-4.82277	12.057	-0.94	3.65
16	1458.824	2.3075E+06	6.36315	-15.908	2.055029E+14	1.6381E-05	-4.78566	11.964	-0.93	3.60
17	1458.821	2.1990E+06	6.34223	-15.856	2.055033E+14	1.5610E-05	-4.80659	12.016	-0.99	3.67
18	1303.446	3.2775E+06	6.51554	-16.289	2.300000E+14	1.8374E-05	-4.65111	11.828	-0.92	3.44
19	1153.048	5.0352E+06	6.70201	-16.755	1.260000E+14	2.2330E-05	-4.65111	11.628	-0.92	3.44
20	999.308	8.2529E+06	6.91661	-17.644	3.000000E+14	3.1437E-05	-4.50256	11.256	-0.88	3.20
21	908.462	1.1419E+07	7.05765	-17.644	3.000000E+14	3.1437E-05	-4.50256	11.256	-0.88	3.20
22	820.588	1.6088E+07	7.20849	-18.016	3.633383E+14	3.6135E-05	-4.44208	11.105	-0.82	3.10
23	820.587	1.3399E+07	7.12707	-17.818	3.633393E+14	3.0295E-05	-4.52150	11.304	-0.92	3.25
24	749.481	1.7756E+07	7.24934	-18.123	4.000000E+14	3.3269E-05	-4.47796	11.195	-0.92	3.18
25	666.206	2.5438E+07	7.40548	-18.514	4.500000E+14	3.7659E-05	-4.42413	11.060	-0.88	3.06
26	599.585	3.6887E+07	7.54266	-18.857	5.000000E+14	4.1835E-05	-4.37846	10.946	-0.84	2.95
27	545.077	4.6223E+07	7.66885	-19.162	5.500000E+14	4.5809E-05	-4.33905	10.848	-0.81	2.85
28	499.634	5.9551E+07	7.77489	-19.437	6.000000E+14	4.9392E-05	-4.30459	10.761	-0.78	2.76
29	461.219	7.4959E+07	7.87482	-19.687	6.500000E+14	5.3188E-05	-4.27418	10.685	-0.75	2.67
30	428.275	9.2514E+07	7.96621	-19.916	7.000000E+14	5.6602E-05	-4.24717	10.618	-0.72	2.59
31	399.723	1.1225E+08	8.05019	-20.125	7.500000E+14	5.9826E-05	-4.22311	10.558	-0.69	2.52
32	375.681	1.3329E+08	8.12479	-20.312	7.980397E+14	6.2743E-05	-4.20244	10.506	-0.65	2.45
33	375.680	1.3328E+08	8.12478	-20.312	7.980413E+14	6.2741E-05	-4.20245	10.506	-0.65	2.45
34	364.706	1.4452E+08	8.15993	-20.400	8.220117E+14	6.4120E-05	-4.19301	10.483	-0.64	2.43
35	364.705	4.6144E+07	7.66411	-19.160	8.220133E+14	2.0473E-05	-4.68883	11.722	-1.14	2.95
36	352.637	4.7593E+07	7.67754	-19.194	8.500000E+14	1.9748E-05	-4.70447	11.761	-1.12	2.91
37	333.103	4.9959E+07	7.69858	-19.246	9.000000E+14	1.8489E-05	-4.73309	11.833	-1.08	2.80
38	315.571	5.2069E+07	7.71658	-19.291	9.500000E+14	1.7296E-05	-4.76205	11.905	-1.05	2.82
39	299.792	5.3993E+07	7.73234	-19.331	1.000000E+15	1.6187E-05	-4.79084	11.977	-1.02	2.77
40	285.517	5.5786E+07	7.74653	-19.366	1.050000E+15	1.5169E-05	-4.81903	12.048	-1.00	2.71
41	272.559	5.7505E+07	7.75970	-19.399	1.100000E+15	1.4248E-05	-4.84626	12.116	-0.97	2.66
42	260.689	5.9198E+07	7.77231	-19.431	1.150000E+15	1.3419E-05	-4.87226	12.181	-0.95	2.61
43	251.382	6.0658E+07	7.78289	-19.457	1.192579E+15	1.2786E-05	-4.89327	12.233	-0.93	2.57
44	251.381	6.0611E+07	7.78255	-19.456	1.192581E+15	1.2776E-05	-4.89360	12.234	-0.93	2.57
45	239.834	6.2644E+07	7.79488	-19.492	1.250000E+15	1.2019E-05	-4.92012	12.300	-0.91	2.51
46	230.610	6.4512E+07	7.80964	-19.524	1.300000E+15	1.1444E-05	-4.94143	12.354	-0.90	2.47
47	222.069	6.6501E+07	7.82283	-19.557	1.350000E+15	1.0939E-05	-4.96102	12.403	-0.88	2.43
48	214.137	6.8623E+07	7.83647	-19.591	1.400000E+15	1.0496E-05	-4.97896	12.447	-0.86	2.38
49	207.737	7.0569E+07	7.84861	-19.622	1.442999E+15	1.0160E-05	-4.99310	12.483	-0.85	2.35
50	207.756	7.0508E+07	7.84824	-19.621	1.443001E+15	1.0151E-05	-4.99348	12.484	-0.85	2.35
51	197.845	7.2024E+07	7.86937	-19.673	1.515290E+15	9.6650E-06	-5.01480	12.537	-0.83	2.29
52	197.845	7.3959E+07	7.86898	-19.672	1.515294E+15	9.6636E-06	-5.01519	12.538	-0.83	2.29
53	193.415	7.7474E+07	7.87936	-19.698	1.550000E+15	9.4520E-06	-5.02448	12.561	-0.82	2.26
54	187.370	7.8454E+07	7.89462	-19.737	1.600000E+15	8.1875E-06	-5.03680	12.592	-0.80	2.23
55	181.692	8.1292E+07	7.91005	-19.775	1.650000E+15	8.9516E-06	-5.04810	12.620	-0.79	2.19
56	171.310	8.7335E+07	7.94119	-19.853	1.750000E+15	8.5493E-06	-5.06807	12.670	-0.76	2.12

	RHDX	T	DTLAMB	DTSURF	DTFLUX	T1	CONV/TOTAL	ERROR	DERIV
1	8.4569E-05	8110.5	-400.0	0.0	0.0	-400.0	0.	-3.106	-15.558
2	1.2256E-04	8110.6	-400.0	0.0	.0	-400.0	0.	-3.107	-20.148
3	1.7384E-04	8110.7	-400.0	0.0	.0	-400.0	0.	-3.108	-24.668
4	2.4299E-04	8110.9	-400.0	0.0	.0	-400.0	0.	-3.108	-30.172
5	3.3616E-04	8111.1	-400.0	0.0	.0	-400.0	0.	-3.110	-35.603
6	4.6172E-04	8111.5	-400.0	0.0	.0	-400.0	0.	-3.113	-40.989
7	6.3103E-04	8112.0	-400.0	0.0	.1	-399.9	0.	-3.117	-46.175
8	8.5962E-04	8112.7	-400.0	0.0	.1	-399.9	0.	-3.124	-50.930
9	1.1687E-03	8113.9	-400.0	0.0	.1	-399.9	0.	-3.136	-55.016
10	1.5889E-03	8115.5	-400.0	0.0	.2	-399.8	0.	-3.154	-58.265
11	2.1628E-03	8117.9	-398.0	0.0	.3	-397.7	0.	-3.182	-60.500
12	2.9481E-03	8121.4	-386.1	0.0	.4	-385.6	0.	-3.224	-61.516
13	4.0250E-03	8126.5	-370.7	0.0	.7	-370.1	0.	-3.286	-61.196
14	5.5016E-03	8134.0	-351.2	0.0	1.0	-350.2	0.	-3.376	-59.428
15	7.5241E-03	8145.0	-327.0	0.0	1.4	-325.5	0.	-3.501	-56.160
16	1.0283E-02	8160.9	-297.7	0.0	2.1	-295.6	0.	-3.673	-51.447
17	1.4016E-02	8184.0	-263.5	0.0	3.3	-260.3	0.	-3.899	-45.455
18	1.9004E-02	8217.4	-224.9	0.0	5.0	-219.9	0.	-4.186	-38.468
19	2.5549E-02	8265.3	-182.9	0.0	7.8	-175.1	0.	-4.534	-30.870
20	3.3922E-02	8333.3	-139.5	0.0	12.4	-127.1	0.	-4.931	-23.157
21	4.4269E-02	8428.6	-97.5	0.0	19.8	-77.7	0.	-5.349	-15.902
22	5.6550E-02	8559.6	-60.1	0.0	31.7	-28.5	0.	-5.747	-9.647
23	7.0464E-02	8735.9	-15.3	0.0	50.4	35.2	0.	-6.072	-4.822
24	8.5456E-02	8967.2	-2.7	0.0	79.0	76.3	0.	-6.279	-1.706
25	1.0092E-01	9262.7	-1	0.0	119.8	119.6	0.	-6.356	-.144
26	1.1660E-01	9631.3	.2	0.0	172.1	172.3	0.	-6.326	.415
27	1.3275E-01	10083.8	.2	0.0	226.6	226.7	0.	-6.191	.728
28	1.5092E-01	10635.2	0.0	0.0	263.5	263.5	0.	-5.878	.893
29	1.7426E-01	11303.9	0.0	0.0	266.8	266.8	0.	-5.366	.816
30	2.0899E-01	12106.6	0.0	0.0	239.1	239.1	0.	-5.195	-.844
31	2.6808E-01	13054.4	0.0	0.0	208.0	208.0	0.	-5.456	-.322
32	3.7049E-01	14154.2	0.0	0.0	188.1	188.1	0.	-4.475	.429
33	5.4375E-01	15412.1	0.0	0.0	167.6	167.6	0.	-2.654	.063
34	8.2768E-01	16835.0	0.0	0.0	140.9	140.9	0.	-1.297	-.104
35	1.2729E+00	18431.5	0.0	0.0	115.3	115.3	0.	-.763	-.121
36	1.9561E+00	20212.5	0.0	0.0	93.9	93.9	0.	-.483	.018
37	2.9784E+00	22191.0	0.0	0.0	77.2	77.2	0.	-.372	-.045
38	4.4825E+00	24382.6	0.0	0.0	67.3	67.3	0.	-.512	-.026
39	6.6085E+00	26805.5	0.0	0.0	71.9	71.9	0.	-1.231	-.032
40	9.5853E+00	29480.4	0.0	0.0	108.9	108.9	0.	-2.084	-.026

	RHOX	T	DTLAMB	DTSURF	DTFLUX	T1	CONV/TOTAL	ERROR	DERIV
1	8.4569E-05	7694.2	4.9	0.0	0.0	4.9	0.	.789	.186
2	1.2256E-04	7699.9	5.1	0.0	-0.0	5.1	0.	.789	.246
3	1.7384E-04	7696.6	4.4	0.0	.0	4.4	0.	.789	.260
4	2.4299E-04	7700.8	5.0	0.0	-0.1	4.9	0.	.789	.351
5	3.3616E-04	7704.6	4.6	0.0	-0.1	4.5	0.	.789	.375
6	4.6172E-04	7709.0	5.1	0.0	-0.1	5.0	0.	.789	.465
7	6.3103E-04	7712.6	4.3	0.0	-0.2	4.1	0.	.789	.440
8	8.5962E-04	7728.6	-1.9	0.0	-0.3	-2.2	0.	.789	-.212
9	1.1687E-03	7732.7	-1.3	0.0	-0.2	-1.5	0.	.789	-.163
10	1.5889E-03	7741.8	-.1	0.0	-0.3	-.4	0.	.789	-.015
11	2.1628E-03	7753.6	.2	0.0	-0.3	-2.2	0.	.789	.024
12	2.9481E-03	7768.5	.2	0.0	-0.4	-2.2	0.	.789	.036
13	4.0250E-03	7786.9	.4	0.0	-0.5	-1.1	0.	.789	.058
14	5.5016E-03	7810.0	.8	0.0	-0.6	.1	0.	.789	.119
15	7.5241E-03	7838.5	.5	0.0	-0.9	-.3	0.	.789	.081
16	1.0283E-02	7879.4	-1.7	0.0	-1.0	-2.8	0.	.789	-.279
17	1.4016E-02	7917.7	5.1	0.0	-1.2	3.8	0.	.790	.809
18	1.9004E-02	7978.8	4.5	0.0	-1.8	2.7	0.	.793	.720
19	2.5549E-02	8054.8	3.4	0.0	-2.3	1.0	0.	.797	.539
20	3.3922E-02	8152.7	3.4	0.0	-3.2	.2	0.	.804	.545
21	4.4269E-02	8280.1	2.6	0.0	-4.5	-1.9	0.	.811	.411
22	5.6550E-02	8442.3	4.9	0.0	-6.3	-1.4	0.	.826	.770
23	7.0464E-02	8646.1	10.3	0.0	-9.5	.8	0.	.881	1.606
24	8.5456E-02	8926.5	-2.4	0.0	-14.4	-16.8	0.	.913	-.754
25	1.0092E-01	9272.1	-3.5	0.0	-20.2	-23.7	0.	.741	-2.163
26	1.1660E-01	9684.7	-.7	0.0	-26.8	-27.5	0.	.533	-.851
27	1.3275E-01	10191.5	-.7	0.0	-31.3	-32.0	0.	.246	-1.574
28	1.5092E-01	10769.6	-.1	0.0	-30.6	-30.6	0.	-.008	-.257
29	1.7426E-01	11438.9	0.0	0.0	-25.9	-25.9	0.	.058	-.115
30	2.0899E-01	12216.1	0.0	0.0	-19.2	-19.2	0.	-.072	-.824
31	2.6808E-01	13139.6	0.0	0.0	-12.2	-12.2	0.	-.163	-.151
32	3.7049E-01	14227.4	0.0	0.0	-9.0	-9.0	0.	.332	-.319
33	5.4375E-01	15463.6	0.0	0.0	-10.2	-10.2	0.	.438	-.720
34	8.2768E-01	16859.0	0.0	0.0	-12.9	-12.9	0.	.499	-.257
35	1.2729E+00	18435.8	0.0	0.0	-15.3	-15.3	0.	.360	-.308
36	1.9561E+00	20202.0	0.0	0.0	-14.4	-14.4	0.	.054	-.082
37	2.9784E+00	22163.7	0.0	0.0	-14.7	-14.7	0.	.400	.014
38	4.4825E+00	24362.3	0.0	0.0	-19.7	-19.7	0.	.405	-.017
39	6.6085E+00	26774.6	0.0	0.0	-19.5	-19.5	0.	-.034	-.015
40	9.5853E+00	29472.6	0.0	0.0	-13.1	-13.1	0.	-.192	-.005

first guess for the temperature distribution, in which case the flux error at optical depth unity would be smaller. A much larger flux error at large depths could be handled by TCORR, say +1000% for radiative models or +1000000% for convective models. Large negative flux errors tend to be unstable.

On the second sample page, that is, the sixth iteration of our example, the flux error is down to 1%, the flux derivative error is down to 2%, and the temperature correction is on the order of 30 K. A few more iterations can be made to bring the errors as close to 0 as required.

In TCORR, the remainder of the subroutine is made up of various fudges for salvaging bad starting guesses or for speeding convergence. Finally, the temperatures are changed to their new values.

After TCORR, ATLAS5(3) would call STATEQ(11, 12) if we were doing statistical equilibrium. STATEQ would first compute the collisional rates for H^- and combine them with the previously calculated radiative rates to find $b(H^-)$. Then STATEQ would do the same for hydrogen.

Next, ATLAS5(3) calls HIGH(99) and TURB(99) to find geometric HEIGHT, VTURB, and PTURB.

At the end of each iteration, ATLAS5 calls PUTOUT(6) to spew out the results for the iteration. If IFPRNT > 1, PUTOUT prints all the variables that it has lying about in labeled COMMON blocks and that are not to be printed in the summary table (see the next two pages). Finally, if IFPRNT > 0, PUTOUT prints the summary shown on page 136. Note that the temperatures on the summary table are the corrected values, so the data in the table are not consistent with the temperatures until the model converges.

Also if IFPNCH > 0, PUTOUT punches the results in a form that can be read in again, as shown on pages 137 and 138, either to continue the calculation if the model has not converged or to accomplish whatever purpose the model was calculated for.

	RHOX	PTOTAL	PTURB	GRDADB	DLTOLP	VELSND	DLRDLT	HEATCP	HSCALE	VCONV	FLXCNV
1	8.457E-05	8.457E-01	0.	1.098E-01	2.082E-05	1.046E+06	-1.516E+00	1.598E+09	9.390E+07	0.	0.
2	1.226E-04	1.226E+00	0.	9.495E-02	3.149E-05	1.033E+06	-1.703E+00	2.057E+09	9.294E+07	0.	0.
3	1.738E-04	1.738E+00	0.	8.439E-02	4.859E-05	1.021E+06	-1.927E+00	2.584E+09	9.175E+07	0.	0.
4	2.430E-04	2.430E+00	0.	7.683E-02	7.395E-05	1.009E+06	-2.180E+00	3.158E+09	9.029E+07	0.	0.
5	3.362E-04	3.362E+00	0.	7.141E-02	1.114E-04	9.967E+05	-2.451E+00	3.748E+09	8.856E+07	0.	0.
6	4.617E-04	4.617E+00	0.	6.755E-02	1.666E-04	9.835E+05	-2.727E+00	4.308E+09	8.656E+07	0.	0.
7	6.310E-04	6.310E+00	0.	6.483E-02	2.476E-04	9.694E+05	-2.987E+00	4.789E+09	8.432E+07	0.	0.
8	8.596E-04	8.596E+00	0.	6.297E-02	3.662E-04	9.544E+05	-3.212E+00	5.149E+09	8.189E+07	0.	0.
9	1.169E-03	1.169E+01	0.	6.179E-02	5.384E-04	9.388E+05	-3.384E+00	5.356E+09	7.933E+07	0.	0.
10	1.589E-03	1.589E+01	0.	6.113E-02	7.874E-04	9.229E+05	-3.492E+00	5.401E+09	7.672E+07	0.	0.
11	2.163E-03	2.163E+01	0.	6.091E-02	1.149E-03	9.071E+05	-3.532E+00	5.296E+09	7.413E+07	0.	0.
12	2.948E-03	2.948E+01	0.	6.108E-02	1.674E-03	8.919E+05	-3.508E+00	5.066E+09	7.164E+07	0.	0.
13	4.025E-03	4.025E+01	0.	6.159E-02	2.437E-03	8.776E+05	-3.428E+00	4.748E+09	6.932E+07	0.	0.
14	5.502E-03	5.502E+01	0.	6.243E-02	3.548E-03	8.646E+05	-3.303E+00	4.381E+09	6.723E+07	0.	0.
15	7.524E-03	7.524E+01	0.	6.356E-02	5.169E-03	8.532E+05	-3.165E+00	3.998E+09	6.540E+07	0.	0.
16	1.028E-02	1.028E+02	0.	6.496E-02	7.546E-03	8.437E+05	-3.011E+00	3.627E+09	6.386E+07	0.	0.
17	1.402E-02	1.402E+02	0.	6.656E-02	1.104E-02	8.364E+05	-2.862E+00	3.291E+09	6.265E+07	0.	0.
18	1.900E-02	1.900E+02	0.	6.828E-02	1.621E-02	8.314E+05	-2.728E+00	3.005E+09	6.179E+07	0.	0.
19	2.555E-02	2.555E+02	0.	6.999E-02	2.386E-02	8.292E+05	-2.621E+00	2.775E+09	6.134E+07	0.	0.
20	3.392E-02	3.392E+02	0.	7.150E-02	3.526E-02	8.300E+05	-2.548E+00	2.624E+09	6.136E+07	0.	0.
21	4.427E-02	4.427E+02	0.	7.261E-02	5.218E-02	8.347E+05	-2.520E+00	2.551E+09	6.329E+07	0.	0.
22	5.655E-02	5.655E+02	0.	7.317E-02	7.710E-02	8.441E+05	-2.543E+00	2.570E+09	6.329E+07	0.	0.
23	7.046E-02	7.046E+02	0.	7.317E-02	1.133E-01	8.597E+05	-2.628E+00	2.697E+09	6.561E+07	0.	0.
24	8.546E-02	8.546E+02	0.	7.283E-02	1.645E-01	8.837E+05	-2.775E+00	2.944E+09	6.928E+07	0.	0.
25	1.009E-01	1.009E+03	0.	7.264E-02	2.321E-01	9.191E+05	-2.963E+00	3.296E+09	7.484E+07	0.	0.
26	1.166E-01	1.166E+03	0.	7.346E-02	3.117E-01	9.692E+05	-3.117E+00	3.657E+09	8.301E+07	0.	0.
27	1.327E-01	1.327E+03	0.	7.660E-02	3.841E-01	1.036E+06	-3.078E+00	3.758E+09	9.435E+07	0.	0.
28	1.509E-01	1.509E+03	0.	8.467E-02	4.185E-01	1.117E+06	-2.679E+00	3.229E+09	1.086E+08	1.470E+03	1.661E+01
29	1.743E-01	1.743E+03	0.	1.037E-01	3.984E-01	1.207E+06	-2.038E+00	2.152E+09	1.238E+08	7.722E+02	1.989E+00
30	2.090E-01	2.090E+03	0.	1.444E-01	3.370E-01	1.304E+06	-1.505E+00	1.191E+09	1.383E+08	2.201E+02	3.53E-02
31	2.681E-01	2.681E+03	0.	2.070E-01	2.743E-01	1.416E+06	-1.225E+00	6.903E+08	1.522E+08	4.044E+01	1.790E-04
32	3.705E-01	3.705E+03	0.	2.444E-01	2.352E-01	1.511E+06	-1.128E+00	5.437E+08	1.667E+08	0.	0.
33	5.438E-01	5.438E+03	0.	2.097E-01	2.162E-01	1.548E+06	-1.158E+00	6.555E+08	1.830E+08	6.459E+00	1.216E-06
34	8.277E-01	8.277E+03	0.	1.921E-01	2.136E-01	1.704E+06	-1.213E+00	8.601E+08	2.026E+08	8.485E+01	4.564E-03
35	1.273E+00	1.273E+04	0.	1.590E-01	2.196E-01	1.866E+06	-1.106E+00	5.279E+08	2.499E+08	0.	0.
36	1.956E+00	1.956E+04	0.	2.590E-01	2.196E-01	1.866E+06	-1.106E+00	5.279E+08	2.499E+08	0.	0.
37	2.978E+00	2.978E+04	0.	3.308E-01	2.275E-01	2.050E+06	-1.040E+00	3.907E+08	2.757E+08	0.	0.
38	4.482E+00	4.482E+04	0.	3.716E-01	2.385E-01	2.209E+06	-1.014E+00	3.397E+08	3.035E+08	0.	0.
39	6.608E+00	6.608E+04	0.	3.881E-01	2.511E-01	2.343E+06	-1.004E+00	3.223E+08	3.338E+08	0.	0.
40	9.585E+00	9.585E+04	0.	3.926E-01	2.922E-01	2.464E+06	-1.001E+00	3.177E+08	3.673E+08	0.	0.

FLUX 4.5118E+10

	XNATCM	ACCRAD	PRAD	XNFPH1	X1.FPH12	X1.FPH1	XNFPHE2	XNFPHE3
1	4.075E+11	6.811E+00	5.065E-04	9.609E+09	3.476E+11	4.075E+10	2.197E+05	3.483E-19
2	5.967E+11	7.549E+00	7.792E-04	1.969E+10	4.977E+11	5.967E+10	2.248E+05	2.492E-19
3	8.574E+11	8.474E+00	1.190E-03	3.838E+10	6.949E+11	8.574E+10	2.314E+05	1.839E-19
4	1.218E+12	9.607E+00	1.816E-03	7.200E+10	9.519E+11	1.218E+11	2.401E+05	1.396E-19
5	1.718E+12	1.096E+01	2.776E-03	1.309E+11	1.284E+12	1.718E+11	2.514E+05	1.086E-19
6	2.414E+12	1.253E+01	4.253E-03	2.316E+11	1.709E+12	2.414E+11	2.658E+05	8.659E-20
7	3.386E+12	1.431E+01	6.531E-03	4.001E+11	2.247E+12	3.386E+11	2.843E+05	7.078E-20
8	4.750E+12	1.627E+01	1.003E-02	6.757E+11	2.924E+12	4.750E+11	3.076E+05	5.932E-20
9	6.666E+12	1.836E+01	1.540E-02	1.117E+12	3.765E+12	6.666E+11	3.369E+05	5.102E-20
10	9.372E+12	2.054E+01	2.359E-02	1.814E+12	4.807E+12	9.372E+11	3.738E+05	4.504E-20
11	1.320E+13	2.277E+01	3.605E-02	2.895E+12	6.092E+12	1.320E+12	4.200E+05	4.089E-20
12	1.862E+13	2.502E+01	5.486E-02	4.545E+12	7.669E+12	1.862E+12	4.781E+05	3.828E-20
13	2.627E+13	2.726E+01	8.306E-02	7.024E+12	9.597E+12	2.627E+12	5.517E+05	3.711E-20
14	3.703E+13	2.951E+01	1.251E-01	1.069E+13	1.195E+13	3.703E+12	6.458E+05	3.753E-20
15	5.206E+13	3.181E+01	1.872E-01	1.601E+13	1.483E+13	5.206E+12	7.683E+05	4.001E-20
16	7.287E+13	3.424E+01	2.784E-01	2.360E+13	1.838E+13	7.287E+12	9.320E+05	4.571E-20
17	1.012E+14	3.698E+01	4.114E-01	3.417E+13	2.278E+13	1.012E+13	1.158E+06	5.731E-20
18	1.392E+14	4.026E+01	6.041E-01	4.847E+13	2.830E+13	1.392E+13	1.486E+06	8.148E-20
19	1.885E+14	4.449E+01	8.814E-01	6.712E+13	3.537E+13	1.885E+13	1.987E+06	1.373E-19
20	2.502E+14	5.031E+01	1.278E+00	9.026E+13	4.461E+13	2.502E+13	2.805E+06	2.904E-19
21	3.233E+14	5.872E+01	1.841E+00	1.170E+14	5.702E+13	3.233E+13	4.249E+06	8.245E-19
22	4.043E+14	7.133E+01	2.636E+00	1.449E+14	7.410E+13	4.043E+13	7.028E+06	3.383E-18
23	4.860E+14	9.068E+01	3.755E+00	1.697E+14	9.809E+13	4.860E+13	1.290E+07	2.146E-17
24	5.581E+14	1.205E+02	5.325E+00	1.852E+14	1.320E+14	5.581E+13	2.661E+07	2.210E-16
25	6.101E+14	1.551E+02	7.513E+00	1.847E+14	1.788E+14	6.101E+13	6.222E+07	3.788E-15
26	6.356E+14	2.275E+02	1.057E+01	1.648E+14	2.411E+14	6.356E+13	1.658E+08	1.079E-13
27	6.366E+14	3.017E+02	1.485E+01	1.272E+14	3.167E+14	6.366E+13	5.119E+08	5.152E-12
28	6.291E+14	3.628E+02	2.093E+01	8.262E+13	3.986E+14	6.291E+13	1.888E+09	4.204E-10
29	6.369E+14	3.792E+02	2.968E+01	4.538E+13	4.796E+14	6.367E+13	8.507E+09	5.780E-08
30	6.835E+14	3.456E+02	4.226E+01	2.265E+13	5.666E+14	6.826E+13	4.559E+10	1.179E-05
31	7.969E+14	2.921E+02	6.107E+01	1.165E+13	6.898E+14	7.915E+13	2.688E+11	2.815E-03
32	1.006E+15	2.474E+02	8.844E+01	6.686E+12	8.867E+14	9.742E+13	1.583E+12	6.224E-01
33	1.344E+15	2.155E+02	1.282E+02	4.341E+12	1.194E+15	1.179E+14	8.286E+12	1.037E+02
34	1.848E+15	1.952E+02	1.862E+02	3.122E+12	1.647E+15	1.198E+14	3.250E+13	1.048E+04
35	2.555E+15	1.814E+02	2.697E+02	2.394E+12	2.280E+15	8.844E+13	8.348E+13	5.558E+05
36	3.541E+15	1.686E+02	3.889E+02	1.927E+12	3.164E+15	5.069E+13	1.517E+14	1.675E+07
37	4.889E+15	1.574E+02	5.551E+02	1.607E+12	4.369E+15	2.657E+13	2.310E+14	3.412E+08
38	6.684E+15	1.490E+02	7.850E+02	1.382E+12	5.975E+15	1.411E+13	3.270E+14	5.231E+09
39	8.957E+15	1.418E+02	1.093E+03	1.201E+12	8.008E+15	7.739E+12	4.437E+14	6.332E+10
40	1.181E+16	1.405E+02	1.511E+03	1.062E+12	1.056E+16	4.464E+12	5.876E+14	6.212E+11

TEFF 10000. GRAVITY 4.000 LTE

TITLE SAMPLE MODEL

OPACITY IFOP 1 1 1 1 1 1 0 0 1 0 0 1 0 0 0 0 0 0 0 0

CONVECTION OFF 1.00 TURBULENCE OFF 0.00 0.00 0.00 0.00

ABUNDANCE SCALE 1.000 ABUNDANCE CHANGE 1 .900 2 .100

ABUNDANCE CHANGE	3	-11.60	4	-9.60	5	-9.20	6	-3.50	7	-4.12	8	-3.28
ABUNDANCE CHANGE	9	-6.60	10	-3.50	11	-6.18	12	-4.57	13	-5.65	14	-4.50
ABUNDANCE CHANGE	15	-6.62	16	-4.84	17	-6.60	18	-5.30	19	-7.00	20	-5.72
ABUNDANCE CHANGE	21	-9.01	22	-7.55	23	-8.13	24	-6.58	25	-7.17	26	-4.50
ABUNDANCE CHANGE	27	-8.40	28	-6.97	29	-7.30	30	-7.63	31	-9.11	32	-8.73
ABUNDANCE CHANGE	33	-9.70	34	-8.80	35	-9.40	36	-8.80	37	-9.42	38	-9.23
ABUNDANCE CHANGE	39	-9.60	40	-9.60	41	-10.30	42	-10.00	43	-20.00	44	-10.40
ABUNDANCE CHANGE	45	-11.20	46	-10.70	47	-11.30	48	-9.98	49	-10.34	50	-10.34
ABUNDANCE CHANGE	51	-10.40	52	-10.00	53	-10.60	54	-10.00	55	-10.90	56	-10.15
ABUNDANCE CHANGE	57	-10.60	58	-10.40	59	-11.20	60	-10.50	61	-20.00	62	-11.00
ABUNDANCE CHANGE	63	-11.30	64	-10.90	65	-11.60	66	-10.80	67	-11.50	68	-11.10
ABUNDANCE CHANGE	69	-11.90	70	-10.90	71	-11.70	72	-11.40	73	-11.70	74	-10.90
ABUNDANCE CHANGE	75	-11.40	76	-10.70	77	-10.80	78	-10.40	79	-11.30	80	-11.10
ABUNDANCE CHANGE	81	-11.50	82	-10.15	83	-11.30	84	-20.00	85	-20.00	86	-20.00
ABUNDANCE CHANGE	87	-20.00	88	-20.00	89	-20.00	90	-11.70	91	-20.00	92	-12.00
ABUNDANCE CHANGE	93	-20.00	94	-20.00	95	-20.00	96	-20.00	97	-20.00	98	-20.00
ABUNDANCE CHANGE	99	-20.00										

READ DECK 40 RHOD, T, P, XNE, ABROSS, PRAD, VTURB

8.45691298E-05	7700.3	8.452E-01	3.460E+11	3.578E-01	5.312E-04	0.
1.22559051E-04	7706.2	1.225E+00	4.857E+11	3.760E-01	8.074E-04	0.
1.73837744E-04	7702.1	1.737E+00	6.618E+11	3.921E-01	1.214E-03	0.
2.42986209E-04	7707.0	2.428E+00	8.835E+11	4.087E-01	1.812E-03	0.
3.36158983E-04	7710.3	3.359E+00	1.158E+12	4.243E-01	2.692E-03	0.
4.61724880E-04	7715.2	4.613E+00	1.497E+12	4.395E-01	3.983E-03	0.
6.31027399E-04	7717.7	6.304E+00	1.909E+12	4.536E-01	5.872E-03	0.
8.59624197E-04	7727.5	8.588E+00	2.428E+12	4.744E-01	8.646E-03	0.
1.16866788E-03	7730.8	1.167E+01	3.038E+12	4.890E-01	1.270E-02	0.
1.58888214E-03	7741.3	1.587E+01	3.788E+12	5.077E-01	1.863E-02	0.
2.16282711E-03	7753.4	2.160E+01	4.709E+12	5.299E-01	2.734E-02	0.
2.94814345E-03	7768.2	2.944E+01	5.844E+12	5.570E-01	4.015E-02	0.
4.02498758E-03	7786.7	4.019E+01	7.249E+12	5.906E-01	5.909E-02	0.
5.50164396E-03	7810.0	5.493E+01	9.005E+12	6.334E-01	8.718E-02	0.
7.52407493E-03	7838.1	7.511E+01	1.121E+13	6.880E-01	1.290E-01	0.
1.02834532E-02	7876.0	1.026E+02	1.410E+13	7.661E-01	1.919E-01	0.
1.40163540E-02	7922.4	1.399E+02	1.761E+13	8.516E-01	2.859E-01	0.
1.90040002E-02	7982.2	1.896E+02	2.242E+13	9.862E-01	4.271E-01	0.
2.55486879E-02	8056.1	2.548E+02	2.879E+13	1.171E+00	6.404E-01	0.
3.39218929E-02	8153.0	3.383E+02	3.748E+13	1.439E+00	9.621E-01	0.
4.42691601E-02	8279.2	4.412E+02	4.960E+13	1.842E+00	1.446E+00	0.
5.65504204E-02	8440.6	5.633E+02	6.670E+13	2.460E+00	2.171E+00	0.
7.04643319E-02	8646.5	7.014E+02	9.097E+13	3.429E+00	3.245E+00	0.
8.54564361E-02	8905.5	8.496E+02	1.278E+14	5.137E+00	4.839E+00	0.
1.00917247E-01	9242.4	1.002E+03	1.792E+14	7.849E+00	7.192E+00	0.
1.16596651E-01	9650.4	1.155E+03	2.457E+14	1.174E+01	1.060E+01	0.
1.32749420E-01	10151.5	1.312E+03	3.240E+14	1.633E+01	1.536E+01	0.
1.50915325E-01	10731.3	1.487E+03	4.009E+14	1.947E+01	2.198E+01	0.
1.74261950E-01	11406.5	1.711E+03	4.733E+14	1.972E+01	3.103E+01	0.
2.08989640E-01	12192.0	2.046E+03	5.532E+14	1.770E+01	4.366E+01	0.
2.68079327E-01	13133.4	2.618E+03	6.716E+14	1.505E+01	6.235E+01	0.
3.70489029E-01	14222.9	3.615E+03	8.651E+14	1.278E+01	8.970E+01	0.
5.43750161E-01	15458.5	5.309E+03	1.180E+15	1.129E+01	1.291E+02	0.
8.27680811E-01	16852.6	8.091E+03	1.673E+15	1.051E+01	1.862E+02	0.
1.27294426E+00	18428.2	1.246E+04	2.397E+15	1.009E+01	2.686E+02	0.
1.95608422E+00	20194.8	1.917E+04	3.402E+15	9.794E+00	3.864E+02	0.

2.97844858E+00	22145.3	2.923E+04	4.750E+15	9.688E+00	5.509E+02	0.
4.48247664E+00	24337.7	4.405E+04	6.523E+15	9.872E+00	7.790E+02	0.
6.60846847E+00	26750.2	6.500E+04	8.765E+15	1.038E+01	1.086E+03	0.
9.58525890E+00	29456.2	9.435E+04	1.156E+16	1.122E+01	1.506E+03	0.
READ FREQUENCIES 78 1 78 COJL						
1 3.28804671E+13	1.64402500E+13	2 3.28805329E+13	3.85635500E+12			
3 4.05931694E+13	3.85635500E+12	4 4.05932506E+13	5.39128550E+12			
5 5.13757296E+13	5.39128550E+12	6 5.13758324E+13	7.86364000E+12			
7 6.71029939E+13	7.86364000E+12	8 6.71031281E+13	1.21158305E+13			
9 9.13346307E+13	1.21158305E+13	10 9.13348133E+13	2.00936390E+13			
11 1.31521868E+14	2.00936390E+13	12 1.31522132E+14	2.55333846E+13			
13 1.82588587E+14	2.55333846E+13	14 1.82588952E+14	4.40620250E+12			
15 1.95000000E+14	1.53829037E+13	16 2.05502919E+14	3.12524966E+12			
17 2.05503331E+14	9.32490356E+12	18 2.30000000E+14	2.85685104E+13			
19 2.60000000E+14	3.68109332E+13	20 3.00000000E+14	3.37166143E+13			
21 3.30000000E+14	3.78116947E+13	22 3.65338525E+14	1.36031090E+13			
23 3.65339255E+14	1.23397723E+13	24 4.00000000E+14	4.60720442E+13			
25 4.50000000E+14	5.17916416E+13	26 5.00000000E+14	4.94576518E+13			
27 5.50000000E+14	5.00000000E+13	28 6.00000000E+14	5.00000000E+13			
29 6.50000000E+14	4.99377588E+13	30 7.00000000E+14	4.84600648E+13			
31 7.50000000E+14	5.66913371E+13	32 7.98039662E+14	1.79512994E+13			
33 7.98041258E+14	1.19860200E+13	34 8.22011678E+14	1.19860200E+13			
35 8.22013322E+14	9.41926567E+12	36 8.50000000E+14	4.11449708E+13			
37 9.00000000E+14	5.32404280E+13	38 9.50000000E+14	4.91828356E+13			
39 1.00000000E+15	5.00000000E+13	40 1.05000000E+15	4.97535082E+13			
41 1.10000000E+15	4.98960590E+13	42 1.15000000E+15	5.22340180E+13			
43 1.19257851E+15	1.56961149E+13	44 1.19258089E+15	2.17291574E+13			
45 1.25000000E+15	6.47593919E+13	46 1.30000000E+15	4.54821099E+13			
47 1.35000000E+15	5.00073710E+13	48 1.40000000E+15	5.25709620E+13			
49 1.44299856E+15	1.58713079E+13	50 1.44300144E+15	3.61460000E+13			
51 1.51529048E+15	3.61460000E+13	52 1.51529352E+15	1.23599776E+13			
53 1.55000000E+15	4.71491758E+13	54 1.60000000E+15	3.86973422E+13			
55 1.65000000E+15	8.84560518E+13	56 1.75000000E+15	8.18550714E+13			
57 1.78796711E+15	4.15928130E+12	58 1.78797069E+15	1.11544291E+13			
59 1.82000000E+15	4.06991086E+13	60 1.84884915E+15	9.02856228E+12			
61 1.84885285E+15	1.20617571E+13	62 1.90000000E+15	8.48029699E+13			
63 1.97231453E+15	2.66007730E+13	64 1.97231847E+15	1.42441540E+13			
65 2.02000000E+15	6.96470460E+13	66 2.07609792E+15	1.98923000E+13			
67 2.07610208E+15	4.74367545E+13	68 2.20000000E+15	1.27770122E+14			
69 2.30000000E+15	1.22435459E+14	70 2.41959758E+15	4.58576637E+13			
71 2.41960242E+15	3.03310636E+13	72 2.50000000E+15	8.85358763E+13			
73 2.60000000E+15	1.39757530E+14	74 2.72539727E+15	4.71755303E+13			
75 2.72540273E+15	2.56441836E+13	76 2.80000000E+15	1.00571733E+14			
77 3.00000000E+15	3.29021965E+14	78 3.28804671E+15	1.07412118E+14			
BEGIN		ITERATION 6 COMPLETED				

ATLAS5(3) continues to iterate on the model for NUMITS iterations. Once the model is completed, ATLAS5 calls READIN for more instructions. If READIN finds an END card, it calls EXIT.

8.2 Control Cards for ATLAS5

The control cards for ATLAS were designed to be simple and straightforward. The easiest way to avoid error is to consider whether all the information needed to calculate a model atmosphere is being supplied to READIN. First, the physical parameters: effective temperature, surface gravity, and abundances. Second, the physical processes: opacities, statistical equilibrium, convection, and turbulence. Third, the operational procedure: the starting model, the frequency set, and the number of iterations. Fourth, the type and form of output.

The data and instructions are either presented as code words or preceded by identifying code words. This allows each set of data identified by a code word to appear in any order, with several to a card. READIN reads with a free-field format in which the end of a field is signified by a blank or a comma (a code word can also be ended with an equal sign). Numbers can be written in any I, E, or F format, and words can be any length but only the first six letters are read. The following are examples of equivalent input cards:

```
TEFF=1.E4
TEFF      1.E 4
TEFF      10000
TEFF=10000
TEFF, 1.E+4,
```

For several models to be calculated in succession, only those data that change need be specified. If no new data are specified, the calculation continues from the last iteration of the previous model.

We list here sample input cards with brief descriptions as necessary. The letters and numbers actually read are underlined. Cards that require special input or produce special output will be discussed further in Section 8.3.

TEFF=10000

Effective temperature, TEFF.

GRAVITY=4 or GRAVITY=1.E4

Gravity, GRAV. The log is assumed if the number is less than 10.

OPACITY ON H LINES, HOT

OPACITY OFF H LINES, HOT

OPACITY IFOP 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

The 20 code words and their defaults are as follows:

1. H1	ON	11. HOT	OFF
2. H2PLUS	ON	12. ELECTRON	ON
3. HMINUS	ON	13. H2RAY	OFF
4. HRAY	ON	14. H LINES	OFF
5. HE1	ON	15. LINES	OFF
6. HE2	ON	16. LINE SCAT	OFF
7. HEMINUS	ON	17. X LINES	OFF
8. HERAY	ON	18. XL SCAT	OFF
9. COOL	ON	19. XCONT	OFF
10. LUKE	OFF	20. XSCAT	OFF

IFOP is a list of all 20 switches.

ITERATIONS 6

Number of iterations, NUMITS. Maximum is 15.

MOLECULES ON

MOLECULES OFF

Molecules in equilibrium equations. If ON, special data are read in separately as described in Section 8.3. Defaults OFF.

CALCULATE STARTING MODEL 40 DEPTHS STARTING AT -3.5 SPACING .125

Used only after TEFF and GRAV are defined. The 40 optical depths are in TAUROS, Rosseland tau, against which READIN defines a temperature distribution, $T = TEFF * (.75 * (.710 + TAUROS - .1331 * EXP(-3.4488 * TAUROS))) ** .25$. Then READIN uses subroutine TTAUP to find T(RHOX). The maximum value for NRHOX, the number of depths, is 40

ABUNDANCE SCALE 1.

ABUNDANCE CHANGE 1 .5, 2 .5, 6 -3

The default abundances (number fractions) are listed in subroutine BLOCKE(32) and stored in array ABUND in COMMON /ELEM/. The actual abundances used are stored in array XABUND in COMMON /XABUND/. The abundances in array ABUND can be changed with an ABUNDANCE CHANGE card by specifying the atomic number and the new abundance. Negative numbers are assumed to be logarithms. The array XABUND is filled by taking the abundances in ABUND and multiplying them, except for H and He, by a scaling factor XSCALE, which defaults 1. Thus we might get abundances for a subdwarf by setting XSCALE to 0.01.

PRINT 1 1 1 1 2

PUNCH 0 0 0 0 1

Requires one integer for each iteration, so the number of iterations must be specified before these cards are read. The print options are (IFPRNT=)

- 0 no print,
- 1 print only summary table,
- 2 print temperature correction, surface fluxes, etc.,
- 3 print 2 and TAUNU, SNU, JNU, etc., at each frequency,
- 4 print 2 and all opacities at each frequency.

Defaults 2. See Section 8.3 for examples of 3 and 4.

The punch options are (IFPNCH=)

- 0 no punch,
- 1 punch model,
- 2 punch 1 and surface fluxes or intensities,
- 5 punch 2 and molecular number densities over partition functions.

Defaults 0, except 1 on the last iteration. See Section 8.3 for examples of 5.

READ FREQUENCIES 65 FREQS. INTEGRATE FROM 1 to 50. TEST1 IS THE ID.

Starting with the next card, reads 65 triplets of subscript, frequency, and integration coefficient in any order on as many cards as necessary. Each card may contain any number of complete triplets. If there are extremely large opacity edges, the model calculation may be left unchanged by simply ignoring regions of high opacity. In this example, integration runs from frequency 1 to frequency 50. TEST1 is simply a name used to identify the frequency set to avoid confusion when several different sets are available.

READ DEPARTURE COEFFICIENTS 40

Starting with the next card, reads a previously calculated set of b's for 40 depths on 40 cards. READIN expects to find RHOX, BHYD for $n = 1$ to 6, and BMIN on each card. The RHOX on these cards is a dummy for identification only. Defaults all b's unity.

READ STARTING T-TAU FOR 40 TAUS

Starting with the next card, reads TAUROS and T for a starting model. TAUROS may be in logarithms. READIN proceeds as for a CALCULATE card

READ DECK 40 RHOX

Starting with the next card, reads 40 cards each with RHOX, T, P, XNE, ABROSS, PRAD, and VTURB. If this deck is to be used as a starting model, the calculation will depend only on RHOX, T, PRAD, and VTURB and can get by with only RHOX and T if PRAD or VTURB is not critical. Once RHOX and T have been read, READIN will supply zeros to fill out the list if the card is left blank after any variable.

LTE

NLTE

NLTE stands for non-LTE, which is a negative way of saying statistical equilibrium calculations are requested. Defaults LTE with all b's unity.

BEGIN MODEL

Marks the end of data for READIN and the return to ATLAS to begin the model calculation.

SCATTERING ON

SCATTERING OFF

Compute the source function exactly with scattering or approximately without. Defaults ON.

END

In ATLAS5 this calls EXIT.

TITLE=TEST OF NEW OPACITY ROUTINES

Columns 7 to 80 are printed as a title on the summary table at the end of each iteration.

CONVECTION ON MIXLTH=1.5

CONVECTION OFF

If ON, the total flux that enters the temperature correction includes convective flux as well as radiative flux. MIXLTH, the ratio of mixing length to scale height, is 1.5. Defaults OFF with MIXLTH 1. The convective flux is always calculated to indicate its possible importance, as long as IFPRES is 1 and MIXLTH > 0.

TURBULENCE ON TRBFDG=0, TRBPOW=0, TRBSND=0, TRBCON=5.

TURBULENCE OFF

If ON, pressure computation includes turbulent pressure. The turbulent velocity in kilometers per second is

$$VTURB = TRBFDG * RHO ** TRBPOW + TRBSND * VELSND / 1. E5 + TRBCON ,$$

where the sound velocity is in centimeters per second. Defaults OFF.

CHANGE RHOX 35 1.E-5, 1.57E-5, etc.

Reads 35 new rhoxes on as many cards as necessary. This card is used, only after a model has been defined, to change point spacing or to extrapolate to greater or smaller depths. In changing RHOX, READIN interpolates T, P, XNE, ABROSS, VTURB, PRAD, BHYD, and BMIN and sets NRHOX to 35.

SURFACE FLUX

SURFACE INTENSITY FOR 5 ANGLES=1., .8, .6, .4, .3

SURFACE OFF

Calculate flux (IFSURF=1) or intensity (IFSURF=2) only at the surface, as in a spectrum calculation. There is a maximum of 20 angles. Defaults OFF.

PRESSURE ON

PRESSURE OFF

Compute pressure and number densities. Defaults ON.

CORRECTION ON

CORRECTION OFF

Do temperature corrections. Defaults ON.

WAVELENGTH 500. BY .001 TO 501.

Instead of frequencies, uses equally spaced wavelengths. The units are nanometers.

SCALE MODEL 40 -4.5 .1666666666 TEFF=5000 GRAVITY=3

This card must come after a model has been defined and TEFF and GRAV have been specified. This instruction scales models with gravity and effective temperature. The numbers define TAUIOS, as on a CALCULATE card, and the TEFF and GRAV for the new model. READIN computes TAUIOS for the existing model by integrating ABROSS. It then interpolates all the existing variables, as with a CHANGE RHOX card, to the new TAUIOS. READIN then makes the scalings

$$T^{\text{new}} = T^{\text{old}} (TEFF^{\text{new}} / TEFF^{\text{old}})$$

and

$$PRAD^{\text{new}} = PRAD^{\text{old}} (TEFF^{\text{new}} / TEFF^{\text{old}})^4 (GRAV^{\text{new}} / GRAV^{\text{old}}) \quad .$$

Then READIN calls TTAUP to find RHOX for the new model. If the new TEFF and GRAV are the same as the old, the result is just an interpolation of the old model onto a log TAUROS scale.

CALL DUMMYR

This allows additional data to be read in by using DUMMYR without having to modify READIN.

8.3 Options

We will go through the control cards again pointing out the results of using special options.

MOLECULES ON

There are two cases. When IFPRES = 1 (PRESSURE ON), NMOLEC(50) solves the molecular equilibrium equations. In the loop DO 20, NMOLEC reads a card for every species to be considered in the molecular equilibrium equations. The data are read by NMOLEC instead of READIN, so NMOLEC can be deleted to save central memory space without leaving a big array behind in READIN. (This can be changed if memory space is no object.) Since NMOLEC reads after READIN has finished, the data cards must come after the BEGIN card. On each card, NMOLEC expects the molecule code and six constants that go into the polynomial form of the Saha equation (Section 4.4) in the format (F18.2, F7.3, 5E11.4). For atoms, these constants can be left blank, in which case NMOLEC uses PFSAHA to do the Saha equation. The cards are printed out as they are read in as shown on the following two pages. The end of the data is denoted by a 0 card or a blank card. Since NMOLEC reads only once each time ATLAS5 is executed, all models run at the same time must include the same molecules.

MOLECULES INPUT

1	1.00	-0.000-0.	-0.	-0.	-0.	-0.
2	1.01	-0.000-0.	-0.	-0.	-0.	-0.
3	2.00	-0.000-0.	-0.	-0.	-0.	-0.
4	2.01	-0.000-0.	-0.	-0.	-0.	-0.
5	2.02	-0.000-0.	-0.	-0.	-0.	-0.
6	6.00	-0.000-0.	-0.	-0.	-0.	-0.
7	6.01	-0.000-0.	-0.	-0.	-0.	-0.
8	7.00	-0.000-0.	-0.	-0.	-0.	-0.
9	7.01	-0.000-0.	-0.	-0.	-0.	-0.
10	8.00	-0.000-0.	-0.	-0.	-0.	-0.
11	8.01	-0.000-0.	-0.	-0.	-0.	-0.
12	9.00	-0.000-0.	-0.	-0.	-0.	-0.
13	11.00	-0.000-0.	-0.	-0.	-0.	-0.
14	11.01	-0.000-0.	-0.	-0.	-0.	-0.
15	12.00	-0.000-0.	-0.	-0.	-0.	-0.
16	12.01	-0.000-0.	-0.	-0.	-0.	-0.
17	13.00	-0.000-0.	-0.	-0.	-0.	-0.
18	13.01	-0.000-0.	-0.	-0.	-0.	-0.
19	14.00	-0.000-0.	-0.	-0.	-0.	-0.
20	14.01	-0.000-0.	-0.	-0.	-0.	-0.
21	15.00	-0.000-0.	-0.	-0.	-0.	-0.
22	16.00	-0.000-0.	-0.	-0.	-0.	-0.
23	17.00	-0.000-0.	-0.	-0.	-0.	-0.
24	19.00	-0.000-0.	-0.	-0.	-0.	-0.
25	19.01	-0.000-0.	-0.	-0.	-0.	-0.
26	20.00	-0.000-0.	-0.	-0.	-0.	-0.
27	20.01	-0.000-0.	-0.	-0.	-0.	-0.
28	20.02	-0.000-0.	-0.	-0.	-0.	-0.
29	101.00	4.477 4.6628E+01	1.8031E-03	5.0239E-07	8.1424E-11	5.0501E-15
30	106.00	3.470 4.5506E+01	1.7112E-03	3.6319E-07	5.0164E-11	2.8716E-15
31	107.00	3.699 4.5244E+01	1.8435E-03	4.9000E-07	7.7353E-11	4.7639E-15
32	108.00	4.395 4.5746E+01	1.7004E-03	4.4905E-07	7.0861E-11	4.3648E-15
33	109.00	5.844 4.6618E+01	1.5382E-03	4.0410E-07	6.4407E-11	3.9816E-15
34	111.00	2.050 4.4709E+01	2.4163E-03	6.1037E-07	9.0492E-11	5.3705E-15
35	112.00	1.999 4.3437E+01	2.2153E-03	5.4885E-07	8.1160E-11	4.8026E-15
36	113.00	2.901 4.5688E+01	1.8402E-03	4.1240E-07	5.7606E-11	3.2768E-15
37	114.00	3.190 4.4770E+01	1.6858E-03	3.7373E-07	5.0857E-11	2.8282E-15
38	115.00	3.300 4.4680E+01	1.8959E-03	4.6737E-07	6.8061E-11	4.0256E-15
39	116.00	3.530 4.5272E+01	1.8600E-03	4.7327E-07	7.1690E-11	4.3041E-15
40	117.00	4.431 4.5886E+01	1.5637E-03	3.9598E-07	6.2107E-11	3.8283E-15
41	606.00	6.156 4.9635E+01	3.4811E-03	1.0492E-06	1.6849E-10	1.0370E-14
42	607.00	8.109 4.7853E+01	1.8656E-03	4.6185E-07	7.1497E-11	4.3750E-15
43	608.00	11.108 4.9170E+01	1.5802E-03	3.4347E-07	4.6870E-11	2.6563E-15
44	609.00	4.966 4.7368E+01	2.0173E-03	4.7759E-07	6.7404E-11	3.8474E-15
45	615.00	6.895 4.7509E+01	2.1172E-03	4.9533E-07	7.2805E-11	4.4007E-15
46	616.00	7.892 4.8547E+01	1.7379E-03	3.6954E-07	4.7608E-11	2.5585E-15
47	617.00	3.340 4.7009E+01	2.4592E-03	6.5348E-07	9.8261E-11	5.8172E-15
48	707.00	9.763 4.8696E+01	1.9224E-03	4.9143E-07	7.4692E-11	4.5399E-15
49	708.00	6.508 4.7365E+01	1.9840E-03	4.9280E-07	7.2933E-11	4.3354E-15
50	709.00	2.819 4.6770E+01	2.2411E-03	5.5102E-07	7.9899E-11	4.6459E-15
51	714.00	4.510 4.7147E+01	1.8720E-03	4.1254E-07	5.3950E-11	2.9053E-15
52	715.00	7.111 4.7683E+01	2.2458E-03	5.5753E-07	7.9113E-11	4.5753E-15
53	716.00	4.987 4.6988E+01	2.2584E-03	5.7344E-07	8.3948E-11	4.9197E-15
54	808.00	5.116 4.8625E+01	1.6321E-03	3.3915E-07	4.6025E-11	2.5839E-15
55	811.00	3.079 4.6421E+01	2.6221E-03	6.8505E-07	1.0200E-10	6.0540E-15
56	812.00	3.903 4.6567E+01	2.3003E-03	4.3846E-07	5.3231E-11	2.8469E-15
57	813.00	4.987 4.7561E+01	2.0103E-03	4.5650E-07	6.2393E-11	3.4674E-15
58	814.00	8.310 4.8477E+01	1.5511E-03	2.9069E-07	3.2807E-11	1.5486E-15
59	815.00	6.071 4.7307E+01	2.4172E-03	6.2096E-07	8.9966E-11	5.2500E-15
60	816.00	5.358 4.7488E+01	1.6987E-03	3.5057E-07	4.4497E-11	2.3647E-15
61	817.00	2.745 4.6832E+01	2.1078E-03	5.1344E-07	7.4414E-11	4.3173E-15

62	909.00	1.592	4.8632E+01	2.0165E-03	4.6054E-07	6.4288E-11	3.6296E-15
63	911.00	4.953	4.6717E+01	2.7566E-03	7.4062E-07	1.1213E-10	6.7066E-15
64	912.00	3.200	4.5468E+01	2.5089E-03	6.5244E-07	9.7170E-11	5.7561E-15
65	913.00	6.790	4.7788E+01	2.1362E-03	5.0666E-07	7.1400E-11	4.0530E-15
66	914.00	5.420	4.6897E+01	2.1060E-03	4.9864E-07	6.8598E-11	3.7971E-15
67	916.00	3.338	4.6706E+01	1.9206E-03	4.3001E-07	5.8062E-11	3.2077E-15
68	917.00	2.616	4.7680E+01	2.1411E-03	5.3239E-07	7.8152E-11	4.5625E-15
69	1111.00	.730	4.5152E+01	3.6917E-03	1.0752E-06	1.7017E-10	1.0459E-14
70	1117.00	4.222	4.6147E+01	3.0037E-03	8.5128E-07	1.3301E-10	8.0960E-15
71	1216.00	2.901	4.6082E+01	2.6137E-03	6.8845E-07	1.0253E-10	6.0759E-15
72	1217.00	2.701	4.4998E+01	2.8447E-03	7.9686E-07	1.2369E-10	7.4944E-15
73	1313.00	1.604	4.7559E+01	2.9097E-03	7.7812E-07	1.1753E-10	6.9499E-15
74	1317.00	5.074	4.7276E+01	2.5438E-03	6.7568E-07	1.0182E-10	6.0055E-15
75	1414.00	3.252	4.7179E+01	2.0256E-03	4.5186E-07	5.7418E-11	2.9577E-15
76	1416.00	6.418	4.7989E+01	1.7935E-03	3.7532E-07	4.5974E-11	2.3242E-15
77	1417.00	4.002	4.6541E+01	2.5534E-03	6.8459E-07	1.0209E-10	5.9733E-15
78	1515.00	5.033	4.8223E+01	2.6898E-03	7.0362E-07	1.0075E-10	5.8493E-15
79	1516.00	5.637	4.6919E+01	2.7644E-03	7.4350E-07	1.0948E-10	6.4205E-15
80	1616.00	4.380	4.7693E+01	1.9029E-03	4.2359E-07	5.5948E-11	3.0438E-15
81	1617.00	2.749	4.7565E+01	3.5631E-03	1.0897E-06	1.7573E-10	1.0805E-14
82	1717.00	2.476	4.8021E+01	2.4184E-03	6.5374E-07	1.0061E-10	6.0420E-15
83	10106.00	8.850	9.3457E+01	2.2374E-03	2.9465E-07	2.7708E-11	1.2186E-15
84	10108.00	9.511	9.3163E+01	2.6530E-03	5.6946E-07	8.3927E-11	5.0416E-15
85	10116.00	7.514	9.2053E+01	2.7514E-03	5.1218E-07	6.6192E-11	3.6540E-15
86	10607.00	13.135	9.6088E+01	3.4106E-03	6.7378E-07	8.7666E-11	4.8365E-15
87	10608.00	12.311	9.4191E+01	3.0252E-03	5.9689E-07	7.7220E-11	4.2351E-15
88	10811.00	8.286	9.2701E+01	4.3703E-03	1.0975E-06	1.6241E-10	9.6222E-15
89	10812.00	6.823	9.1448E+01	3.9729E-03	9.4759E-07	1.3688E-10	8.0099E-15
90	60606.00	13.957	1.0081E+02	3.9913E-03	8.1028E-07	1.0167E-10	5.3621E-15
91	60717.00	12.126	9.8836E+01	4.8667E-03	1.1673E-06	1.6627E-10	9.5674E-15
92	60808.00	16.561	1.0097E+02	3.3659E-03	5.7770E-07	6.3873E-11	3.0525E-15
93	60816.00	14.210	1.0000E+02	3.9763E-03	7.8058E-07	9.5929E-11	4.9686E-15
94	60909.00	10.268	9.7787E+01	3.7637E-03	7.7313E-07	9.9261E-11	5.3065E-15
95	61616.00	11.881	1.0044E+02	4.5422E-03	9.8359E-07	1.2836E-10	6.9210E-15
96	70708.00	11.440	9.9172E+01	3.9917E-03	8.1117E-07	1.0518E-10	5.7309E-15
97	70808.00	9.621	9.7617E+01	3.6891E-03	7.5141E-07	9.6734E-11	5.2293E-15
98	70909.00	6.056	9.6316E+01	4.4386E-03	1.0275E-06	1.4206E-10	7.9873E-15
99	80814.00	13.447	1.0004E+02	3.7484E-03	6.5483E-07	6.8677E-11	3.0007E-15
100	80816.00	11.023	9.8405E+01	3.7855E-03	7.7032E-07	9.7481E-11	5.1594E-15

For this sample run we have put in 100 species, the maximum allowed by the dimensions, to find out which molecules are important in the sun (assuming complete ignorance). The constants are taken from the table in Section 4.4. Once we know which molecules are important, if any, we can restrict the input list to those. There is also a maximum of 25 different elements.

NMOLEC continues to process input data up through statement 28. On any subsequent call to NMOLEC, the data are already in a usable form, so NMOLEC skips directly to statement 30 to make a guess for the number densities at the first depth. Then NMOLEC sets up and differentiates the equilibrium equations to get a set of linear equations for the correction to the number densities (through statement 99) (Section 4.3). NMOLEC calls SOLVIT(17) to solve the equations. The number densities are corrected, and iteration continues until the number densities converge. NMOLEC repeats this process for every depth, then prints out (only on the last iteration, to save paper) the results as shown on the following three pages.

Once NMOLEC has found the number densities, it goes through the list to find number densities/partition functions (in ATLAS5). These are stored in array XNMOL in COMMON. Using blank COMMON saves core on CDC machines, but if space is no object, this could be converted to COMMON /MOLS/. The same COMMON must occur in MOLEC.

Finally, if IFPNCH = 5, NMOLEC prints and punches XNMOL, XNATOM, and RHO, as shown on pages 152 and 153.

XNMOL is used by MOLEC(48) as its source of data. If a molecule is requested that is not in XNMOL, MOLEC quits; if an atom is requested that is not in XNMOL, MOLEC calls PFSAHA. The only way to find a molecular number that is not in XNMOL is to request the neutral-atom number densities for the components and to use a Saha equation to construct the molecular number density completely independently of the molecule routines.

	RHOX	T	P	XNE	XNATOM	RHO
1	2.471E-03	5.300E+03	6.806E+01	1.018E+11	9.282E+13	2.051E-10
2	4.916E-03	5.040E+03	1.354E+02	7.118E+10	1.943E+14	4.295E-10
3	9.407E-03	4.790E+03	2.591E+02	5.386E+10	3.914E+14	8.649E-10
4	1.637E-02	4.530E+03	4.509E+02	5.219E+10	7.202E+14	1.592E-09
5	2.465E-02	4.280E+03	6.789E+02	6.482E+10	1.148E+15	2.537E-09
6	3.422E-02	4.170E+03	9.425E+02	8.055E+10	1.636E+15	3.615E-09
7	4.622E-02	4.190E+03	1.273E+03	1.051E+11	2.199E+15	4.860E-09
8	6.154E-02	4.225E+03	1.695E+03	1.370E+11	2.904E+15	6.418E-09
9	8.118E-02	4.280E+03	2.236E+03	1.798E+11	3.782E+15	8.357E-09
10	1.065E-01	4.330E+03	2.933E+03	2.338E+11	4.904E+15	1.084E-08
11	1.390E-01	4.380E+03	3.828E+03	3.025E+11	6.328E+15	1.398E-08
12	1.810E-01	4.430E+03	4.985E+03	3.903E+11	8.147E+15	1.800E-08
13	2.351E-01	4.490E+03	6.475E+03	5.060E+11	1.044E+16	2.307E-08
14	3.050E-01	4.550E+03	8.400E+03	6.548E+11	1.337E+16	2.954E-08
15	3.950E-01	4.600E+03	1.088E+04	8.398E+11	1.712E+16	3.785E-08
16	5.116E-01	4.660E+03	1.409E+04	1.084E+12	2.190E+16	4.839E-08
17	6.612E-01	4.720E+03	1.821E+04	1.397E+12	2.794E+16	6.175E-08
18	8.547E-01	4.790E+03	2.354E+04	1.812E+12	3.559E+16	7.865E-08
19	1.103E+00	4.895E+03	3.038E+04	2.410E+12	4.494E+16	9.933E-08
20	1.422E+00	5.010E+03	3.917E+04	3.236E+12	5.661E+16	1.251E-07
21	1.828E+00	5.160E+03	5.035E+04	4.509E+12	7.065E+16	1.561E-07
22	2.334E+00	5.330E+03	6.428E+04	6.528E+12	8.733E+16	1.930E-07
23	2.937E+00	5.540E+03	8.089E+04	1.023E+13	1.057E+17	2.336E-07
24	3.617E+00	5.765E+03	9.962E+04	1.690E+13	1.251E+17	2.764E-07
25	4.335E+00	6.035E+03	1.194E+05	3.051E+13	1.432E+17	3.164E-07
26	5.021E+00	6.390E+03	1.383E+05	6.320E+13	1.566E+17	3.460E-07
27	5.330E+00	6.610E+03	1.468E+05	9.622E+13	1.606E+17	3.550E-07
28	5.602E+00	6.860E+03	1.543E+05	1.506E+14	1.626E+17	3.594E-07
29	5.842E+00	7.140E+03	1.609E+05	2.404E+14	1.628E+17	3.599E-07
30	6.053E+00	7.440E+03	1.667E+05	3.822E+14	1.618E+17	3.575E-07
31	6.230E+00	7.750E+03	1.716E+05	5.947E+14	1.596E+17	3.528E-07
32	6.394E+00	8.030E+03	1.761E+05	8.629E+14	1.578E+17	3.488E-07
33	6.543E+00	8.290E+03	1.802E+05	1.193E+15	1.561E+17	3.450E-07
34	6.688E+00	8.520E+03	1.842E+05	1.565E+15	1.549E+17	3.423E-07
35	6.833E+00	8.710E+03	1.882E+05	1.941E+15	1.544E+17	3.413E-07
36	6.986E+00	8.880E+03	1.924E+05	2.339E+15	1.545E+17	3.414E-07
37	7.145E+00	9.050E+03	1.968E+05	2.799E+15	1.546E+17	3.416E-07
38	7.316E+00	9.220E+03	2.015E+05	3.330E+15	1.548E+17	3.422E-07
39	7.494E+00	9.390E+03	2.064E+05	3.937E+15	1.551E+17	3.428E-07
40	7.683E+00	9.560E+03	2.116E+05	4.629E+15	1.555E+17	3.438E-07

MOLECULAR NUMBER DENSITIES

	107.00	108.00	109.00	111.00	112.00	113.00	114.00	115.00	116.00	117.00
1	4.843E+03	7.179E+04	2.659E+02	5.315E-05	3.093E-01	3.728E-03	5.536E+00	1.258E+01	6.699E+02	2.887E+01
2	3.181E+04	5.127E+05	2.237E+03	3.806E-04	2.938E+00	3.285E-02	6.439E+01	8.003E+01	4.327E+03	2.066E+02
3	3.482E+05	2.815E+06	1.815E+04	2.885E-03	2.991E+01	3.085E-01	8.073E+02	4.806E+02	2.647E+04	1.410E+03
4	1.102E+06	2.111E+07	1.372E+05	2.687E-02	3.930E+02	3.685E+00	1.304E+04	2.561E+03	1.444E+05	8.735E+03
5	4.777E+06	9.167E+07	8.287E+05	2.602E-01	5.432E+03	4.650E+01	1.956E+05	1.060E+04	6.140E+05	4.262E+04
6	1.245E+07	2.181E+08	2.543E+06	1.122E+00	2.721E+04	2.270E+02	8.754E+05	2.717E+04	1.596E+06	1.184E+05
7	2.139E+07	3.628E+08	4.246E+06	2.395E+00	5.572E+04	4.728E+02	1.653E+06	4.702E+04	2.755E+06	2.018E+05
8	3.429E+07	5.700E+08	6.470E+06	4.581E+00	1.002E+05	8.675E+02	2.781E+06	7.605E+04	4.437E+06	3.181E+05
9	5.124E+07	8.467E+08	8.930E+06	7.825E+00	1.568E+05	1.391E+03	4.149E+06	1.149E+05	6.659E+06	4.622E+05
10	7.700E+07	1.260E+09	1.251E+07	1.353E+01	2.506E+05	2.274E+03	6.299E+06	1.745E+05	1.005E+07	6.777E+05
11	1.149E+08	1.862E+09	1.742E+07	2.317E+01	3.974E+05	3.685E+03	9.496E+06	2.628E+05	1.506E+07	9.870E+05
12	1.711E+08	2.743E+09	2.425E+07	3.961E+01	6.300E+05	5.969E+03	1.431E+07	3.952E+05	2.251E+07	1.436E+06
13	2.460E+08	3.953E+09	3.250E+07	6.485E+01	9.469E+05	9.179E+03	2.057E+07	5.790E+05	3.278E+07	2.024E+06
14	3.600E+08	5.695E+09	4.370E+07	1.065E+02	1.430E+06	1.418E+04	2.970E+07	8.491E+05	4.778E+07	2.860E+06
15	5.350E+08	8.356E+09	6.100E+07	1.820E+02	2.278E+06	2.305E+04	4.492E+07	1.273E+06	7.129E+07	4.160E+06
16	7.790E+08	1.205E+10	8.257E+07	3.011E+02	3.476E+06	3.594E+04	6.539E+07	1.872E+06	1.042E+08	5.904E+06
17	1.133E+09	1.735E+10	1.119E+08	4.979E+02	5.314E+06	5.613E+04	9.532E+07	2.748E+06	1.523E+08	8.377E+06
18	1.619E+09	2.455E+10	1.474E+08	8.002E+02	7.824E+06	8.456E+04	1.343E+08	3.966E+06	2.184E+08	1.163E+07
19	2.149E+09	3.245E+10	1.743E+08	1.148E+03	9.944E+06	1.106E+05	1.647E+08	5.339E+06	2.916E+08	1.481E+07
20	2.814E+09	4.204E+10	2.024E+08	1.624E+03	1.240E+07	1.421E+05	1.967E+08	7.091E+06	3.842E+08	1.856E+07
21	3.455E+09	5.065E+10	2.143E+08	2.123E+03	1.386E+07	1.648E+05	2.082E+08	8.858E+06	4.754E+08	2.161E+07
22	4.090E+09	5.816E+10	2.169E+08	2.748E+03	1.506E+07	1.867E+05	2.103E+08	1.068E+07	5.679E+08	2.419E+07
23	4.456E+09	6.059E+10	1.976E+08	3.393E+03	1.517E+07	1.981E+05	1.918E+08	1.189E+07	6.257E+08	2.474E+07
24	4.627E+09	5.974E+10	1.720E+08	4.213E+03	1.538E+07	2.121E+05	1.737E+08	1.261E+07	6.575E+08	2.417E+07
25	4.313E+09	5.241E+10	1.323E+08	4.956E+03	1.447E+07	2.132E+05	1.436E+08	1.203E+07	6.222E+08	2.113E+07
26	3.354E+09	3.787E+10	8.232E+07	5.332E+03	1.174E+07	1.885E+05	9.979E+07	9.646E+06	4.943E+08	1.531E+07
27	2.709E+09	2.938E+10	5.884E+07	5.211E+03	9.855E+06	1.663E+05	7.678E+07	7.948E+06	4.053E+08	1.193E+07
28	2.044E+09	2.128E+10	3.918E+07	4.817E+03	7.776E+06	1.396E+05	5.587E+07	6.147E+06	3.119E+08	8.712E+06
29	1.433E+09	1.435E+10	2.431E+07	4.232E+03	5.729E+06	1.115E+05	3.852E+07	4.449E+06	2.243E+08	5.954E+06
30	9.373E+08	9.067E+09	1.423E+07	3.508E+03	3.949E+06	8.548E+04	2.551E+07	3.030E+06	1.516E+08	3.840E+06
31	5.704E+08	5.377E+09	7.903E+06	2.657E+03	2.561E+06	6.244E+04	1.633E+07	1.943E+06	9.626E+07	2.343E+06
32	3.467E+08	3.220E+09	4.513E+06	1.954E+03	1.678E+06	4.575E+04	1.079E+07	1.251E+06	6.129E+07	1.451E+06
33	2.066E+08	1.908E+09	2.586E+06	1.397E+03	1.072E+06	3.333E+04	7.228E+06	7.962E+05	3.846E+07	8.935E+05
34	1.247E+08	1.153E+09	9.742E+05	9.742E+02	6.889E+05	2.464E+04	5.005E+06	5.144E+05	2.448E+07	5.627E+05
35	7.932E+07	7.387E+08	9.695E+05	6.923E+02	4.629E+05	1.882E+04	3.662E+06	3.494E+05	1.638E+07	3.750E+05
36	5.140E+07	4.836E+08	6.317E+05	4.922E+02	3.157E+05	1.457E+04	2.748E+06	2.418E+05	1.165E+07	2.555E+05
37	3.214E+07	3.067E+08	4.007E+05	3.423E+02	2.085E+05	1.104E+04	2.031E+06	1.626E+05	7.380E+06	1.695E+05
38	1.935E+07	1.882E+08	2.472E+05	2.272E+02	1.359E+05	8.182E+03	1.478E+06	1.062E+05	4.726E+06	1.093E+05
39	1.117E+07	1.113E+08	1.476E+05	1.432E+02	8.484E+04	5.954E+03	1.055E+06	6.709E+04	2.919E+06	6.827E+04
40	6.169E+06	6.320E+07	8.523E+04	8.561E+01	5.068E+04	4.222E+03	7.378E+05	4.091E+04	1.736E+06	4.122E+04

NUMBER DENSITIES / PARTITION FUNCTIONS

100 MOLECULES

1.00								
4.172E+13	8.742E+13	1.761E+14	3.241E+14	5.165E+14	7.359E+14	9.892E+14	1.306E+15	
1.701E+15	2.205E+15	2.845E+15	3.663E+15	4.694E+15	6.009E+15	7.697E+15	9.839E+15	
1.255E+16	1.599E+16	2.019E+16	2.543E+16	3.174E+16	3.924E+16	4.751E+16	5.623E+16	
6.437E+16	7.040E+16	7.222E+16	7.309E+16	7.315E+16	7.261E+16	7.154E+16	7.060E+16	
6.966E+16	6.893E+16	6.853E+16	6.835E+16	6.815E+16	6.800E+16	6.783E+16	6.767E+16	
1.01								
9.034E+10	5.398E+10	2.599E+10	6.854E+09	1.056E+09	4.405E+08	5.473E+08	7.672E+08	
1.254E+09	1.948E+09	2.996E+09	4.566E+09	7.413E+09	1.189E+10	1.760E+10	2.764E+10	
4.291E+10	7.019E+10	1.396E+11	2.842E+11	6.648E+11	1.581E+12	3.974E+12	9.190E+12	
2.124E+13	5.226E+13	8.436E+13	1.377E+14	2.263E+14	3.666E+14	5.774E+14	8.438E+14	
1.172E+15	1.542E+15	1.917E+15	2.313E+15	2.772E+15	3.301E+15	3.906E+15	4.597E+15	
2.00								
9.282E+12	1.943E+13	3.914E+13	7.202E+13	1.148E+14	1.636E+14	2.199E+14	2.904E+14	
3.782E+14	4.904E+14	6.328E+14	8.147E+14	1.044E+15	1.337E+15	1.712E+15	2.190E+15	
2.794E+15	3.559E+15	4.494E+15	5.661E+15	7.065E+15	8.733E+15	1.057E+16	1.251E+16	
1.432E+16	1.566E+16	1.606E+16	1.626E+16	1.628E+16	1.618E+16	1.596E+16	1.578E+16	
1.561E+16	1.549E+16	1.544E+16	1.545E+16	1.546E+16	1.548E+16	1.551E+16	1.555E+16	
2.01								
7.182E-01	1.240E-01	1.594E-02	9.123E-04	2.717E-05	5.165E-06	7.427E-06	1.340E-05	
3.227E-05	7.072E-05	1.522E-04	3.222E-04	7.686E-04	1.793E-03	3.599E-03	8.076E-03	
1.776E-02	4.312E-02	1.518E-01	5.617E-01	2.753E+00	1.439E+01	8.960E+01	5.085E+02	
3.161E+03	2.514E+04	7.886E+04	2.601E+05	8.860E+05	2.952E+06	9.241E+06	2.401E+07	
5.501E+07	1.099E+08	1.899E+08	3.042E+08	4.790E+08	7.425E+08	1.134E+09	1.707E+09	
2.02								
4.891E-34	1.120E-34	1.762E-35	9.574E-37	2.109E-38	3.102E-39	3.442E-39	4.824E-39	
9.031E-39	1.549E-38	2.621E-38	4.373E-38	8.211E-38	1.510E-37	2.402E-37	4.257E-37	
7.407E-37	1.417E-36	3.875E-36	1.106E-35	4.067E-35	1.541E-34	6.488E-34	2.366E-33	
8.725E-33	1.221E-31	7.109E-30	5.153E-28	4.323E-26	3.415E-24	2.183E-22	7.086E-21	
1.455E-19	1.811E-18	1.317E-17	7.237E-17	3.735E-16	1.816E-15	8.346E-15	3.639E-14	
6.00								
2.571E+09	6.132E+09	1.307E+10	2.394E+10	3.162E+10	3.345E+10	4.263E+10	5.576E+10	
7.594E+10	1.014E+11	1.344E+11	1.772E+11	2.367E+11	3.141E+11	4.085E+11	5.372E+11	
7.027E+11	9.258E+11	1.247E+12	1.658E+12	2.185E+12	2.800E+12	3.463E+12	4.123E+12	
4.700E+12	5.055E+12	5.110E+12	5.068E+12	4.935E+12	4.724E+12	4.453E+12	4.197E+12	
3.947E+12	3.728E+12	3.560E+12	3.419E+12	3.279E+12	3.143E+12	3.008E+12	2.876E+12	
6.01								
9.349E+08	8.283E+08	5.588E+08	2.032E+08	3.683E+07	1.348E+07	1.539E+07	2.026E+07	
3.189E+07	4.740E+07	6.971E+07	1.015E+08	1.582E+08	2.429E+08	3.421E+08	5.122E+08	
7.571E+08	1.178E+09	2.212E+09	4.186E+09	8.831E+09	1.840E+10	3.897E+10	7.487E+10	
1.395E+11	2.630E+11	3.632E+11	5.002E+11	6.845E+11	9.178E+11	1.195E+12	1.476E+12	
1.757E+12	2.020E+12	2.250E+12	2.463E+12	2.681E+12	2.902E+12	3.123E+12	3.346E+12	
7.00								
1.713E+09	3.600E+09	7.277E+09	1.343E+10	2.139E+10	3.026E+10	4.057E+10	5.349E+10	
6.969E+10	9.036E+10	1.166E+11	1.500E+11	1.923E+11	2.463E+11	3.153E+11	4.031E+11	
5.142E+11	6.550E+11	8.277E+11	1.043E+12	1.301E+12	1.607E+12	1.941E+12	2.291E+12	
2.614E+12	2.845E+12	2.909E+12	2.919E+12	2.893E+12	2.842E+12	2.771E+12	2.708E+12	
2.648E+12	2.598E+12	2.565E+12	2.542E+12	2.518E+12	2.495E+12	2.465E+12	2.435E+12	
7.01								
4.797E+05	2.588E+05	1.117E+05	2.596E+04	3.477E+03	1.346E+03	1.689E+03	2.416E+03	
4.084E+03	6.531E+03	1.034E+04	1.619E+04	2.717E+04	4.500E+04	6.833E+04	1.066E+05	
1.769E+05	2.992E+05	6.251E+05	1.339E+06	3.335E+06	8.468E+06	2.295E+07	5.713E+07	
1.431E+08	3.872E+08	6.593E+08	1.133E+09	1.961E+09	3.344E+09	5.522E+09	8.392E+09	
1.205E+10	1.629E+10	2.067E+10	2.538E+10	3.092E+10	3.739E+10	4.477E+10	5.322E+10	
8.00								
5.475E+09	1.150E+10	2.317E+10	4.198E+10	5.996E+10	7.342E+10	9.627E+10	1.265E+11	
1.682E+11	2.211E+11	2.889E+11	3.763E+11	4.920E+11	6.413E+11	8.277E+11	1.074E+12	
1.387E+12	1.799E+12	2.352E+12	3.055E+12	3.935E+12	4.973E+12	6.112E+12	7.282E+12	
8.354E+12	9.121E+12	9.337E+12	9.424E+12	9.401E+12	9.299E+12	9.129E+12	8.981E+12	
8.836E+12	8.721E+12	8.653E+12	8.612E+12	8.571E+12	8.536E+12	8.498E+12	8.463E+12	

1.104E-18	1.182E-18	1.126E-18	1.014E-18	8.680E-19	7.159E-19	5.735E-19	4.642E-19
3.876E-19	3.283E-19	2.888E-19	2.595E-19	2.331E-19	2.099E-19	1.888E-19	1.701E-19
60909.00							
9.899E-33	1.207E-31	1.218E-30	8.948E-30	3.554E-29	8.211E-29	1.858E-28	4.122E-28
9.142E-28	1.978E-27	4.208E-27	8.872E-27	1.866E-26	3.892E-26	8.016E-26	1.654E-25
3.382E-25	6.905E-25	1.391E-24	2.741E-24	5.163E-24	9.194E-24	1.488E-23	2.205E-23
2.873E-23	3.112E-23	2.989E-23	2.713E-23	2.345E-23	1.953E-23	1.581E-23	1.307E-23
1.091E-23	9.338E-24	8.287E-24	7.509E-24	6.806E-24	6.185E-24	5.620E-24	5.116E-24
61616.00							
5.332E-30	6.589E-29	6.738E-28	5.029E-27	2.036E-26	4.764E-26	1.080E-25	2.396E-25
5.303E-25	1.146E-24	2.434E-24	5.125E-24	1.075E-23	2.238E-23	4.606E-23	9.486E-23
1.936E-22	3.943E-22	7.882E-22	1.540E-21	2.867E-21	5.039E-21	8.031E-21	1.172E-20
1.501E-20	1.593E-20	1.512E-20	1.356E-20	1.157E-20	9.505E-21	7.591E-21	6.196E-21
5.111E-21	4.326E-21	3.805E-21	3.421E-21	3.076E-21	2.774E-21	2.501E-21	2.259E-21
70708.00							
5.083E-27	5.486E-26	5.261E-25	3.841E-24	1.651E-23	4.373E-23	1.016E-22	2.264E-22
4.912E-22	1.048E-21	2.203E-21	4.594E-21	9.481E-21	1.946E-20	3.985E-20	8.125E-20
1.645E-19	3.310E-19	6.475E-19	1.245E-18	2.285E-18	3.995E-18	6.382E-18	9.400E-18
1.223E-17	1.333E-17	1.289E-17	1.171E-17	1.018E-17	8.589E-18	7.090E-18	5.990E-18
5.120E-18	4.482E-18	4.056E-18	3.741E-18	3.452E-18	3.193E-18	2.938E-18	2.703E-18
70808.00							
1.422E-26	1.533E-25	1.466E-24	1.051E-23	4.049E-23	9.284E-23	2.109E-22	4.687E-22
1.038E-21	2.245E-21	4.778E-21	1.008E-20	2.123E-20	4.436E-20	9.156E-20	1.894E-19
3.884E-19	7.956E-19	1.611E-18	3.191E-18	6.047E-18	1.082E-17	1.759E-17	2.615E-17
3.422E-17	3.740E-17	3.620E-17	3.310E-17	2.896E-17	2.460E-17	2.045E-17	1.739E-17
1.495E-17	1.317E-17	1.198E-17	1.110E-17	1.029E-17	9.560E-18	8.864E-18	8.224E-18
70909.00							
5.547E-33	5.959E-32	5.704E-31	4.222E-30	2.022E-29	6.247E-29	1.487E-28	3.326E-28
7.055E-28	1.483E-27	3.070E-27	6.317E-27	1.275E-26	2.567E-26	5.205E-26	1.044E-25
2.081E-25	4.108E-25	7.766E-25	1.450E-24	2.586E-24	4.438E-24	7.017E-24	1.031E-23
1.344E-23	1.473E-23	1.431E-23	1.315E-23	1.156E-23	9.884E-24	8.277E-24	7.096E-24
6.160E-24	5.475E-24	5.024E-24	4.697E-24	4.397E-24	4.131E-24	3.876E-24	3.644E-24
80814.00							
6.884E-30	1.398E-28	2.871E-27	6.432E-26	9.291E-25	3.803E-24	9.432E-24	2.172E-23
4.711E-23	1.012E-22	2.142E-22	4.501E-22	9.223E-22	1.882E-21	3.896E-21	7.919E-21
1.600E-20	3.171E-20	5.768E-20	1.012E-19	1.595E-19	2.340E-19	3.038E-19	3.745E-19
4.085E-19	3.649E-19	3.162E-19	2.585E-19	2.013E-19	1.523E-19	1.132E-19	8.779E-20
6.966E-20	5.739E-20	4.964E-20	4.412E-20	3.932E-20	3.522E-20	3.162E-20	2.848E-20
80816.00							
5.907E-28	6.393E-27	6.138E-26	4.424E-25	1.721E-24	3.990E-24	9.082E-24	2.019E-23
4.459E-23	9.630E-23	2.046E-22	4.312E-22	9.057E-22	1.889E-21	3.894E-21	8.039E-21
1.646E-20	3.364E-20	6.783E-20	1.339E-19	2.526E-19	4.502E-19	7.283E-19	1.078E-18
1.405E-18	1.526E-18	1.473E-18	1.350E-18	1.184E-18	1.009E-18	8.418E-19	7.189E-19
6.213E-19	5.498E-19	5.025E-19	4.679E-19	4.362E-19	4.080E-19	3.820E-19	3.583E-19
XNATCM,RHD							
9.282E+13	2.051E+10	1.943E+14	4.295E+10	3.914E+14	8.649E+10	7.202E+14	1.592E+09
1.148E+15	2.537E+09	1.636E+15	3.615E+09	2.199E+15	4.860E+09	2.904E+15	6.418E+09
3.782E+15	8.357E+09	4.904E+15	1.084E+08	6.328E+15	1.398E+08	8.147E+15	1.800E+08
1.044E+16	2.307E+08	1.337E+16	2.954E+08	1.712E+16	3.785E+08	2.190E+16	4.839E+08
2.794E+16	6.175E+08	3.559E+16	7.865E+08	4.494E+16	9.933E+08	5.661E+16	1.251E+07
7.065E+16	1.561E+07	8.733E+16	1.930E+07	1.057E+17	2.336E+07	1.251E+17	2.764E+07
1.432E+17	3.164E+07	1.566E+17	3.460E+07	1.606E+17	3.550E+07	1.626E+17	3.594E+07
1.628E+17	3.599E+07	1.618E+17	3.575E+07	1.596E+17	3.528E+07	1.578E+17	3.488E+07
1.561E+17	3.450E+07	1.549E+17	3.423E+07	1.544E+17	3.413E+07	1.545E+17	3.414E+07
1.546E+17	3.416E+07	1.548E+17	3.422E+07	1.551E+17	3.428E+07	1.555E+17	3.438E+07

The second case for MOLECULES ON is IFPRES = 0 (PRESSURE OFF), where NMOLEC is not called but MOLEC reads XNMOL as a punch deck, which must come after the BEGIN card. MOLEC prints the data as they are read in.

PRINT 3 and PRINT 4

Samples of the printout for these two options appear on the next two pages.

NLTE

If IFPRNT > 0, STATEQ(11) prints out H^- and H rates and b's, as shown on the third, fourth, and fifth pages following. If IFPNCH > 0, PUTOUT(7) punches the deck listed on the sixth page following.

SURFACE INTENSITY

PUTOUT prints and punches surface intensities instead of surface fluxes, as follows:

Print:

WAVE	FREQUENCY	TAUONE	TAUNU	MU	INTENSITY	
109.999	2.725403E+15	-2.04	1.83	1.000	1.732E-08	etc.

Punch:

FREQUENCY	2.725403E+15	1.000	1.732E-08	etc.
-----------	--------------	-------	-----------	------

#WAVELENGTH 109.999 FREQUENCY 2.725403E+15

	RHOX	TAUNU	ABTOT	ALPHA	BNU	SNU	JNU	JMNS	HNU
1	8.457E-05	0.	7.261E+00	4.224E-02	1.253E-08	1.233E-08	7.767E-09	-4.559E-09	4.052E-09
2	1.226E-04	1.053E-03	9.927E+00	3.199E-02	1.269E-08	1.252E-08	7.819E-09	-4.704E-09	4.047E-09
3	1.738E-04	1.655E-03	1.352E+01	2.447E-02	1.258E-08	1.249E-08	7.844E-09	-4.647E-09	4.044E-09
4	2.430E-04	2.737E-03	1.771E+01	1.944E-02	1.271E-08	1.259E-08	7.886E-09	-4.708E-09	4.039E-09
5	3.362E-04	4.631E-03	2.287E+01	1.567E-02	1.280E-08	1.273E-08	7.955E-09	-4.780E-09	4.030E-09
6	4.617E-04	7.896E-03	2.902E+01	1.284E-02	1.295E-08	1.286E-08	8.061E-09	-4.795E-09	4.014E-09
7	6.310E-04	1.346E-02	3.654E+01	1.060E-02	1.302E-08	1.299E-08	8.222E-09	-4.768E-09	3.988E-09
8	8.596E-04	2.281E-02	4.508E+01	8.906E-03	1.330E-08	1.322E-08	8.465E-09	-4.751E-09	3.943E-09
9	1.169E-03	3.839E-02	5.553E+01	7.472E-03	1.339E-08	1.338E-08	8.817E-09	-4.560E-09	3.871E-09
10	1.589E-03	6.420E-02	6.699E+01	6.362E-03	1.371E-08	1.368E-08	9.327E-09	-4.351E-09	3.756E-09
11	2.163E-03	1.066E-01	8.022E+01	5.444E-03	1.407E-08	1.405E-08	1.003E-08	-4.021E-09	3.579E-09
12	2.948E-03	1.756E-01	9.517E+01	4.688E-03	1.453E-08	1.451E-08	1.097E-08	-3.545E-09	3.318E-09
13	4.025E-03	2.874E-01	1.118E+02	4.064E-03	1.512E-08	1.511E-08	1.218E-08	-2.931E-09	2.958E-09
14	5.502E-03	4.664E-01	1.300E+02	3.550E-03	1.590E-08	1.589E-08	1.368E-08	-2.210E-09	2.501E-09
15	7.524E-03	7.501E-01	1.498E+02	3.123E-03	1.689E-08	1.688E-08	1.544E-08	-1.437E-09	1.993E-09
16	1.028E-02	1.193E+00	1.703E+02	2.778E-03	1.830E-08	1.829E-08	1.748E-08	-8.057E-10	1.513E-09
17	1.402E-02	1.866E+00	1.891E+02	2.517E-03	2.017E-08	2.017E-08	1.983E-08	-3.351E-10	1.153E-09
18	1.900E-02	2.858E+00	2.079E+02	2.304E-03	2.282E-08	2.282E-08	2.272E-08	-9.601E-11	9.632E-10
19	2.555E-02	4.277E+00	2.244E+02	2.144E-03	2.653E-08	2.653E-08	2.657E-08	4.046E-11	9.319E-10
20	3.392E-02	6.208E+00	2.352E+02	2.047E-03	3.217E-08	3.217E-08	3.227E-08	9.586E-11	1.073E-09
21	4.427E-02	8.666E+00	2.383E+02	2.016E-03	4.108E-08	4.106E-08	4.120E-08	1.434E-10	1.389E-09
22	5.655E-02	1.156E+01	2.318E+02	2.058E-03	5.557E-08	5.555E-08	5.583E-08	2.746E-10	2.057E-09
23	7.046E-02	1.467E+01	2.142E+02	2.195E-03	8.038E-08	8.027E-08	8.085E-08	5.820E-10	3.530E-09
24	8.546E-02	1.771E+01	1.897E+02	2.436E-03	1.248E-07	1.257E-07	1.283E-07	2.685E-09	7.908E-09
25	1.009E-01	2.036E+01	1.524E+02	2.915E-03	2.132E-07	2.132E-07	2.188E-07	5.647E-09	1.624E-08
26	1.166E-01	2.244E+01	1.122E+02	3.715E-03	3.877E-07	3.878E-07	4.089E-07	2.105E-08	4.252E-08
27	1.327E-01	2.393E+01	7.411E+01	5.113E-03	7.570E-07	7.575E-07	8.449E-07	8.739E-08	1.233E-07
28	1.503E-01	2.499E+01	4.498E+01	7.504E-03	1.519E-06	1.521E-06	1.862E-06	3.406E-07	3.548E-07
29	1.743E-01	2.580E+01	2.576E+01	1.183E-02	3.125E-06	3.138E-06	4.252E-06	1.114E-06	9.660E-07
30	2.090E-01	2.647E+01	1.473E+01	1.939E-02	6.541E-06	6.595E-06	9.295E-06	2.700E-06	2.353E-06
31	2.681E-01	2.714E+01	8.870E+00	3.122E-02	1.411E-05	1.426E-05	1.886E-05	4.601E-06	5.010E-06
32	3.705E-01	2.789E+01	6.040E+00	4.533E-02	3.027E-05	3.053E-05	3.596E-05	5.434E-06	9.083E-06
33	5.438E-01	2.880E+01	4.751E+00	5.789E-02	6.314E-05	6.342E-05	6.796E-05	4.543E-06	1.401E-05
34	8.277E-01	3.006E+01	4.237E+00	6.634E-02	1.272E-04	1.274E-04	1.304E-04	3.006E-06	1.897E-05
35	1.273E+00	3.191E+01	4.084E+00	7.089E-02	2.470E-04	2.471E-04	2.488E-04	1.664E-06	2.344E-05
36	1.956E+00	3.469E+01	4.061E+00	7.272E-02	4.599E-04	4.600E-04	4.608E-04	8.447E-07	2.684E-05
37	2.978E+00	3.887E+01	4.129E+00	7.205E-02	8.146E-04	8.146E-04	8.151E-04	4.085E-07	2.928E-05
38	4.482E+00	4.518E+01	4.263E+00	7.000E-02	1.390E-03	1.390E-03	1.390E-03	1.796E-07	3.092E-05
39	6.608E+00	5.442E+01	4.425E+00	6.752E-02	2.263E-03	2.263E-03	2.263E-03	6.511E-08	3.187E-05
40	9.585E+00	6.784E+01	4.578E+00	6.534E-02	3.561E-03	3.561E-03	3.561E-03	7.821E-08	3.225E-05

MINUS STATISTICAL EQUILIBRIUM

	RHOX	QSELECT	QASSOC	QCHIARG	QORDKHM	QORDMK	FMIN
1	8.457E-05	3.655E+02	7.304E+01	1.196E+04	6.328E+06	6.006E+06	1.0536
2	1.226E-04	5.126E+02	1.417E+02	1.681E+04	6.342E+06	6.007E+06	1.0556
3	1.738E-04	6.990E+02	2.663E+02	2.292E+04	6.332E+06	6.008E+06	1.0538
4	2.430E-04	9.322E+02	4.686E+02	3.063E+04	6.344E+06	6.009E+06	1.0555
5	3.362E-04	1.222E+03	7.986E+02	4.019E+04	6.352E+06	6.010E+06	1.0565
6	4.617E-04	1.577E+03	1.316E+03	5.199E+04	6.365E+06	6.012E+06	1.0581
7	6.310E-04	2.010E+03	2.126E+03	6.628E+04	6.371E+06	6.015E+06	1.0585
8	8.596E-04	2.552E+03	3.319E+03	8.365E+04	6.395E+06	6.019E+06	1.0616
9	1.169E-03	3.191E+03	5.140E+03	1.045E+05	6.403E+06	6.024E+06	1.0619
10	1.589E-03	3.971E+03	7.772E+03	1.305E+05	6.430E+06	6.031E+06	1.0646
11	2.163E-03	4.925E+03	1.161E+04	1.622E+05	6.460E+06	6.041E+06	1.0674
12	2.948E-03	6.094E+03	1.714E+04	2.010E+05	6.497E+06	6.054E+06	1.0705
13	4.025E-03	7.532E+03	2.504E+04	2.492E+05	6.544E+06	6.074E+06	1.0740
14	5.502E-03	9.314E+03	3.620E+04	3.093E+05	6.604E+06	6.101E+06	1.0779
15	7.524E-03	1.154E+04	5.187E+04	3.842E+05	6.677E+06	6.139E+06	1.0816
16	1.028E-02	1.440E+04	7.340E+04	4.792E+05	6.776E+06	6.193E+06	1.0861
17	1.402E-02	1.783E+04	1.026E+05	6.075E+05	6.899E+06	6.271E+06	1.0898
18	1.900E-02	2.244E+04	1.412E+05	7.691E+05	7.060E+06	6.380E+06	1.0930
19	2.555E-02	2.843E+04	1.908E+05	9.804E+05	7.264E+06	6.536E+06	1.0941
20	3.392E-02	3.635E+04	2.510E+05	1.268E+06	7.538E+06	6.758E+06	1.0938
21	4.427E-02	4.701E+04	3.190E+05	1.666E+06	7.904E+06	7.073E+06	1.0912
22	5.655E-02	6.141E+04	3.887E+05	2.224E+06	8.389E+06	7.518E+06	1.0855
23	7.046E-02	8.077E+04	4.483E+05	3.021E+06	9.034E+06	8.139E+06	1.0765
24	8.546E-02	1.086E+05	4.825E+05	4.073E+06	9.886E+06	9.001E+06	1.0648
25	1.009E-01	1.440E+05	4.680E+05	5.617E+06	1.106E+07	1.019E+07	1.0530
26	1.166E-01	1.850E+05	4.026E+05	7.632E+06	1.257E+07	1.179E+07	1.0391
27	1.327E-01	2.262E+05	2.922E+05	9.989E+06	1.457E+07	1.389E+07	1.0279
28	1.509E-01	2.575E+05	1.800E+05	1.229E+07	1.707E+07	1.653E+07	1.0183
29	1.743E-01	2.773E+05	9.667E+04	1.433E+07	2.021E+07	1.981E+07	1.0116
30	2.090E-01	2.934E+05	4.916E+04	1.643E+07	2.418E+07	2.390E+07	1.0070
31	2.681E-01	3.185E+05	2.558E+04	1.942E+07	2.940E+07	2.922E+07	1.0037
32	3.705E-01	3.641E+05	1.496E+04	2.428E+07	3.605E+07	3.596E+07	1.0015
33	5.438E-01	4.382E+05	1.000E+04	3.185E+07	4.438E+07	4.434E+07	1.0005
34	8.277E-01	5.460E+05	7.413E+03	4.282E+07	5.476E+07	5.474E+07	1.0001
35	1.273E+00	6.840E+05	5.788E+03	5.770E+07	6.770E+07	6.769E+07	1.0000
36	1.956E+00	8.463E+05	4.708E+03	7.782E+07	8.368E+07	8.368E+07	1.0000
37	2.978E+00	1.029E+06	3.984E+03	1.045E+08	1.030E+08	1.030E+08	1.0000
38	4.482E+00	1.226E+06	3.421E+03	1.387E+08	1.268E+08	1.268E+08	1.0000
39	6.608E+00	1.430E+06	2.983E+03	1.803E+08	1.553E+08	1.553E+08	1.0000
40	9.585E+00	1.633E+06	2.610E+03	2.300E+08	1.879E+08	1.899E+08	1.0000

STATISTICAL EQUILIBRIUM FOR HYDROGEN

RHOX	B1	B2	B3	B4	B5	B6
1 8.4569E-05	.9613	.9601	1.0720	1.0783	1.0362	1.0122
2 1.2256E-04	.9665	.9655	1.0649	1.0617	1.0276	1.0091
3 1.7384E-04	.9650	.9640	1.0548	1.0482	1.0211	1.0069
4 2.4299E-04	.9697	.9688	1.0475	1.0385	1.0165	1.0054
5 3.3616E-04	.9729	.9722	1.0404	1.0308	1.0130	1.0042
6 4.6172E-04	.9770	.9764	1.0344	1.0249	1.0104	1.0033
7 6.3103E-04	.9790	.9785	1.0287	1.0201	1.0083	1.0027
8 8.5962E-04	.9850	.9845	1.0248	1.0164	1.0067	1.0021
9 1.1687E-03	.9862	.9858	1.0206	1.0134	1.0054	1.0017
10 1.5889E-03	.9905	.9902	1.0178	1.0111	1.0045	1.0014
11 2.1628E-03	.9942	.9940	1.0154	1.0092	1.0037	1.0012
12 2.9481E-03	.9976	.9974	1.0135	1.0077	1.0030	1.0009
13 4.0250E-03	1.0005	1.0004	1.0118	1.0064	1.0025	1.0008
14 5.5016E-03	1.0029	1.0029	1.0104	1.0054	1.0021	1.0006
15 7.5241E-03	1.0043	1.0043	1.0090	1.0045	1.0017	1.0005
16 1.0283E-02	1.0056	1.0056	1.0079	1.0037	1.0014	1.0004
17 1.4016E-02	1.0057	1.0057	1.0068	1.0031	1.0011	1.0003
18 1.9004E-02	1.0052	1.0052	1.0057	1.0025	1.0009	1.0003
19 2.5549E-02	1.0038	1.0038	1.0045	1.0019	1.0007	1.0002
20 3.3922E-02	1.0024	1.0024	1.0035	1.0015	1.0005	1.0002
21 4.4269E-02	1.0012	1.0011	1.0026	1.0011	1.0004	1.0001
22 5.6550E-02	1.0001	1.0001	1.0018	1.0007	1.0003	1.0001
23 7.0464E-02	.9994	.9993	1.0012	1.0005	1.0002	1.0000
24 8.5456E-02	.9990	.9989	1.0007	1.0003	1.0001	1.0000
25 1.0092E-01	.9992	.9992	1.0005	1.0002	1.0001	1.0000
26 1.1660E-01	.9993	.9993	1.0002	1.0001	1.0000	1.0000
27 1.3275E-01	.9996	.9996	1.0002	1.0001	1.0000	1.0000
28 1.5092E-01	.9997	.9997	1.0001	1.0000	1.0000	1.0000
29 1.7426E-01	.9998	.9998	1.0000	1.0000	1.0000	1.0000
30 2.0899E-01	.9999	.9999	1.0000	1.0000	1.0000	1.0000
31 2.6808E-01	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
32 3.7049E-01	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
33 5.4375E-01	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
34 8.2768E-01	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
35 1.2729E+00	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
36 1.9561E+00	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
37 2.9784E+00	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
38 4.4825E+00	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
39 6.6085E+00	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
40 9.5853E+00	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

READ DEPARTURE	COEFFICIENTS	40	RHOX	BHYD	1-6	BMIN	
8.4569E-05	.9613	.9601	1.0720	1.0783	1.0362	1.0122	1.0536
1.2256E-04	.9665	.9655	1.0649	1.0617	1.0276	1.0091	1.0556
1.7384E-04	.9650	.9640	1.0548	1.0482	1.0211	1.0069	1.0538
2.4299E-04	.9697	.9688	1.0475	1.0385	1.0165	1.0054	1.0555
3.3616E-04	.9729	.9722	1.0404	1.0308	1.0130	1.0042	1.0565
4.6172E-04	.9770	.9764	1.0344	1.0249	1.0104	1.0033	1.0581
6.3103E-04	.9790	.9785	1.0287	1.0201	1.0083	1.0027	1.0585
8.5962E-04	.9850	.9845	1.0248	1.0164	1.0067	1.0021	1.0616
1.1687E-03	.9862	.9858	1.0206	1.0134	1.0054	1.0017	1.0619
1.5889E-03	.9905	.9902	1.0178	1.0111	1.0045	1.0014	1.0646
2.1628E-03	.9942	.9940	1.0154	1.0092	1.0037	1.0012	1.0674
2.9481E-03	.9976	.9974	1.0135	1.0077	1.0030	1.0009	1.0705
4.0250E-03	1.0005	1.0004	1.0118	1.0064	1.0025	1.0008	1.0740
5.5016E-03	1.0029	1.0029	1.0104	1.0054	1.0021	1.0006	1.0779
7.5241E-03	1.0043	1.0043	1.0090	1.0045	1.0017	1.0005	1.0816
1.0283E-02	1.0056	1.0056	1.0079	1.0037	1.0014	1.0004	1.0861
1.4016E-02	1.0057	1.0057	1.0068	1.0031	1.0011	1.0003	1.0898
1.9004E-02	1.0052	1.0052	1.0057	1.0025	1.0009	1.0003	1.0930
2.5549E-02	1.0038	1.0038	1.0045	1.0019	1.0007	1.0002	1.0941
3.3922E-02	1.0024	1.0024	1.0035	1.0015	1.0005	1.0002	1.0938
4.4269E-02	1.0012	1.0011	1.0026	1.0011	1.0004	1.0001	1.0912
5.6550E-02	1.0001	1.0001	1.0018	1.0007	1.0003	1.0001	1.0855
7.0464E-02	.9994	.9993	1.0012	1.0005	1.0002	1.0000	1.0765
8.5456E-02	.9990	.9989	1.0007	1.0003	1.0001	1.0000	1.0648
1.0092E-01	.9992	.9992	1.0005	1.0002	1.0001	1.0000	1.0530
1.1660E-01	.9993	.9993	1.0002	1.0001	1.0000	1.0000	1.0391
1.3275E-01	.9996	.9996	1.0002	1.0001	1.0000	1.0000	1.0279
1.5092E-01	.9997	.9997	1.0001	1.0000	1.0000	1.0000	1.0183
1.7426E-01	.9998	.9998	1.0000	1.0000	1.0000	1.0000	1.0116
2.0899E-01	.9999	.9999	1.0000	1.0000	1.0000	1.0000	1.0070
2.6808E-01	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0037
3.7049E-01	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0015
5.4375E-01	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0005
8.2768E-01	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0001
1.2729E+00	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1.9561E+00	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2.9784E+00	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
4.4825E+00	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
6.6085E+00	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
9.5853E+00	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

8.4 Programing Details of ATLAS5

ATLAS5 is programed in essentially machine-independent FORTRAN IV. The whole program can be logically divided into six blocks of subroutines:

MAIN	READIN	POPS	KAPP		JOSH	CONVEC
ATLAS5	READIN	POPS	KAPP	HOP	JOSH	CONVEC
PUTOUT	DUMMYR	NELECT	COULX	COULFF	BLOCKJ	HIGH
TCORR	FREEFR	PFSAHA	H2PLOP	HMINOP	BLOCKH	TURB
STATEQ	FREEFF	MOLEC	HRAYOP	HE1OP		
ROSS	IWORDF	NMOLEC	HE2OP	HEMIOP		
RADIAP	TTAUP		HERAOP	COOLOP		
DERIV	BLOCKE		C1OP	SEATON		
INTEG	BLOCKR		MG1OP	AL1OP		
PARCOE			SI1OP	LUKEOP		
MAP1			N1OP	O1OP		
SOLVIT			MG2OP	SI2OP		
EXPI			CA2OP	HOTOP		
W			ELECOP	H2RAOP		
			HLINOP	STARK		
			LINOP	LINSOP		
			XLINOP	XLISOP		
			XCONOP	XSOP		

As presented in this report, the blocks are not distinguished but are loaded together. This requires slightly less than 120000 octal locations on a CDC 6400. If the molecule routines were completely integrated without use of blank COMMON, the requirement would be about 130000. However, it is more often necessary to cut down on field length, in which case subroutines that are not used can be replaced by dummies or the blocks can be treated as overlays.

Some possible deletions are as follows:

if no statistical equilibrium, STATEQ;

if no molecules, MOLEC and NMOLEC;

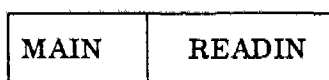
if opacity not needed, LUKEOP and its functions or HOTOP, etc.;

if no convection, CONVEC.

Some modification is required to set up overlays because of calls to block POPS from several points in block KAPP. The opacity routines call POPS individually so that they are completely self-contained for easy deletion or change. The calls to POPS can be removed from the subroutines and put into ATLAS5, and the data can be transmitted to the subroutines through additional common blocks.

The overlay layout would be as follows:

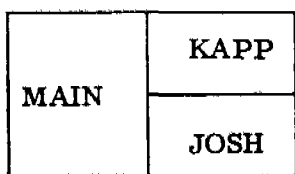
Start model



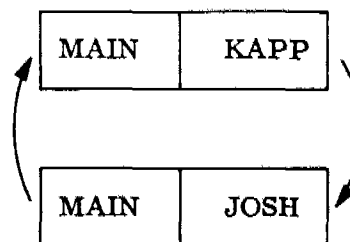
Start iteration



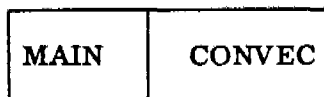
Start frequency integration



or



Finish iteration



The second alternative for KAPP and JOSH would require changing overlays at every frequency.

8.5 Subroutines

ATLAS5(1)	We discussed ATLAS5 fully in Section 8. 1.
PUTOUT(4)	Output (see Section 8. 1). The only thing to mention here is that there are alternate formats for different p scaling on different computers.
TCORR(8)	Temperature correction (see Sections 7 and 8. 1).
STATEQ(11)	Statistical equilibrium (see Sections 3. 5, 3. 6, 8. 1, and 8. 3).
ROSS(13)	Rosseland opacity and optical depth (see Section 2. 12).
RADIAP(14)	Radiation pressure (see Section 2. 11).
DERIV(14)	Derivatives (see Section 2. 8). A scaling factor is included to avoid truncation problems.
INTEG(15)	Integrals (see Section 2. 5). Uses PARCOE.
PARCOE(15)	Parabolic interpolation coefficients (see Section 2. 5).
MAP1(16)	Parabolic interpolation. (Maps one vector at a time.) Uses same formulas as PARCOE but is faster. MAP1 is set equal to the number of points required for the inverse interpolation, as in JOSH.
SOLVIT(17)	Solves linear equations using Gauss-Jordan elimination.
EXPI(18)	Exponential integrals.

W(18) Writes debugging aids. For example, CALL W(6HOPACIT, AHYD, 1000) would produce an opacity table 1000 words long, and CALL W(6HI , FLOAT(I), 1) would print a subscript.

READIN(19) Reads input (see Sections 8.1 and 8.2). This routine is very long, but the logic is easy to follow once FREEFR, FREEFF, and IWORDF are understood. Data not read in are filled in from BLOCKE and BLOCKR. The printout is produced in the section with statement numbers in the 1500's.

DUMMYR(28) Dummy routine for modifying READIN.

FREEFF(29) Free-field function for reading numbers. FREEFF is called once for every number required from array CARD. CARD is an array of LAST Hollerith characters, the last one of which must be a blank. The most convenient way to read cards is to dimension an array CARD for 80, equivalence a blank to CARD(81), and set LAST to 81. In general, there is no restriction on the length of CARD, nor does LAST have to be the last member of CARD (but simply the last member to be searched). To find a number, FREEFF sets IFFAIL to 0 and starts searching through CARD, starting at CARD(NUMCOL), for any field in an E, F, or I format that is followed by either a comma or a blank and with an exponent less than MAXPOW. If FREEFF does not find a number, it calls EXIT when MORE = 0, or it returns with a 0. and IFFAIL = 1 when MORE = 1. When FREEFF returns, NUMCOL is set at the blank or the comma marking the end of the number. All numbers are returned floating point, so an integer is produced with a statement like M=FREEFF(CARD).

FREEFR(30) Free-field routine for reading numbers from cards. FREEFR calls FREEFF with MORE = 1. If FREEFF does not find a number, FREEFR reads another card and calls FREEFF again.

- IWORDF(31)** Free-field function for reading words as integers. Any method for reading words in a machine-independent fashion turns out to be rather cumbersome. The approach here is based on converting each letter or digit to an integer, then combining the integers into one large integer. The maximum word length is set by the computer with the smallest integer size, $2^{31}-1$ for an IBM 360. This allows 6-digit base-37 numbers, so that words of up to six characters can be converted uniquely. Words longer than six characters are truncated after the first six. The processing logic for IWORDF is similar to that for FREEFF except that LETCOL marks the starting place. Words can be made up of any number of letters and decimal digits as long as the word starts with a letter. Ends of words are marked by blanks, commas, or equal signs. IWORDF also stores the characters it reads in array WORD.
- TTAUP(34)** Solves the pressure-balance equation for a $T(\tau)$ distribution (see Section 4.2). TTAUP uses an opacity table, which is produced by a special version of ATLAS5, listed in Section 9. TTAUP is currently set up for Rosseland depths and Rosseland opacity for $3100 < T < 28000$ and $0.01 < P < 10^6$. The table would have to be recalculated for significantly higher or lower temperatures or pressures or for radically nonstandard abundances. Opacities other than Rosseland can also be used.
- BLOCKE(32)** This is actually a BLOCK DATA for COMMON /ELEM/.
- BLOCKR(33)** This is actually a BLOCK DATA for many of the COMMON's that appear in READIN.
- POPS(37)** Populations (see Section 8.1). The argument MODE can take the values
- 1 or 11 for the number density/partition function of the atom
or molecule CODE;

2 or 12 for the number density of the atom or molecule CODE.

If IFMOL = 1, calls to POPS must be all 1's and 11's
or 2's and 12's.

11 and 12 are the same as 1 and 2 except that if CODE is an atom,
POPS returns all ionization stages through CODE.

NELECT(38) Finds the electron number (see Sections 4.3, 4.4, and 8.1). The
only point we have not already discussed is that the iteration is
speeded up by dropping elements from the calculation if they con-
tribute less than 10^{-5} of the electrons.

PFSAHA(39) Partition functions, Saha equations for ionization fractions (see
Sections 4.4 and 8.1). Since the partition-function table is com-
plicated, the easiest way to explain it is to decode an example.
For 2.01 the table reads

200020001, 200020071, 208524971, 382669341, 128222452, 5440302, D+F

The code letters at the end of the row refer to the source, Drawin
and Felenbok. Others refer to the ground state only, summed energy
levels, and fake sources for the partition function. The number
5440302 decodes into the ionization potential, 54.403, and the scaling
factor G, 2. The other numbers decode into the partition function
at 10 temperatures, as follows:

	T	U
54.403* 2000/22 *	3 = 14837	2.000
	5 = 24728	2.000
	7 = 34620	2.000
	9 = 44511	2.007
	11 = 54403	2.085
	13 = 64294	2.497
	15 = 74186	3.826
	17 = 84077	6.934
	19 = 93969	12.82
	21 = 103860	22.45

For any given T , the partition function is found by linear interpolation or extrapolation in this table. PFSAHA finds the ionization fractions by first computing n^{1+1}/n^1 for the ions considered, then solving the equation

$$\frac{n^1}{n} + \frac{n^1}{n} \frac{n^2}{n^1} + \frac{n^1}{n} \frac{n^2}{n^1} \frac{n^3}{n^2} + \dots = 1$$

for n^1/n , and finally constructing each ionization fraction n^1/n .

MOLEC(48)	Molecular and atomic number densities/partition functions (see Sections 8.1 and 8.3).
NMOLEC(50)	Solves molecular equilibrium equations (see Sections 4.3, 4.4, 8.1, and 8.3). We have described the general features, but the details are too complicated to explain without going through every statement. In ATLAS5, NMOLEC is called with a MODE 1 or 11 to get number densities/partition functions, but for other applications it can be called with a MODE 2 or 12 to get number densities.
KAPP(55)	See Sections 5 and 8.1.
HOP(56)	Uses COULX and COULFF (see Section 5.1).
COULX(57)	See Section 5.1.
COULFF(57)	See Section 5.1.
H2PLOP(58)	See Section 5.2.
HMINOP(58)	See Section 5.3.
HRAYOP(57)	See Section 5.4.
HEIOP(59)	Uses COULFF (see Section 5.5).

HE2OP(60)	Uses COULX and COULFF (see Section 5.6).
HEMIOP(60)	See Section 5.7.
HERAOP(61)	See Section 5.8.
COOLOP(61)	Uses C1OP, MG1OP, AL1OP, and SI1OP (see Section 5.9).
C1OP(62)	Uses SEATON (see Section 5.9).
SEATON(62)	Seaton's cross-section formula, $a_{\nu} = a_0 \left[A \left(\frac{\nu_0}{\nu} \right)^p + (1 - A) \left(\frac{\nu_0}{\nu} \right)^{p+1} \right] .$
MG1OP(63)	See Section 5.9.
AL1OP(62)	See Section 5.9.
SI1OP(64)	See Section 5.9.
LUKEOP(65)	Uses N1OP, O1OP, MG2OP, SI2OP, and CA2OP (see Section 5.10).
N1OP(65)	Uses SEATON (see Section 5.10).
O1OP(65)	Uses SEATON (see Section 5.10).
MG2OP(66)	Uses SEATON (see Section 5.10).
SI2OP(67)	See Section 5.10.
CA2OP(66)	Uses SEATON (see Section 5.10).

HOTOP(68)	See Section 5. 11. The last column in the table is a subscript for identifying ions in XNFP. In DO 10, those cross sections that do not contribute a significant amount of opacity are passed over.
ELECOP(70)	See Section 5. 12.
H2RAOP(70)	See Section 5. 13.
HLINOP(71)	Uses STARK (see Section 5. 14).
STARK(72)	See Section 5. 14.
LINOP(73)	See Section 5. 15.
LINSOP(73)	See Section 5. 16.
XLINOP(73)	See Section 5. 17.
XLISOP(73)	See Section 5. 18.
XCONOP(73)	See Section 5. 19.
XSOP(73)	See Section 5. 20.
JOSH(74)	Finds J and S and H (and I) (see Sections 2. 7, 2. 8, 2. 9, 5, and 8. 1).
BLOCKJ(77)	This is actually a BLOCK DATA for COMMON /MATX/. The data are computed by program PRETAB, listed in Section 9. 2.
BLOCKH(86)	This is actually a BLOCK DATA for COMMON /MATX/. The data are computed by PRETAB.

CONVEC(96)	Calculates thermodynamic derivatives and convective flux (see Sections 4.6 and 6).
HIGH(99)	Geometric height in kilometers (see Section 4.5).
TURB(99)	Turbulent velocity and pressure (see Section 4.1).

8.6 Listing of ATLAS5

```

PROGRAM ATLAS5(INPUT=513,OUTPUT=513,PUNCH=513,TAPE5=INPUT,
1 TAPE6=OUTPUT,TAPE7=PUNCH)
COMMON /ABROSS/ABROSS(40),TAUROS(40)
COMMON /ABTOT/ABTOT(40),ALPHA(40)
COMMON /CONV/DLTDL(40),HEATCP(40),DLRDLT(40),VELSND(40),
1 GRDADB(40),HSCALE(40),FLXCNV(40),VCONV(40),MIXLTH,
2 IFCONV
REAL MIXLTH
COMMON /DEPART/BHYD(40,6),BMIN(40),NLTEON
COMMON /ELEM/ABUND(99),ATMASS(99),ELEM(99)
COMMON /FLUX/ FLUX,FLXERR(40),FLXDRV(40),FLXRAD(40)
COMMON /FREQ/FREQ,FREQLG,EHVKT(40),STIM(40),BNJ(40)
COMMON /FRESE/FRESE(500),RCOSET(500),NULO,NULI,NUMNJ
COMMON /HEIGHT/HEIGHT(40)
COMMON /IF/IFCORR,IFPRES,IFSURF,IFSCAT,IFMOL
COMMON /IFOP/IFOP(20)
COMMON /IONS/XNFP(40,2),XNFPHE(40,3)
COMMON /ITER/ ITER,IFPRNT(15),IFPNC(15),NUMITS
COMMON /JUNK/TITLE(74),FREQID(6),WLTE,XSCALE
COMMON /MUS/ANGLE(20),SURFI(20),NMU
COMMON /OPS/AHYD(40),AH2P(40),AHMIN(40),SIGH(40),AHE1(40),
1 AHE2(40),AHEMIN(40),SIGHE(40),ACOO(40),ALUKE(40),AHOT(40),
2 SIGEL(40),SIGH2(40),AHLIN(40),ALINES(40),SIGLIN(40),
3 AXLINE(40),SIGXL(40),AXCONT(40),SIGX(40),SHYD(40),
4 SHMIN(40),SHLINE(40),SXLIN(40),SXCONT(40)
COMMON /OPTOT/ACONT(40),SCONT(40),ALINE(40),SLINE(40),SIGMAC(40),
1 SIGMAL(40)
COMMON /PTOTAL/PTOTAL(40)
COMMON /PUT/PUT,IPUT
COMMON /RAD/ ACCRAD(40),PRAD(40)
COMMON /RHOX/RHOX(40),NRHOX
COMMON /STATE/P(40),XNE(40),XNATOM(40),RHO(40)
COMMON /TAUSHJ/TAUNU(40),SNJ(40),HNU(40),JNU(40),JMINS(40)
REAL JNJ,JMINS
COMMON /TEFF/TEFF,GRAV,GLOG
COMMON /TEMP/T(40),TKEV(40),TK(40),HKT(40),TLOG(40),ITEMP
COMMON /TURBPR/VTURB(40),PTJRB(40),TRBFDG,TRBCON,TRBPOW,TRBSND,
1 IFTURB
COMMON /WAVEY/WBEGIN,DELTA,IFWAVE
COMMON /XABUND/XABUND(99),WTMOLE
C <=1.38054E-16
C H=6.6256E-27
C C=2.997925E10
C E=1.60210E-19
C ATMASS=1.660E-24
C
C INPUT SECTION
C PREFIX P PRESSURE
C PREFIX T TEMPERATURE
C PREFIX X ABUNDANCE FRACTION
C PREFIX F IONIZATION FRACTION
C PREFIX R FREQUENCY INTEGRAL OR INTEGRATION COEFFICIENT
C PREFIX A OR AB MASS ABSORPTION COEFFICIENT
C PREFIX XNFP NUMBER DENSITY OVER PARTITION FUNCTION
C ALPHA IS THE FRACTION OF OPACITY CAUSED BY SCATTERING
C NLTEON=0 LTE
C NLTEON=1 NLTE
C BHYD STATISTICAL EQUILIBRIUM FACTOR FOR HYDROGEN
C BMIN STATISTICAL EQUILIBRIUM FACTOR FOR HMINUS

```

```

C      ABUND CONTAINS THE NORMALLY ASSUMED ABUNDANCES
C      ELEM CONTAINS THE LETTER CODES FOR ELEMENTS
C      RCOSET HAS INTEGRATION COEFFICIENTS FOR THE FREQUENCIES IN FRESET
C      NUMNU  NUMBER OF FREQUENCIES IN THE FREQUENCY SET
C      NULO  NUMBER OF THE FREQUENCY AT WHICH INTEGRATION STARTS
C      NUHI  NUMBER OF THE FREQUENCY AT WHICH INTEGRATION STOPS
C      IFCORR  TEMPERATURE CORRECTION ON OR OFF
C      IFPRES  PRESSURE INTEGRATION ON OR OFF
C      IFSJRF=0  CALCULATE FLUX FOR EVERY DEPTH
C      IFSJRF=1  CALCULATE FLUX AT SURFACE ONLY
C      IFSJRF=2  CALCULATE INTENSITY AT SURFACE
C      IFSCAT=0  NO SCATTERING IN SOURCE FUNCTION  SNU=BNU
C      IFSCAT=1  SCATTERING IN SOURCE FUNCTION  SOLVE MATRIX EQUATION
C      IFMOL=1  SET UP EQUILIBRIUM EQUATIONS FOR NUMBER DENSITIES
C      IFMOL=0  ASSUME NO MOLECULES AND ITERATE FOR NUMBER DENSITIES
C      NUMITS  NUMBER OF ITERATIONS
C      FREQID IS A LABEL FOR THE FREQUENCY SET
C      XSCALE IS A SCALING FACTOR FOR METAL ABUNDANCES
C      IFPRNT(I)=0  DO NOT PRINT ANYTHING FOR ITERATION I
C      IFPRNT(I)=1  PRINT MINIMAL SUMMARY TABLE AT END OF ITERATION
C      IFPRNT(I)=2  PRINT ALL FREQUENCY INDEPENDENT DATA
C      IFPRNT(I)=3  PRINT SNU,TAUNU,JNU,ETC.
C      IFPRNT(I)=4  PRINT OPACITIES
C      IFPNCH(I)=0  DO NOT PUNCH FOR ITERATION I
C      IFPNCH(I)=1  PUNCH STRUCTURE
C      IFPNCH(I)=2  PUNCH STRUCTURE AND SURFACE FLUX OR INTENSITY
C      IFPNCH(I)=5  PUNCH 2 AND MOLECULAR NUMBER DENSITIES/PART FVS
C      FOR IFSJRF=2  HAVE NMU ANGLES
C      IFWAVE=1  STEP NUMNU WAVELENGTHS STARTING AT WBEGIN BY WSTEP
C      XABUND ARE THE ABUNDANCES USED IN THE MODEL
C      EXP10(X)=EXP(X*2.30258509299405E0)
C      ITEMP=0
1  CALL READIN(1)

C
C      ITERATION SECTION
C      DO 100 ITERAT=1,NUMITS
C      ITER=ITERAT
C      CHANGING ITEMP TELLS THE SUBROUTINES THEY HAVE A NEW TEMPERATURE
C      ITEMP=ITEMP+ITER

C
C      IF(IFPRES.EQ.0)GO TO 12
C      INTEGRATE EQUATION OF HYDROSTATIC EQUILIBRIUM
C      DO 11 J=1,NRHGX
C      PTOTAL(J)=GRAV*RHGX(J)
11  P(J)=PTOTAL(J)-PRAD(J)-PTURB(J)
C      IF(RHGX(1).EQ.0.)P(1)=P(2)/2.
C      IF(RHGX(1).EQ.0.)PTOTAL(1)=PTOTAL(2)/2.
C      CALL POPS(0.,1,XNE)
12  CONTINUE
C      CALL PUTOUT(1)

C
C      ERASE FREQUENCY INTEGRALS
C      IF(IFCORR.EQ.1)CALL TCORR(1,0)
C      CALL ROSS(1,0)
C      CALL RADIAP(1,0)
C      IF(NLTEON.EQ.1)CALL STATEQ(1,0)

C
C      FREQUENCY INTEGRATION SECTION
C      DO 25 NU=NULO,NUHI
C      IF(IFWAVE.EQ.0)GO TO 21

```



```

WAVE=WBEGIN*FLOAT(NU-NULO)*DELTAW
FREQ=2.997925E17/WAVE
RCO=ABS(DELTAW/WAVE*FREQ)
GO TO 22
21 FREQ=FRESET(NU)
RCO=RCOSET(NU)
22 FREQLG=ALOG(FREQ)
DO 20 J=1,NRHOX
EHVKT(J)=EXP(-FREQ*HKT(J))
STIM(J)=1.-EHVKT(J)
20 BNU(J)=1.47439E-47*FREQ**3*EHVKT(J)/STIM(J)
CALL PUTOUT(2)
N=0
24 N=N+1
CALL KAPP(N,NSTEPS,STEPWT)
CALL JDSH(IFSCAT,IFSURF)
RCOWT=RCO*STEPWT
C
IF(IFSURF.GT.0)GO TO 23
IF(IFCORR.EQ.1)CALL TCORR(2,RCOWT)
CALL RADIAP(2,RCOWT)
CALL ROSS(2,RCOWT)
IF(NLTEON.EQ.1)CALL STATEQ(2,RCOWT)
C
THIS PASSES VALUE OF STEPWT TO PUTOUT
23 PUT=STEPWT
IPUT=NSTEPS
CALL PUTOUT(3)
IF(N.LT.NSTEPS)GO TO 24
CALL PUTOUT(4)
25 CONTINUE
IF(IFSURF.GT.0)GO TO 1
C
FINISH ITERATION
C
CALL ROSS(3,0)
IF(IFPRES.EQ.1)CALL CONVEC
CALL RADIAP(3,0)
IF(IFCORR.EQ.1)CALL TCORR(3,0)
IF(NLTEON.EQ.1)CALL STATEQ(3,0)
CALL HIGH
IF(IFTURB.EQ.1)CALL TURB
CALL PUTOUT(5)
C
100 CONTINUE
GO TO 1
END

```

```

SUBROUTINE PUTOUT(MODE)
COMMON /ABROSS/ABROSS(40),TAJROS(40)
COMMON /ABTOT/ABTOT(40),ALPHA(40)
COMMON /CONV/DLTDLP(40),HEATCP(40),DLRDLT(40),VELSND(40),
1      GRDADB(40),HSCALE(40),FLXCNV(40),VCONV(40),MIXLTH,
2      IFCONV
REAL MIXLTH
COMMON /DEPART/BHYD(40,6),BMIN(40),NLTEON
COMMON /ELEM/ABUND(99),ATMASS(99),ELEM(99)
COMMON /FLUX/ FLUX,FLXERR(40),FLXDRV(40),FLXRAD(40)
COMMON /FREQ/FREQ,FREQLG,EHVKT(40),STIM(40),BNJ(40)
COMMON /FRESE/FRESE(500),RCOSET(500),NULO,NU-I,NUMNJ
COMMON /HEIGHT/HEIGHT(40)
COMMON /IF/IFCORR,IFPRES,IFSJRF,IFSCAT,IFMOL
COMMON /IFOP/IFOP(20)
COMMON /IONS/XNFPH(40,2),XNFPHE(40,3)
COMMON /ITER/ ITER,IFPRNT(15),IFPNCH(15),NUMITS
COMMON /JUNK/TITLE(74),FREQID(6),WLTE,XSCALE
COMMON /MUS/ANGLE(20),SURFI(20),NMJ
COMMON /OPS/AHYD(40),AH2P(40),AHMIN(40),SIGH(40),AHE1(40),
1      AHE2(40),AHEMIN(40),SIGHE(40),ACCOOL(40),ALUKE(40),AHOT(40),
2      SIGEL(40),SIGH2(40),AHLIN(40),ALINES(40),SIGLIN(40),
3      AXLINE(40),SIGXL(40),AXCONT(40),SIGX(40),SHYD(40),
4      SHMIN(40),SHLINE(40),SXLIN(40),SXCONT(40)
COMMON /OPTOT/ACONT(40),SCONT(40),ALINE(40),SLINE(40),SIGMAC(40),
1      SIGMAL(40)
COMMON /PTOTAL/PTOTAL(40)
COMMON /PUT/PUT,IPUT
COMMON /RAD/ ACCRAD(40),PRAD(40)
COMMON /RHOX/RHOX(40),NRHOX
COMMON /STATE/P(40),XNE(40),XNATOM(40),RHO(40)
COMMON /TAUSHJ/TAUNU(40),SNJ(40),HNU(40),JNU(40),JMIN(40)
REAL JNU,JMIN
COMMON /TEFF/TEFF,GRAV,LOGG
COMMON /TEMP/T(40),TKEV(40),TK(40),HKT(40),TLOG(40),ITEMP
COMMON /TURBPR/VTURB(40),PTJRB(40),TRBFDG,TRBCON,TRBPOW,TRBSND,
1      IFTURB
COMMON /WAVEY/WBEGIN,DELTAW,IFWAVE
COMMON /XABUND/XABUND(99),WTMOLE
DIMENSION SURFIN(20),F(20),DUMMY(40,25),ABLOG(20)
EQUIVALENCE (DUMMY(1),AHYD(1)),(F(1),STIM(1))
DATA ON,OFF/3HON ,3HOFF/
EXP10(X)=EXP(X*2.30258509299405E0)

C
GO TO(100,200,300,400,500),MODE

C
C HEADINGS
100 IF(IFPRNT(ITER).EQ.0)RETURN
IFHEAD=0
NU=NULO-1
RETURN

C
C INITIALIZE SUMS OVER STEPS
200 HSURF=0.
HNU(1)=0.
WAVE=2.997925E17/FREQ
NU=NU+1
DO 201 MU=1,NMU
201 SURFIN(MU)=0.
N=0

```

```

      RETURN
C
C      SUM OVER STEPS AND STEP DEPENDENT QUANTITIES
300 N=N+1
      NSTEPS=IPUT
      STEPWT=PUT
      HSURF=HSURF+HNU(1)*STEPWT
      DO 301 MU=1,NMU
301 SURFIN(MU)=SURFIN(MU)+SURFI(MU)*STEPWT
      IF(IFPRNT(ITER).EQ.0)RETURN
      IF(NSTEPS.EQ.1)GO TO 310
      IF(IFHEAD.EQ.0)WRITE(6,101)
      IFHEAD=1
      IF(N.EQ.1)WRITE(6,303)
303 FORMAT(1H0)
      HNULG=ALOG10(HNU(1))
      IDUM=MAP1(TAUNU,RHOX,NRHOX,1.,RHOX1,1)
      RHOX1=ALOG10(RHOX1)
      TAUEND=ALOG10(TAUNU(NRHOX))
      WRITE(6,305)STEPWT,HNU(1),HNULG,RHOX1,TAUEND
305 FORMAT(61X,F10.8,1PE13.4,0PF12.5,19X,2F6.2)
C 305 FORMAT(61X,F10.8,0PE13.4,0PF12.5,19X,2F6.2)
310 IF(IFPRNT(ITER).EQ.4)GO TO 320
      IF(IFPRNT(ITER).NE.3)RETURN
      WRITE(6,312)WAVE,FREQ,(J,RHOX(J),TAUNJ(J),ABTOT(J),
      1ALPHA(J),BNU(J),SNU(J),JNU(J),JMIN(J),HNU(J),J=1,NRHOX)
C 312 FORMAT(1H1//6X10HWAWELENGTHF9.3,3X9HFREQUENCY0PE13.6/
312 FORMAT(1H1//6X10HWAWELENGTHF9.3,3X9HFREQUENCY1PE13.6/
      1/12X4HRHOX,7X5HTAUNU,6X5HABTOT,5X5HALPHA,8X3HBNU,8X3HSNU,
      28X3HJNU,7X5HJMIN,7X3HHNU/(6X12.1P9E11.3))
C 28X3HJNU,7X5HJMIN,7X3HHNU/(6X12.0P9E11.3))
      RETURN
320 WRITE(6,321)
321 FORMAT(126H1          AHYD AH2P AHMIN SIGH AHE1 AHE2 AHEMIN SIGHE
      1 ACQOL ALUKE AHOT SIGEL SIGH2 AHLINELINESSIGLINAXLINE SIGXLAXCONT
      2 SIGX)
      DO 325 J=1,NRHOX
      DO 322 I=1,20
      ABLOG(I)=0.
      IF(DUMMY(J,I).GT.0.)ABLOG(I)=ALOG10(DJMMY(J,I))
322 CONTINUE
325 WRITE(6,326)J,ABLOG,J
326 FORMAT(14,2X20F6.2,1X13)
      RETURN
C
C      PRINT SJMS OVER STEPS
400 IF(IFPRNT(ITER).EQ.0)RETURN
      IDUM=MAP1(TAUNU,RHOX,NRHOX,1.,RHOX1,1)
      RHOX1=ALOG10(RHOX1)
      TAUEND=ALOG10(TAUNU(NRHOX))
      IF(NSTEPS.GT.1)RHOX1=0.
      IF(NSTEPS.GT.1)TAUEND=0.
      IF(IFSURF.NE.0.AND.IFSURF.NE.1)GO TO 405
      IF(IFHEAD.EQ.0)WRITE(6,101)
101 FORMAT(1H1/////10X4HWAVE,7X7HHLAMBDA,7X5HLOG H,7X3HMAG,
      110X9HFREQUENCY,8X3HHNU,10X5HLOG H,7X3HMAG,10X6HTAUONE,6H TAUNU)
      IFHEAD=1
      IF(HSURF.LE.0.)HSURF=1.E-30
      HLAM=HSURF*FREQ/WAVE
      HNULG=ALOG10(HSURF)

```

```

      HLAMLG=ALOG10(HLAM)
      HLAMMG=-2.5*HLAMLG
      HNULG=-2.5*HNULG
      WRITE (6,401) NU,WAVE,HLAM,HLAMLG,HLAMMG,FREQ,HSURF,HNULG,HNUMG,
      1 RHGX1,TAUEND,NU
C 401 FORMAT(15,F11.3,0PE13.4,0PF12.5,F10.3,0PE20.6,E13.4,0PF12.5,F10.3,
401 FORMAT(15,F11.3,1PE13.4,0PF12.5,F10.3,1PE20.6,E13.4,0PF12.5,F10.3,
      1 9X2F6.2,15)
405 IF(IFSURF.NE.2)GO TO 410
      IF(IFHEAD.EQ.0)WRITE(6,102)
402 FORMAT(1H1/////10X4HWAVE,5X9HFREQUENCY,3X12HTAUONE TAJNU,
      15(17H MU INTENSITY ))
      IFHEAD=1
      WRITE(6,406) NU,WAVE,FREQ,RHGX1,TAUEND,
      1 (ANGLE(MU),SURFIN(MU),MU=1,NMU)
406 FORMAT(15,F10.3,1PE15.6,0P2F6.2,(5(0PF6.3,1PE11.3)))
C 406 FORMAT(15,F10.3,0PE15.6,0P2F6.2,(5(0PF6.3,0PE11.3)))
410 IF(IFPNCH(ITER).LT.2)RETURN
      IF(IFSURF.GT.2)RETURN
      IF(IFSURF.EQ.2)GO TO 415
      WRITE(7,411)FREQ,HSURF
411 FORMAT(4HFLUX,1PE20.6,E13.4)
C 411 FORMAT(4HFLUX,0PE20.6,E13.4)
      RETURN
415 WRITE(7,416)FREQ,(ANGLE(MU),SURFIN(MU),MU=1,NMU)
416 FORMAT(9HINTENSITY,1PE15.6,3(0PF5.2,1PE11.4)/(5(0PF5.2,1PE11.4)))
C 416 FORMAT(9HINTENSITY,0PE15.6,3(0PF5.2,0PE11.4)/(5(0PF5.2,0PE11.4)))
      RETURN
C
C      SUMMARIES
500 IF(IFPRNT(ITER).EQ.0)GO TO 550
      IF(IFPRNT(ITER).EQ.1)GO TO 540
      WRITE(6,501) (J,RHGX(J),PTOTAL(J),PTURB(J),GRDADB(J),DLTDLP(J),
      1VELSND(J),DLRDLT(J),HEATCP(J),HSCALE(J),VCONV(J),FLXCNV(J),
      2J=1,NRHGX)
501 FORMAT(1H1/////132H          RHGX          PTOTAL          PTURB          GRDADB
      1      DLTDLP          VELSND          DLRDLT          HEATCP          HSCALE          VCONV
      2      FLXCNV          /(13,1P11E11.3))
C 2      FLXCNV          /(13,0P11E11.3))
      WRITE(6,502)FLUX
502 FORMAT(1H0108X4HFLUX1PE12.4)
C 502 FORMAT(1H0108X4HFLUX0PE12.4)
      WRITE(6,503) (J,XNATOM(J),ACCRAD(J),PRAD(J),XNFPH(J,1),XNFPH(J,2),
      1XNFPHE(J,1),XNFPHE(J,2),XNFPHE(J,3),J=1,NRHGX)
503 FORMAT(1H1/////132H          XNATOM          ACCRAD          PRAD          XNFPH1
      1      XNFPH2          XNFPHE1          XNFPHE2          XNFPHE3
      2          /(13,1P8E11.3))
C 2          /(13,0P8E11.3))
      DO 539 J=1,NRHGX
      IF(IFCORR.EQ.0)FLXRAD(J)=FLUX-FLXCNV(J)
539 FLXCNV(J)=FLXCNV(J)/(FLXCNV(J)+FLXRAD(J))
540 WRITE(6,541) TEFF,GLOG,TITLE,ITER
541 FORMAT(1H1/////5H TEFF,F8.0,8H LOG G,F7.3,10X74A1,2X,
      19HITERATION,I3)
      WRITE(6,542) (J,RHGX(J),T(J),P(J),XNE(J),RHO(J),ABROSS(J),
      1HEIGHT(J),TAUROS(J),FLXCNV(J),VTURB(J),FLXERR(J),FLXDRV(J),
      2J=1,NRHGX)
542 FORMAT(132H0          ELECTRON
      1 ROSSELAND          HEIGHT          ROSSELAND          FRACTION          PE
      2R CENT FLUX/132H          RHGX          TEMP          PRESSURE          NUMBER          DEN

```

```

      4SITY      MEAN      (KM)      DEPTH      CONV FLUX      VTURB
      5      ERROR      DERIV/(I3,1PE10.3,0PF9.1,1P8E11.3,0PF14.3,F8.3))
C      5      ERROR      DERIV/(I3,0PE10.3,0PF9.1,0P8E11.3,0PF14.3,F8.3))
550 IF(IFPNCH(ITER).EQ.0)RETURN
C
C      PUNCHOUT
      A=OFF
      IF(IFCONV.EQ.1)A=ON
      B=OFF
      IF(IFTURB.EQ.1)B=ON
      WRITE(7,552) TEFF,GLOG,WLTE,TITLE,IFOP,A,MIXLTH,B,TRBFDG,
      1TRBPOW,TRBSND,TRBCON,XSCALE,(I2,ABUND(I2),I2=1,99)
552 FORMAT(5HTEFF F7.0,9H GRAVITY F5.3,1XA4/6HTITLE 74A1
      1/13H OPACITY IFOP20I2/12H CONVECTION A3,F6.2,12H TURBULENCE A3,
      24F6.2/16HABUNDANCE SCALE F7.3,17H ABUNDANCE CHANGE2(I2,F6.3)/
      3(17H ABUNDANCE CHANGE6(I3,F7.2)))
      WRITE(7,554)NRHOX,(RHOX(J),T(J),P(J),XNE(J),ABROSS(J),PRAD(J),
      1VTURB(J),J=1,NRHOX)
554 FORMAT(9HREAD DECKI3,31H RHOX,T,P,XNE,ABROSS,PRAD,VTURB/
      1(1PE15.8,0PF9.1,1P5E10.3))
C      1(0PE15.8,0PF9.1,0P5E10.3))
      IF(NLTECN.EQ.0)GO TO 560
      WRITE(7,556)NRHOX,(RHOX(J),(BHYD(J,I),I=1,6),BMIN(J),J=1,NRHOX)
556 FORMAT(27HREAD DEPARTURE COEFFICIENTSI3,21H RHOX BHYD 1-6 BMIN/
      1(1PE11.4,0P7F9.4))
C      1(0PE11.4,0P7F9.4))
560 IF(IFWAVE.EQ.1)GO TO 570
      WRITE(7,562)NUMNU,NULO,NUMI,FREQID,(NJ,FRESET(NJ),RCOSET(NJ),
      1NU=1,NUMNU)
562 FORMAT(16HREAD FREQUENCIES3I4,3X6A1/(I5,1P2E17.8,I5,2E17.8))
C 562 FORMAT(16HREAD FREQUENCIES3I4,3X6A1/(I5,0P2E17.8,I5,2E17.8))
570 WRITE(7,571)ITER
571 FORMAT(5HBEGIN,20X10HITERATION I3,10H COMPLETED )
      RETURN
      END

```

```

SUBROUTINE TCORR(MODE,RCOWT)
COMMON /ABROSS/ABROSS(40),TAUROS(40)
COMMON /ABTOT/ABTOT(40),ALPHA(40)
COMMON /CONV/DLTDL(40),HEATCP(40),DLRDLT(40),VELSND(40),
1      GRDADB(40),HSCALE(40),FLXCNV(40),VCONV(40),MIXLTH,
2      IFCONV
REAL MIXLTH
COMMON /FLUX/ FLUX,FLXERR(40),FLXDRV(40),FLXRAD(40)
COMMON /FREQ/FREQ,FREQLG,EHVKT(40),STIM(40),BNJ(40)
COMMON /ITER/ ITER,IFPRNT(15),IFPNCH(15),NUMITS
COMMON /PTOTAL/PTOTAL(40)
COMMON /RAD/ ACCRAD(40),PRAD(40)
COMMON /RHOX/RHOX(40),NRHOX
COMMON /STATE/P(40),XNE(40),XNATOM(40),RHO(40)
COMMON /TAUSHJ/TAUNU(40),SNU(40),HNU(40),JNU(40),JMINS(40)
REAL JNU,JMINS
COMMON /TEFF/TEFF,GRAV,GLOG
COMMON /TEMP/T(40),TKEV(40),TK(40),HKT(40),TLOG(40),ITEMP
COMMON /TURBPR/VTURB(40),PTJRB(40),TRBFDG,TRBCON,TRBPDW,TRBSND,
1      IFTURB
DIMENSION RJMINS(40),RDABH(40),RDIAGJ(40),JLDT1(40)
DIMENSION DABTOT(40),DTDRHX(40),HRATIO(40),CODRHX(40),G(40),
1GFLUX(40),DDL(40),DRHOX(40),DTFLUX(40),DTLAMB(40),DUM(40),
2TINTEG(40),DTSURF(40),T1(40),CNVFLX(40),GRDEFF(40),RHOXL(40)
EQUIVALENCE (HKT(1),G(1),DUM(1),DTSURF(1))
EQUIVALENCE (TKEV(1),CNVFLX(1),RHOXL(1))
EQUIVALENCE (TLOG(1),DTDRHX(1),DTFLUX(1)),(TK(1),T1(1))
EQUIVALENCE (FLXERR(1),DABTOT(1),DRHOX(1)),(TAJNU(1),DDL(1))
EQUIVALENCE (RDABH(1),CODRHX(1),GFLUX(1),TINTEG(1),HRATIO(1))
EQUIVALENCE (RDIAGJ(1),DTLAMB(1),GRDEFF(1))
GO TO (10,20,30),MODE
C
ERASE FREQUENCY INTEGRALS
10 DO 11 J=1,NRHOX
    RJMINS(J)=0.
    RDABH(J)=0.
    RDIAGJ(J)=0.
11 FLXRAD(J)=0.
    RETURN
C
C
FREQUENCY INTEGRATION
20 DO 21 J=1,NRHOX
    RJMINS(J)=RJMINS(J)+ABTOT(J)*JMINS(J)*RCOWT
21 FLXRAD(J)=FLXRAD(J)+HNU(J)*RCOWT
    TERM2=0.
    DO 24 J=1,NRHOX
        TERM1=TERM2
        IF(J.NE.NRHOX)D=TAUNU(J+1)-TAUNU(J)
        IF(D.LE..01)GO TO 23
        EX=0.
        IF(D.LT.10.)EX=EXPI(3,D)
        TERM2=.5*(D+EX-.5)/D
        GO TO 22
23 TERM2=(.922784335098467-ALOG(D))*D*(.25+D*(8.333333333333333E-2+D*
1(1.041666666666667E-2+D*1.388888888888889E-3)))
22 DIAGJ=TERM1+TERM2
    DBDT=BNJ(J)*FREQ*HKT(J)/T(J)/STIM(J)
24 RDIAGJ(J)=RDIAGJ(J)+ABTOT(J)*(DIAGJ-1.)/(1.-ALPHA(J)*DIAGJ)*
1(1.-ALPHA(J))*DBDT*RCOWT
    RETURN
C

```

```

C   AVRETT-KROOK TAU CORRECTION MODIFIED FOR CONVECTION
30  CALL DERIV(RHOX,T,DTDRHX,NRHOX)
    CALL DERIV(RHOX,DLTDLP,DDLT,NRHOX)
    DO 31 J=1,NRHOX
      CNVFLX(J)=0.
      DEL=1.
      D=0.
      IF(IFCONV.EQ.1) CNVFLX(J)=FLXCNV(J)
      IF(CNVFLX(J).GT.0.) DEL=DLTDLP(J)-GRDADB(J)
      VCO=.5*MIXLTH*SQRT(-.5*PTOTAL(J)/RHO(J)*DLRDLT(J))
      FLUXCO=.5*RHO(J)*HEATCP(J)*T(J)*MIXLTH/12.5664
      IF(MIXLTH.GT.0.) D=8.*5.6697E-5*T(J)**4/
1  (ABROSS(J)*HSCALE(J)*RHO(J))/(FLUXCO*12.5664)/VCO
      D=D**2/2.
31  CODRHX(J)=(RDABH(J)+CNVFLX(J)*(DTDRHX(J)/T(J)*(1.-9.*D/(D+DEL))+
1  1.5*DDLT(J)/DEL*(1.+D/(D+DEL))))/(FLXRAD(J)+CNVFLX(J)*
2  1.5*DLTDLP(J)/DEL*(1.+D/(D+DEL)))
    CALL INTEG(RHOX,CODRHX,G,NRHOX)
    DO 32 J=1,NRHOX
      G(J)=EXP(G(J))
32  GFLUX(J)=G(J)*(FLXRAD(J)+CNVFLX(J)-FLUX)/(FLXRAD(J)+CNVFLX(J)*
1  1.5*DLTDLP(J)/DEL*(1.+D/(D+DEL)))
    CALL INTEG(RHOX,GFLUX,DRHOX,NRHOX)
    DO 33 J=1,NRHOX
      DRHOX(J)=DRHOX(J)/G(J)
      DRHOX(J)=AMAX1(-TAUROS(J)/ABROSS(J)/2.,AMIN1(TAUROS(J)/ABROSS(J),
1  DRHOX(J)))
33  DTFLUX(J)=-DRHOX(J)*DTDRHX(J)
    DTFLUX(1)=0.

C
    DO 41 J=1,NRHOX
41  FLXERR(J)=(FLXRAD(J)+CNVFLX(J)-FLUX)/FLUX*100.
    CALL DERIV(TAUROS,FLXERR,FLXDRV,NRHOX)
    TEFF25=TEFF/25.
    DO 43 J=1,NRHOX
      IF(CNVFLX(J)/FLXRAD(J).LT.1.E-5) FLXDRV(J)=RJMIN5(J)/ABROSS(J)/
1  FLUX*100.
    DTLAMB(J)=-FLXDRV(J)*FLUX/100./RDIAGJ(J)*ABROSS(J)
    IF(CNVFLX(J)/FLXRAD(J).LT.1.E-5.AND.TAUROS(J).LT.1.) GO TO 42
    DTLAMB(J)=0.
    DTLAMB(J-1)=DTLAMB(J-1)/2.
    DTLAMB(J-2)=DTLAMB(J-2)/2.
    DTLAMB(J-3)=DTLAMB(J-3)/2.
    DTLAMB(J-4)=DTLAMB(J-4)/2.
    DTLAMB(J-5)=DTLAMB(J-5)/2.
C   FUDGE TO AVOID VERY LARGE TEMPERATURE CORRECTIONS
42  DTLAMB(J)=AMAX1(-TEFF25,AMIN1(TEFF25,DTLAMB(J)))
43  CONTINUE

C
    DTSJR=(FLUX-FLXRAD(1))/FLUX*.25*T(1)
    DTSJR=AMAX1(-TEFF25,AMIN1(TEFF25,DTSJR))
    DO 45 J=1,NRHOX
45  DUM(J)=DTFLUX(J)+DTLAMB(J)
    CALL INTEG(TAUROS,DUM,TINTEG,NRHOX)
    IDUM=MAP1(TAUROS,TINTEG,NRHOX,.1,TONE,1)
    IDUM=MAP1(TAUROS,TINTEG,NRHOX,.2,TTWO,1)
    TAV=(TTWO-TONE)/2.
    IF(DTSJR*TAV.LE.0.) TAV=0.
    IF(ABS(TAV).GT.ABS(DTSJR)) TAV=DTSJR
    DTSUR=DTSUR-TAV

```

```

      DO 49 J=1,NRHGX
49 DTSURF(J)=DTSUR
C
      DO 50 J=1,NRHGX
      HRATIO(J)=CNVFLX(J)/(CNVFLX(J)+FLXRAD(J))
50 T1(J)=DTFLUX(J)+DTLAMB(J)+DTSURF(J)
      IF(IFPRNT(ITER).LE.1)GO TO 60
      WRITE(6,100) (J,RHOX(J),T1(J),DTLAMB(J),DTSURF(J),DTFLUX(J),T1(J),
1HRATIO(J),FLXERR(J),FLXDRV(J),J=1,NRHGX)
100 FORMAT(1H1//94H0      RHOX      T      DTLAMB      DTSURF      DTFL
1JX      T1      CONV/TOTAL      ERROR      DERIV/
2(I3,1PE12.4,0PF10.1,4F9.1,1X1PE11.3,1X0P2F10.3))
C
C      2(I3,0PE12.4,0PF10.1,4F9.1,1X0PE11.3,1X0P2F10.3))
C
      DO 61 J=1,NRHGX
      IF(IFCONV.EQ.1)GO TO 62
      IF(ITER.EQ.1)GO TO 62
      IF(OLDT1(J)*T1(J).GT.0.)T1(J)=T1(J)*1.25
      IF(OLDT1(J)*T1(J).LT.0.)T1(J)=T1(J)*.5
62 OLDT1(J)=T1(J)
61 T(J)=T(J)+T1(J)
C
C      FUDGES TO MAKE UP FOR BAD STARTING GUESSES
      IF(IFCONV.EQ.1)GO TO 71
      IF(ITER.GT.1)GO TO 80
      IF(FLXERR(NRHGX).LT.90..AND.FLXERR(NRHGX).GT.-50.)GO TO 80
      DO 70 J=1,NRHGX
70 T(J)=TEFF*(.75*(.710+TAUROS(J)-.1331*EXP(-3.4488*TAUROS(J))))**.25
      GO TO 80
71 DO 72 J=1,NRHGX
      IF(FLXERR(J).GT.1000.)GO TO 73
72 CONTINUE
      GO TO 80
73 DO 74 J=1,NRHGX
      GRDEFF(J)=(FLXRAD(J)*DLTDLP(J)+FLXCNV(J)*GRDADB(J))/(FLXRAD(J)+
1FLXCNV(J))
      IF(FLXCNV(J).GT.0.)GRDEFF(J)=AMAX1(GRDEFF(J),(1.+DLTDLP(J))/3.)
74 RHOXL(J)=ALOG(RHOX(J))
      CALL INTEG(RHOXL,GRDEFF,TLOG,NRHGX)
      DO 75 JSTART=1,NRHGX
      IF(FLXCNV(JSTART).GT.0.)GO TO 76
75 CONTINUE
      GO TO 80
76 DO 77 J=JSTART,NRHGX
77 T(J)=T(J-1)*EXP(TLOG(J)-TLOG(J-1))
80 DO 81 J=1,NRHGX
      TK(J)=1.38054E-16*T(J)
      HKT(J)=6.6256E-27/TK(J)
      TKEV(J)=8.6171E-5*T(J)
81 TLOG(J)=ALOG(T(J))
      RETURN
      END

```



```

C      SUBROUTINE STATEQ(MODE,RCWT)
C      THE BOUND-BOUND COLLISION RATES WERE DERIVED FROM AN ANALYTIC FIT
C      TO THE CROSS SECTION CALCULATIONS OF BURKE,ORMONDE AND WHITAKER.
C      PROC. PHYS. SOC., 1968, VOL 92, 319
C
C      THE CROSS SECTION USED (IN UNITS OF  $\pi A_0^{*2}$ ) IS
C
C       $Q_{IJ} = 4 * F_{IJ} * (E_H/E_0)^{**2} * (\log(E/E_0) / (E/E_0) + .148 / (E/E_0)^{**6})$ 
C
C      FIJ = OSCILLATOR STRENGTH
C      EH = GROUND STATE BINDING ENERGY
C      E0 = THRESHOLD ENERGY
C
C
C      D M PETERSON MAY 1968
C
COMMON /DEPART/BHYD(40,6),BMIN(40),NLTEON
COMMON /FREQ/FREQ,FREQLG,EHVKT(40),STIM(40),BNJ(40)
COMMON /IONS/XNFPH(40,2),XNFPHE(40,3)
COMMON /ITER/ ITER,IFPRNT(15),IFPNCH(15),NUMITS
COMMON /RHOX/RHOX(40),NRHOX
COMMON /STATE/P(40),XNE(40),XNATOM(40),RHO(40)
COMMON /TAUSHJ/TAUNU(40),SNJ(40),HNU(40),JNU(40),JMIN(40)
REAL JNU,JMIN
COMMON /TEMP/T(40),TKEV(40),TK(40),HKT(40),TLOG(40),ITEMP
DIMENSION QRAIK(40,6),QRAKI(40,6),QRDHMK(40),QRDKHM(40)
DIMENSION DQRA(40,6),DQRD(40),TOLD(40)
DIMENSION HCONT(6),DUMMY(6)
DIMENSION A(6,6),RIGHT(6),QCOLL(8,8)
EQUIVALENCE (A(1),TAUNU(1)),(QCOLL(1),HNU(1)),(HCONT(1),DJMMY(1))
DIMENSION F(8,8)
DATA F/8*0.,.4162,7*0.,.07910,.6408,6*0.,.02899,.1193,.8420,5*0.,
1.01394,.04467,.1506,1.038,4*0.,.007800,.02209,.05585,.1794,1.231,
23*0.,.004814,.01271,.02768,.06551,.2070,1.425,2*0.,.003184,.008037
3.,.01604,.03229,.07455,.2340,1.615,0./
GO TO(10,20,30),MODE
C
C      ERASE FREQUENCY INTEGRALS
10 DO 11 I=1,6
DO 11 J=1,NRHOX
TOLD(J)=T(J)
QRDHMK(J)=0.
QRDKHM(J)=0.
DQRD(J)=0.
DQRA(J,I)=0.
QRAKI(J,I)=0.
11 QRAIK(J,I)=0.
RETURN
C
C      FREQUENCY INTEGRALS
20 RFRWT=12.5664/6.6256E-27*RCWT/FREQ
HVC=2.*6.6256E-27*FREQ*(FREQ/2.997925E10)**2
DO 21 N=2,6
21 HCONT(N)=COULX(N,FREQ,1.)
HMINBF=0.
IF(FREQ.GT.1.8259E14.AND.FREQ.LT.2.111E14)HMINBF=
1 3.695E-16+(-1.251E-1+1.052E13/FREQ)/FREQ
IF(FREQ.GE.2.111E14)HMINBF=6.801E-20+(5.358E-3+(1.481E13+
1(-5.519E27+4.808E41/FREQ)/FREQ)/FREQ)/FREQ
DO 25 J=1,NRHOX
RJ=RFRWT*JNU(J)
RJE=RFRWT*EHVKT(J)*(JNU(J)+HVC)
RJEDT=RJE*HKT(J)*FREQ/T(J)
DO 26 I=2,6
QRAIK(J,I)=QRAIK(J,I)+HCONT(I)*RJ

```

```

      DQRAD(J,I)=DQRAD(J,I)+HCONT(I)*RJEDT
26  QRADKI(J,I)=QRADKI(J,I)+HCONT(I)*RJE
      QRDHMK(J)=QPDHMK(J)+HMINBF*RJ
      DQRD(J)=DQRD(J)+HMINBF*RJEDT
25  QRDKHM(J)=QRDKHM(J)+HMINBF*RJE
      RETURN
C
30  IF(IFPRNT(ITER).GT.0)WRITE(6,201)
201 FORMAT(1H1/////36X30HHMINUS STATISTICAL EQUILIBRIUM/10X4HRHOX,
1  7X6HQELECT,6X6HQASSOC,6X6HQCHARG,6X6HQRDKHM,6X6HQRDHMK,7X4HBMIN)
      DO 210 J=1,NRHOX
      DT=T(J)-TOLD(J)
      THETA=5040./T(J)
      QELECT=10.**(-8.7)*THETA**(1.5)*XNE(J)
      QASSOC=10.**(-8.7)*2.*BHYD(J,1)*XNFPH(J,1)
      QCHARG=10.**(-7.4)*THETA**.333333*XNFPH(J,2)
      QRDKHM(J)=QRDKHM(J)+DQRD(J)*DT
      BMIN(J)=(QRDKHM(J)+QELECT+QASSOC+QCHARG)/
1  (QRDHMK(J)+QELECT+QASSOC+QCHARG)
210  WRITE(6,211)J,RHOX(J),QELECT,QASSOC,QCHARG,QRDKHM(J),
1  QRDHMK(J),BMIN(J)
211  FORMAT(15,1P6E12.3,0PF10.4)
C 211  FORMAT(15,0P6E12.3,0PF10.4)
C
      IF(IFPRNT(ITER).GT.0)WRITE(6,31)
31  FORMAT(1H1/////30X83HSTATISTICAL EQUILIBRIUM RATES      RATE=SIGN(AL
1  OG10(AMAX1(ABS(RATE*1.E20),1.)),RATE) /
2132H0 RAD      1-K      K-1      2-K      K-2      3-K      K-3      4-K      K-4      5-K
3K-5      6-K      K-6      COLL      1-K      2-K      3-K      4-K      5-K      6-K      5-8
46-8      /
5132H COLL      1-2      1-3      1-4      1-5      1-6      1-7      2-3      2-4      2-5
62-6      2-7      3-4      3-5      3-6      3-7      4-5      4-6      4-7      5-6      5-7
76-7      )
C
      DO 120 J=1,NRHOX
      DT=T(J)-TOLD(J)
      TH=13.595/TKEV(J)
      DO 50 I=1.8
      Y=I
      QCOLL(I,I)=2.2E-8*Y**3/SQRT(TH)*EXP(-TH/Y**2)*XNE(J)
C  QCOLL(I,I) IS THE BOUND FREE RATE
      IF (I.EQ.8) GO TO 50
      I1=I+1
      DO 40 K=I1.8
      Z=K
      GIK=1./Y**2-1./Z**2
      X0=TH*GIK
      Q=2.186E-10*(I,K)/GIK**2*X0*SQRT(T(J))*(EXPI(1,X0)+.148*X0*
2  EXPI(5,X0))
      QCOLL(I,K)=Q*XNE(J)
      QCOLL(K,I)=QCOLL(I,K)*(Y/Z)**2*EXP(X0)
40  CONTINUE
50  CONTINUE
      DO 65 I=1.6
      A(I,I)=QRADIK(J,I)
      QRADKI(J,I)=QRADKI(J,I)+DQRAD(J,I)*DT
      RIGHT(I)=QRADKI(J,I)+QCOLL(I,I)+QCOLL(I,7)+QCOLL(I,8)
      DO 55 K=1.8
      55  A(I,I)=A(I,I)+QCOLL(I,K)

```

```

      IF (I.EQ.6) GO TO 65
      I1=I+1
      DO 60 K=I1,6
      A(I,K)=-QCOLL(I,K)
60  A(K,I)=-QCOLL(K,I)
65  CONTINUE
C
      CALL SOLVIT(A,6,RIGHT,DUMMY)
      DO 80 L=1,6
80  BHYD(J,L)=RIGHT(L)
      IF (IFPRNT(ITER).LE.1) GO TO 120
      DO 90 I=1,6
      QRADKI(J,I)=SIGN(ALOG10(AMAX1(ABS(QRADKI(J,I)*1.E20),1.)),
1 QRADKI(J,I))
90  QRADIK(J,I)=SIGN(ALOG10(AMAX1(ABS(QRADIK(J,I)*1.E20),1.)),
1 QRADIK(J,I))
      DO 95 I=1,8
      DO 95 K=1,8
95  QCOLL(I,K)=SIGN(ALOG10(AMAX1(ABS(QCOLL(I,K)*1.E20),1.)),
1 QCOLL(I,K))
      WRITE (6,100) J,(QRADIK(J,I),QRADKI(J,I),I=1,6),
1 (QCOLL(I,I),I=1,6),QCOLL(5,8),QCOLL(6,8)
100 FORMAT (1H0I5,12F6.2,6X8F6.2)
      WRITE (6,110) (QCOLL(1,K),K=2,7),(QCOLL(2,K),K=3,7),(QCOLL(3,K),
1 K=4,7),(QCOLL(4,K),K=5,7),(QCOLL(5,K),K=6,7),QCOLL(6,7)
110 FORMAT (6X21F6.2)
120 CONTINUE
C
160 WRITE (6,170) (J,RHOX(J),(BHYD(J,I),I=1,6),J=1,NRHOX)
170 FORMAT(1H1/////30X36HSTATISTICAL EQUILIBRIUM FOR HYDROGEN/
1 15X4HRHOX,10X2HB1,8X2HB2,8X2HB3,8X2HB4,8X2HB5,8X2HB6/
2(8XI2,1PE11.4,1XOP6F10.4))
2(8XI2,0PE11.4,1XOP6F10.4))
C
      RETJRN
      END

```

```

      SUBROUTINE ROSS(MODE,RCOWT)
      COMMON /ABROSS/ABROSS(40),TAUROS(40)
      COMMON /ABTOT/ABTOT(40),ALPHA(40)
      COMMON /FREQ/FREQ,FREQLG,EHVKT(40),STIM(40),BNJ(40)
      COMMON /RHOX/RHOX(40),NRHOX
      COMMON /TEMP/T(40),TKEV(40),TK(40),HKT(40),TLOG(40),ITEMP
      GO TO(10,20,30),MODE
10  DO 11 J=1,NRHOX
11  ABROSS(J)=0.
      RETJRN
20  DO 21 J=1,NRHOX
      DBDT=BNJ(J)*FREQ*HKT(J)/T(J)/STIM(J)
21  ABROSS(J)=ABROSS(J)+DBDT/ABTOT(J)*RCOWT
      RETJRN
30  DO 31 J=1,NRHOX
31  ABROSS(J)=(4.*5.6697E-5/3.14159)*T(J)**3/ABROSS(J)
      RHOX0=RHOX(1)
      RHOX(1)=0.
      CALL INTEG(RHOX,ABROSS,TAUROS,NRHOX)
      RHOX(1)=RHOX0
      RETJRN
      END

```

```

SUBROUTINE RADIAP(MODE,RCOWT)
COMMON /ABTOT/ABTOT(40),ALPHA(40)
COMMON /FLUX/ FLUX,FLXERR(40),FLXDRV(40),FLXRAD(40)
COMMON /RAD/ACCRAD(40),PRAD(40)
COMMON /RHOX/RHOX(40),NRHOX
COMMON /TAUSHJ/TAUNU(40),SNU(40),HNU(40),JNU(40),JMIN5(40)
REAL JNU,JMIN5
DIMENSION DUM(40),H(40)
EQUIVALENCE (DUM(1),ABTOT(1))
GO TO (10,20,30),MODE
10 DO 11 J=1,NRHOX
   H(J)=0.
11 ACCRAD(J)=0.
   RETURN
20 DO 21 J=1,NRHOX
   H(J)=H(J)+HNU(J)*RCOWT
21 ACCRAD(J)=ACCRAD(J)+ABTOT(J)*HNU(J)*RCOWT
   RETURN
30 DO 31 J=1,NRHOX
   ACCRAD(J)=ACCRAD(J)*12.5664/2.997925E10
C   FUDGE TO KEEP MODEL FROM BLOWING UP WITH LARGE FLUX ERRORS
   IF (H(J)/FLUX.GT.1.) ACCRAD(J)=ACCRAD(J)*FLUX/H(J)
31 CONTINUE
   CALL INTEG(RHOX,ACCRAD,PRAD,NRHOX)
   RETURN
END

SUBROUTINE DERIV(X,F,DFDX,N)
C   ASSUMES THAT ANY ZERO IN X OCCURS AT A ENDPOINT
DIMENSION X(1),F(1),DFDX(1)
DFDX(1)=(F(2)-F(1))/(X(2)-X(1))
N1=N-1
DFDX(N)=(F(N)-F(N1))/(X(N)-X(N1))
IF (N.EQ.2) RETURN
S=ABS(X(2)-X(1))/(X(2)-X(1))
DO 1 J=2,N1
   SCALE=AMAX1(ABS(F(J-1)),ABS(F(J)),ABS(F(J+1)))/ABS(X(J))
   IF (SCALE.EQ.0.) SCALE=1.
   D1=(F(J+1)-F(J))/(X(J+1)-X(J))/SCALE
   D=(F(J)-F(J-1))/(X(J)-X(J-1))/SCALE
   TAN1=D1/(S*SQRT(1.+D1**2)+1.)
   TAN=D/(S*SQRT(1.+D**2)+1.)
1 DFDX(J)=(TAN1+TAN)/(1.-TAN1*TAN)*SCALE
   RETURN
END

```

```

SUBROUTINE INTEG(X,F,FINT,N)
  DIMENSION X(1),F(1),FINT(1)
  DIMENSION A(40),B(40),C(40)
  CALL PARCOE(F,X,A,B,C,N)
  FINT(1)=(A(1)+(B(1)/2.+C(1)/3.*X(1))*X(1))*X(1)
  FINT(2)=(A(1)+(B(1)/2.+C(1)/3.*X(2))*X(2))*X(2)
  IF(N.EQ.2)RETURN
  N1=N-1
  DO 10 I=2,N1
10 FINT(I+1)=FINT(I)+(A(I)+B(I)/2.*(X(I+1)+X(I))+
  1 C(I)/3.*((X(I+1)+X(I))*X(I+1)+X(I)*X(I)))*(X(I+1)-X(I))
  RETURN
  END

```

```

SUBROUTINE PARCOE(F,X,A,B,C,N)
  DIMENSION F(1),X(1),A(1),B(1),C(1)
  C(1)=0.
  B(1)=(F(2)-F(1))/(X(2)-X(1))
  A(1)=F(1)-X(1)*B(1)
  N1=N-1
  C(N)=0.
  B(N)=(F(N)-F(N1))/(X(N)-X(N1))
  A(N)=F(N)-X(N)*B(N)
  IF(N.EQ.2)RETURN
  DO 1 J=2,N1
  J1=J-1
  D=(F(J)-F(J1))/(X(J)-X(J1))
  C(J)=F(J+1)/((X(J+1)-X(J))*X(J+1)-X(J1))-F(J)/((X(J)-X(J1))*
  1 (X(J+1)-X(J)))+F(J1)/((X(J)-X(J1))*X(J+1)-X(J1))
  B(J)=D-(X(J)+X(J1))*C(J)
1 A(J)=F(J1)-X(J1)*D+X(J)*X(J1)*C(J)
  N1=N1-1
  DO 2 J=2,N1
  IF(C(J).EQ.0.)GO TO 2
  J1=J+1
  WT=ABS(C(J1))/(ABS(C(J1))+ABS(C(J)))
  A(J)=A(J1)+WT*(A(J)-A(J1))
  B(J)=B(J1)+WT*(B(J)-B(J1))
  C(J)=C(J1)+WT*(C(J)-C(J1))
2 CONTINUE
  RETURN
  END

```

```

      FUNCTION MAP1(XOLD,FOLD,NOLD,XNEW,FNEW,NNEW)
      DIMENSION XOLD(1),FOLD(1),XNEW(1),FNEW(1)
      L=2
      LL=0
      DO 50 K=1,NNEW
10    IF(XNEW(K).LT.XOLD(L))GO TO 20
      L=L+1
      IF(L.GT.NOLD)GO TO 30
      GO TO 10
20    IF(L.EQ.LL)GO TO 50
      IF(L.EQ.2)GO TO 30
      L1=L-1
      IF(L.GT.LL+1.OR.L.EQ.3)GO TO 21
      CBAC=CFOR
      BBAC=BFOR
      ABAC=AFOR
      IF(L.EQ.NOLD)GO TO 22
      GO TO 25
21    L2=L-2
      D=(FOLD(L1)-FOLD(L2))/(XOLD(L1)-XOLD(L2))
      CBAC=FOLD(L)/((XOLD(L)-XOLD(L1))*(XOLD(L)-XOLD(L2)))+
      1(FOLD(L2)/(XOLD(L)-XOLD(L2))-FOLD(L1)/(XOLD(L)-XOLD(L1)))/
      2(XOLD(L1)-XOLD(L2))
      BBAC=D-(XOLD(L1)+XOLD(L2))*CBAC
      ABAC=FOLD(L2)-XOLD(L2)*D+XOLD(L1)*XOLD(L2)*CBAC
      IF(L.LT.NOLD)GO TO 25
22    C=CBAC
      B=BBAC
      A=ABAC
      LL=L
      GO TO 50
25    D=(FOLD(L)-FOLD(L1))/(XOLD(L)-XOLD(L1))
      CFOR=FOLD(L+1)/((XOLD(L+1)-XOLD(L))*(XOLD(L+1)-XOLD(L1)))+
      1(FOLD(L1)/(XOLD(L+1)-XOLD(L1))-FOLD(L)/(XOLD(L+1)-XOLD(L)))/
      2(XOLD(L)-XOLD(L1))
      BFOR=D-(XOLD(L)+XOLD(L1))*CFOR
      AFOR=FOLD(L1)-XOLD(L1)*D+XOLD(L)*XOLD(L1)*CFOR
      WT=0.
      IF(ABS(CFOR).NE.0.)WT=ABS(CFOR)/(ABS(CFOR)+ABS(CBAC))
      A=AFOR+WT*(ABAC-AFOR)
      B=BFOR+WT*(BBAC-BFOR)
      C=CFOR+WT*(CBAC-CFOR)
      LL=L
      GO TO 50
30    IF(L.EQ.LL)GO TO 50
      L=AMINO(NOLD,L)
      C=0.
      B=(FOLD(L)-FOLD(L-1))/(XOLD(L)-XOLD(L-1))
      A=FOLD(L)-XOLD(L)*B
      LL=L
50    FNEW(K)=A+(B+C*XNEW(K))*XNEW(K)
      MAP1=LL-1
      RETJRN
      END

```

```

SUBROUTINE SOLVIT(A,N,B,IPIVOT)
C SOLVES LINEAR EQUATIONS
C A IS A COMPLETELY FILLED N BY N ARRAY WHICH IS DESTROYED.
C B IS THE RIGHT SIDE VECTOR OF LENGTH N AND RETURNS AS THE SOLUTION
C IPIVOT IS A SCRATCH AREA OF LENGTH N.
  DIMENSION A(1),B(1),IPIVOT(1)
  EQUIVALENCE(AMAX,SWAP,PIVOT,T)
  DO 20 J=1,N
20  IPIVOT(J)=0
  DO 550 I=1,N
    AMAX=0.
    DO 105 J=1,N
      IF(IPIVOT(J).EQ.1)GO TO 105
      JK=J-N
      DO 100 K=1,N
        JK=JK+N
        IF(IPIVOT(K).EQ.1)GO TO 100
        AA=ABS(A(JK))
        IF(AMAX.GE.AA)GO TO 100
        IROW=J
        ICOLUM=K
        AMAX=AA
100  CONTINUE
105  CONTINUE
      IPIVOT(ICOLUM)=IPIVOT(ICOLUM)+1
      IF(IROW.EQ.ICOLUM)GO TO 260
      IRL=IROW-N
      ICL=ICOLUM-N
      DO 200 L=1,N
        IRL=IRL+N
        SWAP=A(IRL)
        ICL=ICL+N
        A(IRL)=A(ICL)
200  A(ICL)=SWAP
        SWAP=B(IROW)
        B(IROW)=B(ICOLUM)
        B(ICOLUM)=SWAP
260  ICIC=ICOLUM*N+ICOLUM-N
        PIVOT=A(ICIC)
        A(ICIC)=1.
        ICL=ICOLUM-N
        DO 350 L=1,N
          ICL=ICL+N
350  A(ICL)=A(ICL)/PIVOT
        B(ICOLUM)=B(ICOLUM)/PIVOT
        LIIC=ICOLUM*N-N
        DO 550 LI=1,N
          LIIC=LIIC+1
          IF(LI.EQ.ICOLUM)GO TO 550
          T=A(LIIC)
          A(LIIC)=0.
          LIIL=LI-N
          ICL=ICOLUM-N
          DO 450 L=1,N
            LIIL=LIIL+N
            ICL=ICL+N
450  A(LIIL)=A(LIIL)-A(ICL)*T
        B(LI)=B(LI)-B(ICOLUM)*T
550  CONTINUE
      RETURN
  END

```

```

FUNCTION EXPI(N,X)
C   EXPONENTIAL INTEGRAL FOR POSITIVE ARGJMENTS AFTER CODY AND
C   THACHER, MATH. OF COMP., 22, 641 (1968)
DATA X1/-1.E20/
DATA A0,A1,A2,A3,A4,A5,B0,B1,B2,B3,B4/
1-44178.5471728217,57721.7247139444,9938.31388962037,
2 1842.11088668000,101.093806161906,5.03416184097568,
3 76537.3323337614,32597.1881290275,6106.10794245759,
4 635.419418378382,37.2298352833327/
DATA C0,C1,C2,C3,C4,C5,C6,D1,D2,D3,D4,D5,D6/
1 4.65627107975096E-7,
2 .999979577051595,9.04161556946329,24.3784088791317,
3 23.0192559391333,6.90522522784444,.430967839469389,
4 10.0411643829054,32.4264210695138,41.2807841891424,
5 20.4494785013794,3.31909213593302,.103400130404874/
DATA E0,E1,E2,E3,E4,E5,E6,F1,F2,F3,F4,F5,F6/
1-.999999999998447,-26.6271060431811,-241.055827097015,
2-895.927957772937,-1298.85688746484,-545.374158883133,
3-5.66575206533869, 28.6271060422192, 292.310039388533,
4 1332.78537748257, 2777.61949509163, 2404.01713225909,
5 631.657483280800/
IF(X.EQ.X1)GO TO 40
EX=EXP(-X)
X1=X
IF(X.GT.4.)GO TO 10
IF(X.GT.1.)GO TO 20
IF(X.GT.0.)GO TO 30
EX1=0.
GO TO 40
10 EX1=(EX+EX*(E0+(E1+(E2+(E3+(E4+(E5+E6/X)/X)/X)/X)/X)/X)/
1 (X+ F1+(F2+(F3+(F4+(F5+F6/X)/X)/X)/X)/X)/X
GO TO 40
20 EX1=EX*(C6+(C5+(C4+(C3+(C2+(C1+C0*X)*X)*X)*X)*X)/
1 (D6+(D5+(D4+(D3+(D2+(D1*X)*X)*X)*X)*X)*X)
GO TO 40
30 EX1=(A0+(A1+(A2+(A3+(A4+A5*X)*X)*X)*X)*X)/
1 (B0+(B1+(B2+(B3+(B4*X)*X)*X)*X)*X)-ALOG(X)
40 EXPI=EX1
IF(N.EQ.1)RETURN
N1=N-1
DO 41 I=1,N1
41 EXPI=(EX-X*EXPI)/FLOAT(I)
RETURN
END

SUBROUTINE W(A,B,N)
DIMENSION B(1)
WRITE(6,100)A,(B(I),I=1,N)
C 100 FORMAT(1H0,A6,0P10E12.4/(7X,10E12.4))
100 FORMAT(1H0,A6,1P10E12.4/(7X,10E12.4))
RETURN
END

```



```

SUBROUTINE READIN(MODE)
C  MODE=1 COMPUTE A MODEL
C  MODE=2 READ A PREVIOUSLY CALCULATED MODEL FOR SOME APPLICATION
C  MODE=20 SAME AS 2 BUT ON ENCOUNTERING END RETURN WITH NRHOX=0
COMMON /ABROSS/ABROSS(40),TAUROS(40)
COMMON /CONV/DLTDL(40),HEATCP(40),DLRDLT(40),VELSND(40),
1      GRDADB(40),HSCALE(40),FLXCNV(40),VCONV(40),MIXLTH,
2      IFCONV
REAL MIXLTH
COMMON /DEPART/BHYD(40,6),BMIN(40),NLTEON
COMMON /ELEM/ABUND(99),ATMASS(99),ELEM(99)
COMMON /FLUX/ FLUX,FLXERR(40),FLXDRV(40),FLXRAD(40)
COMMON /FREE/WORD(6),NUMCOL,LETCOL,LAST,MORE,IFFAIL,MAXPOW
COMMON /FRESE/FRESE(500),RCOSET(500),NULO,NUHI,NUMNU
COMMON /HEIGHT/HEIGHT(40)
COMMON /IF/IFCORR,IFPRES,IFSURF,IFSCAT,IFMOL
COMMON /IFOP/IFOP(20)
COMMON /ITER/ ITER,IFPRNT(15),IFPNCH(15),NUMITS
COMMON /JUNK/TITLE(74),FREQID(6),WLTE,XSCALE
COMMON /MUS/ANGLE(20),SURFI(20),NMJ
COMMON /PTOTAL/PTOTAL(40)
COMMON /RAD/ACCRAD(40),PRAD(40)
COMMON /RHOX/RHOX(40),NRHOX
COMMON /STATE/P(40),XNE(40),XNATOM(40),RHO(40)
COMMON /TEFF/TEFF,GRAV,GLOG
COMMON /TEMP/T(40),TKEV(40),TK(40),HKT(40),TLOG(40),ITEMP
COMMON /TURBPR/VTURB(40),PTJRB(40),TR3FDG,TRBCON,TRBPOW,TRBSND,
1      IFTURB
COMMON /WAVEY/WBEGIN,DELTAW,IFWAVE
COMMON /XABUND/XABUND(99),WTMOLE
DIMENSION CARD(80)
EQUIVALENCE (CARD(1),XABUND(1)),(CARD81,XABUND(81))
DIMENSION RHOXA(40),DUM1(40),DUM2(40),DUM3(40),DUM4(40),DUM5(40)
DIMENSION DUM6(40),DUM7(40),DUM8(40),TAUSTD(40)
EQUIVALENCE (DUM1(1),DLTDLP(1)),(DUM2(1),HEATCP(1))
EQUIVALENCE (DUM3(1),DLRDLT(1)),(DUM4(1),VELSND(1))
EQUIVALENCE (DUM5(1),GRDADB(1)),(DUM6(1),HSCALE(1))
EQUIVALENCE (DUM7(1),FLXCNV(1)),(RHOXA(1),VCONV(1),DUM8(1))
EQUIVALENCE (TAUSTD(1),XNATOM(1))
DIMENSION IFOP1(20)
C  -H1,H2PLJS,HMINUS,HRAY,HE1,HE2,HEMINUS,HERAY,COOL,LUKE,
C  -HOT,ELECTRON,H2RAY,H1LINES,LINES,LINESCAT,XLINES,XLSCAT,XCONT,XSCAT
DATA IFOP1/324,609929997,579591588,429928,11165,11166,564793810,
1 15271257,173061,636997,11527,369467847,16486929,577716835,
2 22965179,849711626,1687220147,1687711471,45152896,45946435/
DATA WWLTE,WWNLTE/4HLTE,4HNLTE/
DATA BLANK/1H /
EXP10(X)=EXP(X*2.30258509299405E0)
CARD81=BLANK
LAST=81
MAXPOW=38
98 MORE=0
LETCOL=1
99 READ(5,1) CARD
1  FORMAT(80A1)
C  (M)ACHINE (I)NDEPENDENT (A)LPHAMERIC (C)ODE
C  BASE 37 A=1, Z=26, 0=27, 9=36
MIAC=IWORDF(CARD)
NUMCOL=LETCOL
C  TEFF

```

```

3 IF(MIAC.EQ.1020133)GO TO 100
C GRAVITY
  IF(MIAC.EQ.519223721)GO TO 200
C DPACITY
  IF(MIAC.EQ.1070201044)GO TO 300
C KAPPA
  IF(MIAC.EQ.20688921)GO TO 400
C ITERATIONS
  IF(MIAC.EQ.661856797)GO TO 500
C MOLECJLES
  IF(MIAC.EQ.930198669)GO TO 600
C CALCULATE
  IF(MIAC.EQ.210518764)GO TO 700
C ABUNDANCE
  IF(MIAC.EQ.74175307)GO TO 800
C PRINT
  IF(MIAC.EQ.30911189)GO TO 900
C PUNCH
  IF(MIAC.EQ.31069574)GO TO 1000
C READ
  IF(MIAC.EQ.918640)GO TO 1100
C LTE
  IF(MIAC.EQ.17173)GO TO 1200
C NLTE
  IF(MIAC.EQ.726315)GO TO 1300
C BEGIN
  IF(MIAC.EQ.4011517)GO TO 1500
C SCATTERING
  IF(MIAC.EQ.1323236444)GO TO 1600
C END
  IF(MIAC.EQ.7367)GO TO 1700
C TITLE
  IF(MIAC.EQ.37966926)GO TO 1800
C CONVECTION
  IF(MIAC.EQ.236883734)GO TO 1900
C TURBULENCE
  IF(MIAC.EQ.1427151802)GO TO 2000
C CHANGE RHOX
  IF(MIAC.EQ.223095242)GO TO 2100
C FREQUENCIES
  IF(MIAC.EQ.450075960)GO TO 2200
C SURFACE
  IF(MIAC.EQ.1357812572)GO TO 2300
C PRESSURE
  IF(MIAC.EQ.1143518210)GO TO 2400
C CORRECTION
  IF(MIAC.EQ.237080870)GO TO 2500
C WAVELENGTH
  IF(MIAC.EQ.1597906832)GO TO 2600
C SCALE MODEL
  IF(MIAC.EQ.35762836)GO TO 2700
C CALL
  IF(MIAC.EQ.153784)GO TO 2800
C
9000 WRITE(6,2) CARD
      2 FORMAT(21H I DO NOT UNDERSTAND 80A1)
      CALL EXIT
97 LETCOL=MAX0(LETCOL,NUMCOL)
  MORE=1
  MIAC=IWORDF(CARD)

```

```

      IF(IFFAIL.EQ.1)GO TO 98
      MORE=0
      GO TO 3
C*****
  100 TEFF=FREEFF(CARD)
      FLUX=5.6697E-5/12.5664*TEFF**4
      GO TO 97
C*****
  200 GRAV=FREEFF(CARD)
      IF(GRAV.LT.10.)GRAV=EXP10(GRAV)
      GLOG=ALOG10(GRAV)
      GO TO 97
C*****
  300 MIAC=IWORDF(CARD)
C      ON
      IF(MIAC.EQ.569)GO TO 380
C      OFF
      IF(MIAC.EQ.20763)GO TO 390
C      IFOP
      IF(MIAC.EQ.464662)GO TO 370
      GO TO 9000
  370 NUMCOL=LETCOL
      DO 371 I=1,20
  371 IFOP(I)=FREEFF(CARD)
      GO TO 98
C      ON
  380 ISWCH=1
      GO TO 391
C      OFF
  390 ISWCH=0
  391 MORE=1
  395 MIAC=IWORDF(CARD)
      IF(IFFAIL.EQ.1)GO TO 97
      DO 392 I=1,20
      II=I
      IF(MIAC.EQ.IFOP1(I))GO TO 393
  392 CONTINUE
      GO TO 9000
  393 IFOP(II)=ISWCH
      GO TO 395
C*****
  400 GO TO 9000
C*****
  500 NUMITS=FREEFF(CARD)
      DO 501 I=1,15
  501 IFPNCH(I)=0
      IFPNCH(NUMITS)=1
      GO TO 97
C*****
  600 MIAC=IWORDF(CARD)
C      ON
      IF(MIAC.EQ.569)GO TO 610
C      OFF
      IF(MIAC.EQ.20763)GO TO 620
      GO TO 9000
  610 IFMOL=1
      GO TO 97
  620 IFMOL=0
      GO TO 97
C*****

```

```

700 NRHOX=FREEFF(CARD)
    TAU1LG=FREEFF(CARD)
    STEPLG=FREEFF(CARD)
    DO 701 J=1,NRHOX
        XNE(J)=0.
        PRAD(J)=0.
        VTURB(J)=0.
        PTURB(J)=0.
        TAUROS(J)=EXP10(TAU1LG+FLOAT(J-1)*STEPLG)
701 T(J)=TEFF*(.75*(.710+TAUROS(J)-.1331*EXP(-3.4488*TAUROS(J))))**.25
    CALL TTAUP(T,TAUROS,ABROSS,PTOTAL,P,PRAD,PTURB,GRAV,NRHOX)
    DO 702 J=1,NRHOX
702 RHOX(J)=PTOTAL(J)/GRAV
    GO TO 97
C*****
800 MIAC=IWORDF(CARD)
C    SCALE
    IF(MIAC.EQ.35762836)GO TO 810
C    CHANGE
    IF(MIAC.EQ.223095242)GO TO 820
    GO TO 9000
810 NUMCOL=LETCOL
    XSCALE=FREEFF(CARD)
    GO TO 97
820 MORE=1
821 IZ=FREEFF(CARD)
    IF(IFFAIL.EQ.1)GO TO 98
    ABUND(IZ)=FREEFF(CARD)
    GO TO 821
C*****
900 DO 901 I=1,NUMITS
901 IFPRNT(I)=FREEFF(CARD)
    GO TO 97
C*****
1000 DO 1001 I=1,NUMITS
1001 IFPNCH(I)=FREEFF(CARD)
    GO TO 97
C*****
1100 MIAC=IWORDF(CARD)
    NUMCOL=LETCOL
C    FREQUENCIES
    IF(MIAC.EQ.450075960)GO TO 1110
C    DEPARTURE COEFFICIENTS
    IF(MIAC.EQ.287559136)GO TO 1120
C    STARTING T-TAU
    IF(MIAC.EQ.1355094447)GO TO 1130
C    DECK
    IF(MIAC.EQ.209579)GO TO 1140
    GO TO 9000
C    FREQUENCIES
1110 NUM=FREEFF(CARD)
    NULJ=FREEFF(CARD)
    NUHI=FREEFF(CARD)
    NUMNU=NUM
    LETCOL=NUMCOL
    NDUMMY=IWORDF(CARD)
    DO 1111 I=1,6
1111 FREQID(I)=WORD(I)
    NUMCOL=LETCOL
    DO 1112 I=1,NUMNU

```

```

      NU=FREEFR(CARD)
      FRESET(NU)=FREEFF(CARD)
C     PROVISION FOR READING WAVELENGTHS
      IF(FRESET(NU).LT.1.E7)FRESET(NU)=2.997925E17/FRESET(NU)
1112  RCOSET(NU)=FREEFF(CARD)
      GO TO 98
C     DEPARTURE COEFFICIENTS
1120  NRHOX=FREEFF(CARD)
      DO 1122 J=1,NRHOX
      NUMCOL=1
      READ(5,1)CARD
      DUMMY=FREEFF(CARD)
      DO 1121 I=1,6
1121  BHYD(J,I)=FREEFF(CARD)
1122  BMIN(J)=FREEFF(CARD)
      WLTE=WWNLTE
      NLTEON=1
      GO TO 98
1130  NRHOX=FREEFF(CARD)
      DO 1131 J=1,NRHOX
      NUMCOL=1
      READ(5,1)CARD
      TAUROS(J)=FREEFF(CARD)
      T(J)=FREEFF(CARD)
      PRAD(J)=0.
      XNE(J)=0.
      VTURB(J)=0.
1131  PTURB(J)=0.
      IF(TAJRDS(1).GT.0.)GO TO 1135
      DO 1132 J=1,NRHOX
1132  TAUROS(J)=EXP10(TAUROS(J))
1135  CALL TTAUP(T,TAUROS,ABROSS,PTOTAL,P,PRAD,PTURB,GRAV,NRHOX)
      DO 1136 J=1,NRHOX
1136  RHOX(J)=PTOTAL(J)/GRAV
      GO TO 98
1140  NRHOX=FREEFF(CARD)
      DO 1141 J=1,NRHOX
      NUMCOL=1
      READ(5,1)CARD
      RHOX(J)=FREEFF(CARD)
      T(J)=FREEFF(CARD)
      MORE=1
      P(J)=FREEFF(CARD)
      XNE(J)=FREEFF(CARD)
      ABROSS(J)=FREEFF(CARD)
      PRAD(J)=FREEFF(CARD)
      VTURB(J)=FREEFF(CARD)
1141  MORE=0
      IF(RHOX(1).GE.0.)GO TO 98
      DO 1142 J=1,NRHOX
1142  RHOX(J)=EXP10(RHOX(J))
      GO TO 98
C*****
1200  NLTEON=0
      WLTE=WWLTE
      DO 1202 J=1,40
      DO 1201 I=1,6
1201  BHYD(J,I)=1.
1202  BMIN(J)=1.
      GO TO 97

```

```

C*****
1300 NLTEON=1
      WLTE=WWNLTE
      GO TO 97
C*****
1500 IF(MODE.NE.1)GO TO 1510
      IF(NUMITS.EQ.0)WRITE(6,1501)
      IF(NRHOX.EQ.0)WRITE(6,1502)
      IF(NUMNJ.EQ.0)WRITE(6,1503)
      IF(TEFF.EQ.0.)WRITE(6,1504)
      IF(GRAV.EQ.0.)WRITE(6,1505)
1501 FORMAT(20H HOW MANY ITERATIONS)
1502 FORMAT(14H HOW MANY RHOX)
1503 FORMAT(21H HOW MANY FREQUENCIES)
1504 FORMAT(10H WHAT TEFF)
1505 FORMAT(13H WHAT GRAVITY)
      IF(NUMITS.EQ.0)CALL EXIT
      IF(NRHOX.EQ.0)CALL EXIT
      IF(NUMNJ.EQ.0)CALL EXIT
      IF(TEFF.EQ.0.)CALL EXIT
      IF(GRAV.EQ.0.)CALL EXIT
1510 CONTINUE
      IF(ABJND(1).LT.0.)ABUND(1)=EXP10(ABUND(1))
      IF(ABJND(2).LT.0.)ABUND(2)=EXP10(ABUND(2))
      DO 1511 IZ=3,99
        IF(ABJND(IZ).GT.0.)ABUND(IZ)=ALOG10(ABUND(IZ))
1511 CONTINUE
      WRITE(6,1512)TEFF,GLOG,WLTE,TITLE,XSCALE,
1(ELEM(IZ),ABUND(IZ),IZ=1,99)
1512 FORMAT(1H1////5H TEFF7.0,8H LOG GF6.2,3XA4/
17HOTITLE ,74A1/7H0XSCALEF8.3,2(3X,A2,F6.3)/(10(1XA2,F6.2)))
      DO 1513 IZ=3,99
        XABJND(IZ)=EXP10(ABUND(IZ))*XSCALE
        XABUND(1)=ABUND(1)
        XABJND(2)=ABUND(2)
        WTMOLE=0.
      DO 1514 IZ=1,99
1514 WTMOLE=WTMOLE+XABUND(IZ)*ATMASS(IZ)
      DO 1516 J=1,NRHOX
        TK(J)=1.38054E-16*T(J)
        HKT(J)=6.6256E-27/TK(J)
        TKEV(J)=8.6171E-5*T(J)
        TLOG(J)=ALOG(T(J))
        XNATOM(J)=P(J)/TK(J)-XNE(J)
        RHO(J)=XNATOM(J)*WTMOLE*1.660E-24
1516 PTURB(J)=.5*RHO(J)*VTURB(J)**2
      WRITE(6,1517)IFOP
1517 FORMAT(3H0H1I2,7H H2PLUSI2,7H HMINUSI2,5H HRAYI2,4H HE1I2,
1 4H HE2I2,8H HEMINUSI2,6H HERAYI2,5H COOLI2,5H LUKEI2/
2 4H HOTI2,9H ELECTRONI2,6H H2RAYI2,7H HLINEI2,6H LINEI2,
3 9H LINECATI2,7H XLINESI2,7H XLSCATI2,6H XCONTI2,6H XSCATI2)
      WRITE(6,1518)IFCORR,IFPRES,IFSURF,IFSCAT,IFCONV,MIXLTH,IFMOL,
1IFTJRB,TRBFDG,TRBPOW,TRBSND,TRBCON
1518 FORMAT(7H0IFCORRI2,8H IFPRESI2,8H IFSURFI2,8H IF>CATI2,
1 8H IFCONVI2,8H MIXLTHF6.2,7H IFMOLI2/7H IFTURBI2,
2 8H TRBFDGF6.2,8H TRBPOWF6.2,8H TRBSNDF6.2,8H TRBCONF6.2)
      IF(MODE.NE.1)GO TO 1575
      WRITE(6,1521)NUMITS,IFPRNT,IFPNCH
1521 FORMAT(7H NUMITSI3,8H IFPRNTI5I2,8H IFPNCHI5I2)
      IF(IFWAVE.EQ.0)GO TO 1560

```

```

WRITE(6,1536)WBEGIN,DELTAW,NUMNU
1536 FORMAT(7H0WBEGINF11.4,9H DELTAWF7.4,8H NUMNU15)
GO TO 1575
1560 WRITE(6,1561)FREQID,NUMNU,NJLO,NUHI
1561 FORMAT(8H0FREQID 6A1,8H NJMNU14,7H NULO14,7H NUHI14)
NN=(NJMNU*3)/4
NNN=NJMNU-NN*3
IF(NNN.LT.1)NN=1
IF(NNN.LT.1)NNN=1
WRITE(6,1563)((NU,FRESET(NU),RCOSET(NJ),NU=I,NJMNU,NN),I=1,NNN)
1563 FORMAT((4(3X13,1P2E13.6)))
C1563 FORMAT((4(3X13,0P2E13.6)))
IF(NN.EQ.NNN)GO TO 1575
NNN=NN+1
WRITE(6,1564)((NU,FRESET(NU),RCOSET(NJ),NU=I,NJMNU,NN),I=NNN,NN)
1564 FORMAT((3(3X13,1P2E13.6)))
C1564 FORMAT((3(3X13,0P2E13.6)))
C
1575 CONTINUE
WRITE(6,1576)(J,RHOX(J),T(J),P(J),XNE(J),ABROSS(J),PRAD(J),
1VTURB(J),(BHYD(J,I),I=1,6),BMIN(J),J=1,NRHOX)
1576 FORMAT(1H1////8X4HRHOX,9X1HT,8X1HP,8X3HXNE,6X6HABROSS,5X4HPRAD,
1 6X5HVTURB,24X4HBHYD,25X4HBMIN/
2(I3,1PE13.6,0PF9.1,1P5E10.3,1X0P7F8.4))
C 2(I3,0PE13.6,0PF9.1,0P5E10.3,1X0P7F8.4))
C
RETURN
C*****
1600 MIAC=IWORDF(CARD)
C ON
IF(MIAC.EQ.569)GO TO 1610
C OFF
IF(MIAC.EQ.20763)GO TO 1620
GO TO 9000
1610 IFSCAT=1
GO TO 97
1620 IFSCAT=0
GO TO 97
C*****
1700 IF(MODE.NE.20)CALL EXIT
NRHOX=0
RETURN
C*****
1800 DO 1801 I=1,74
1801 TITLE(I)=CARD(I+6)
GO TO 98
C*****
1900 MIAC=IWORDF(CARD)
C ON
IF(MIAC.EQ.569)GO TO 1910
C OFF
IF(MIAC.EQ.20763)GO TO 1920
GO TO 9000
1910 IFCONV=1
NUMCOL=LETCOL
MIXLTH=FREEFF(CARD)
GO TO 97
1920 IFCONV=0
MIXLTH=1.
DO 1921 J=1,NRHOX

```

```

      DLTDLT(J)=0.
      HEATCP(J)=0.
      DLRDLT(J)=0.
      VELSDN(J)=0.
      GRDADB(J)=0.
      HSCALE(J)=0.
      FLXCNV(J)=0.
1921 VCONV(J)=0.
      GO TO 97
C*****
2000 MIAC=IWORDF(CARD)
C      ON
      IF(MIAC.EQ.569)GO TO 2010
C      OFF
      IF(MIAC.EQ.20763)GO TO 2020
      GO TO 9000
2010 IFTURB=1
      NUMCOL=LETCOL
      TRBFDG=FREEFF(CARD)
      TRBPOW=FREEFF(CARD)
      TRBSND=FREEFF(CARD)
      TRBCON=FREEFF(CARD)
      GO TO 97
2020 IFTURB=0
      TRBFDG=0.
      TRBPOW=0.
      TRBSND=0.
      TRBCON=0.
      GO TO 97
C*****
2100 NNEW=FREEFF(CARD)
      DO 2101 J=1,NNEW
2101 RHOXA(J)=FREEFF(CARD)
      IDUM=MAP1(RHOX,T,NRHOX,RHOXA,DUM1,NNEW)
      IDUM=MAP1(RHOX,P,NRHOX,RHOXA,DUM2,NNEW)
      IDUM=MAP1(RHOX,XNE,NRHOX,RHOXA,DUM3,NNEW)
      IDUM=MAP1(RHOX,ABROSS,NRHOX,RHOXA,DUM4,NNEW)
      IDUM=MAP1(RHOX,VTURB,NRHOX,RHOXA,DUM5,NNEW)
      IDUM=MAP1(RHOX,PRAD,NRHOX,RHOXA,DUM6,NNEW)
      IDUM=MAP1(RHOX,BMIN,NRHOX,RHOXA,DUM7,NNEW)
      DO 2102 J=1,NNEW
      T(J)=DUM1(J)
      P(J)=DUM2(J)
      XNE(J)=DUM3(J)
      ABROSS(J)=DUM4(J)
      VTURB(J)=DUM5(J)
      PRAD(J)=DUM6(J)
2102 BMIN(J)=DUM7(J)
      DO 2105 I=1,6
      IDUM=MAP1(RHOX,BHYD(1,I),NRHOX,RHOXA,DUM1,NNEW)
      DO 2104 J=1,NNEW
2104 BHYD(J,I)=DUM1(J)
2105 CONTINUE
      NRHOX=NNEW
      DO 2106 J=1,NRHOX
2106 RHOX(J)=RHOXA(J)
      GO TO 97
C*****
2300 MIAC=IWORDF(CARD)
C      INTENSITY

```



```

      IF(MIAC.EQ.651354309)GO TO 2310
C     FLUX
      IF(MIAC.EQ.321147)GO TO 2320
C     OFF
      IF(MIAC.EQ.20763)GO TO 2330
      GO TO 9000
2310 NMU=FREEFF(CARD)
      DO 2311 MU=1,NMU
2311 ANGLE(MU)=FREEFF(CARD)
      IFSJRF=2
      GO TO 97
2320 IFSJRF=1
      GO TO 97
2330 IFSJRF=0
      GO TO 97
C*****
2400 MIAC=IWORDF(CARD)
C     ON
      IF(MIAC.EQ.569)GO TO 2410
C     OFF
      IF(MIAC.EQ.20763)GO TO 2420
      GO TO 9000
2410 IFPRES=1
      GO TO 97
2420 IFPRES=0
      GO TO 97
C*****
2500 MIAC=IWORDF(CARD)
C     ON
      IF(MIAC.EQ.569)GO TO 2510
C     OFF
      IF(MIAC.EQ.20763)GO TO 2520
      GO TO 9000
2510 IFCORR=1
      GO TO 97
2520 IFCORR=0
      DO 2521 J=1,4
      FLXERR(J)=0.
2521 FLXDRV(J)=0.
      GO TO 97
C*****
2600 WBEGIN=FREEFF(CARD)
      DELTAW=FREEFF(CARD)
      WEND=FREEFF(CARD)
      IFWAVE=1
      NULO=1
      NUHI=IFIX((WEND-WBEGIN)/DELTAW+.5)+1
      NUMNU=NUHI
      GO TO 97
C*****
C     SCALING MODELS OR CHANGING RHOX SPACING TO BE UNIFORM IN TAUROS
2700 NRHOX=FREEFF(CARD)
      TAU1LG=FREEFF(CARD)
      STEPLG=FREEFF(CARD)
      MORE=1
      TEFF1=FREEFF(CARD)
      GNEW=FREEFF(CARD)
      IF(GNEW.LT.10.)GNEW=EXP10(GNEW)
      MORE=0
      DO 2701 J=1,NRHOX

```

```

2701 TAUSTD(J)=EXP10(TAU1LG*FLOAT(J-1)*STEPLG)
      RHOX=RHOX(1)
      RHOX(1)=0.
      CALL INTEG(RHOX,ABROSS,TAUROS,NRHOX)
      RHOX(1)=RHOX0
      IDUM=MAP1(TAUROS,RHOX,NRHOX,TAUSTD,DUM1,NRHOX)
      IDUM=MAP1(TAUROS,T,NRHOX,TAJSTD,DUM2,NRHOX)
      IDUM=MAP1(TAUROS,P,NRHOX,TAJSTD,DUM3,NRHOX)
      IDUM=MAP1(TAUROS,XNE,NRHOX,TAUSTD,DUM4,NRHOX)
      IDUM=MAP1(TAUROS,ABROSS,NRHOX,TAUSTD,DUM5,NRHOX)
      IDUM=MAP1(TAUROS,PRAD,NRHOX,TAUSTD,DUM6,NRHOX)
      IDUM=MAP1(TAUROS,VTURB,NRHOX,TAUSTD,DUM7,NRHOX)
      IDUM=MAP1(TAUROS,BMIN,NRHOX,TAUSTD,DUM8,NRHOX)
      DO 2702 J=1,NRHOX
        RHOX(J)=DUM1(J)
        T(J)=DUM2(J)
        P(J)=DUM3(J)
        XNE(J)=DUM4(J)
        ABROSS(J)=DUM5(J)
        PRAD(J)=DUM6(J)
        VTURB(J)=DUM7(J)
2702 BMIN(J)=DUM8(J)
      DO 2704 I=1,6
        IDUM=MAP1(TAUROS,BHYD(1,I),NRHOX,TAUSTD,DUM1,NRHOX)
      DO 2703 J=1,NRHOX
2703 BHYD(J,I)=DUM1(J)
2704 CONTINUE
      IF(TEFF1.EQ.0.)GO TO 97
      IF(TEFF1.EQ.TEFF.AND.GNEW.EQ.GRAV)GO TO 97
      DO 2710 J=1,NRHOX
        TAUROS(J)=TAUSTD(J)
        T(J)=T(J)*TEFF1/TEFF
C      FOR DETAILED WORK WITH RADIATION PRESSURE OR TURBULENT PRESSURE
C      BETTER METHODS FOR SCALING THOSE QUANTITIES SHOULD BE INSERTED
        PTURB(J)=0.
2710 PRAD(J)=PRAD(J)*(TEFF1/TEFF)**4*(GNEW/GRAV)
        TEFF=TEFF1
        FLUX=5.6697E-5/12.5664*TEFF**4
        GRAV=GNEW
        GLOG=ALOG10(GRAV)
        CALL TTAUP(T,TAUROS,ABROSS,PTOTAL,P,PRAD,PTURB,GRAV,NRHOX)
      DO 2711 J=1,NRHOX
2711 RHOX(J)=PTOTAL(J)/GRAV
      GO TO 97
C*****
2800 CALL DUMMYR
      GO TO 97
C*****
      END

C      SUBROUTINE DUMMYR
      DUMMY INPUT ROUTINE FOR MODIFYING READIN
      RETJRN
      END

```

```

FUNCTION FREEFF(CARD)
COMMON /FREE/WORD(6),NUMCOL,LETCOL,LAST,MORE,IFFAIL,MAXPOW
DIMENSION CARD(1)
DIMENSION A(10)
DATA A/1H0,1H1,1H2,1H3,1H4,1H5,1H6,1H7,1H8,1H9/
DATA OPT/1H./,QCM/1H./,QMI/1H-/ ,QE/1HE/,QPL/1H+/,QBL/1H /
IFFAIL=0
IF(NUMCOL.GT.LAST)GO TO 3002
ANSWER=0.
ASIGN=1.
ISIGN=1
NPT=0
IFO=0
N=0
ASSIGN 100 TO NSWCH
DO 1000 NCOL=NUMCOL, LAST
C=CARD(NCOL)
GO TO NSWCH,(100,200,300,400)
100 IF(C.EQ.QBL)GO TO 104
DO 101 I=1,10
IF(C.EQ.A(I))GO TO 102
101 CONTINUE
IF(C.EQ.OPT)GO TO 103
IF(C.EQ.QCM)GO TO 104
IF(C.EQ.QMI)GO TO 105
999 ASIGN=1.
ANSWER=0.
NPT=0
IFO=0
N=0
ASSIGN 100 TO NSWCH
GO TO 1000
102 N=N+1
ANSWER=10.*ANSWER+FLOAT(I-1)
GO TO 1000
103 ASSIGN 200 TO NSWCH
GO TO 1000
104 IF(N.EQ.0)GO TO 999
FREEFF=ANSWER*ASIGN
998 NUMCOL=NCOL+1
RETURN
105 IF(N.EQ.0)GO TO 106
GO TO 999
106 ASIGN=-1.
GO TO 1000
200 DO 201 I=1,10
IF(C.EQ.A(I))GO TO 202
201 CONTINUE
IF(C.EQ.QE )GO TO 203
IF(C.EQ.QBL)GO TO 204
IF(C.EQ.QCM)GO TO 204
GO TO 999
202 N=N+1
NPT=NPT+1
ANSWER=10.*ANSWER+FLOAT(I-1)
GO TO 1000
203 ASSIGN 300 TO NSWCH
GO TO 1000
204 IF(N.EQ.0)GO TO 999
FREEFF=ANSWER*ASIGN/10.**NPT

```

```

      GO TO 998
300 DO 301 I=1,10
      IF(C.EQ.A(I))GO TO 302
301 CONTINUE
      IF(C.EQ.QBL)GO TO 303
      IF(C.EQ.QMI)GO TO 304
      IF(C.EQ.QPL)GO TO 303
      GO TO 999
302 NPOWER=I-1
      IFO=1
310 ASSIGN 400 TO NSWCH
      GO TO 1000
303 NPOWER=0
      GO TO 310
304 ISIGN=-1
      NPOWER=0
      GO TO 310
400 DO 401 I=1,10
      IF(C.EQ.A(I))GO TO 402
401 CONTINUE
      IF(C.EQ.QCM)GO TO 403
      IF(C.EQ.QBL)GO TO 403
      GO TO 999
402 NPOWER=10*NPOWER+I-1
      IFO=1
      IF(NPOWER.GE.MAXPOW)GO TO 999
      GO TO 1000
403 IF(IFO.EQ.0)GO TO 999
      FREEFF=ANSWER*ASIGN*10.**((ISIGN*NPOWER-NPT)
      GO TO 998
1000 CONTINUE
      NUMCOL=LAST+1
3002 IFFAIL=1
      IF(MORE.GT.0)GO TO 3000
      WRITE(6,3001)(CARD(I),I=1,LAST)
3001 FORMAT(28H1FREEFF HAS READ OFF THE END/(1X80A1))
      CALL EXIT
3000 FREEFF=0.
      RETJRN
      END

```

```

      FUNCTION FREEFR(CARD)
      COMMON /FREE/WORD(6),NUMCOL,LETCOL,LAST,MORE,IFFAIL,MAXPOW
      DIMENSION CARD(1)
      MORE=1
      FREEFR=FREEFF(CARD)
      IF(IFFAIL.EQ.0)RETURN
      L=LAST-1
      READ(5,1)(CARD(I),I=1,L)
1  FORMAT(80A1)
      NUMCOL=1
      FREEFR=FREEFF(CARD)
      RETJRN
      END

```

```

FUNCTION IWORDF(CARD)
COMMON /FREE/WORD(6),NUMCOL,LETCOL,LAST,MORE,IFFAIL,MAXPOW
DIMENSION CARD(1)
DIMENSION A(36)
EQUIVALENCE (QE,A(5))
DATA A/1HA,1HB,1HC,1HD,1HE,1HF,1HG,1HH,1HI,1HJ,1HK,1HL,1HM,1HN,
1HO,1HP,1HQ,1HR,1HS,1HT,1HU,1HV,1HW,1HX,1HY,1HZ,1HO,1HI,1H2,1H3,
21H4,1H5,1H6,1H7,1H8,1H9/
DATA OPT/1H./,QCM/1H./,QEQ/1H./,QBL/1H /
DO 1 I=1,6
1 WORD(I)=QBL
IFFAIL=0
IF(LETCOL.GT.LAST)GO TO 4002
N=0
C (M)ACHINE (I)NDEPENDENT (A)LPHAMERIC (C)ODE
MIAC=0
ASSIGN 500 TO NSWCH
DO 2000 NCOL=LETCOL,LAST
C=CARD(NCOL)
GO TO NSWCH,(500,600)
500 IF(C.EQ.QBL)GO TO 1999
DO 501 II=1,26
IF(C.EQ.A(II))GO TO 502
501 CONTINUE
1999 MIAC=0
N=0
ASSIGN 500 TO NSWCH
GO TO 2000
502 IF(C.NE.QE )GO TO 506
IF(NCOL.EQ.1)GO TO 506
C=CARD(NCOL-1)
DO 503 I=27,36
IF(C.EQ.A(I))GO TO 504
503 CONTINUE
IF(C.NE.OPT)GO TO 506
504 C=CARD(NCOL+1)
DO 505 I=27,36
IF(C.EQ.A(I))GO TO 1999
505 CONTINUE
IF(C.EQ.QBL)GO TO 1999
506 N=N+1
MIAC=II
WORD(1)=A(II)
ASSIGN 600 TO NSWCH
GO TO 2000
600 IF(C.EQ.QBL)GO TO 603
IF(C.EQ.QEQ)GO TO 603
IF(C.EQ.QCM)GO TO 603
DO 601 II=1,36
IF(C.EQ.A(II))GO TO 602
601 CONTINUE
GO TO 1999
602 N=N+1
IF(N.GT.6)GO TO 604
MIAC=37*MIAC+II
WORD(N)=A(II)
604 GO TO 2000
603 IWORDF=MIAC
LETCOL=NCOL+1
RETURN

```

```

2000 CONTINUE
      LETCOL=LAST+1
4002 IFFAIL=1
      IF(MORE.GT.0)GO TO 4000
      WRITE(6,4001)(CARD(I),I=1,LAST)
4001 FORMAT(28H11WORDF HAS READ OFF THE END/(1X80A1))
      CALL EXIT
4000 IWORDF=0
      RETURN
      END

```

```

SUBROUTINE BLOCKE
COMMON /ELEM/ABUND(99),ATMASS(99),ELEM(99)

```

```

C      1H      2HE
C      DATA ABUND/      .9,      .1,
C      3LI      4BE      5B      6C      7N      8O      9F      10NE      11NA      12MG
1-11.6, -9.6, -9.2,-3.50,-4.12,-3.28, -6.6, -3.5,-6.18,-4.57,
C      13AL      14SI      15P      16S      17CL      18AR      19K      20CA      21SC      22TI
2-5.65,-4.50,-6.62,-4.84, -6.6, -5.3,-7.00,-5.72,-9.01,-7.55,
C      23V      24CR      25MN      26FE      27CO      28NI      29CU      30ZN      31GA      32GE
3-8.13,-6.58,-7.17,-4.5, -8.4,-6.97, -7.3,-7.63,-9.11,-8.73,
C      33AS      34SE      35BR      36KR      37RB      38SR      39Y      40ZR      41NB      42MO
4 -9.7, -8.8, -9.4, -8.8,-9.42,-9.23, -9.6, -9.6,-10.3,-10.0,
C      43TC      44RU      45RH      46PD      47AG      48CD      49IN      50SN      51SB      52TE
5-20.0,-10.4,-11.2,-10.7,-11.3,-9.98,-10.34,-10.34,-10.4,-10.0,
C      53I      54XE      55CS      56BA      57LA      58CE      59PR      60ND      61PM      62SM
6-10.6,-10.0,-10.9,-10.15,-10.6,-10.4,-11.2,-10.5,-20.0,-11.0,
C      63EU      64GD      65TB      66DY      67HO      68ER      69TM      70YB      71LU      72HF
7-11.3,-10.9,-11.6,-10.8,-11.5,-11.1,-11.9,-10.9,-11.7,-11.4,
C      73TA      74W      75RE      76OS      77IR      78PT      79AU      80HG      81TL      82PB
8-11.7,-10.9,-11.4,-10.7,-10.8,-10.4,-11.3,-11.1,-11.5,-10.15,
C      83BI      84PO      85AT      86RN      87FR      88RA      89AC      90TH      91PA      92J
9-11.3,-20.0,-20.0,-20.0,-20.0,-20.0,-20.0,-20.0,-11.7,-20.0,-12.0,
C      93NP      94PU      95AM      96CM      97BK      98CF      99ES
T-20.0,-20.0,-20.0,-20.0,-20.0,-20.0,-20.0,-20.0/
DATA ATMASS/ 1.008,4.003,
1 6.939,9.013,10.81,12.01,14.01,16.00,19.00,20.18,22.99,24.31,
2 26.98,28.09,30.98,32.07,35.45,39.95,39.10,40.08,44.96,47.90,
3 50.94,52.00,54.94,55.85,58.94,58.71,63.55,65.37,69.72,72.60,
4 74.92,78.96,79.91,83.80,85.48,87.63,88.91,91.22,92.91,95.95,
5 99.00,101.1,102.9,106.4,107.9,112.4,114.8,118.7,121.8,127.6,
6 126.9,131.3,132.9,137.4,138.9,140.1,140.9,144.3,147.0,150.4,
7 152.0,157.3,158.9,162.5,164.9,167.3,168.9,173.0,175.0,178.5,
8 181.0,183.9,186.3,190.2,192.2,195.1,197.0,200.6,204.4,207.2,
9 209.0,210.0,211.0,222.0,223.0,226.1,227.1,232.0,231.0,238.0,
T 237.0,244.0,243.0,247.0,251.0,254.0/
DATA ELEM/ 2HH, 2HHE,
1 2HLI, 2HBE, 2HB, 2HC, 2HN, 2HO, 2HF, 2HNE, 2HNA, 2HMG,
2 2HAL, 2HSI, 2HP, 2HS, 2HCL, 2HAR, 2HK, 2HCA, 2HSC, 2HTI,
3 2HV, 2HCR, 2HMN, 2HFE, 2HCO, 2HNI, 2HCU, 2HZN, 2HGA, 2HGE,
4 2HAS, 2HSE, 2HBR, 2HKB, 2HRS, 2HY, 2HZR, 2HNB, 2HMO,
5 2HTC, 2HRU, 2HRH, 2HPD, 2HAG, 2HCD, 2HIN, 2HSN, 2HSB, 2HTE,
6 2HI, 2HXE, 2HCS, 2HBA, 2HLA, 2HCE, 2HPR, 2HND, 2HPM, 2HSM,
7 2HEU, 2HGD, 2HTB, 2HDY, 2HDO, 2HER, 2HTM, 2HYB, 2HLU, 2HMF,
8 2HTA, 2HW, 2HRE, 2HOS, 2HIR, 2HPT, 2HAU, 2HMS, 2HTL, 2HPB,
9 2HSI, 2HPO, 2HAT, 2HRN, 2HFR, 2HRA, 2HAC, 2HTH, 2HPA, 2HJ,
T 2HNP, 2HPU, 2HAM, 2HCM, 2HBK, 2HCF, 2HES/
END

```

```

SUBROUTINE BLOCKR
COMMON /CONV/DLTDLP(40),HEATCP(40),DLRDLT(40),VELSND(40),
1      GRDADB(40),HSCALE(40),FLXCNV(40),VCONV(40),MIXLTH,
2      IFCONV
REAL MIXLTH
COMMON /DEPART/BHYD(40,6),BMIN(40),NLTEON
COMMON /FLUX/ FLUX,FLXERR(40),FLXDRV(40),FLXRAD(40)
COMMON /FRESET/FRESET(500),RCOSET(500),NULO,NUHI,NUMNU
COMMON /IF/IFCORR,IFPRES,IFSURF,IFSCAT,IFMOL
COMMON /IFOP/IFOP(20)
COMMON /IONS/XNFPH(40,2),XNFPHE(40,3)
COMMON /ITER/ ITER,IFPRNT(15),IFPNCH(15),NUMITS
COMMON /JUNK/TITLE(74),FREQID(6),WLTE,XSCALE
COMMON /MUS/ANGLE(20),SURFI(20),NMU
COMMON /RAD/ACCRAD(40),PRAD(40)
COMMON /RHOX/RHOX(40),NRHOX
COMMON /TEFF/TEFF,GRAV,GLOG
COMMON /TURBPR/VTURB(40),PTJRB(40),TRBFDG,TRBCON,TRBPOW,TRBSND,
1      IFTURB
COMMON /WAVEY/WBEGIN,DELTAW,IFWAVE
DATA DLTDLP,HEATCP,DLRDLT,VELSND,GRDADB,HSCALE,FLXCNV,VCONV/
1 40*0.,40*0.,40*0.,40*0.,40*0.,40*0.,40*0.,40*0.,40*0./
DATA IFCONV,MIXLTH/0,1./
DATA BHYD,BMIN/40*1.,40*1.,40*1.,40*1.,40*1.,40*1.,40*1.,40*1./
DATA NLTEON/0/
DATA FLJX/0./
DATA FLXERR,FLXDRV/40*0.,40*0./
DATA NUMNU/0/
DATA IFCORR,IFPRES,IFSURF,IFSCAT,IFMOL/1,1,0,1,0/
DATA IFOP/1,1,1,1,1,1,0,0,1,0,0,1,0,0,0,0,0,0,0/
DATA XNFPH,XNFPHE/40*0.,40*0.,40*0.,40*0.,40*0./
DATA IFPRNT/2,2,2,2,2,2,2,2,2,2,2,2,2,2,2/
DATA IFPNCH/0,0,0,0,0,0,0,0,0,0,0,0,0,0,0/
DATA NUMITS/0/
DATA TITLE/74*1H /
DATA WLTE/4HLTE /
DATA XSCALE/1./
DATA SURFI/20*0./,NMU/1/
DATA ACCRAD/40*0./,PRAD/40*0./
DATA NRHOX/0/
DATA TEFF/0./
DATA GRAV/0./
DATA VTURB/40*0./
DATA PTJRB/40*0./
DATA IFTURB,TRBFDG,TRBPOW,TRBSND,TRBCON/0,0.,0.,0.,0./
DATA IFWAVE/0/
END

```

```

SUBROUTINE TTAUP(T,TAU,ABSTD,PTOTAL,P,PRAD,PTURB,GRAV,NUMTAU)
C  ROSSELAND OPACITY, NORMAL ABUNDANCES, T=3100 TO 28000, P=-2 TO +6
C  TAUS MUST HAVE LOG SPACING
DIMENSION T(1),TAU(1),ABSTD(1),PTOTAL(1),P(1),PRAD(1),PTURB(1)
DIMENSION TABT(30),TABP(30)
DIMENSION TABKAP(30,30),KTAB(30,30),PKAP(30)
EQUIVALENCE (TABKAP(1),KTAB(1))
DIMENSION KTAB01(30),KTAB02(30),KTAB03(30),KTAB04(30)
DIMENSION KTAB05(30),KTAB06(30),KTAB07(30),KTAB08(30)
DIMENSION KTAB09(30),KTAB10(30),KTAB11(30),KTAB12(30)
DIMENSION KTAB13(30),KTAB14(30),KTAB15(30),KTAB16(30)
DIMENSION KTAB17(30),KTAB18(30),KTAB19(30),KTAB20(30)
DIMENSION KTAB21(30),KTAB22(30),KTAB23(30),KTAB24(30)
DIMENSION KTAB25(30),KTAB26(30),KTAB27(30),KTAB28(30)
DIMENSION KTAB29(30),KTAB30(30)
EQUIVALENCE (KTAB(001),KTAB01(1)),(KTAB(031),KTAB02(1))
EQUIVALENCE (KTAB(061),KTAB03(1)),(KTAB(091),KTAB04(1))
EQUIVALENCE (KTAB(121),KTAB05(1)),(KTAB(151),KTAB06(1))
EQUIVALENCE (KTAB(181),KTAB07(1)),(KTAB(211),KTAB08(1))
EQUIVALENCE (KTAB(241),KTAB09(1)),(KTAB(271),KTAB10(1))
EQUIVALENCE (KTAB(301),KTAB11(1)),(KTAB(331),KTAB12(1))
EQUIVALENCE (KTAB(361),KTAB13(1)),(KTAB(391),KTAB14(1))
EQUIVALENCE (KTAB(421),KTAB15(1)),(KTAB(451),KTAB16(1))
EQUIVALENCE (KTAB(481),KTAB17(1)),(KTAB(511),KTAB18(1))
EQUIVALENCE (KTAB(541),KTAB19(1)),(KTAB(571),KTAB20(1))
EQUIVALENCE (KTAB(601),KTAB21(1)),(KTAB(631),KTAB22(1))
EQUIVALENCE (KTAB(661),KTAB23(1)),(KTAB(691),KTAB24(1))
EQUIVALENCE (KTAB(721),KTAB25(1)),(KTAB(751),KTAB26(1))
EQUIVALENCE (KTAB(781),KTAB27(1)),(KTAB(811),KTAB28(1))
EQUIVALENCE (KTAB(841),KTAB29(1)),(KTAB(871),KTAB30(1))
DATA NT,NP/30,30/
DATA TABT/      3.500, 3.525, 3.550, 3.575, 3.600, 3.625, 3.650,
1 3.675, 3.700, 3.725, 3.750, 3.775, 3.800, 3.825, 3.850, 3.875,
2 3.900, 3.925, 3.950, 3.975, 4.000, 4.050, 4.100, 4.150, 4.200,
3 4.250, 4.300, 4.350, 4.400, 4.450/
DATA TABP/      -2.000,-1.500,-1.000, -.500, 0.000,  .500, 1.000,
1 1.250, 1.500, 1.750, 2.000, 2.250, 2.500, 2.750, 3.000, 3.200,
2 3.400, 3.600, 3.800, 4.000, 4.200, 4.400, 4.600, 4.800, 5.000,
3 5.200, 5.400, 5.600, 5.800, 6.000/
DATA KTAB01/
1-4282,-4245,-4166,-3949,-3612,-3220,-2804,-2383,-1967,-1564,      -2.000
2-1187, -865, -661, -585, -566, -563, -563, -564, -563, -558,      -2.000
3 -541, -521, -519, -519, -520, -520, -518, -490, -480, -479/      -2.000
DATA KTAB02/
1-4287,-4248,-4198,-4055,-3772,-3410,-3015,-2608,-2200,-1799,      -1.500
2-1414,-1060, -776, -618, -566, -556, -557, -559, -560, -560,      -1.500
3 -551, -522, -518, -518, -518, -519, -519, -500, -481, -479/      -1.500
DATA KTAB03/
1-4298,-4246,-4206,-4122,-3906,-3583,-3212,-2821,-2424,-2029,      -1.000
2-1641,-1271, -938, -691, -571, -539, -538, -544, -549, -553,      -1.000
3 -553, -526, -517, -515, -515, -517, -518, -510, -483, -479/      -1.000
DATA KTAB04/
1-4310,-4235,-4195,-4145,-4003,-3731,-3389,-3018,-2635,-2247,      -.500
2-1860,-1481,-1121, -809, -597, -508, -494, -504, -518, -530,      -.500
3 -538, -528, -513, -512, -511, -512, -514, -513, -489, -479/      -.500
DATA KTAB05/
1-4309,-4205,-4154,-4120,-4041,-3836,-3531,-3185,-2820,-2444,      0.000
2-2060,-1676,-1300, -948, -656, -476, -415, -418, -442, -469,      0.000
3 -492, -513, -502, -504, -504, -503, -506, -509, -496, -479/      0.000
DATA KTAB06/
1-4276,-4136,-4061,-4031,-3995,-3867,-3613,-3296,-2953,-2594,      .500

```


2-2221,-1839,-1454,-1078,-733,-462,-311,-275,-298,-340,	.500
3 -384,-451,-469,-482,-490,-491,-491,-496,-496,-477/	.500
DATA KTAB07/	1.000
1-4202,-4018,-3905,-3857,-3842,-3784,-3598,-3317,-2999,-2662,	1.000
2-2308,-1937,-1555,-1169,-795,-462,-213,-90,-78,-122,	1.000
3 -185,-309,-386,-424,-455,-468,-469,-472,-479,-470/	1.000
DATA KTAB08/	1.250
1-4146,-3940,-3804,-3739,-3723,-3691,-3546,-3287,-2981,-2656,	1.250
2-2313,-1952,-1577,-1193,-813,-460,-173,2,52,18,	1.250
3 -48,-200,-313,-373,-422,-447,-454,-456,-463,-460/	1.250
DATA KTAB09/	1.500
1-4074,-3849,-3691,-3605,-3579,-3564,-3461,-3230,-2938,-2623,	1.500
2-2291,-1942,-1576,-1198,-818,-453,-137,87,186,176,	1.500
3 111,-63,-214,-303,-374,-416,-433,-437,-442,-444/	1.500
DATA KTAB10/	1.750
1-3986,-3746,-3565,-3458,-3417,-3409,-3344,-3147,-2872,-2567,	1.750
2-2245,-1907,-1553,-1185,-809,-440,-103,161,313,341,	1.750
3 290,101,-86,-211,-306,-371,-403,-412,-417,-422/	1.750
DATA KTAB11/	2.000
1-3881,-3631,-3430,-3301,-3242,-3232,-3197,-3040,-2785,-2491,	2.000
2-2178,-1851,-1510,-1153,-786,-418,-70,224,426,503,	2.000
3 478,288,69,-94,-217,-308,-359,-381,-388,-393/	2.000
DATA KTAB12/	2.250
1-3761,-3505,-3288,-3139,-3060,-3040,-3025,-2911,-2681,-2399,	2.250
2-2096,-1778,-1449,-1105,-749,-387,-36,279,520,650,	2.250
3 664,492,251,47,-104,-225,-300,-337,-352,-358/	2.250
DATA KTAB13/	2.500
1-3627,-3372,-3142,-2973,-2875,-2841,-2835,-2760,-2562,-2296,	2.500
2-2001,-1693,-1374,-1043,-700,-347,1,327,598,776,	2.500
3 839,706,453,215,32,-118,-220,-279,-305,-315/	2.500
DATA KTAB14/	2.750
1-3481,-3231,-2993,-2807,-2691,-2639,-2632,-2591,-2430,-2182,	2.750
2-1897,-1597,-1288,-970,-639,-299,43,372,663,880,	2.750
3 994,922,671,406,194,13,-119,-201,-245,-263/	2.750
DATA KTAB15/	3.000
1-3324,-3085,-2844,-2644,-2508,-2439,-2424,-2405,-2285,-2060,	3.000
2-1787,-1496,-1196,-888,-570,-242,90,417,718,964,	3.000
3 1123,1132,897,616,377,170,7,-102,-167,-199/	3.000
DATA KTAB16/	3.200
1-3192,-2964,-2724,-2515,-2366,-2282,-2256,-2247,-2158,-1956,	3.200
2-1695,-1410,-1117,-818,-509,-192,132,454,758,1019,	3.200
3 1209,1290,1080,793,536,314,127,-4,-88,-134/	3.200
DATA KTAB17/	3.400
1-3055,-2839,-2603,-2389,-2226,-2128,-2090,-2084,-2023,-1847,	3.400
2-1599,-1323,-1036,-744,-445,-137,177,493,797,1067,	3.400
3 1281,1434,1262,977,704,471,264,110,6,-56/	3.400
DATA KTAB18/	3.600
1-2916,-2710,-2481,-2264,-2090,-1978,-1927,-1917,-1878,-1732,	3.600
2-1499,-1232,-953,-667,-376,-78,226,534,835,1111,	3.600
3 1341,1563,1440,1164,880,638,416,242,118,37/	3.600
DATA KTAB19/	3.800
1-2774,-2578,-2358,-2140,-1957,-1831,-1767,-1749,-1726,-1609,	3.800
2-1396,-1139,-867,-589,-305,-16,279,578,874,1151,	3.800
3 1392,1674,1610,1351,1062,812,581,390,247,148/	3.800
DATA KTAB20/	4.000
1-2632,-2443,-2233,-2017,-1827,-1689,-1610,-1583,-1568,-1480,	4.000
2-1289,-1044,-779,-508,-232,48,335,625,914,1190,	4.000
3 1438,1768,1770,1538,1248,991,757,552,393,277/	4.000
DATA KTAB21/	4.200
1-2489,-2306,-2105,-1894,-1700,-1551,-1458,-1419,-1405,-1342,	4.200

		PAGE 36
2-1176, -945, -690, -425, -157, 115, 393, 675, 957, 1229,	4.200	
3 1480, 1846, 1916, 1720, 1436, 1173, 938, 725, 554, 423/	4.200	
DATA KTAB22/	4.400	
1-2347, -2167, -1976, -1771, -1575, -1416, -1311, -1259, -1241, -1198,	4.400	
2-1058, -844, -598, -341, -79, 185, 455, 728, 1002, 1269,	4.400	
3 1519, 1912, 2046, 1897, 1625, 1357, 1124, 906, 725, 583/	4.400	
DATA KTAB23/	4.600	
1-2206, -2027, -1844, -1646, -1452, -1286, -1168, -1103, -1078, -1047,	4.600	
2 -934, -738, -503, -254, 0, 258, 519, 784, 1049, 1310,	4.600	
3 1558, 1968, 2158, 2065, 1812, 1543, 1311, 1093, 906, 755/	4.600	
DATA KTAB24/	4.800	
1-2067, -1887, -1710, -1520, -1329, -1158, -1029, -951, -917, -892,	4.800	
2 -804, -629, -406, -165, 81, 332, 586, 842, 1099, 1353,	4.800	
3 1597, 2016, 2253, 2220, 1996, 1730, 1498, 1283, 1092, 935/	4.800	
DATA KTAB25/	5.000	
1-1929, -1747, -1574, -1393, -1206, -1033, -895, -804, -759, -735,	5.000	
2 -667, -515, -306, -74, 165, 409, 655, 903, 1152, 1399,	5.000	
3 1637, 2060, 2332, 2361, 2175, 1917, 1684, 1475, 1282, 1121/	5.000	
DATA KTAB26/	5.200	
1-1794, -1608, -1437, -1264, -1082, -909, -765, -662, -605, -577,	5.200	
2 -525, -396, -203, 18, 251, 487, 726, 967, 1208, 1447,	5.200	
3 1680, 2101, 2399, 2484, 2345, 2103, 1870, 1666, 1475, 1312/	5.200	
DATA KTAB27/	5.400	
1-1660, -1470, -1300, -1133, -958, -787, -637, -525, -456, -421,	5.400	
2 -379, -272, -96, 114, 339, 568, 800, 1033, 1266, 1498,	5.400	
3 1724, 2140, 2457, 2591, 2504, 2285, 2055, 1855, 1669, 1504/	5.400	
DATA KTAB28/	5.600	
1-1528, -1335, -1163, -1000, -833, -665, -513, -392, -312, -268,	5.600	
2 -230, -142, 14, 213, 430, 652, 876, 1102, 1328, 1552,	5.600	
3 1771, 2180, 2507, 2682, 2649, 2462, 2239, 2043, 1862, 1699/	5.600	
DATA KTAB29/	5.800	
1-1397, -1201, -1027, -867, -706, -543, -390, -263, -172, -119,	5.800	
2 -80, -8, 129, 315, 523, 738, 955, 1174, 1392, 1609,	5.800	
3 1821, 2221, 2553, 2759, 2779, 2631, 2421, 2228, 2054, 1893/	5.800	
DATA KTAB30/	6.000	
1-1268, -1069, -892, -733, -578, -420, -268, -137, -37, 25,	6.000	
2 67, 128, 248, 420, 619, 826, 1037, 1248, 1460, 1669,	6.000	
3 1874, 2263, 2596, 2825, 2892, 2789, 2600, 2411, 2244, 2088/	6.000	
DATA ISTART/O/		
EXP10(X)=EXP(X*2.30258509299405E0)		
IF(ISTART.EQ.1)GO TO 19		
ISTART=1		
DO 13 IP=1,NP		
DO 13 IT=1,NT		
13 TABKAP(IT,IP)=FLOAT(KTAB(IT,IP))/1000.		
19 DLGTAJ=ALOG(TAU(2)/TAU(1))		
PLOG3=0.		
PLOG2=0.		
PLOG1=0.		
DPLOG2=0.		
DPLOG1=0.		
C ASSJME CONSTANT OPACITY NEAR SURFACE. FIRST GUESS=.1		
ABSTD(1)=.1		
DO 22 J=1,NUMTAU		
DO 24 IP=1,NP		
IDUM=MAP1(TABT,TABKAP(1,IP),NT,ALOG10(T(J)),PKAP(IP),1)		
24 CONTINUE		
IF(J.EQ.1)PLOG=ALOG(GRAV/ABSTD(1)*TAU(1))		
IF(J.GT.1.AND.J.LE.4)PLOG=PLOG1+DPLOG1		
IF(J.GT.4)PLOG=(3.*PLOG4+8.*DPLOG1-4.*DPLOG2+8.*DPLOG3)/3.		
ERRCR=1.		

```

      GO TO 21
20  IF (J.EQ.1) PNEW=ALOG (GRAV/ABSTD(1)*TAU(1))
      IF (J.GT.1.AND.J.LE.4) PNEW=(PLOG+2.*PLOG1+DPLOG+DPLOG1)/3.
      IF (J.GT.4) PNEW=(126.*PLOG1-14.*PLOG3+9.*PLOG4+42.*DPLOG+
1  108.*DPLOG1-54.*DPLOG2+24.*DPLOG3)/121.
      ERROR=ABS(PNEW-PLOG)
      PLOG=PNEW
21  PTOTAL(J)=EXP(PLOG)
      P(J)=PTOTAL(J)-PRAD(J)-PTURB(J)
      IDUM=MAP1(TAUP,PKAP,NP,ALOG10(P(J)),ABSTD(J),1)
      ABSTD(J)=EXP10(ABSTD(J))
      DPLOG=GRAV/ABSTD(J)*TAU(J)/PTOTAL(J)*DLGTAU
      IF(ERROR.GT..00005) GO TO 20
      PLOG4=PLOG3
      PLOG3=PLOG2
      PLOG2=PLOG1
      PLOG1=PLOG
      DPLOG3=DPLOG2
      DPLOG2=DPLOG1
      DPLOG1=DPLOG
22  CONTINUE
      RETRN
      END

```

```

      SUBROUTINE POPS(CODE,MODE,NUMBER)
      DIMENSION NUMBER(40,1)
      REAL NUMBER
      COMMON /IF/IFCORR,IFPRES,IFSJRF,IFSCAT,IFMOL
      COMMON /RHOX/RHOX(40),NRHOX
      COMMON /STATE/P(40),XNE(40),XNATOM(40),RHO(40)
      COMMON /TEMP/T(40),TKEV(40),TK(40),HKT(40),TLGG(40),ITEMP
      COMMON /XABUND/XABUND(99),WTMOLE
      DATA ITEMPI/0/
      IF(IFMOL.EQ.1) GO TO 200
      IF(IFPRES.EQ.1.AND.ITEMP.NE.ITEMPI) CALL NSELECT
      ITEMPI=ITEMP
      IF(CODE.EQ.0) RETURN
      IF(CODE.LT.100.) GO TO 110
      WRITE(6,106)
106  FORMAT(14H1MOLECULES OFF)
      CALL EXIT
110  IZ=CODE
      NION=(CODE-FLOAT(IZ))*100.+1.5
      DO 115 J=1,NRHOX
      CALL PFSAHA(J,IZ,NION,MODE,NUMBER)
C    PFSAHA RETURNS IONIZATION FRACTIONS OR IONIZATION FRACTIONS/
C    PARTITION FUNCTIONS SO CONVERT TO NUMBER DENSITIES
      NNNN=NION
      IF(MODE.LT.10) NNNN=1
      DO 115 ION=1,NNNN
115  NUMBER(J,ION)=NUMBER(J,ION)*XNATOM(J)*XABUND(IZ)
      RETRN
200  IF(IFPRES.EQ.1.AND.ITEMP.NE.ITEMPI) CALL NMOLEC(MODE)
      ITEMPI=ITEMP
      IF(CODE.EQ.0) RETURN
      CALL MOLEC(CODE,MODE,NUMBER)
      RETRN
      END

```

```

SUBROUTINE NELECT
COMMON /ELEM/ABUND(99),ATMASS(99),ELEM(99)
COMMON /ITER/ ITER,IFPRNT(15),IFPNCH(15),NUMITS
COMMON /RHOX/RHOX(40),NRHOX
COMMON /STATE/P(40),XNE(40),XNATOM(40),RHO(40)
COMMON /TEMP/T(40),TKEV(40),TK(40),HKT(40),TLOG(40),ITEMP
COMMON /XABUND/XABUND(99),WTMOLE
DIMENSION ELEC(40),E(10),X(10),MASK(10),NELEMZ(10),NIONZ(10)
DATA NELEMZ/1,2,6,11,12,13,14,19,20,26/
DATA NIONZ/1,2,2,2,2,2,2,2,2,2/
IF(ITER.LT.NUMITS)GO TO 406
DO 401 I=1,NZ
NELEM=NELEMZ(I)
401 E(I)=ELEM(NELEM)
WRITE(6,402)(E(I),I=1,NZ),(E(I),I=1,NZ)
402 FORMAT(1H1////50X22HELECTRON CONTRIBUTIONS/2X,20(4X,A2))
406 XNE(1)=P(1)/TK(1)/2.
DO 500 J=1,NRHOX
IF(J.GT.1)XNE(J)=XNE(J-1)*P(J)/P(J-1)
XNTOT=P(J)/TK(J)
XNATOM(J)=XNTOT-XNE(J)
DO 1 I=1,NZ
1 MASK(I)=1
DO 20 L=1,200
XNENEW=0.
DO 11 I=1,NZ
IF(MASK(I).EQ.0)GO TO 11
IZ=NELEMZ(I)
NION=NIONZ(I)
CALL PFSAHA(J,IZ,NION,4,ELEC)
E(I)=ELEC(J)
X(I)=ELEC(J)*XNATOM(J)*XABUND(IZ)
XNENEW=XNENEW+X(I)
11 CONTINUE
XNENEW=(XNENEW+XNE(J))/2.
ERROR=ABS((XNE(J)-XNENEW)/XNENEW)
XNE(J)=XNENEW
XNATOM(J)=XNTOT-XNE(J)
IF(ERROR.LT..0005)GO TO 400
IF(J.EQ.1)GO TO 20
X1=.00001*XNE(J)
IF(ERROR.LT..05)X1=X1*10.
DO 12 I=1,NZ
IF(X(I).LT.X1)MASK(I)=0
12 CONTINUE
20 CONTINUE
WRITE(6,250)
250 FORMAT(22H XNE DOES NOT CONVERGE)
CALL EXIT
400 RHO(J)=XNATOM(J)*WTMOLE*1.660E-24
IF(ITER.LT.NUMITS)GO TO 500
DO 403 I=1,NZ
403 X(I)=X(I)/XNE(J)
WRITE(6,404)J,(X(I),I=1,NZ),(E(I),I=1,NZ)
404 FORMAT(13,20F6.3)
500 CONTINUE
RETURN
END

```

```

SUBROUTINE PFSAHA(J,IZ,NION,MODE,ANSWER)
C   MODE 1 RETURNS IONIZATION FRACTION /PARTITION FUNCTION
C   MODE 2 RETURNS IONIZATION FRACTION
C   MODE 3 RETURNS PARTITION FUNCTION
C   MODE 4 RETURNS NUMBER OF ELECTRONS PRODUCED
C   MODE + 10 RETURN ALL IONS TO NION.  MODE ALONE RETURN NION ONLY.
COMMON /DEPART/BHYD(40,6),BMIN(40),NLTEON
COMMON /STATE/P(40),XNE(40),XNATOM(40),RHO(40)
COMMON /TEMP/T(40),TKEV(40),TK(40),HKT(40),TLOG(40),ITEMP
DIMENSION ANSWER(40,6),F(6),IP(6),PART(6),POTLO(6),LOCZ(24)
REAL IP
DIMENSION SCALE(4)
DIMENSION NNN(6,353)
DIMENSION NNN01(54),NNN02(54),NNN03(54),NNN04(54),NNN05(54)
DIMENSION NNN06(54),NNN07(54),NNN08(54),NNN09(54),NNN10(54)
DIMENSION NNN11(54),NNN12(54),NNN13(54),NNN14(54),NNN15(54)
DIMENSION NNN16(54),NNN17(54),NNN18(54),NNN19(54),NNN20(54)
DIMENSION NNN21(54),NNN22(54),NNN23(54),NNN24(54),NNN25(54)
DIMENSION NNN26(54),NNN27(54),NNN28(54),NNN29(54),NNN30(54)
DIMENSION NNN31(54),NNN32(54),NNN33(54),NNN34(54),NNN35(54)
DIMENSION NNN36(54),NNN37(54),NNN38(54),NNN39(54),NNN40(12)
EQUIVALENCE (NNN( 1),NNN01(1)),(NNN( 55),NNN02(1))
EQUIVALENCE (NNN(109),NNN03(1)),(NNN(163),NNN04(1))
EQUIVALENCE (NNN(217),NNN05(1)),(NNN(271),NNN06(1))
EQUIVALENCE (NNN(325),NNN07(1)),(NNN(379),NNN08(1))
EQUIVALENCE (NNN(433),NNN09(1)),(NNN(487),NNN10(1))
EQUIVALENCE (NNN(541),NNN11(1)),(NNN(595),NNN12(1))
EQUIVALENCE (NNN(649),NNN13(1)),(NNN(703),NNN14(1))
EQUIVALENCE (NNN(757),NNN15(1)),(NNN(811),NNN16(1))
EQUIVALENCE (NNN(865),NNN17(1)),(NNN(919),NNN18(1))
EQUIVALENCE (NNN(973),NNN19(1)),(NNN(1027),NNN20(1))
EQUIVALENCE (NNN(1081),NNN21(1)),(NNN(1135),NNN22(1))
EQUIVALENCE (NNN(1189),NNN23(1)),(NNN(1243),NNN24(1))
EQUIVALENCE (NNN(1297),NNN25(1)),(NNN(1351),NNN26(1))
EQUIVALENCE (NNN(1405),NNN27(1)),(NNN(1459),NNN28(1))
EQUIVALENCE (NNN(1513),NNN29(1)),(NNN(1567),NNN30(1))
EQUIVALENCE (NNN(1621),NNN31(1)),(NNN(1675),NNN32(1))
EQUIVALENCE (NNN(1729),NNN33(1)),(NNN(1783),NNN34(1))
EQUIVALENCE (NNN(1837),NNN35(1)),(NNN(1891),NNN36(1))
EQUIVALENCE (NNN(1945),NNN37(1)),(NNN(1999),NNN38(1))
EQUIVALENCE (NNN(2053),NNN39(1)),(NNN(2107),NNN40(1))
C   ( 1)( 2)  ( 3)( 4)  ( 5)( 6)  ( 7)( 8)  ( 9)(10)  ( IP ) G  REF
DATA NNN01/
1 200020001, 200020011, 201620881, 231228281, 378953411, 1359502, D+F 1.00
2 100010001, 100010001, 100010001, 100010001, 100010001, 1359500, G 1.01
3 100010001, 100010011, 102111241, 145022061, 363059451, 2458104, D+F 2.00
4 200020001, 200020071, 208524971, 382669341, 128222452, 5440302, D+F 2.01
5 100010001, 100010001, 100010001, 100010001, 100010001, 5440300, G 2.02
6 200020011, 201220481, 212922881, 258731081, 394251691, 538901, D+F 3.00
7 100010001, 100010201, 126225521, 67216512, 351165562, 7561907, D+F 3.01
8 200020001, 200020211, 227936571, 69610342, 137217102, 12241800, D+F 3.02
9 100010001, 100010001, 100010001, 100010001, 100010001, 12241800, G 3.03
DATA NNN02/
1 100010051, 104311441, 131615641, 190623681, 298037691, 931900, AEL 4.00
2 200120231, 211422771, 249627631, 309034911, 398545051, 1820600, AEL 4.01
3 100010001, 100010201, 126225521, 67216512, 351165562, 15385000, AEL 4.02
4 200020001, 200020011, 201220661, 223426161, 332644691, 21765700, AEL 4.03
5 600060001, 600560281, 608761991, 637466191, 693973361, 829500, AEL 5.00
6 100310831, 132016901, 214226411, 315736741, 419147071, 2514900, AEL 5.01
7 200721061, 233526401, 297533311, 369040481, 440747651, 3792000, AEL 5.02

```

8	100010001.	100010001.	100010001.	100010001.	100010001.	25929800.	G	5.03
9	893292271.	96110042.	105311262.	126315202.	196126432.	1125508/	D+F	6.00
DATA NNN03/								
1	595060251.	620865751.	713280191.	95712292.	167623542.	2437501.	D+F	6.01
2	105513201.	180324851.	341851341.	68416332.	296550722.	4787101.	D+F	6.02
3	204922771.	262630421.	350941931.	494556971.	644872001.	6447600.	D+F	6.03
4	403141851.	457051681.	594071181.	92913362.	203331152.	1452915.	D+F	7.00
5	919899541.	107211512.	124914302.	182526232.	403762662.	2959202.	D+F	7.01
6	596862721.	684177081.	88110342.	128317062.	239334312.	4742501.	D+F	7.02
7	112816481.	240733751.	462068491.	116419932.	283736822.	7744900.	D+F	7.03
8	210124681.	293634211.	391145791.	539862151.	703178471.	9786200.	D+F	7.04
9	874789691.	924795711.	99410492.	115213492.	169022242.	1361307/	D+F	8.00
DATA NNN04/								
1	424151091.	622874781.	91312832.	221842502.	79914013.	3510711.	D+F	8.01
2	95610702.	118113032.	149619922.	329761642.	101914173.	5488500.	D+F	8.02
3	603567171.	775391141.	106612482.	143716252.	181420032.	7739300.	D+F	8.03
4	124420321.	306943181.	606281181.	101712232.	142916342.	11387300.	D+F	8.04
5	215026541.	323137551.	421546491.	508255151.	594863811.	13807900.	AEL	8.05
6	575958511.	589859231.	595860671.	636470031.	815199581.	1741802.	D+F	9.00
7	900296401.	102610802.	113912542.	152921152.	318348952.	3498003.	D+F	9.01
8	469162651.	791295541.	121419552.	402686872.	154822203.	6264500.	D+F	9.02
9	99511422.	129214572.	170523002.	320140922.	498458762.	8713900/	D+F	9.03
DATA NNN05/								
1	615472711.	87710602.	127215002.	172919582.	218624152.	11421300.	D+F	9.04
2	135324181.	377252001.	661580261.	94410852.	122613672.	15711700.	AEL	9.05
3	100010001.	100010051.	105313051.	210239461.	74013022.	2155808.	D+F10.00	
4	580158751.	591759741.	642687101.	159332652.	64111533.	4106907.	D+F10.01	
5	93510272.	110411662.	127116062.	257647882.	75110223.	6350000.	D+F10.02	
6	529774371.	94611322.	135816202.	188221442.	240626682.	9701900.	D+F10.03	
7	103312152.	140616092.	181320182.	222224262.	263128352.	12630000.	AEL10.04	
8	629178711.	98311802.	136715512.	173619202.	210422892.	15790900.	AEL10.05	
9	200020001.	200320211.	207322131.	253031421.	417657451.	513802/	D+F11.00	
DATA NNN06/								
1	100010001.	100010161.	119621261.	50711872.	246445382.	4728901.	D+F11.01	
2	580158751.	591860351.	71813142.	321968812.	106014333.	7165000.	D+F11.02	
3	96910772.	116012242.	130714232.	153916552.	177118872.	9888000.	D+F11.03	
4	601386081.	108812932.	148916832.	187820722.	226624612.	13836900.	AEL11.04	
5	105712442.	144616652.	189221182.	234425702.	279630222.	17209000.	AEL11.05	
6	100010011.	101410621.	118414581.	204831781.	509479731.	764404.	D+F12.00	
7	200120051.	202921001.	226926901.	368457091.	92814872.	1503101.	D+F12.01	
8	100010001.	100110611.	177455431.	176546012.	99718753.	8011905.	D+F12.02	
9	579758751.	591459501.	600560591.	611461681.	622362781.	10928900/	AEL12.03	
DATA NNN07/								
1	100611232.	120612752.	134214102.	147815462.	161416822.	14122900.	AEL12.04	
2	674896701.	121814462.	167018942.	211723412.	256527892.	18648900.	AEL12.05	
3	558857701.	583558761.	593260591.	635969541.	796790971.	598400.	D+F13.00	
4	100310211.	110313021.	172828201.	55311252.	215637942.	1882203.	D+F13.01	
5	200320201.	208622331.	250530971.	410251081.	611571211.	2844000.	D+F13.02	
6	100010001.	100210881.	207436531.	523168101.	838999681.	11996000.	D+F13.03	
7	577758651.	591259631.	604461351.	622563161.	640764981.	15377000.	AEL13.04	
8	103511582.	124713242.	140014772.	155316292.	170517812.	19042000.	AEL13.05	
9	825189211.	95210052.	106211532.	134317202.	237934082.	814913/	D+F14.00	
DATA NNN08/								
1	563057761.	588160311.	631768671.	791097651.	127817282.	1634000.	D+F14.01	
2	101110771.	126716471.	232438081.	71914052.	262045302.	3346001.	D+F14.02	
3	200720521.	217224081.	284439171.	551370951.	86810262.	4513000.	D+F14.03	
4	100010001.	100210881.	207436531.	523168101.	838999681.	16672900.	FAK14.04	
5	575458521.	591459851.	610063201.	672674071.	843698661.	20510900.	AEL14.05	
6	402643441.	496757481.	658274401.	833492941.	103511532.	1048300.	AEL15.00	
7	874497931.	106011282.	119812802.	138415142.	164717802.	1972000.	AEL15.01	

8 564058061, 604164611, 709579551, 90410172, 112912422, 3015500, AEL15.02
 9 100811411, 149720221, 280936121, 441552181, 602168241, 5135400/ AEL15.03

DATA NNN09/

1 200420781, 227025361, 281430911, 336936471, 392542021, 6500700, AEL15.04
 2 100010001, 100010001, 100010001, 100010001, 100010001, 22041300, G 15.05
 3 822887891, 930697831, 102610932, 121614492, 185124742, 1035708, D+F16.00
 4 443056011, 694982961, 96911522, 144218572, 227326892, 2339900, D+F16.01
 5 91610392, 113512242, 136416942, 233429882, 364242962, 3500000, D+F16.02
 6 560058861, 633871081, 82410062, 123314602, 168619132, 4728900, D+F16.03
 7 104512901, 177025421, 375163021, 122420462, 286036742, 7250000, D+F16.04
 8 202321571, 241428261, 358355061, 78310152, 124814802, 8802800, D+F16.05
 9 538155931, 571657911, 598067191, 89013782, 227737172, 1300916/ D+F17.00

DATA NNN10/

1 873396771, 104411072, 118513532, 175525872, 406763932, 2379903, D+F17.01
 2 506569571, 87610522, 134421682, 439092662, 182132573, 3990006, D+F17.02
 3 95110872, 120013232, 154921252, 345149322, 641378942, 5350000, D+F17.03
 4 558960371, 677779341, 95311692, 138816082, 182720472, 6780000, D+F17.04
 5 100010001, 100010051, 106913911, 240147261, 90716112, 1575411, D+F18.00
 6 550256831, 578158781, 636585461, 151530162, 58010303, 2762007, D+F18.01
 7 92110362, 112412002, 133216772, 254443722, 76512833, 4090003, D+F18.02
 8 582082081, 103112292, 149920212, 309750502, 720793642, 5978900, D+F18.03
 9 97111072, 123213982, 172625622, 463976582, 106413633, 7500000/ D+F18.04

DATA NNN11/

1 200020011, 200720361, 211923291, 280137141, 525575741, 433803, D+F19.00
 2 100010001, 100110341, 135929551, 79119282, 405274892, 3180905, D+F19.01
 3 554657081, 581260301, 73012702, 285363872, 129023363, 4600005, D+F19.02
 4 96010862, 118413212, 180836632, 90321023, 416863253, 6090000, D+F19.03
 5 657793361, 119515082, 195826322, 352944302, 533162332, 8259900, D+F19.04
 6 100110061, 104311741, 145919971, 294345051, 69010322, 611003, D+F20.00
 7 205822781, 279234761, 427553061, 688994901, 136319772, 1186701, D+F20.01
 8 100010001, 100510821, 168744821, 130232522, 69012813, 5121003, D+F20.02
 9 555157161, 585662471, 82816862, 42510013, 168423663, 6700000/ D+F20.03

DATA NNN12/

1 99411262, 123814062, 182930402, 484766392, 84310223, 8438900, D+F20.04
 2 924696691, 105212282, 151219062, 240530032, 368944512, 653900, AEL21.00
 3 190424662, 297634542, 391743752, 482952832, 573761912, 1280000, AEL21.01
 4 976799291, 101110322, 105810882, 111911502, 118112122, 2475000, AEL21.02
 5 100010001, 100510821, 168744821, 130232522, 69012813, 7390000, FAK21.03
 6 555157161, 585662471, 82816862, 42510013, 168423663, 9200000, FAK21.04
 7 181021172, 260333222, 430155582, 710089242, 110213293, 681900, D+F22.00
 8 474659872, 721284672, 98211413, 134515623, 177919963, 1356900, D+F22.01
 9 228327012, 308134272, 381143862, 534563472, 734983512, 2747000/ D+F22.02

DATA NNN13/

1 971498311, 99210032, 102610572, 108711172, 114711782, 4324000, D+F22.03
 2 100010001, 100510821, 168744821, 130232522, 69012813, 9980000, FAK22.04
 3 272835172, 425851532, 632278322, 97212013, 146817723, 674000, AEL23.00
 4 373954132, 743597002, 121414713, 173920143, 229225713, 1464900, AEL23.01
 5 323142642, 519660272, 679975352, 824789522, 96610363, 2930900, AEL23.02
 6 248329302, 324234952, 373439752, 421744582, 469949412, 4800000, AEL23.03
 7 970698231, 990699881, 100710152, 102410322, 104010482, 6500000, AEL23.04
 8 717277611, 92911652, 152620872, 295141952, 550468122, 676400, D+F24.00
 9 71611552, 205635512, 558281952, 115315823, 205625293, 1649000/ D+F24.01

DATA NNN14/

1 280639822, 538369722, 87610823, 129115003, 170919183, 3095000, D+F24.02
 2 377150952, 616070292, 791788382, 97610683, 116012523, 5000000, D+F24.03
 3 264730962, 341436462, 394042872, 463549832, 533056782, 7300000, D+F24.04
 4 600060321, 629270891, 86911302, 151020222, 267534752, 743100, AEL25.00
 5 739594821, 139921212, 309342852, 567372412, 97112553, 1563600, AEL25.01
 6 98417472, 265535782, 454754842, 641973532, 828792212, 3369000, AEL25.02
 7 328847052, 586668342, 771785912, 94710343, 112112093, 5300000, AEL25.03

8	422055132,	636770792,	779285062,	921999322,	106411363,	7600000,	AEL25.04
9	197023222,	274433302,	416753952,	723799822,	139419053,	787038/	D+F26.00
DATA NNN15/							
1	409453722,	686687452,	110213823,	174322233,	286437043,	1617902,	D+F26.01
2	262136422,	501167232,	87911303,	138916483,	190721673,	3064300,	D+F26.02
3	98723522,	420363072,	87011423,	145117913,	215925463,	5700000,	AEL26.03
4	38854482,	666275742,	846693572,	102511143,	120312923,	7900000,	D+F26.04
5	199427202,	335740022,	474957182,	708090462,	118315403,	786000,	D+F27.00
6	279739202,	490858232,	684582472,	104713233,	159818733,	1704900,	D+F27.01
7	279836622,	461857562,	720693022,	124915873,	192522633,	3349000,	D+F27.02
8	262136422,	501167232,	87911303,	138916483,	190821673,	5300000,	FAK27.03
9	98723522,	420363072,	87011423,	145117913,	215925463,	8300000/	FAK27.04
DATA NNN16/							
1	227027622,	306233052,	356839222,	446052912,	652382292,	763314,	D+F28.00
2	108416342,	222428472,	353944332,	577378932,	110314303,	1814900,	D+F28.01
3	198724282,	293236452,	468362702,	86511123,	136016073,	3516000,	D+F28.02
4	279836622,	461857562,	720693022,	124915873,	192522633,	5600000,	FAK28.03
5	262136422,	501167232,	87911303,	138916483,	190721673,	7900000,	FAK28.04
6	201620781,	231026761,	314737361,	450555381,	692386911,	772301,	D+F29.00
7	109415761,	247938311,	58910042,	190937022,	68311693,	2028903,	D+F29.01
8	897195961,	107212972,	165021182,	260230862,	356940532,	3682900,	D+F29.02
9	100010001,	100410231,	108712611,	167124841,	388460411,	939102/	D+F30.00
DATA NNN17/							
1	200020021,	201620761,	223726341,	351352061,	80812472,	1796001,	D+F30.01
2	100610471,	122617301,	300566361,	149924112,	332342352,	3970000,	D+F30.02
3	403245601,	493151431,	529654331,	559358091,	611065171,	600000,	AEL31.00
4	99710051,	104511541,	135016501,	208226431,	321837921,	2050900,	AEL31.01
5	199820071,	204521391,	229124761,	266028451,	302932131,	3070000,	AEL31.02
6	502665261,	755183501,	901496201,	102410942,	117912812,	787900,	AEL32.00
7	422848161,	512153401,	557458941,	636270361,	794489061,	1593000,	AEL32.01
8	100010261,	114613921,	175221251,	249826711,	324436181,	3421000,	AEL32.02
9	403143241,	491856701,	649173781,	840396751,	113013392,	981000/	AEL33.00
DATA NNN18/							
1	593676641,	884697521,	105911572,	129515012,	180322212,	1858700,	AEL33.01
2	484470541,	91510972,	125614082,	157017612,	199722912,	2829900,	AEL33.02
3	630172361,	799686381,	919797221,	102810942,	117712832,	975000,	AEL34.00
4	438055511,	691582151,	94510732,	121413672,	152016732,	2150000,	AEL34.01
5	651982921,	94610382,	113212492,	139515462,	169718482,	3200000,	AEL34.02
6	437347431,	498951671,	538559501,	74710812,	169126672,	1183910,	D+F35.00
7	705183611,	93510092,	111614162,	222932532,	427652992,	2160000,	D+F35.01
8	510869921,	87410312,	123116552,	236530712,	377744832,	3590000,	D+F35.02
9	100010001,	100010051,	105012781,	198535971,	65911422,	1399507/	D+F36.00
DATA NNN19/							
1	461049811,	522254261,	609088131,	168935052,	68612253,	2455908,	D+F36.01
2	759990901,	101911142,	129017782,	302856642,	99414333,	3690000,	D+F36.02
3	200020011,	200720361,	211523021,	269434141,	459163351,	417502,	D+F37.00
4	100010001,	100110321,	129524961,	61014202,	291753192,	2750004,	D+F37.01
5	473650891,	533156051,	66810932,	232950852,	99915303,	4000000,	D+F37.02
6	100110041,	104111741,	146019721,	281941411,	607785251,	569202,	D+F38.00
7	202621931,	255331271,	384347931,	624085761,	122417632,	1102600,	D+F38.01
8	100010001,	100110321,	129524961,	61014202,	291753192,	4300000,	FAK38.02
9	791587851,	100012192,	155119942,	254031782,	389946932,	637900/	AEL39.00
DATA NNN20/							
1	118217102,	220827002,	319036792,	416646512,	513256072,	1223000,	AEL39.01
2	92510012,	104710862,	112311612,	120212472,	132814282,	2050000,	AEL39.02
3	141320802,	291439702,	531170262,	92712273,	162521053,	684000,	D+F40.00
4	354454352,	724689652,	107212643,	148517093,	193321573,	1312900,	D+F40.01
5	209727032,	324537052,	415446282,	510255752,	604965222,	2298000,	D+F40.02
6	256636022,	465759302,	749693962,	116514243,	171520333,	687900,	AEL41.00
7	335157222,	84511463,	147718363,	221826083,	299933893,	1431900,	AEL41.01

PAGE 43

8	223725352,	280830972,	340937362,	406844002,	473150632,	2503900,	AEL41.02
9	703972941,	82610822,	154822682,	327244912,	571469372,	709900/	D+F42.00
DATA NNN21/							
1	75714552,	274347322,	718897632,	123414913,	174920063,	1614900,	D+F42.01
2	267645462,	669890262,	115514323,	173620673,	242528083,	2714900,	AEL42.02
3	90613732,	184823562,	291735332,	419949102,	565764332,	728000,	AEL43.00
4	131318312,	227126932,	311735452,	397644072,	483852692,	1525900,	AEL43.01
5	204721573,	234725733,	284031463,	348738613,	426546943,	3000000,	AEL43.02
6	176824122,	318941082,	515263202,	761790472,	106112303,	736400,	AEL44.00
7	221934542,	501968372,	88911173,	136316243,	189221613,	1675900,	AEL44.01
8	210622722,	241025422,	267928262,	297731272,	327834282,	2846000,	AEL44.02
9	148520202,	255230902,	364942462,	489656082,	638872352,	746000/	AEL45.00
DATA NNN22/							
1	153421292,	288137912,	484660322,	720187062,	101011483,	1807000,	AEL45.01
2	254537212,	492362292,	770592182,	107312243,	137615273,	3104900,	AEL45.02
3	115919551,	320746011,	607576761,	95011642,	141817172,	832900,	AEL46.00
4	755087211,	105913442,	173122222,	282034722,	412247732,	1941900,	AEL46.01
5	180223462,	289735212,	414247632,	538460052,	662672472,	3292000,	AEL46.02
6	200020001,	200220141,	206422141,	257633021,	455164681,	757403,	D+F47.00
7	100810581,	125817401,	260641031,	66210072,	135316982,	2148000,	D+F47.01
8	795887491,	977111762,	156620252,	248329422,	340038582,	3481900,	D+F47.02
9	100010001,	100410241,	109212891,	176827421,	444268771,	899003/	D+F48.00
DATA NNN23/							
1	200020021,	201720921,	233329881,	451475371,	127520782,	1690301,	D+F48.01
2	100310281,	114815371,	246138311,	519265531,	791492761,	3747000,	D+F48.02
3	252431921,	368440461,	433746521,	512259221,	723389021,	578400,	D+F49.00
4	100110071,	104611651,	146118581,	225426511,	304734431,	1886000,	D+F49.01
5	200120111,	205021611,	243628031,	317035371,	390442701,	2802900,	D+F49.02
6	232637101,	488058571,	669074381,	816189091,	97210632,	734200,	AEL50.00
7	286335941,	408144471,	479351961,	571862901,	686274341,	1462700,	AEL50.01
8	100010251,	114013811,	175321601,	256829751,	338337901,	3049000,	AEL50.02
9	404043481,	494656811,	646772781,	813490751,	101411372,	863900/	AEL51.00
DATA NNN24/							
1	303147981,	618472951,	827392621,	103711702,	131214532,	1650000,	AEL51.01
2	313037601,	429347901,	536260591,	689477591,	862494881,	2529900,	AEL51.02
3	526258801,	657372351,	784284071,	897095741,	102711082,	900900,	AEL52.00
4	440855541,	686481251,	93810792,	125414792,	176321132,	1860000,	AEL52.01
5	349054751,	699883081,	96611302,	134216202,	197724212,	2800000,	AEL52.02
6	405342041,	438645621,	475751071,	587974491,	102214572,	1045404,	D+F53.00
7	568567471,	773485861,	94510362,	112712182,	130914002,	1909000,	D+F53.01
8	514269581,	86910562,	130716652,	215327742,	351843662,	3200000,	AEL53.02
9	100010001,	100010091,	109515351,	291060661,	119621482,	1212716/	D+F54.00
DATA NNN25/							
1	414844131,	465649111,	538464651,	87112232,	158019362,	2120000,	D+F54.01
2	615475101,	867797531,	112213462,	157618062,	203622662,	3209900,	D+F54.02
3	200020001,	201020501,	215623871,	283536181,	462756261,	389300,	D+F55.00
4	100010001,	100310371,	119016501,	269146361,	77912412,	2510000,	D+F55.01
5	424445601,	481750061,	516953311,	549356551,	581759791,	3500000,	D+F55.02
6	101210791,	135119351,	282340571,	574580391,	111015062,	521002,	D+F56.00
7	262638511,	504160621,	698579371,	91010692,	129115952,	1000000,	D+F56.01
8	100010001,	100310351,	118416321,	264945521,	76512182,	3700000,	FAK56.02
9	71111992,	172323592,	312540402,	510763182,	765791012,	558000/	AEL57.00
DATA NNN26/							
1	204529582,	383647882,	582469262,	807992692,	104911723,	1106000,	AEL57.01
2	94712552,	148416582,	179819212,	203621522,	227424042,	1916900,	AEL57.02
3	295959132,	103515693,	215527593,	335939413,	449650223,	565000,	AEL58.00
4	79718153,	289639443,	495159253,	686877533,	863794813,	1085000,	AEL58.01
5	298640242,	475053692,	596965912,	725379692,	872094692,	2008000,	AEL58.02
6	460693672,	158523823,	327242303,	519661563,	709379783,	541900,	FAK59.00
7	455480232,	114014653,	178521013,	240927073,	299232633,	1055000,	AEL59.01

PAGE 44

11	46410533.	183826893.	354443773.	518459633.	674375243.	2320000.	AEL59.02
9	139623042.	364860002.	96114603.	209828633.	373446973.	549000/	AEL60.00
DATA NNN27/							
1	460493592.	158523823.	327142303.	519661563.	709279783.	1073000.	AEL60.01
2	455480232.	114014653.	178521013.	240927073.	299232633.	2000000.	FAK60.02
3	131720482.	280535692.	441254492.	676583972.	103412583.	555000.	AEL61.00
4	139623042.	364860002.	96114603.	209828633.	373446973.	1089900.	FAK61.01
5	460493682.	158523823.	327142303.	519661563.	709279783.	2000000.	FAK61.02
6	92915672.	222431062.	444763802.	89612173.	159520253.	562900.	AEL62.00
7	315059662.	97114563.	204627093.	342541693.	490556383.	1106900.	AEL62.01
8	269037812.	520270372.	91111273.	133915483.	172719093.	2000000.	AEL62.02
9	800080571.	851699301.	127617362.	240433032.	444958442.	568000/	AEL63.00
DATA NNN28/							
1	125416052.	211828182.	375549622.	644381732.	101112213.	1125000.	AEL63.01
2	800080571.	851699301.	127617362.	240433032.	444958442.	2000000.	FAK63.02
3	240432982.	427555202.	708489962.	112613853.	167319843.	615900.	AEL64.00
4	534793262.	139219123.	247730843.	371043333.	495055893.	1210000.	AEL64.01
5	364145232.	514756362.	604864112.	673870372.	732276072.	2000000.	AEL64.02
6	480767202.	89011393.	144118243.	230028753.	354142883.	584900.	AEL65.00
7	480767192.	89011393.	144118243.	230028753.	354142883.	1151900.	FAK65.01
8	480767202.	89011393.	144118243.	230028753.	354142883.	2000000.	FAK65.02
9	343147532.	645887152.	115314793.	183322063.	257729373.	593000/	FAK66.00
DATA NNN29/							
1	343147532.	645887142.	115314793.	183322063.	257729373.	1167000.	AEL66.01
2	343147532.	645887142.	115314793.	183322063.	257729373.	2000000.	FAK66.02
3	222635002.	542276772.	100312353.	145716713.	187020703.	602000.	FAK67.00
4	222635002.	542276772.	100312353.	145716713.	187020703.	1180000.	FAK67.01
5	222635002.	542276772.	100312353.	145716713.	187020703.	2000000.	AEL67.02
6	133715382.	209130152.	429859382.	79410293.	129815983.	609900.	AEL68.00
7	265934782.	497877532.	120517733.	245032063.	400448073.	1193000.	AEL68.01
8	265934782.	497877532.	120517733.	245032063.	400448073.	2000000.	FAK68.02
9	800381111.	87510702.	147621462.	310343462.	585475982.	618000/	AEL69.00
DATA NNN30/							
1	156718872.	279244452.	678196342.	128316243.	197823443.	1205000.	AEL69.01
2	93517192.	364666132.	103414613.	192624193.	293334613.	2370000.	AEL69.02
3	100010011.	101310651.	118613951.	169120661.	250629971.	625000.	AEL70.00
4	200120901.	270345231.	81714042.	223533112.	461959862.	1217000.	AEL70.01
5	100312561.	250851931.	91914182.	198626022.	323638692.	2000000.	AEL70.02
6	514664441.	759086851.	99211442.	133315612.	182721252.	609900.	AEL71.00
7	125924831.	438667801.	98714112.	199727872.	380850742.	1389900.	AEL71.01
8	323948621.	661297271.	158626482.	426865032.	93712843.	1900000.	AEL71.02
9	659294081.	128016962.	222528952.	372047062.	585171462.	700000/	AEL72.00
DATA NNN31/							
1	99117882.	274638812.	520867322.	84410313.	123314453.	1489900.	AEL72.01
2	187427702.	343739872.	448049452.	539358282.	625266642.	2329900.	AEL72.02
3	65210892.	171325762.	373552252.	705192012.	116414343.	787900.	AEL73.00
4	192837842.	600784802.	111113823.	165419233.	218524383.	1620000.	AEL73.01
5	99117872.	274638812.	520867312.	84410313.	123314453.	2400000.	FAK73.02
6	398981651.	130019172.	273438022.	516168382.	88411163.	797900.	AEL74.00
7	131429482.	523279952.	111414623.	183422233.	262130233.	1770000.	AEL74.01
8	192837842.	600784792.	111113823.	165419233.	218524383.	2500000.	FAK74.02
9	600963001.	75910412.	150121572.	301940972.	539168952.	787000/	AEL75.00
DATA NNN32/							
1	73710852.	190731262.	464964142.	83810503.	127315053.	1660000.	AEL75.01
2	131429482.	523279952.	111414623.	183422233.	262130233.	2600000.	FAK75.02
3	110815502.	216829732.	398752322.	672484682.	104612673.	850000.	AEL76.00
4	168225972.	362046562.	566766422.	757484612.	93010103.	1700000.	AEL76.01
5	73710852.	190731262.	464964142.	83810503.	127315053.	2700000.	FAK76.02
6	129117892.	239430882.	388748292.	596173252.	89510843.	910000.	AEL77.00
7	110815502.	216829732.	398752322.	672484682.	104612673.	2000000.	FAK77.01

PAGE 45

8	168225972,	362046562,	566766422,	757484612,	93010103,	2800000,	FAK77.02
9	158918512,	207523002,	254328242,	316335762,	407246582,	9000000,	AEL78.00
DATA NNN33/							
1	98115462,	224930742,	401150612,	623475412,	89910583,	1855900,	AEL78.01
2	110815502,	216829732,	398752322,	672484682,	104612673,	2900000,	FAK78.02
3	203222611,	265731251,	364042301,	494958601,	702084731,	922000,	AEL79.00
4	120521331,	357753801,	75310062,	130516572,	206925452,	2050000,	AEL79.01
5	651780821,	108814772,	195925252,	316338622,	460853882,	3000000,	AEL79.02
6	100010001,	100110111,	105211851,	152122101,	341552811,	1043002,	D+F80.00
7	200320211,	210023021,	268834231,	480472341,	111416912,	1875000,	D+F80.01
8	104012871,	186129471,	458664151,	82410072,	119013732,	3420000,	D+F80.02
9	200420711,	222424271,	265429161,	325637371,	442853911,	6105000,	AEL81.00
DATA NNN34/							
1	100010021,	101910801,	121414641,	189525811,	358949721,	2041900,	AEL81.01
2	200020311,	216624611,	296337451,	489064791,	85711212,	2979900,	AEL81.02
3	103411711,	147819101,	244331781,	434862751,	93113762,	741404,	D+F82.00
4	204122231,	248227841,	311535621,	429153941,	651976431,	1502800,	D+F82.01
5	100210131,	106812201,	154522671,	381665951,	95512512,	3192900,	D+F82.02
6	400140351,	416944121,	474851591,	564362181,	690477231,	728700,	AEL83.00
7	106814451,	204427341,	350744811,	586879131,	108314772,	1667900,	AEL83.01
8	205523051,	264830231,	345439921,	469156001,	675281671,	2555900,	AEL83.02
9	500950661,	518153561,	559058941,	628968071,	748483501,	8430000,	AEL84.00
DATA NNN35/							
1	443756241,	696282451,	95411012,	128615262,	182922012,	1900000,	FAK84.01
2	336953201,	682481011,	93810882,	127915272,	184622442,	2700000,	FAK84.02
3	402841621,	431544771,	463148311,	520059491,	734896851,	930000,	FAK85.00
4	576168741,	788387631,	96910642,	116012552,	135014462,	2000000,	FAK85.01
5	490265341,	812797201,	116614322,	179622692,	285035302,	2900000,	FAK85.02
6	100010001,	100010031,	102311051,	133018071,	264539391,	1074500,	AEL86.00
7	402841621,	431544771,	463148311,	520059491,	734996851,	2000000,	FAK86.01
8	576168741,	788387631,	96910642,	116012552,	135014462,	3000000,	FAK86.02
9	200020011,	201220591,	218124481,	296538611,	488859141,	4000000,	FAK87.00
DATA NNN36/							
1	100010001,	100010031,	102311051,	133018071,	264539401,	2200000,	FAK87.01
2	421645151,	477449611,	511852711,	542455761,	572958821,	3300000,	FAK87.02
3	100010041,	105212131,	153220271,	270435641,	460258111,	527600,	AEL88.00
4	201221791,	258131471,	381645781,	546365131,	777592781,	1014400,	AEL88.01
5	100010001,	100010031,	102311051,	133018071,	264539391,	3400000,	FAK88.02
6	510064491,	82710872,	142718412,	232328712,	348341572,	690000,	AEL89.00
7	228951571,	88513232,	183324132,	305537492,	448152402,	1210000,	AEL89.01
8	723989131,	103511752,	130814352,	155416652,	177018682,	2000000,	AEL89.02
9	620099241,	162725772,	391457072,	80110833,	141818023,	6000000,	AEL90.00
DATA NNN37/							
1	620099241,	162725772,	391457072,	80110833,	141818023,	1200000,	FAK90.01
2	620099251,	162725772,	391457072,	80110833,	141818023,	2000000,	FAK90.02
3	347877992,	129318323,	240730533,	380546863,	570368573,	600000,	AEL91.00
4	347877992,	129318323,	240730533,	380546863,	570368573,	1200000,	FAK91.01
5	347777992,	129318323,	240730533,	380546863,	570368573,	2000000,	FAK91.02
6	209530092,	450866762,	96613623,	186524763,	318839893,	600000,	AEL92.00
7	209530092,	450866762,	96613623,	186524763,	318839893,	1200000,	FAK92.01
8	209530092,	450866762,	96613623,	186524763,	318839893,	2000000,	FAK92.02
9	209530092,	450866762,	96613623,	186524763,	318839893,	6000000,	FAK93.00
DATA NNN38/							
1	209530092,	450866762,	96613623,	186524763,	318839893,	1200000,	FAK93.01
2	209530092,	450866762,	96613623,	186524763,	318839893,	2000000,	FAK93.02
3	209530092,	450866762,	96613623,	186524763,	318839893,	600000,	FAK94.00
4	209530092,	450866762,	96613623,	186524763,	318839893,	1200000,	FAK94.01
5	209530092,	450866762,	96613623,	186524763,	318839893,	2000000,	FAK94.02
6	209530092,	450866762,	96613623,	186524763,	318839893,	600000,	FAK95.00
7	209530092,	450866762,	96613623,	186524763,	318839893,	1200000,	FAK95.01

PAGE 46

```

8 209530092, 450866762, 96613623, 186524763, 318839893, 2000000, FAK95.02
9 209530092, 450866762, 96613623, 186524763, 318839893, 600000/ FAK96.00
  DATA NN439/
1 209530092, 450866762, 96613623, 186524763, 318839893, 1200000, FAK96.01
2 209530092, 450866762, 96613623, 186524763, 318839893, 2000000, FAK96.02
3 209530092, 450866762, 96613623, 186524763, 318839893, 600000, FAK97.00
4 209530092, 450866762, 96613623, 186524763, 318839893, 1200000, FAK97.01
5 209530092, 450866762, 96613623, 186524763, 318839893, 2000000, FAK97.02
6 209530092, 450866762, 96613623, 186524763, 318839893, 600000, FAK98.00
7 209530092, 450866762, 96613623, 186524763, 318839893, 1200000, FAK98.01
8 209530092, 450866762, 96613623, 186524763, 318839893, 2000000, FAK98.02
9 209530092, 450866762, 96613623, 186524763, 318839893, 600000/ FAK99.00
  DATA NN440/
1 209530092, 450866762, 96613623, 186524763, 318839893, 1200000, FAK99.01
2 209530092, 450866762, 96613623, 186524763, 318839893, 2000000/ FAK99.02
  DATA LOCZ/1,3,6,10,14,18,22,27,33,39,45,51,57,63,69,75,81,86,91,
196,101,106,111,116,121,126,131,136,141/
  DATA SCALE/.001,.01,.1,1./
C
  MODEL=MODE
  IF(MODE1.GT.10)MODEL=MODEL-10
C
  LOWERING OF THE IONIZATION POTENTIAL IN VOLTS FOR UNIT ZEFF
  CHARGE=XNE(J)*2.
  EXCESS=2.*XNE(J)-P(J)/TK(J)
C
  ALLOWANCE FOR DOUBLY IONIZED HELIUM
  IF(EXCESS.GT.0.)CHARGE=CHARGE-EXCESS*(2.*EXCESS)*4.
  DEBYE=SQRT(TK(J)/2.8965E-18/CHARGE)
C
  DEBYE=SQRT(TK(J)/12.5664/4.801E-10**2/CHARGE)
  POTLOW=AMIN1(1.,1.44E-7/DEBYE)
  TV=TKEV(J)
  IF(IZ.LE.28)N=LOCZ(IZ)
  IF(IZ.GT.28)N=3*IZ+54
  IF(IZ.LE.28)NIONS=LOCZ(IZ+1)-N
  IF(IZ.GT.28)NIONS=3
  NION2=MIN0(NION+2,NIONS)
  N=N-1
C
  DO 18 ION=1,NION2
  Z=ION
  POTLO(ION)=POTLOW*Z
  N=N+1
  NNN100=NNN(6,N)/100
  IP(ION)=FLOAT(NNN100)/1000.
  G=NNN(6,N)-NNN100*100
  IF(N.EQ.1)GO TO 16
  T2000=IP(ION)*2000./11.
  IT=MAX0(1,MIN0(9,IFIX(T(J)/T2000-.5)))
  DT=T(J)/T2000-FLOAT(IT)/.5
  PMIN=1.
  I=(IT+1)/2
  K1=NNN(I,N)/100000
  K2=NNN(I,N)-K1*100000
  K3=K2/10
  KSCALE=K2-K3*10
  IF(MOD(IT,2).EQ.0)GO TO 12
  P1=FLOAT(K1)*SCALE(KSCALE)
  P2=FLOAT(K3)*SCALE(KSCALE)
  IF(DT.GE.0.)GO TO 13
  IF(KSCALE.GT.1)GO TO 13
  KP1=P1

```

```

      IF(KP1.NE.IFIX(P2+.5))GO TO 13
      PMIN=KP1
      GO TO 13
12  P1=FLOAT(K3)*SCALE(KSCALE)
      K1=NNN(I+1,N)/100000
      KSCALE=MOD(NNN(I+1,N),10)
      P2=FLOAT(K1)*SCALE(KSCALE)
13  PART(ION)=AMAX1(PMIN,P1+(P2-P1)*DT)
      IF(G.EQ.0..OR.POTLO(ION).LT..1..OR.T(J).LT.T2000*4.)GO TO 18
      IF(T(J).GT.(T2000*11.))TV=(T2000*11.)*8.6171E-5
      D1=.1/TV
14  D2=POTLO(ION)/TV
      PART(ION)=PART(ION)+G*EXP(-IP(ION)/TV)*(SQRT(13.595*Z*Z/TV/D2)**3*
      1(1./3.+(1.-(.5+(1./18.+D2/120.)*D2)*D2)*D2)-
      2SQRT(13.595*Z*Z/TV/D1)**3*
      3(1./3.+(1.-(.5+(1./18.+D1/120.)*D1)*D1)*D1))
      TV=TKEV(J)
      GO TO 18
16  PART(1)=2.*BHYD(J,1)
      IF(T(J).LT.9000.)GO TO 18
      PART(1)=PART(1)+8.*BHYD(J,2)*EXP(-10.196/TV)+18.*BHYD(J,3)*
      1EXP(-12.084/TV)+32.*BHYD(J,4)*EXP(-12.745/TV)+50.*BHYD(J,5)*
      2EXP(-13.051/TV)+72.*BHYD(J,6)*EXP(-13.217/TV)
      D1=13.595/6.5/6.5/TV
      D2=POTLO(1)/TV
      GO TO 14
18  CONTINUE
C
19  IF(MODE1.EQ.3)GO TO 35
C
      N=N-NION2
      CF=2.*2.4148E15*T(J)*SQRT(T(J))/XNE(J)
      DO 20 ION=2,NION2
      N=N+1
C
      THE AMIN IS FOR ANY UNFORTUNATE WHO HAS A 360
20  F(ION)=CF*PART(ION)/PART(ION-1)*
      1EXP(-AMIN1((IP(ION-1)-POTLO(ION-1))/TV,100.))
      F(1)=1.
      L=NION2+1
      DO 21 ION=2,NION2
      L=L-1
21  F(1)=1.+F(L)*F(1)
      F(1)=1./F(1)
      DO 22 ION=2,NION2
22  F(ION)=F(ION-1)*F(ION)
C
35  IF(MODE.LT.10)GO TO 40
      GO TO(23,25,27,29).MODE1
23  DO 24 ION=1,NION
24  ANSWER(J,ION)=F(ION)/PART(ION)
      RETJRN
25  DO 26 ION=1,NION
26  ANSWER(J,ION)=F(ION)
      RETURN
27  DO 28 ION=1,NION
28  ANSWER(J,ION)=PART(ION)
      RETURN
29  ANSWER(J,1)=0.
      DO 30 ION=2,NION2
30  ANSWER(J,1)=ANSWER(J,1)+F(ION)*FLOAT(ION-1)

```

```

      RETJRN
40  GO TO(41,42,43,29),MODE1
41  ANSWER(J,1)=F(NION)/PART(NION)
      RETJRN
42  ANSWER(J,1)=F(NION)
      RETJRN
43  ANSWER(J,1)=PART(NION)
      RETJRN
      END

```

```

      SUBROUTINE MOLEC(CODOUT,MODE,NUMBER)
      DIMENSION NUMBER(40,1)
      REAL NUMBER
      COMMON /ELEM/ABUND(99),ATMASS(99),ELEM(99)
      COMMON /IF/IFCORR,IFPRES,IFSURF,IFSCAT,IFMOL
      COMMON /RHOX/RHOX(40),NRHOX
      COMMON /STATE/P(40),XNE(40),XNATOM(40),RHO(40)
      COMMON /TEMP/T(40),TKEV(40),TK(40),HKT(40),TLGS(40),ITEMP
      COMMON /XABUND/XABUND(99),WTMOLE
      COMMON NUMMOL,CODE(100),XNMOL(40,100)
      DATA IREAD/0/
      IF(IREAD.EQ.1)GO TO 200
      IF(IFPRES.EQ.1)GO TO 200
      READ(5,151)NUMMOL
151  FORMAT(I5)
      DO 155 JMOL=1,NUMMOL
      READ(5,152)CODE(JMOL)
152  FORMAT(F20.2)
      READ(5,153)(XNMOL(J,JMOL),J=1,NRHOX)
153  FORMAT(1P8E10.3)
C 153  FORMAT(OP8E10.3)
      WRITE(6,154)CODE(JMOL),(XNMOL(J,JMOL),J=1,NRHOX)
154  FORMAT(F20.2/(1P8E10.3))
C 154  FORMAT(F20.2/(OP8E10.3))
155  CONTINUE
      READ(5,158)
      READ(5,158)(XNATOM(J),RHO(J),J=1,NRHOX)
      WRITE(6,158)(XNATOM(J),RHO(J),J=1,NRHOX)
158  FORMAT(1P8E10.3)
C 158  FORMAT(OP8E10.3)
      IREAD=1
200  IF(CODOUT.LT.100.)GO TO 300
      DO 201 JMOL=1,NUMMOL
      IF(CODE(JMOL).EQ.CODOUT)GO TO 203
201  CONTINUE
      WRITE(6,202)CODOUT
202  FORMAT(22H1BETTER LUCK NEXT TIMEF20.2)
      CALL EXIT
203  DO 204 J=1,NRHOX
204  NUMBER(J,ION)=XNMOL(J,JMOL)
      RETJRN
300  C=CODOUT
      NN=1
      IF(MODE.EQ.11)NN=(C-FLOAT(IFIX(C)))*100.+1.5
      DO 321 I=1,NN
      DO 301 JMOL=1,NUMMOL
      ION=NN-I+1

```

```
IF (CODE(JMOL)+.001.GT.C.AND.CODE(JMOL)-.001.LT.C)GO TO 303
301 CONTINUE
GO TO 305
303 DO 304 J=1,NRHOX
304 NUMBER(J,ION)=XNMOL(J,JMOL)
GO TO 321
305 ID=CODOJT
DO 311 JMOL=1,NUMMOL
IF (IFIX(CODE(JMOL)).EQ.ID)GO TO 313
311 CONTINUE
GO TO 400
313 DO 314 J=1,NRHOX
314 NUMBER(J,ION)=0.
321 C=C-.01
RETURN
400 ION=(CDDOUT-FLOAT(ID))*100.+1.5
NN=ION
IF (MODE.EQ.1)NN=1
DO 401 J=1,NRHOX
CALL PFSAHA(J,ID,ION,MODE,NUMBER)
DO 401 I=1,NN
401 NUMBER(J,I)=NUMBER(J,I)*XNATOM(J)*XABJND(ID)
RETURN
END
```

```

SUBROUTINE NMOLEC(MODE)
COMMON /ELEM/ABUND(99),ATMASS(99),ELEM(99)
COMMON /ITER/ ITER,IFPRNT(15),IFPNCH(15),NUMITS
COMMON /RHOX/RHOX(40),NRHOX
COMMON /STATE/P(40),XNE(40),XNATOM(40),RHO(40)
COMMON /TEMP/T(40),TKEV(40),TK(40),HKT(40),TLOG(40),ITEMP
COMMON /XABUND/XABUND(99),WTMOLE
DIMENSION EQUILJ(100),LOCJ(101),KCOMP5(300)
DIMENSION XNZ(40,25)
DIMENSION IFEQUA(101)
DIMENSION EQUIL(6,100)
DIMENSION EQ(25),XN(25),XAB(25),DTERM(25),DEQ(625)
DIMENSION FRAC(40,6)
EQUIVALENCE (FRAC(1),DEQ(1))
DIMENSION EQOLD(25)
DIMENSION IDEQUA(25)
DIMENSION XCODE(8)
COMMON NUMMOL,CODE(100),XNMOL(40,100)
DATA XCODE/1.E14,1.E12,1.E10,1.E8,1.E6,1.E4,1.E2,1.E0/
DATA IREAD/0/
C MAKE TABLE OF ALL COMPONENTS OF ALL MOLECULES
C SAMPLE CODES FOR ATOMS AND MOLECULES
C
C      EXTERNAL CODE      INTERNAL COMPONENTS
C CARBON DIOXIDE      60808.      6,8,8
C HMINUS      100.      1,100
C NEUTRAL IRON      26.      26
C H2PLUS      101.01      1,1,101
C HYDROGEN ION      1.01      1,101
C SILICON 3+      14.03      14,101,101,101
C IF(IREAD.EQ.1)GO TO 30
C IREAD=1
C DO 1 JMOL=1,100
C CODE(JMOL)=0.
C DO 1 J=1,NRHOX
1 XNMOL(J,JMOL)=0.
C WRITE(6,10)
10 FORMAT(16H1MOLECULES INPUT)
C DO 11 I=1,101
11 IFEQUA(I)=0
C IF IFEQUA=1 AN EQUATION MUST BE SET UP FOR ELEMENT I
C KLOC=1
C LOCJ(1)=1
C DO 20 JMOL=1,101
C IF(KLOC.EQ.301)WRITE(6,199)
C READ(5,13)C,E1,E2,E3,E4,E5,E6
13 FORMAT(F18.2,F7.3,5E11.4)
C IF(C.EQ.0.)GO TO 23
C WRITE(6,14)JMOL,C,E1,E2,E3,E4,E5,E6
14 FORMAT(15,F18.2,F7.3,1P5E11.4)
C 14 FORMAT(15,F18.2,F7.3,0P5E11.4)
C DO 15 II=1,8
C IF(C.5E,XCODE(II))GO TO 16
15 CONTINUE
C CALL EXIT
16 X=C
C DO 17 I=II,8
C ID=X/XCODE(I)
C X=X-FLOAT(ID)*XCODE(I)
C IF(ID.EQ.0)ID=100
C IFEQUA(ID)=1

```



```

      <COMPS(<LOC)=ID
17 <LOC=<LOC+1
      ION=X*100.+0.5
      IF(ION.LT.1)GO TO 19
      IFEQUA(100)=1
      IFEQUA(101)=1
      DO 18 I=1,ION
      <COMPS(KLOC)=101
18 <LOC=<LOC+1
19 LOCJ(JMOL+1)=KLOC
      CODE(JMOL)=C
      EQUIL(1,JMOL)=E1
      EQUIL(2,JMOL)=E2
      EQUIL(3,JMOL)=E3
      EQUIL(4,JMOL)=E4
      EQUIL(5,JMOL)=E5
20 EQUIL(6,JMOL)=E6
      WRITE(6,199)
199 FORMAT(19H100 MANY MOLECULES)
23 NUMMOL=JMOL-1
      NLOC=KLOC-1
C      ASSIGN AN EQUATION NUMBER TO EACH COMPONENT
C      THE FIRST EQUATION IS FOR THE TOTAL NUMBER OF PARTICLES
C      THE FIRST VARIABLE IS XNATOM
C      IF ANY COMPONENT IS 100 OR 101 VARIABLE NEQUA IS XNE
C      AND EQUATION NEQUA IS CHARGE CONSERVATION
C      FOR PROGRAMMING CONVENIENCE VARIABLE NEQUA1 IS INVERSE XNE
C      DIMENSIONS ARE SET FOR A MAXIMUM 25 EQUATIONS
      IEQUA=1
      DO 25 I=1,100
      IF(IFEQJA(I).EQ.0)GO TO 25
      IEQJA=IEQUA+1
      IFEQUA(I)=IEQUA
      IDEQUA(IEQUA)=I
25 CONTINUE
      NEQJA=IEQUA
      NEQUA1=NEQUA+1
      IFEQUA(101)=NEQUA1
      NEONEQ=NEQUA**2
      DO 28 KLOC=1,NLOC
      ID=<COMPS(KLOC)
28 <COMPS(KLOC)=IFEQUA(ID)
30 DO 31 K=2,NEQUA
      ID=IDEQJA(K)
      IF(ID.LT.100)XAB(K)=AMAX1(XABUND(ID),1.E-20)
31 CONTINUE
      IF(ID.EQ.100)XAB(NEQUA)=0.
      XNTOT=P(1)/TK(1)
      XN(1)=XNTOT/2.
      X=XN(1)/10.
      DO 32 K=2,NEQUA
32 XN(K)=X*XAB(K)
      IF(ID.EQ.100)XN(NEQUA)=X
      XNE(1)=X
      DO 110 J=1,NRHOX
      XNTOT=P(J)/TK(J)
      IF(J.EQ.1)GO TO 34
      RATIO=P(J)/P(J-1)
      XNE(J)=XNE(J-1)*RATIO
      DO 33 K=1,NEQUA
33 XN(K)=XN(K)*RATIO

```

```

34 DO 37 JMOL=1,NUMMOL
    NCOMP=LOCJ(JMOL+1)-LOCJ(JMOL)
    IF(EQUIL(1,JMOL).EQ.0.)GO TO 35
    ION=(CODE(JMOL)-FLOAT(IFIX(CODE(JMOL))))*100.+5
    EQUILJ(JMOL)=EXP(EQUIL(1,JMOL)/TKEV(J)-EQUIL(2,JMOL)+
1(EQUIL(3,JMOL)+(-EQUIL(4,JMOL)+(EQUIL(5,JMOL)-EQUIL(6,JMOL)*
2T(J))*T(J))*T(J))*T(J)-1.5*(FLOAT(NCOMP-ION-ION-1))*TLOG(J))
    GO TO 37
35 IF(NCOMP.GT.1)GO TO 36
    EQUILJ(JMOL)=1.
    GO TO 37
36 ID=CODE(JMOL)
    ION=NCOMP-1
    CALL PFSAHA(J,ID,NCOMP,12,FRAC)
    EQUILJ(JMOL)=FRAC(J,NCOMP)/FRAC(J,1)*XNE(J)**ION
37 CONTINUE
    DO 48 K=1,NEQUA
48 EQOLD(K)=0.
C
C     SET UP 1ST ORDER EQUATIONS FOR THE CHANGE IN NUMBER DENSITY OF
C     EACH ELEMENT.
50 DO 60 KL=1,NEQNEQ
60 DEQ(KL)=0.
    EQ(1)=-XNTOT
    K1=1
    KK=1
    DO 61 K=2,NEQUA
    EQ(1)=EQ(1)+XN(K)
    K1=K1+NEQUA
C    K1 IS ACTUALLY 1K
    DEQ(K1)=1.
    EQ(K)=XN(K)-XAB(K)*XN(1)
    KK=KK+NEQUA1
    DEQ(KK)=1.
61 DEQ(K)=-XAB(K)
    IF(IDEQJA(NEQUA).LT.100)GO TO 62
    EQ(NEQJA)=-XN(NEQUA)
    DEQ(NEQNEQ)=-1.
62 CONTINUE
    DO 99 JMOL=1,NUMMOL
    NCOMP=LOCJ(JMOL+1)-LOCJ(JMOL)
    IF(NCOMP.EQ.1)GO TO 99
    TERM=EQUILJ(JMOL)
    LOCJ1=LOCJ(JMOL)
    LOCJ2=LOCJ(JMOL+1)-1
    DO 80 LOCK=LOCJ1,LOCJ2
    K=KCOMPS(LOCK)
    IF(K.EQ.NEQUA1)GO TO 79
    TERM=TERM*XN(K)
    GO TO 80
79 TERM=TERM/XN(NEQUA)
80 CONTINUE
    EQ(1)=EQ(1)+TERM
    DO 85 LOCK=LOCJ1,LOCJ2
    K=KCOMPS(LOCK)
    IF(K.LT.NEQUA1)GO TO 81
    K=NEQUA
    D=-TERM/XN(K)
    GO TO 82
81 D=TERM/XN(K)
82 EQ(K)=EQ(K)+TERM

```

```

      NEQJAK=NEQUA*K-NEQUA
      K1=NEQJAK+1
      DEQ(K1)=DEQ(K1)+D
      DO 83 LOCJ=LOCJ1,LOCJ2
      M=KCOMPS(LOCJ)
      IF (M.EQ.NEQUA1) M=NEQUA
      MK=M+NEQJAK
83  DEQ(MK)=DEQ(MK)+D
85  CONTINUE
99  CONTINUE

C
      CALL SOLVIT(DEQ,NEQUA,EQ,DTERM)
      IFERR=0
      SCALE=100.
      DO 105 K=1,NEQUA
      RATIO=ABS(EQ(K)/XN(K))
      IF (RATIO.GT..001) IFERR=1
      IF (EQOLD(K)*EQ(K).LT.0.) EQ(K)=EQ(K)*.69
      XNEQ=XN(K)-EQ(K)
      XN100=XN(K)/100.
      IF (XNEQ.LT.XN100) GO TO 101
      XN100=XN(K)*100.
C
      IF (XNEQ.GT.XN100) GO TO 102
      XN(K)=XNEQ
      GO TO 105
101 XN(K)=XN(K)/SCALE
      IF (EQOLD(K)*EQ(K).LT.0.) SCALE=SQRT(SCALE)
      GO TO 105
102 XN(K)=XN100
105 EQOLD(K)=EQ(K)
      IF (IFERR.EQ.1) GO TO 50

C
      DO 107 K=1,NEQUA
107  XNZ(J,K)=XN(K)
      XNATOM(J)=XN(1)
      RHO(J)=XNATOM(J)*WTMOLE*1.660E-24
      IF (IDEQJA(NEQUA).EQ.100) XNE(J)=XN(NEQJA)
      DO 109 JMOL=1,NUMMOL
      NCOMP=LOCJ(JMOL+1)-LOCJ(JMOL)
      XNMOL(J,JMOL)=EQUILJ(JMOL)
      LOCJ1=LOCJ(JMOL)
      LOCJ2=LOCJ(JMOL+1)-1
      DO 109 LOCK=LOCJ1,LOCJ2
      K=KCOMPS(LOCK)
      IF (K.EQ.NEQUA1) GO TO 108
      XNMOL(J,JMOL)=XNMOL(J,JMOL)*XN(K)
      GO TO 109
108 XNMOL(J,JMOL)=XNMOL(J,JMOL)/XN(NEQUA)
109 CONTINUE
110 CONTINUE
      IF (ITER.LT.NUMITS) GO TO 120
      WRITE(6,112) (J,RHOX(J),T(J),P(J),XNE(J),XNATOM(J),RHO(J),
      1J=1,NRHOX)
112  FORMAT(1H1////11X4HRHOX,9X1HT,11X1HP,10X3HXNE,8X6HXNATOM,8X3HRHO/
      1(15,1P6E12,3))
C
      1(15,0P6E12,3))
      NN=(NUMMOL/10)*10
      IF (NN.LT.NUMMOL) NN=NN+10
      DO 111 JMOL1=1,NN,10
      JMOL10=JMOL1+9
111  WRITE(6,113) (CODE(JMOL),JMOL=JMOL1,JMOL10),(J,(XNMOL(J,JMOL),

```

```

      1JMOL=JMOL1,JMOL10),J=1,NRHOX)
113 FORMAT(1H1///50X26HMOLECULAR NUMBER DENSITIES/5X10F12.2/
      1(I5.1P10E12.3))
C 1(I5.0P10E12.3))
120 IF(MODE.EQ.2.OR.MODE.EQ.12)GO TO 149
      DO 125 K=2,NEQUA
      ID=IDEQJA(K)
      IF(ID.EQ.100)GO TO 122
      DO 121 J=1,NRHOX
C  CALCULATE PARTITION FUNCTIONS
      CALL PFSAHA(J,ID,1,3,FRAC)
121 XNZ(J,K)=XNZ(J,K)/FRAC(J,1)/1.8786E20/SQRT((ATMASS(ID)*T(J))**3)
      GO TO 125
122 DO 123 J=1,NRHOX
123 XNZ(J,K)=XNZ(J,K)/2./2.4148E15/T(J)/SQRT(T(J))
125 CONTINUE
      DO 140 JMOL=1,NUMMOL
      NCOMP=LOCJ(JMOL+1)-LOCJ(JMOL)
      IF(EQJIL(1,JMOL).EQ.0.)GO TO 135
      DO 126 J=1,NRHOX
126 XNMOL(J,JMOL)=EXP(EQUIL(1,JMOL)/T(J))
      AMASS=0.
      LOCJ1=LOCJ(JMOL)
      LOCJ2=LOCJ(JMOL+1)-1
      DO 130 LOCK=LOCJ1,LOCJ2
      <=KCOMPS(LOCK)
      IF(<.EQ.NEQUA1)GO TO 128
      ID=IDEQJA(K)
      IF(ID.LT.100)AMASS=AMASS+ATMASS(ID)
      DO 127 J=1,NRHOX
127 XNMOL(J,JMOL)=XNMOL(J,JMOL)*XNZ(J,K)
      GO TO 130
128 DO 129 J=1,NRHOX
129 XNMOL(J,JMOL)=XNMOL(J,JMOL)/XNZ(J,NEQJA)
130 CONTINUE
      DO 131 J=1,NRHOX
131 XNMOL(J,JMOL)=XNMOL(J,JMOL)*1.8786E20*SQRT((AMASS*T(J))**3)
      GO TO 140
135 ID=CODE(JMOL)
      DO 136 J=1,NRHOX
      CALL PFSAHA(J,ID,NCOMP,3,FRAC)
136 XNMOL(J,JMOL)=XNMOL(J,JMOL)/FRAC(J,1)
140 CONTINUE
149 IF(IFPNCH(ITER).NE.5)RETURN
      WRITE(6,150)
150 FORMAT(1H120X38HNUMBER DENSITIES / PARTITION FUNCTIONS)
      WRITE(6,151)NUMMOL
      WRITE(7,151)NUMMOL
151 FORMAT(15,10H MOLECULES)
      DO 155 JMOL=1,NUMMOL
      WRITE(6,152)CODE(JMOL),(XNMOL(J,JMOL),J=1,NRHOX)
      WRITE(7,152)CODE(JMOL),(XNMOL(J,JMOL),J=1,NRHOX)
152 FORMAT(F20.2/(1P8E10.3))
C 152 FORMAT(F20.2/(0P8E10.3))
155 CONTINUE
      WRITE(6,158)(XNATOM(J),RHO(J),J=1,NRHOX)
      WRITE(7,158)(XNATOM(J),RHO(J),J=1,NRHOX)
158 FORMAT(11H XNATOM,RHO/(1P8E10.3))
C 158 FORMAT(11H XNATOM,RHO/(0P8E10.3))
      RETJRN
      END

```

```

SUBROUTINE KAPP(N,NSTEPS,STEPWT)
COMMON /FREQ/FREQ,FREQLG,EHVKT(40),STIM(40),BNJ(40)
COMMON /IFOP/IFOP(20)
COMMON /IONS/XNFPH(40,2),XNFPHE(40,3)
COMMON /OPS/AHYD(40),AH2P(40),AHMIN(40),SIGH(40),AHE1(40),
1    AHE2(40),AHEMIN(40),SIGHE(40),ACOL(40),ALUKE(40),AHOT(40),
2    SIGEL(40),SIGH2(40),AHLIN(40),ALINES(40),SIGLIN(40),
3    AXLINE(40),SIGXL(40),AXCONT(40),SIGX(40),SHYD(40),
4    SHMIN(40),SHLINE(40),SXLIN(40),SXCONT(40)
COMMON /OPTOT/ACONT(40),SCONT(40),ALINE(40),SLINE(40),SIGMAC(40),
1    SIGMAL(40)
COMMON /RHOX/RHOX(40),NRHOX
COMMON /STATE/P(40),XNE(40),XNATOM(40),RHO(40)
COMMON /TEMP/T(40),TKEV(40),TK(40),HKT(40),TLOG(40),ITEMP
DIMENSION DUMMY(40,25)
EQUIVALENCE (AHYD(1),DUMMY(1))
DATA ITEMPI/0/
IF(ITEMP.EQ.ITEMPI)GO TO 90
ITEMPI=ITEMP
IF(IFOP(1).EQ.1)CALL POP5(1.01,11,XNFPH)
IF(IFOP(5)+IFOP(7).GT.0)CALL POP5(2.02,11,XNFPHE)
90 STEPWT=1.
NSTEPS=1
IF(N.GT.1)GO TO 200
DO 91 J=1,NRHOX
DO 91 I=1,25
91 DUMMY(J,I)=0.
IF(IFOP(1).EQ.1)CALL HOP
IF(IFOP(2).EQ.1)CALL H2PLOP
IF(IFOP(3).EQ.1)CALL HMINOP
IF(IFOP(4).EQ.1)CALL HRAYOP
IF(IFOP(5).EQ.1)CALL HEIOP
IF(IFOP(6).EQ.1)CALL HEZOP
IF(IFOP(7).EQ.1)CALL HEMIOP
IF(IFOP(8).EQ.1)CALL HERAOP
IF(IFOP(9).EQ.1)CALL COOLOP
IF(IFOP(10).EQ.1)CALL LUKEOP
IF(IFOP(11).EQ.1)CALL HOTOP
IF(IFOP(12).EQ.1)CALL ELECOP
IF(IFOP(13).EQ.1)CALL H2RAOP
IF(IFOP(14).EQ.1.AND.N.GT.0)CALL HLINOP
IF(IFOP(15).EQ.1.AND.N.GT.0)CALL LINOP(N,NSTEPS,STEPWT)
IF(IFOP(16).EQ.1.AND.N.GT.0)CALL LINSOP(N,NSTEPS,STEPWT)
IF(IFOP(17).EQ.1.AND.N.GT.0)CALL XLINOP
IF(IFOP(18).EQ.1.AND.N.GT.0)CALL XLISOP
IF(IFOP(19).EQ.1)CALL XCONOP
IF(IFOP(20).EQ.1)CALL XSOP
DO 100 J=1,NRHOX
A=A+2P(J)+AHE1(J)+AHE2(J)+AHEMIN(J)+ACOL(J)+ALUKE(J)+AHOT(J)
ACONT(J)=A+AHYD(J)+AHMIN(J)+AXCONT(J)
SCONT(J)=BNU(J)
IF(ACONT(J).GT.0.)SCONT(J)=(A*BNU(J)+AHYD(J)*SHYD(J)+AHMIN(J)*
1SHMIN(J)+AXCONT(J)*SXCONT(J))/ACONT(J)
ALINE(J)=AHLIN(J)+ALINES(J)+AXLINE(J)
SLINE(J)=BNU(J)
IF(ALINE(J).GT.0.)SLINE(J)=(AHLIN(J)*SHLINE(J)+ALINES(J)*BNU(J)+
1AXLINE(J)*SXLIN(J))/ALINE(J)
SIGMAC(J)=SIGH(J)+SIGHE(J)+SIGEL(J)+SIGH2(J)+SIGX(J)
100 SIGMAL(J)=SIGLIN(J)+SIGXL(J)
RETURN

```

```

200 IF (IFOP(15).EQ.1) CALL LINOP(N,NSTEPS,STEPWT)
    IF (IFOP(16).EQ.1) CALL LINSOP(N,NSTEPS,STEPWT)
    DO 201 J=1,NRHOX
        ALINE(J)=AHLIN(J)+ALINES(J)+AXLINE(J)
        IF (ALINE(J).GT.0.) SLINE(J)=(AHLIN(J)*SHLINE(J)+ALINES(J)*BNU(J)+
1AXLINE(J)*SXLINE(J))/ALINE(J)
201 SIGMAL(J)=SIGLIN(J)+SIGXL(J)
    RETJRN
    END

```

```

C SUBROUTINE HOP
  REQUIRES FUNCTIONS COULX AND COULFF
  COMMON /DEPART/BHYD(40,6),BMIN(40),NLTEON
  COMMON /FREQ/FREQ,FREQLG,EHVKT(40),STIM(40),BNJ(40)
  COMMON /IONS/XNFPH(40,2),XNFPHE(40,3)
  COMMON /OPS/AHYD(40),D1(40,19),SHYD(40),D2(40,4)
  COMMON /RHOX/RHOX(40),NRHOX
  COMMON /STATE/P(40),XNE(40),XNATOM(40),RHO(40)
  COMMON /TEMP/T(40),TKEV(40),TK(40),HKT(40),TLGG(40),ITEMP
  DIMENSION CONT(8),BOLT(40,8),EXLIM(40),FREET(40),BOLTEX(40)
  DATA ITEMPI/0/
  IF (ITEMP.EQ.ITEMPI) GO TO 20
  ITEMPI=ITEMP
  DO 15 J=1,NRHOX
    DO 11 N=1,8
11 BOLT(J,N)=EXP(-(13.595-13.595/FLOAT(N*N))/TKEV(J))*2.*FLOAT(N*N)*
    XNFPH(J,1)/RHO(J)
    DO 12 N=1,6
12 BOLT(J,N)=BOLT(J,N)*BHYD(J,N)
    FREET(J)=XNE(J)*XNFPH(J,2)/RHO(J)/SORT(T(J))
    XR=XNFPH(J,1)*(2./2./13.595)*TKEV(J)/RHO(J)
    BOLTEX(J)=EXP(-13.427/TKEV(J))*XR
15 EXLIM(J)=EXP(-13.595/TKEV(J))*XR
20 DO 21 N=1,8
21 CONT(N)=COULX(N,FREQ,1.)
    FREQ3=FREQ**3
    CFREE=3.6919E8/FREQ3
    C=2.815E29/FREQ3
    DO 32 J=1,NRHOX
      EX=BOLTEX(J)
      IF (FREQ.LT.4.05933E13) EX=EXLIM(J)/EHVKT(J)
      H=(CONT(7)*BOLT(J,7)+CONT(8)*BOLT(J,8)+(EX-EXLIM(J))*C+
1COULFF(J,1)*FREET(J)*CFREE)*STIM(J)
      S=H*BNJ(J)
      DO 31 N=1,6
      H=H*CONT(N)*BOLT(J,N)*(1.-EHVKT(J)/BHYD(J,N))
31 S=S*CONT(N)*BOLT(J,N)*BNU(J)*STIM(J)/BHYD(J,N)
      AHYD(J)=H
32 SHYD(J)=S/H
    RETURN
    END

```

```

FUNCTION COULX(N,FREQ,Z)
DIMENSION A(6),B(6),C(6)
DATA A/.9916,1.105,1.101,1.101,1.102,1.0986/
DATA B/2.719E13,-2.375E14,-9.863E13,-5.765E13,-3.909E13,-2.704E13/
DATA C/-2.268E30,4.077E28,1.035E28,4.593E27,2.371E27,1.229E27/
IF(FREQ.LT.Z*Z*3.28805E15/FLOAT(N*N))GO TO 1
COULX=2.815E29/FREQ/FREQ/FREQ/FLOAT(N**5)*Z**4
IF(N.GT.6)RETURN
COULX=COULX*(A(N)+(B(N)+C(N)*(Z*Z/FREQ))*(Z*Z/FREQ))
RETURN
1 COULX=0.
RETURN
END

```

```

FUNCTION COULFF(J,NZ)
COMMON /FREQ/FREQ,FREQLG,EHVKT(40),STIM(40),BNJ(40)
COMMON /TEMP/T(40),TKEV(40),TK(40),HKT(40),TLOG(40),ITEMP
DIMENSION Z4LOG(6),A(11,12)
DATA Z4LOG/0.,1.20412,1.90849,2.40824,2.79588,3.11261/
DATA A/
15.53,5.49,5.46,5.43,5.40,5.25,5.00,4.69,4.48,4.16,3.85,
24.91,4.87,4.84,4.80,4.77,4.63,4.40,4.13,3.87,3.52,3.27,
34.29,4.25,4.22,4.18,4.15,4.02,3.80,3.57,3.27,2.98,2.70,
43.64,3.61,3.59,3.56,3.54,3.41,3.22,2.97,2.70,2.45,2.20,
53.00,2.98,2.97,2.95,2.94,2.81,2.65,2.44,2.21,2.01,1.81,
62.41,2.41,2.41,2.41,2.41,2.32,2.19,2.02,1.84,1.67,1.50,
71.87,1.89,1.91,1.93,1.95,1.90,1.80,1.68,1.52,1.41,1.30,
81.33,1.39,1.44,1.49,1.55,1.56,1.51,1.42,1.33,1.25,1.17,
90.90,0.95,1.00,1.08,1.17,1.30,1.32,1.30,1.20,1.15,1.11,
A0.45,0.48,0.52,0.60,0.75,0.91,1.15,1.18,1.15,1.11,1.08,
30.33,0.36,0.39,0.46,0.59,0.76,0.97,1.09,1.13,1.10,1.08,
C0.19,0.21,0.24,0.28,0.38,0.53,0.76,0.96,1.08,1.09,1.09/
C GAMLOG=ALOG10(158000*Z*Z/T)*2
GAMLOG=10.39638-TLOG(J)/1.15129+Z4LOG(NZ)
IGAM=MAX0(MIN0(IFIX(GAMLOG+7.),10),1)
C HVKTLG=ALOG10(HVKT)*2
HVKTLG=(FREQLG-TLOG(J))/1.15129-20.63764
IHVKT=MAX0(MIN0(IFIX(HVKTLG+9.),11),1)
P=GAMLOG-FLOAT(IGAM-7)
Q=HVKTLG-FLOAT(IHVKT-9)
COULFF=((1.-P)*((1.-Q)*A(IGAM,IHVKT)+Q*A(IGAM,IHVKT+1))+
1P*((1.-Q)*A(IGAM+1,IHVKT)+Q*A(IGAM+1,IHVKT+1)) -
RETURN
END

```

```

SUBROUTINE HRAYOP
COMMON /DEPART/BHYD(40,6),BMIN(40),NLTEON
COMMON /FREQ/FREQ,FREQLG,EHVKT(40),STIM(40),BNJ(40)
COMMON /IONS/XNFPH(40,2),XNFPHE(40,3)
COMMON /OPS/D1(40,3),SIGH(40),D2(40,21)
COMMON /RHOX/RHOX(40),NRHOX
COMMON /STATE/P(40),XNE(40),XNATOM(40),RHO(40)
WAVE=2.997925E18/AMIN1(FREQ,2.463E15)
WW=WAVE**2
SIG=(5.799E-13+1.422E-6/WW+2.784/(WW*WW))/(WW*WW)
DO 2 J=1,NRHOX
2 SIGH(J)=SIG*XNFPH(J,1)*2.*BHYD(J,1)/RHO(J)
RETURN
END

```

```

SUBROUTINE H2PLOP
COMMON /DEPART/BHYD(40,6),BMIN(40),NLTEON
COMMON /FREQ/FREQ,FREQLG,EHVKT(40),STIM(40),BNJ(40)
COMMON /IONS/XNFPH(40,2),XNFPHE(40,3)
COMMON /OPS/D1(40),AH2P(40),D2(40,23)
COMMON /RHOX/RHOX(40),NRHOX
COMMON /STATE/P(40),XNE(40),XNATOM(40),RHO(40)
COMMON /TEMP/T(40),TKEV(40),TK(40),HKT(40),TLOG(40),ITEMP
IF (FREQ.GT.3.28805E15) RETURN
FR=-3.0233E3+(3.7797E2+(-1.82496E1+(3.9207E-1-3.1672E-3*FREQLG)*
1 FREQLG)*FREQLG)*FREQLG
ES=-7.342E-3+(-2.409E-15+(1.028E-30+(-4.230E-46+(1.224E-61-
1 1.351E-77*FREQ)*FREQ)*FREQ)*FREQ)*FREQ
DO 10 J=1,NRHOX
10 AH2P(J)=EXP(-ES/TKEV(J)+FR)*XNFPH(J,1)*2.*BHYD(J,1)*XNFPH(J,2)/
1 RHO(J)*STIM(J)
RETURN
END

```

```

SUBROUTINE HMINOP
COMMON /DEPART/BHYD(40,6),BMIN(40),NLTEON
COMMON /FREQ/FREQ,FREQLG,EHVKT(40),STIM(40),BNJ(40)
COMMON /IONS/XNFPH(40,2),XNFPHE(40,3)
COMMON /OPS/D1(40,2),AHMIN(40),D2(40,18),SHMIN(40),D3(40,3)
COMMON /RHOX/RHOX(40),NRHOX
COMMON /STATE/P(40),XNE(40),XNATOM(40),RHO(40)
COMMON /TEMP/T(40),TKEV(40),TK(40),HKT(40),TLOG(40),ITEMP
DIMENSION XHMIN(40)
DATA ITEMP1/0/
IF (ITEMP.EQ.ITEMP1) GO TO 20
ITEMP1=ITEMP
DO 11 J=1,NRHOX
11 XHMIN(J)=EXP(.7552/TKEV(J))/(2.*2.4148E15*T(J)*SQRT(T(J)))*
1 BMIN(J)*BHYD(J,1)*XNFPH(J,1)*XNE(J)
20 B=(1.3727E-25+4.3748E-10/FREQ)/FREQ
C=-2.5993E-7/FREQ**2
IF (FREQ.LE.1.8259E14) GO TO 23
IF (FREQ.GE.2.111E14) GO TO 22
4MINBF=3.695E-16+(-1.251E-1+1.052E13/FREQ)/FREQ
GO TO 30
22 4MINBF=6.801E-20+(5.358E-3+(1.481E13+(-5.519E27+4.808E41/FREQ)/
1 FREQ)/FREQ)/FREQ
GO TO 30
23 4MINBF=0.
30 DO 31 J=1,NRHOX
4MINFF=(B+C/T(J))*XNFPH(J,1)*2.*BHYD(J,1)*XNE(J)/RHO(J)
H=4MINBF*(1.-EHVKT(J)/BMIN(J))*XHMIN(J)/RHO(J)
AHMIN(J)=H+4MINFF
31 SHMIN(J)=(H*BNU(J)*STIM(J)/(BMIN(J)-EHVKT(J))+4MINFF*BNU(J))/
1 AHMIN(J)
RETURN
END

```



```

C      SUBROUTINE HE1OP
      REQUIRES FUNCTIONS COULX AND COULFF
      COMMON /FREQ/FREQ,FREQLG,EHVKT(40),STIM(40),BNJ(40)
      COMMON /IONS/XNFPH(40,2),XNFPHE(40,3)
      COMMON /OPS/D1(40,4),AHE1(40),D2(40,20)
      COMMON /RHOX/RHOX(40),NRHOX
      COMMON /STATE/P(40),XNE(40),XNATOM(40),RHO(40)
      COMMON /TEMP/T(40),TKEV(40),TK(40),HKT(40),TLOG(40),ITEMP
      DIMENSION CHI(10),BOLT(40,10),EXLIM(40),HEFREQ(10),TRANS(10),G(10)
      DIMENSION BOLTEX(40),FREET(40)
      DATA G/1.,3.,1.,9.,3.,3.,1.,9.,20.,3./
      DATA HEFREQ/5.945209E15,1.152844E15,.9603331E15,.8761076E15,
1 .8147104E15,.4519048E15,.4030971E15,.3821191E15,.3660215E15,
2 .3627891E15/
      DATA CHI/0.,19.819,20.615,20.964,21.217,22.718,22.920,23.006,
1 23.073,23.086/
      DATA ITEMPL/0/
      IF(ITEMP.EQ.ITEMPL)GO TO 10
      ITEMPL=ITEMP
      DO 5 J=1,NRHOX
      DO 4 N=1,10
4      BOLT(J,N)=EXP(-CHI(N)/TKEV(J))*G(N)*XNFPHE(J,1)/RHO(J)
      FREET(J)=XNE(J)*XNFPHE(J,2)/RHO(J)/SQRT(T(J))
      XR=XNFPHE(J,1)*(4./2./13.595)*TKEV(J)/RHO(J)
      BOLTEX(J)=EXP(-23.730/TKEV(J))*XR
5      EXLIM(J)=EXP(-24.587/TKEV(J))*XR
10     FREQ3=FREQ**3
      CFREE=3.6919E8/FREQ3
      C=2.815E29/FREQ3
      DO 15 NMIN=1,10
      TRANS(NMIN)=0.
      IF(HEFREQ(NMIN).LE.FREQ)GO TO 16
15     CONTINUE
      GO TO 40
16     GO TO (21,22,23,24,25,26,27,28,29,30),NMIN
21     TRANS(1)=EXP(33.32-2.*FREQLG)
22     TRANS(2)=EXP(-390.026+(21.035-.318*FREQLG)*FREQLG)
23     TRANS(3)=EXP(26.83-1.91*FREQLG)
24     TRANS(4)=EXP(61.21-2.9*FREQLG)
25     TRANS(5)=EXP(81.35-3.5*FREQLG)
26     TRANS(6)=EXP(12.69-1.54*FREQLG)
27     TRANS(7)=EXP(23.85-1.86*FREQLG)
28     TRANS(8)=EXP(49.30-2.60*FREQLG)
29     TRANS(9)=EXP(85.20-3.69*FREQLG)
30     TRANS(10)=EXP(58.81-2.89*FREQLG)
40     DO 45 J=1,NRHOX
      EX=BOLTEX(J)
      IF(FREQ.LT.2.055E14)EX=EXLIM(J)/EHVKT(J)
      HE1=(EX-EXLIM(J))*C
      DO 41 N=1,10
41     HE1=HE1+TRANS(N)*BOLT(J,N)
45     AHE1(J)=(HE1+COULFF(J,1)*FREET(J)*CFREE)*STIM(J)
      RETJRN
      END

```

```

SUBROUTINE HE2OP
C   REQUIRES FUNCTIONS COULX AND COULFF
C   FREQUENCIES ARE 4X HYDROGEN, CHI ARE FOR ION POT=54.403
COMMON /FREQ/FREQ,FREQLG,EHVKT(40),STIM(40),BNJ(40)
COMMON /IONS/XNFPH(40,2),XNFPHE(40,3)
COMMON /OPS/D1(40,5),AHE2(40),D2(40,19)
COMMON /RHOX/RHOX(40),NRHOX
COMMON /STATE/P(40),XNE(40),XNATOM(40),RHO(40)
COMMON /TEMP/T(40),TKEV(40),TK(40),HKT(40),TLOG(40),ITEMP
DIMENSION CONT(9),BOLT(40,9),EXLIM(40),FREET(40),BOLTEX(40)
DATA ITEMPL/0/
IF (ITEMP.EQ.ITEMPL) GO TO 20
ITEMPL=ITEMP
DO 15 J=1,NRHOX
DO 14 N=1,9
14 BOLT(J,N)=EXP(-(54.403-54.403/FLOAT(N*N))/TKEV(J))*2.*FLOAT(N*N)*
   1 XNFPHE(J,2)/RHO(J)
   FREET(J)=XNE(J)*XNFPHE(J,3)/RHO(J)/SQRT(T(J))
   XR=XNFPHE(J,2)*(2./2./13.595)*TKEV(J)/RHO(J)
   BOLTEX(J)=EXP(-53.859/TKEV(J))*XR
15 EXLIM(J)=EXP(-54.403/TKEV(J))*XR
20 DO 21 N=1,9
21 CONT(N)=COULX(N,FREQ,2.)
   FREQ3=FREQ**3
   CFREE=3.6919E8/FREQ3*4.
   C=2.815E29*2.*2./FREQ3
   DO 35 J=1,NRHOX
   EX=BOLTEX(J)
   IF (FREQ.LT.1.31522E14) EX=EXLIM(J)/EHVKT(J)
   HE2=(EX-EXLIM(J))*C
   DO 31 N=1,9
31 HE2=HE2+CONT(N)*BOLT(J,N)
35 AHE2(J)=(HE2+COULFF(J,2)*CFREE*FREET(J))*STIM(J)
RETURN
END

```

```

SUBROUTINE HEMIOP
COMMON /FREQ/FREQ,FREQLG,EHVKT(40),STIM(40),BNJ(40)
COMMON /IONS/XNFPH(40,2),XNFPHE(40,3)
COMMON /OPS/D1(40,6),AHEMIN(40),D2(40,18)
COMMON /RHOX/RHOX(40),NRHOX
COMMON /STATE/P(40),XNE(40),XNATOM(40),RHO(40)
COMMON /TEMP/T(40),TKEV(40),TK(40),HKT(40),TLOG(40),ITEMP
A=3.397E-46+(-5.216E-31+7.039E-15/FREQ)/FREQ
B=-4.116E-42+(1.067E-26+8.135E-11/FREQ)/FREQ
C=5.081E-37+(-8.724E-23-5.659E-8/FREQ)/FREQ
DO 3 J=1,NRHOX
3 AHEMIN(J)=(A*T(J)+B+C/T(J))*XNE(J)*XNFPHE(J,1)/RHO(J)
RETURN
END

```

```

SUBROUTINE HERAOP
COMMON /FREQ/FREQ,FREQLG,EHVKT(40),STIM(40),BNJ(40)
COMMON /IONS/XNFPH(40,2),XNFPHE(40,3)
COMMON /OPS/D1(40,7),SIGHE(40),D2(40,17)
COMMON /RHOX/RHOX(40),NRHOX
COMMON /STATE/P(40),XNE(40),XNATOM(40),RHO(40)
WAVE=2.997925E18/AMIN1(FREQ,5.15E15)
WW=WAVE**2
SIG=5.484E-14/WW/WW*(1.+(2.44E5+5.94E10/(WW-2.90E5))/WW)**2
DO 2 J=1,NRHOX
2 SIGHE(J)=SIG*XNFPHE(J,1)/RHO(J)
RETURN
END

```

```

C SUBROUTINE COOLOP
SI1,MG1,AL1,C1
COMMON /FREQ/FREQ,FREQLG,EHVKT(40),STIM(40),BNJ(40)
COMMON /OPS/D1(40,8),ACCOL(40),D2(40,16)
COMMON /RHOX/RHOX(40),NRHOX
COMMON /STATE/P(40),XNE(40),XNATOM(40),RHO(40)
COMMON /TEMP/T(40),TKEV(40),TK(40),HKT(40),TLOG(40),ITEMP
DIMENSION XNFPC(40),XNFPMG(40),XNFPAL(40),XNFPSI(40)
REAL MG1OP
DATA ITEMPI/0/
IF(ITEMP.EQ.ITEMPI)GO TO 10
ITEMPI=ITEMP
CALL POPS(6.,11,XNFPC)
CALL POPS(12.,11,XNFPMG)
CALL POPS(13.,11,XNFPAL)
CALL POPS(14.,11,XNFPSI)
10 DO 20 J=1,NRHOX
20 ACCOL(J)=(C1OP(J)*XNFPC(J)+MG1OP(J)*XNFPMG(J)+AL1OP(J)*XNFPAL(J)+
1SI1OP(J)*XNFPSI(J))*STIM(J)/RHO(J)
RETURN
END

```

```

C      FUNCTION C10P(J)
      CROSS-SECTION TIMES THE PARTITION FUNCTION
      COMMON /FREQ/FREQ,FREQLG,EHVKT(40),STIM(40),BNJ(40)
      COMMON /RHOX/RHOX(40),NRHOX
      COMMON /TEMP/T(40),TKEV(40),TK(40),HKT(40),TLOG(40),ITEMP
      DIMENSION C1240(40),C1444(40)
      DATA FREQ1,ITEMP1/0.,0/
      IF(ITEMP.EQ.ITEMP1)GO TO 30
      ITEMPI=ITEMP
      DO 20 K=1,NRHOX
      C1240(K)=5.*EXP(-1.264/TKEV(K))
20  C1444(K)=EXP(-2.683/TKEV(K))
30  IF(FREQ.EQ.FREQ1)GO TO 40
      X1444=0.
      X1240=0.
      X1100=0.
      IF(FREQ.GE.2.7254E15)X1100=SEATON(2.7254E15,1.219E-17,2.,3.317)
      IF(FREQ.GE.2.4196E15)X1240=SEATON(2.4196E15,1.03E-17,1.5,2.789)
      IF(FREQ.GE.2.0761E15)X1444=SEATON(2.0761E15,9.59E-18,1.5,3.501)
      FREQ1=FREQ
40  C10P=X1100*9.+X1240*C1240(J)+X1444*C1444(J)
      RETURN
      END

```

```

      FUNCTION SEATON(FREQ0,XSECT,POWER,A)
      COMMON /FREQ/FREQ,FREQLG,EHVKT(40),STIM(40),BNJ(40)
      SEATON=XSECT*(A+(1.-A)*(FREQ0/FREQ))
1  SQRT((FREQ0/FREQ)**(IFIX(2.*POWER+.01)))
      RETURN
      END

```

```

C      FUNCTION AL10P(J)
      CROSS-SECTION TIMES THE PARTITION FUNCTION
      COMMON /FREQ/FREQ,FREQLG,EHVKT(40),STIM(40),BNJ(40)
      AL10P=0.
      IF(FREQ.GE.1.443E15)AL10P=2.1E-17*(1.443E15/FREQ)**3*6.
      RETURN
      END

```

```

REAL FUNCTION MG1OP(J)
C CROSS-SECTION TIMES THE PARTITION FUNCTION
COMMON /FREQ/FREQ,FREQLG,EHVKT(40),STIM(40),BNJ(40)
COMMON /RHOX/RHOX(40),NRHOX
COMMON /TEMP/T(40),TKEV(40),TK(40),HKT(40),TLOG(40),ITEMP
DIMENSION FLOG(9),FREQMG(7),PEACH(7,15),X(7),TLG(7),DT(40),NT(40)
DATA PEACH/
C
      4000      5000      6000      7000      8000      9000      10000      WAVE(A)
1 -42.474, -42.350, -42.109, -41.795, -41.467, -41.159, -40.883, 1500
2 -41.808, -41.735, -41.582, -41.363, -41.115, -40.866, -40.631, 1550
3 -41.273, -41.223, -41.114, -40.951, -40.755, -40.549, -40.347, 1621
4 -45.583, -44.008, -42.957, -42.205, -41.639, -41.198, -40.841, 1622
5 -44.324, -42.747, -41.694, -40.939, -40.370, -39.925, -39.566, 2513
6 -50.969, -48.388, -46.630, -45.344, -44.355, -43.568, -42.924, 2514
7 -50.633, -48.026, -46.220, -44.859, -43.803, -42.957, -42.264, 3756
8 -53.028, -49.643, -47.367, -45.729, -44.491, -43.520, -42.736, 3757
9 -51.785, -48.352, -46.050, -44.393, -43.140, -42.157, -41.363, 6549
T -52.285, -48.797, -46.453, -44.765, -43.486, -42.480, -41.668, 6550
1 -52.028, -48.540, -46.196, -44.507, -43.227, -42.222, -41.408, 7234
2 -52.384, -48.876, -46.513, -44.806, -43.509, -42.488, -41.660, 7235
3 -52.363, -48.856, -46.493, -44.786, -43.489, -42.467, -41.639, 7291
4 -54.704, -50.772, -48.107, -46.176, -44.707, -43.549, -42.611, 7292
5 -54.359, -50.349, -47.643, -45.685, -44.198, -43.027, -42.418, 9000
DATA FREQMG/1.9341452E15,1.8488510E15,1.1925797E15,7.9804046E14,
1 4.5772110E14,4.1440977E14,4.1113514E14/
DATA FLOG/35.23123,35.19844,35.15334,34.71490,34.31318,33.75728,
1 33.65788,33.64994,33.43947/
DATA TLG/8.29405,8.51719,8.69951,8.85367,8.98720,9.10498,9.21034/
DATA FREQ1,ITEMP1/0.,0/
IF(ITEMP.EQ.ITEMP1)GO TO 20
ITEMP1=ITEMP
DO 11 K=1,NRHOX
N=MAX0(MINO(6,IFIX(T(K)/1000.))-3),1)
NT(K)=N
11 DT(K)=(TLOG(K)-TLG(N))/(TLG(N+1)-TLG(N))
GO TO 21
20 IF(FREQ.EQ.FREQ1)GO TO 30
21 FREQ1=FREQ
DO 22 N=1,7
IF(FREQ.GT.FREQMG(N))GO TO 23
22 CONTINUE
N=8
23 D=(FREQLG-FLOG(N))/(FLOG(N+1)-FLOG(N))
IF(N.GT.2)N=2*N-2
D1=1.-D
DO 24 IT=1,7
24 X(IT)=PEACH(IT,N+1)*D+PEACH(IT,N)*D1
30 N=NT(J)
MG1OP=EXP(X(N)*(1.-DT(J))+X(N+1)*DT(J))
RETURN
END

```

```

      FUNCTION SILOP(J)
C     CROSS-SECTION TIMES THE PARTITION FUNCTION
      COMMON /FREQ/FREQ,FREQLG,EHVKT(40),STIM(40),BNJ(40)
      COMMON /RHOX/RHOX(40),NRHOX
      COMMON /TEMP/T(40),TKEV(40),TK(40),HKT(40),TLG(40),ITEMP
      DIMENSION FLOG(11),FREQSI(9),X(9),TLG(9),DT(40),NT(40)
      DIMENSION PEACH(9,19)
      DATA PEACH/
C
      4000    5000    6000    7000    8000    9000    10000    11000    12000    WAVE(A)
1  38.136,38.138,38.140,38.141,38.143,38.144,38.144,38.145,38.145, 1200
2  37.834,37.839,37.843,37.847,37.850,37.853,37.855,37.857,37.858, 1400
3  37.898,37.898,37.897,37.897,37.897,37.896,37.895,37.895,37.894, 1519
4  40.737,40.319,40.047,39.855,39.714,39.604,39.517,39.445,39.385, 1520
5  40.581,40.164,39.893,39.702,39.561,39.452,39.366,39.295,39.235, 1676
6  45.521,44.456,43.753,43.254,42.878,42.580,42.332,42.119,41.930, 1677
7  45.520,44.455,43.752,43.251,42.871,42.569,42.315,42.094,41.896, 1978
8  55.068,51.783,49.553,47.942,46.723,45.768,44.997,44.360,43.823, 1979
9  53.868,50.369,48.031,46.355,45.092,44.104,43.308,42.652,42.100, 5379
T  54.133,50.597,48.233,46.539,45.261,44.262,43.456,42.790,42.230, 5380
1  54.051,50.514,48.150,46.454,45.176,44.175,43.368,42.702,42.141, 5624
2  54.442,50.854,48.455,46.733,45.433,44.415,43.592,42.912,42.340, 5625
3  54.320,50.722,48.313,46.583,45.277,44.251,43.423,42.738,42.160, 6260
4  55.691,51.965,49.444,47.615,46.221,45.119,44.223,43.478,42.848, 6261
5  55.661,51.933,49.412,47.582,46.188,45.085,44.189,43.445,42.813, 6349
6  55.973,52.193,49.630,47.769,46.349,45.226,44.314,43.555,42.913, 6350
7  55.922,52.141,49.577,47.715,46.295,45.172,44.259,43.500,42.858, 6491
8  56.828,52.821,50.110,48.146,46.654,45.477,44.522,43.730,43.061, 6492
9  56.657,52.653,49.944,47.983,46.491,45.315,44.360,43.569,42.901/ 6900
C
      3P,1D,1S,1D,3D,3F,1D,3P
      DATA FREQSI/2.1413750E15,1.9723165E15,1.7879689E15,1.5152920E15,
1  5.5723927E14,5.3295914E14,4.7886458E14,4.7216422E14,4.6185133E14/
      DATA FLOG/35.45438,35.30022,35.21799,35.11986,34.95438,33.95402,
1  33.90947,33.80244,33.78835,33.76626,33.70518/
      DATA TLG/8.29405,8.51719,8.69951,8.85367,8.98720,9.10498,9.21034,
1  9.30565,9.39266/
      DATA FREQ1,ITEMP1/0.,0/
      IF(ITEMP.EQ.ITEMP1)GO TO 20
      ITEMPI=ITEMP
      DO 11 K=1,NRHOX
      N=MAX0(MINO(8,IFIX(T(K)/1000.)-3),1)
      NT(K)=N
11  DT(K)=(TLOG(K)-TLG(N))/(TLG(N+1)-TLG(N))
      GO TO 21
20  IF(FREQ.EQ.FREQ1)GO TO 30
21  FREQ1=FREQ
      DO 22 N=1,9
      IF(FREQ.GT.FREQSI(N))GO TO 23
22  CONTINUE
      N=10
23  D=(FREQLG-FLOG(N))/(FLOG(N+1)-FLOG(N))
      IF(N.GT.2)N=2*N-2
      D1=1.-D
      DO 24 IT=1,9
24  X(IT)=PEACH(IT,N+1)*D+PEACH(IT,N)*D1
30  N=NT(J)
      SILOP=EXP(-(X(N)*(1.-DT(J))+X(N+1)*DT(J)))*9.
      RETURN
      END

```

```

C      SUBROUTINE LUKEOP
      SI2,MG2,CA2,N1,O1
      COMMON /FREQ/FREQ,FREQLG,EHVKT(40),STIM(40),BNJ(40)
      COMMON /OPS/D1(40,9),ALUKE(40),D2(40,15)
      COMMON /RHOX/RHOX(40),NRHOX
      COMMON /STATE/P(40),XNE(40),XNATOM(40),RHO(40)
      COMMON /TEMP/T(40),TKEV(40),TK(40),HKT(40),TLOG(40),ITEMP
      DIMENSION XNFPN(40),XNFPO(40),XNFPMG(40),XNFPSI(40),XNFPCA(40)
      REAL N1OP,MG2OP
      DATA ITEMPL/0/
      IF(ITEMP.EQ.ITEMPL)GO TO 10
      ITEMPL=ITEMP
      CALL POPS(7.,1,XNFPN)
      CALL POPS(8.,1,XNFPO)
      CALL POPS(12.01,1,XNFPMG)
      CALL POPS(14.01,1,XNFPSI)
      CALL POPS(20.01,1,XNFPCA)
10  DO 11 J=1,NRHOX
11  ALUKE(J)=(N1OP(J)*XNFPN(J)+O1OP(J)*XNFPO(J)+MG2OP(J)*XNFPMG(J)+
      1SI2OP(J)*XNFPSI(J)+CA2OP(J)*XNFPCA(J))*STIM(J)/RHO(J)
      RETURN
      END

C      REAL FUNCTION N1OP(J)
      CROSS-SECTION TIMES PARTITION FUNCTION
      COMMON /FREQ/FREQ,FREQLG,EHVKT(40),STIM(40),BNJ(40)
      COMMON /RHOX/RHOX(40),NRHOX
      COMMON /TEMP/T(40),TKEV(40),TK(40),HKT(40),TLOG(40),ITEMP
      DIMENSION C1130(40),C1020(40)
      DATA FREQ1,ITEMPL/0.,0/
      IF(ITEMP.EQ.ITEMPL)GO TO 30
      ITEMPL=ITEMP
      DO 20 K=1,NRHOX
      C1130(K)=6.*EXP(-3.575/TKEV(K))
20  C1020(K)=10.*EXP(-2.384/TKEV(K))
30  IF(FREQ.EQ.FREQ1)GO TO 40
      X1130=0.
      X1020=0.
      X853=0.
      IF(FREQ.GE.3.517915E15)X853=SEATON(3.517915E15,1.142E-17,2.,4.29)
      IF(FREQ.GE.2.941534E15)X1020=SEATON(2.941534E15,4.41E-18,1.5,3.85)
      IF(FREQ.GE.2.653317E15)X1130=SEATON(2.653317E15,4.2E-18,1.5,4.34)
      FREQ1=FREQ
40  N1OP=X853*4.+X1020*C1020(J)+X1130*C1130(J)
      RETURN
      END

C      FUNCTION O1OP(J)
      CROSS-SECTION TIMES PARTITION FUNCTION
      COMMON /FREQ/FREQ,FREQLG,EHVKT(40),STIM(40),BNJ(40)
      DATA FREQ1/0./
      IF(FREQ.EQ.FREQ1)GO TO 1
      X911=0.
      IF(FREQ.GE.3.28805E15)X911=SEATON(3.28805E15,2.94E-18,1.,2.66)
      FREQ1=FREQ
1  O1OP=X911*9.
      RETURN
      END

```

```

      REAL FUNCTION MG2OP(J)
      CROSS-SECTION TIMES PARTITION FUNCTION
      COMMON /FREQ/FREQ,FREQLG,EHVKT(40),STIM(40),BNJ(40)
      COMMON /RHOX/RHOX(40),NRHOX
      COMMON /TEMP/T(40),TKEV(40),TK(40),HKT(40),TLOG(40),ITEMP
      DIMENSION C1169(40)
      DATA FREQ1,ITEMP1/0.,0/
      IF(ITEMP.EQ.ITEMP1)GO TO 30
      ITEMPI=ITEMP
      DO 20 K=1,NRHOX
      C1169(K)=6.*EXP(-4.43/TKEV(K))
      20 IF(FREQ.EQ.FREQ1)GO TO 40
      X1169=0.
      X824=0.
      IF(FREQ.GE.3.635492E15)X824=SEATON(3.635492E15,1.40E-19,4.,6.7)
      IF(FREQ.GE.2.564306E15)X1169=5.11E-19*(2.564306E15/FREQ)**3
      FREQ1=FREQ
      40 MG2OP=X824*2.*X1169*C1169(J)
      RETURN
      END

```

```

      FUNCTION CA2OP(J)
      CROSS-SECTION TIMES THE PARTITION FUNCTION
      COMMON /FREQ/FREQ,FREQLG,EHVKT(40),STIM(40),BNJ(40)
      COMMON /RHOX/RHOX(40),NRHOX
      COMMON /TEMP/T(40),TKEV(40),TK(40),HKT(40),TLOG(40),ITEMP
      DIMENSION C1218(40),C1420(40)
      DATA FREQ1,ITEMP1/0.,0/
      IF(ITEMP.EQ.ITEMP1)GO TO 30
      ITEMPI=ITEMP
      DO 20 K=1,NRHOX
      C1218(K)=10.*EXP(-1.697/TKEV(K))
      20 C1420(K)=6.*EXP(-3.142/TKEV(K))
      30 IF(FREQ.EQ.FREQ1)GO TO 40
      X1420=0.
      X1218=0.
      X1044=0.
      IF(FREQ.GE.2.870454E15)X1044=5.4E-20*(2.870454E15/FREQ)**3
      IF(FREQ.GE.2.460127E15)X1218=1.64E-17*SQR(2.460127E15/FREQ)
      IF(FREQ.GE.2.110779E15)X1420=SEATON(2.110779E15,4.13E-18,3.,.69)
      FREQ1=FREQ
      40 CA2OP=X1044*2.*X1218*C1218(J)+X1420*C1420(J)
      RETURN
      END

```



```

FUNCTION SI2OP(J)
C CROSS-SECTION TIMES THE PARTITION FUNCTION
COMMON /FREQ/FREQ,FREQLG,EHVKT(40),STIM(40),BNJ(40)
COMMON /RHOX/RHOX(40),NRHOX
COMMON /TEMP/T(40),TKEV(40),TK(40),HKT(40),TLOG(40),ITEMP
DIMENSION FLOG(9),FREQSI(7),PEACH(6,14),X(6),TLG(6),DT(40),NT(40)
DATA PEACH/
C      10000      12000      14000      16000      18000      20000      WAVE(A)
1 -43.8941, -43.8941, -43.8941, -43.8941, -43.8941, -43.8941, 500
2 -42.2444, -42.2444, -42.2444, -42.2444, -42.2444, -42.2444, 600
3 -40.6054, -40.6054, -40.6054, -40.6054, -40.6054, -40.6054, 759
4 -54.2389, -52.2906, -50.8799, -49.8033, -48.9485, -48.2490, 760
5 -50.4108, -48.4892, -47.1090, -46.0672, -45.2510, -44.5933, 1905
6 -52.0936, -50.0741, -48.5999, -47.4676, -46.5649, -45.8246, 1906
7 -51.9548, -49.9371, -48.4647, -47.3340, -46.4333, -45.6947, 1975
8 -54.2407, -51.7319, -49.9178, -48.5395, -47.4529, -46.5709, 1976
9 -52.7355, -50.2218, -48.4059, -47.0267, -45.9402, -45.0592, 3245
T -53.5387, -50.9189, -49.0200, -47.5750, -46.4341, -45.5082, 3246
1 -53.2417, -50.6234, -48.7252, -47.2810, -46.1410, -45.2153, 3576
2 -53.5097, -50.8535, -48.9263, -47.4586, -46.2994, -45.3581, 3577
3 -54.0561, -51.2365, -49.1980, -47.6497, -46.4302, -45.4414, 3900
4 -53.8469, -51.0256, -48.9860, -47.4368, -46.2162, -45.2266, 4200
DATA FREQSI/4.9965417E15,3.9466738E15,1.5736321E15,1.5171539E15,
1 9.2378947E14,8.3825004E14,7.6869872E14/
C 2P,2D,2P,2D,2P
DATA FLOG/36.32984,36.14752,35.91165,34.99216,34.95561,34.45951,
1 34.36234,34.27572,34.20161/
DATA TLG/9.21034,9.39266,9.54681,9.68034,9.79813,9.90349/
DATA FREQ1,ITEMP1/0.,0/
IF(ITEMP.EQ.ITEMP1)GO TO 20
ITEMP1=ITEMP
DO 11 K=1,NRHOX
N=MAX0(MINO(5,IFIX(T(K)/2000.))-4),1)
NT(K)=N
11 DT(K)=(TLOG(K)-TLG(N))/(TLG(N+1)-TLG(N))
GO TO 21
20 IF(FREQ.EQ.FREQ1)GO TO 30
21 FREQ1=FREQ
DO 22 N=1,7
IF(FREQ.GT.FREQSI(N))GO TO 23
22 CONTINUE
N=8
23 D=(FREQLG-FLOG(N))/(FLOG(N+1)-FLOG(N))
IF(N.GT.2)N=2*N-2
IF(N.EQ.14)N=13
D1=1.-D
DO 24 IT=1,6
24 X(IT)=PEACH(IT,N+1)*D+PEACH(IT,N)*D1
30 N=NT(J)
SI2OP=EXP(X(N)*(1.-DT(J))+X(N+1)*DT(J))*6.
RETURN
END

```

```

SUBROUTINE HOTOP
COMMON /FREQ/FREQ,FREQLG,EHVKT(40),STIM(40),BNJ(40)
COMMON /OPS/D1(40,10),AHOT(40),D2(40,14)
COMMON /RHOX/RHOX(40),NRHOX
COMMON /STATE/P(40),XNE(40),XNATOM(40),RHO(40)
COMMON /TEMP/T(40),TKEV(40),TK(40),HKT(40),TLOS(40),ITEMP
DIMENSION XNFP(40,21)
DIMENSION A(420)
DIMENSION A1(63),A2(63),A3(63),A4(63),A5(63),A6(63),A7(42)
EQUIVALENCE (A(1),A1(1)),(A(64),A2(1)),(A(127),A3(1))
EQUIVALENCE (A(190),A4(1)),(A(253),A5(1)),(A(316),A6(1))
EQUIVALENCE (A(379),A7(1))
DATA A1/

```

1	4.149945E15,	6.90E-18,	1.000,	6.,	6.,	13.71,	2.,	6.01
2	4.574341E15,	2.50E-18,	1.000,	4.,	2.,	11.96,	2.,	6.01
3	5.220770E15,	1.08E-17,	1.000,	4.,	10.,	9.28,	2.,	6.01
4	5.222307E15,	5.35E-18,	3.769,	2.,	1.,	0.00,	16.,	10.00
5	5.892577E15,	4.60E-18,	1.950,	6.,	6.,	0.00,	2.,	6.01
6	6.177022E15,	3.50E-18,	1.000,	4.,	12.,	5.33,	2.,	6.01
7	6.181062E15,	6.75E-18,	3.101,	5.,	1.,	4.05,	6.,	7.01
8	6.701879E15,	6.65E-18,	2.789,	5.,	5.,	1.90,	6.,	7.01
9	7.158382E15,	6.65E-18,	2.860,	6.,	9.,	0.00,	6./	7.01

```
DATA A2/
```

1	7.284488E15,	3.43E-18,	4.174,	5.,	6.,	5.02,	11.,	8.01
2	7.693612E15,	3.53E-18,	3.808,	5.,	10.,	3.33,	11.,	8.01
3	7.885955E15,	2.32E-18,	3.110,	5.,	6.,	5.02,	11.,	8.01
4	8.295079E15,	3.97E-18,	3.033,	5.,	10.,	3.33,	11.,	8.01
5	8.497686E15,	7.32E-18,	3.837,	5.,	4.,	0.00,	11.,	8.01
6	8.509966E15,	2.00E-18,	1.750,	7.,	3.,	12.69,	3.,	6.02
7	8.572854E15,	1.68E-18,	3.751,	5.,	6.,	5.02,	11.,	8.01
8	9.906370E15,	4.16E-18,	2.717,	3.,	6.,	0.00,	17.,	10.01
9	1.000693E16,	2.40E-18,	1.750,	7.,	9.,	6.50,	3./	6.02

```
DATA A3/
```

1	1.046078E16,	4.80E-18,	1.000,	4.,	10.,	12.53,	7.,	7.02
2	1.067157E16,	2.71E-18,	2.148,	3.,	6.,	0.00,	17.,	10.01
3	1.146734E16,	2.06E-18,	1.626,	6.,	6.,	0.00,	7.,	7.02
4	1.156813E16,	5.20E-19,	2.126,	3.,	6.,	0.00,	17.,	10.01
5	1.157840E16,	9.10E-19,	4.750,	4.,	1.,	0.00,	3.,	6.02
6	1.177220E16,	5.30E-18,	1.000,	4.,	12.,	7.10,	7.,	7.02
7	1.198813E16,	3.97E-18,	2.780,	6.,	1.,	5.35,	12.,	8.02
8	1.267503E16,	3.79E-18,	2.777,	6.,	5.,	2.51,	12.,	8.02
9	1.327649E16,	3.65E-18,	2.014,	6.,	9.,	0.00,	12./	8.02

```
DATA A4/
```

1	1.361466E16,	7.00E-18,	1.000,	2.,	5.,	7.48,	12.,	8.02
2	1.365932E16,	9.30E-19,	1.500,	7.,	6.,	8.00,	4.,	6.03
3	1.481487E16,	1.10E-18,	1.750,	7.,	3.,	16.20,	8.,	7.03
4	1.490032E16,	5.49E-18,	3.000,	5.,	1.,	6.91,	18.,	10.02
5	1.533389E16,	1.80E-18,	2.277,	4.,	9.,	0.00,	18.,	10.02
6	1.559452E16,	8.70E-19,	3.000,	6.,	2.,	0.00,	4.,	6.03
7	1.579688E16,	4.17E-18,	2.074,	4.,	5.,	3.20,	18.,	10.02
8	1.643205E16,	1.39E-18,	2.792,	5.,	5.,	3.20,	18.,	10.02
9	1.656208E16,	2.50E-18,	2.346,	5.,	9.,	0.00,	18./	10.02

```
DATA A5/
```

1	1.671401E16,	1.30E-18,	1.750,	7.,	9.,	8.35,	8.,	7.03
2	1.719725E16,	1.48E-18,	2.225,	5.,	9.,	0.00,	18.,	10.02
3	1.737839E16,	2.70E-18,	1.000,	4.,	10.,	15.74,	13.,	8.03
4	1.871079E16,	1.27E-18,	.831,	6.,	6.,	0.00,	13.,	8.03
5	1.873298E16,	9.10E-19,	3.000,	4.,	1.,	0.00,	8.,	7.03
6	1.903597E16,	2.90E-18,	1.000,	4.,	12.,	8.88,	13.,	8.03
7	2.060738E16,	4.60E-18,	1.000,	3.,	12.,	22.84,	19.,	10.03

8	2.125492E16,	5.90E-19,	1.000,	6.,	6.,	9.99,	9.,	
9	2.162610E16,	1.69E-18,	1.937,	5.,	6.,	7.71,	19./	
	DATA A6/							
1	2.226127E16,	1.69E-18,	1.841,	5.,	10.,	5.08,	19.,	
2	2.251163E16,	9.30E-19,	2.455,	6.,	6.,	7.71,	19.,	
3	2.278001E16,	7.90E-19,	1.000,	6.,	9.,	10.20,	14.,	
4	2.317678E16,	1.65E-18,	2.277,	6.,	10.,	5.08,	19.,	
5	2.348946E16,	3.11E-18,	1.963,	6.,	4.,	0.00,	19.,	
6	2.351911E16,	7.30E-19,	1.486,	5.,	6.,	7.71,	19.,	
7	2.366973E16,	5.00E-19,	1.000,	4.,	2.,	0.00,	9.,	
8	2.507544E16,	6.90E-19,	1.000,	6.,	3.,	19.69,	14.,	
9	2.754065E16,	7.60E-19,	1.000,	2.,	1.,	0.00,	14./	
	DATA A7/							
1	2.864850E16,	1.54E-18,	2.104,	6.,	1.,	7.92,	20.,	
2	2.965598E16,	1.53E-18,	2.021,	6.,	5.,	3.76,	20.,	
3	3.054151E16,	1.40E-18,	1.471,	6.,	9.,	0.00,	20.,	
4	3.085141E16,	2.80E-18,	1.000,	4.,	5.,	11.01,	20.,	
5	3.339687E16,	3.60E-19,	1.000,	6.,	2.,	0.00,	15.,	
6	3.818757E16,	4.90E-19,	1.145,	6.,	6.,	0.00,	21./	
	DATA NUM/60/							
	DATA ITEMP1/0/							
	IF (ITEMP.EQ.ITEMP1)GO TO 95							
	ITEMP1=ITEMP							
	CALL POPS(6.03,11,XNFP)							
	CALL POPS(7.04,11,XNFP(1,5))							
	CALL POPS(8.05,11,XNFP(1,10))							
	CALL POPS(10.05,11,XNFP(1,16))							
95	L=-6							
	DO 20 I=1,NUM							
	L=L+7							
	IF (FREQ.LT.A(L))GO TO 20							
	XSECT=A(L+1)*(A(L+2)+(A(L)/FREQ)-A(L+2)*(A(L)/FREQ))*							
	1 Sqrt((A(L)/FREQ)**IFIX(A(L+3)))							
	ID=A(L+6)							
	DO 10 J=1,NRHOX							
	XX=XSECT*XNFP(J,ID)*A(L+4)							
	IF (XX.GT.AHOT(J)/100.)AHOT(J)=AHOT(J)+XX/EXP(A(L+5)/TKEV(J))							
10	CONTINUE							
20	CONTINUE							
	DO 30 J=1,NRHOX							
30	AHOT(J)=AHOT(J)*STIM(J)/RHOX(J)							
	RETJRN							
	END							

```

SUBROUTINE ELECOP
COMMON /OPS/D1(40,11),SIGEL(40),D2(40,13)
COMMON /RHOX/RHOX(40),NRHOX
COMMON /STATE/P(40),XNE(40),XNATOM(40),RHO(40)
DO 1 J=1,NRHOX
1 SIGEL(J)=.6653E-24*XNE(J)/RHO(J)
RETJRN
END

```

```

SUBROUTINE H2RAOP
COMMON /DEPART/BHYD(40,6),BMIN(40),NLTEON
COMMON /FREQ/FREQ,FREQLG,EHVKT(40),STIM(40),BNJ(40)
COMMON /IONS/XNFPH(40,2),XNFPHE(40,3)
COMMON /OPS/D1(40,12),SIGH2(40),D2(40,12)
COMMON /RHOX/RHOX(40),NRHOX
COMMON /STATE/P(40),XNE(40),XNATOM(40),RHO(40)
COMMON /TEMP/T(40),TKEV(40),TK(40),HKT(40),TLOG(40),ITEMP
DIMENSION XNH2(40)
DATA ITEMPI/0/
IF(ITEMP.EQ.ITEMPI)GO TO 20
ITEMPI=ITEMP
DO 11 J=1,NRHOX
11 XNH2(J)=(XNFPH(J,1)*2.*BHYD(J,1))**2*EXP(4.477/TKEV(J)-4.6628E1+
1(1.8031E-3+(-5.0239E-7+(8.1424E-11-5.0501E-13*T(J))*T(J))*T(J))*
2T(J)-1.5*TLOG(J))/RHO(J)
20 WAVE=2.997925E18/AMIN1(FREQ,2.922E15)
WW=WAVE**2
SIG=(8.14E-13+1.28E-6/WW+1.61/(WW*WW))/(WW*WW)
DO 21 J=1,NRHOX
21 SIGH2(J)=SIG*XNH2(J)
RETJRN
END

```

```

SUBROUTINE HLINOP
C   REQUIRES STARK AND COULX
COMMON /DEPART/BHYD(40,6),BMIN(40),NLTEON
COMMON /FREQ/FREQ,FREQLG,EHVKT(40),STIM(40),BNU(40)
COMMON /IONS/XNFPH(40,2),XNFPHE(40,3)
COMMON /OPS/D1(40,13),AHLN(40),D2(40,8),SHLINE(40),D3(40,2)
COMMON /RHOX/RHOX(40),NRHOX
COMMON /STATE/P(40),XNE(40),XNATOM(40),RHO(40)
COMMON /TEMP/T(40),TKEV(40),TK(40),HKT(40),TLOG(40),ITEMP
DIMENSION BOLT(40,4),MLAST(40)
DATA ITEMP1/0/
IF(ITEMP.EQ.ITEMP1)GO TO 20
DO 10 J=1,NRHOX
  MLAST(J)=1100./XNE(J)**.133333333
DO 10 N=1,4
10 BOLT(J,N)=EXP(-(13.595-13.595/FLOAT(N*N))/TKEV(J))*2.*FLOAT(N*N)*
  1BHYD(J,N)*XNFPH(J,1)/RHO(J)
  ITEMP1=ITEMP
20 N=SQRT(3.28805E15/FREQ)
  IF(N.EQ.0.OR.N.GT.4)RETURN
  GO TO (21,22,30,30),N
21 IF(FREQ.LT.2.E15)RETURN
  GO TO 30
22 IF(FREQ.LT.4.44E14)RETURN
30 MFREQ=SQRT(3.28805E15/(3.28805E15/FLOAT(N*N)-FREQ))
  DO 50 J=1,NRHOX
    M1=MFREQ
    M2=M1+1
    M1=MAX0(M1,N+1)
    H=0.
    S=0.
    IF(M1.LE.6)GO TO 39
    IF(M1.GT.MLAST(J))GO TO 45
    M1=M1-1
    M2=M2+3
    IF(N.LT.4.OP.M1.GT.8)GO TO 39
    H=STARK(3,4,J)*(1.-EHVKT(J)*BHYD(J,4)/BHYD(J,3))*BOLT(J,3)
    S=H*BNU(J)*STIM(J)/(BHYD(J,3)/BHYD(J,4)-EHVKT(J))
39 DO 40 M=M1,M2
    BHYDJM=1.
    IF(M.LE.6)BHYDJM=BHYD(J,M)
C   ASSUMING FREQ APPROXIMATELY FREQNM
    A=STARK(N,M,J)*(1.-EHVKT(J)*BHYDJM/BHYD(J,N))*BOLT(J,N)
    H=H+A
40 S=S+A*BNU(J)*STIM(J)/(BHYD(J,N)/BHYDJM-EHVKT(J))
    AHLN(J)=H
    SHLINE(J)=S/H
    GO TO 50
45 AHLN(J)=COULX(N,3.28806E15/FLOAT(N*N),1.)*(1.-EHVKT(J)/
  1BHYD(J,N))*BOLT(J,N)
    SHLINE(J)=BNU(J)*STIM(J)/(BHYD(J,N)-EHVKT(J))
50 CONTINUE
  RETRN
  END

```

```

FUNCTION STARK(N,M,J)
COMMON /FREQ/FREQ,FREQLG,EHVKT(40),STIM(40),BNJ(40)
COMMON /RHOX/RHOX(40),NRHOX
COMMON /STATE/P(40),XNE(40),XNATOM(40),RHO(40)
COMMON /TEMP/T(40),TKEV(40),TK(40),HKT(40),TLOG(40),ITEMP
DIMENSION FO(40)
DIMENSION KNMTAB(5,4),FSTARK(10,4)
REAL NN,MM,IMPACT,KNM,KNMTAB
DATA KNMTAB/.000356,.000523,.00109,.00149,.00225,.0125,.0177,.028,
1.0348,.0493,.124,.171,.223,.261,.342,.683,.866,1.02,1.19,1.46/
DATA FSTARK/.1387,.07910,.02126,.01394,.006462,.004814,.002779,
1.002216,.001443,.001201,.3921,.1193,.03766,.02209,.01139,
2.008036,.005007,.003850,.002658,.002151,.6103,.1506,.04931,
3.02768,.01485,.01023,.006588,.004996,.003542,.002838,.8163,.1788,
4.05985,.03189,.01762,.01196,.007825,.005882,.004233,.003375/
C IF YOJR RYDBERG IS DIFFERENT YOU MAY GET LINES IN STRANGE PLACES
DATA RYD/3.28805E15/
DATA ITEMPI/0/
EXINT(X)=-ALOG(X)-.57516+(-.97996-(-.21654-(-.033572-(-.0029222-
1.05439E-4*X)*X)*X)*X)*X
IF(ITEMP.EQ.ITEMPI)GO TO 20
DO 10 K=1,NRHOX
10 FO(K)=1.25E-9*XNE(K)**.6666667
ITEMPI=ITEMP
20 XN=X
XM=X
X=XN/XM
XX=X**2
NN=N*X
MM=M*X
MMINN=M-N
IF(MMINN.GT.5)GO TO 21
KNM=KNMTAB(MMINN,N)
GO TO 22
21 KNM=5.5E-5*(NN*MM)**2/(MM-NN)
22 IF(MMINN.GT.10)GO TO 23
FNM=FSTARK(MMINN,N)
GO TO 30
23 FNM=FSTARK(10,N)*((20.*XN+100.)/(XN+10.)/XM/(1.-XX))**3
30 FREQNM=RYD*(1./NN-1./MM)
DEL=ABS(FREQ-FREQNM)
DBETA=2.997925E18/FREQNM**2/FO(J)/KNM
BETA=DBETA*DEL
Y1=MM*DEL*HKT(J)/2.
Y2=(3.14159*3.14159/2./0.0265384/2.997925E10)*DEL**2/XNE(J)
QSTAT=1.5+.5*(Y1**2-1.384)/(Y1**2+1.384)
IMPACT=0.
IF(Y1.GT.8..OR.Y1.GE.Y2)GO TO 40
EXY2=0.
IF(Y2.LE.8.)EXY2=EXINT(Y2)
IMPACT=1.438*SQRT(Y1*(1.-XX))*(.4*EXP(-Y1)+EXINT(Y1)-.5*EXY2)
40 IF(BETA.GT.20.)GO TO 45
PROF=8./(80.+BETA**3)
RATIO=QSTAT+IMPACT
GO TO 50
45 PROF=1.5/BETA/BETA/SQRT(BETA)
DIOI=6.28*1.48E-25*(2.*MM*RYD/DEL)*XNE(J)*(SQRT(2.*MM*RYD/DEL)*
1(1.3*QSTAT+.30*IMPACT)-3.9*RYD*HKT(J))
RATIO=QSTAT*AMINI(1.+DIOI,1.25)+IMPACT
50 STARK=.0265384*FNM*PROF*DBETA*RATIO
RETURN
END

```

```

C      SUBROUTINE LINOP(J,NSTEPS,STEPWT)
      DUMMY FOR LINE ABSORPTION DISTRIBUTION FUNCTIONS
      COMMON /OPS/D1(40,14),ALINES(40),D2(40,10)
      RETJRN
      END

```

```

C      SUBROUTINE LINSOP(J,NSTEPS,STEPWT)
      COMMON /OPS/D1(40,15),SIGLIN(40),D2(40,9)
      DUMMY FOR LINE ABSORPTION DISTRIBUTION FUNCTIONS      S=J
      RETJRN
      END

```

```

C      SUBROUTINE XLINOP
      COMMON /OPS/D1(40,16),AXLINE(40),D2(40,6),SXLINE(40),D3(40)
      DUMMY LINE OPACITY ROUTINE
      RETJRN
      END

```

```

C      SUBROUTINE XLISOP
      COMMON /OPS/D1(40,17),SIGXL(40),D2(40,7)
      DUMMY LINE SCATTERING ROUTINE
      RETJRN
      END

```

```

C      SUBROUTINE XCONOP
      COMMON /OPS/D1(40,18),AXCONT(40),D2(40,5),SXCONT(40)
      DUMMY CONTINUOUS OPACITY ROUTINE
      RETJRN
      END

```

```

C      SUBROUTINE XSOP
      COMMON /OPS/D1(40,19),SIGX(40),D2(40,5)
      DUMMY SCATTERING ROUTINE
      RETJRN
      END

```

```

SUBROUTINE JUSH(IFS CAT,IFS JRF)
C   IFS CAT=1 SOLVE INTEGRAL EQJATION FOR SOURCE FJUNCTION
C   IFS CAT=0 SET SNU=SHAR
C   IFS JRF=0 CALCULATE J AND H
C   IFS JRF=1 CALCULATE SURFACE FLUX
C   IFS JRF=2 CALCULATE SURFACE SPECIFIC INTENSITY
COMMON /ABTOT/ABTOT(40),ALPHA(40)
C   COMMON /MATX/COEFJ(43,43),COEFH(43,43),XTAU(43),NXTAU
COMMON /MATX/C1(43),C2(43),C3(43),C4(43),C5(43),C6(43),C7(43),
1      C8(43),C9(43),C10(43),C11(43),C12(43),C13(43),
2      C14(43),C15(43),C16(43),C17(43),C18(43),C19(43),
3      C20(43),C21(43),C22(43),C23(43),C24(43),C25(43),
4      C26(43),C27(43),C28(43),C29(43),C30(43),C31(43),
5      C32(43),C33(43),C34(43),C35(43),C36(43),C37(43),
6      C38(43),C39(43),C40(43),C41(43),C42(43),C43(43),
C   7      COEFH(43,43),XTAU(43),NXTAU
7      D1(43),D2(43),D3(43),D4(43),D5(43),D6(43),D7(43),
8      D8(43),D9(43),D10(43),D11(43),D12(43),D13(43),
9      D14(43),D15(43),D16(43),D17(43),D18(43),D19(43),
1     D20(43),D21(43),D22(43),D23(43),D24(43),D25(43),
1     D26(43),D27(43),D28(43),D29(43),D30(43),D31(43),
2     D32(43),D33(43),D34(43),D35(43),D36(43),D37(43),
3     D38(43),D39(43),D40(43),D41(43),D42(43),D43(43),
4     XTAU(43),NXTAU
DIMENSION COEFJ(43,43)
DIMENSION COEFH(43,43)
EQUIVALENCE (COEFJ(1),C1(1))
EQUIVALENCE (COEFH(1),D1(1))
COMMON /MJS/ANGLE(20),SURFI(20),NMU
COMMON /OPTOT/ACONT(40),SCONT(40),ALINE(40),SLINE(40),SIGMAC(40),
1     SIGNAL(40)
COMMON /RHOX/RHOX(40),NRHOX
COMMON /TAUSHJ/TAUNU(40),SNU(40),HNU(40),JNU(40),JMINS(40)
REAL JNU,JMINS
DIMENSION XS(43),XSBAR(43),XALPHA(43),DIAG(43),XH(43),XJS(43)
EQUIVALENCE (XSBAR(1),XH(1)),(XALPHA(1),XJS(1))
DIMENSION A(40),B(40),C(40),SNUBAR(40)
EQUIVALENCE (A(1),HNU(1)),(B(1),JNU(1)),(C(1),JMINS(1))
REAL NEW
DO 10 J=1,NRHOX
ABTOT(J)=ACONT(J)+ALINE(J)+SIGMAC(J)+SIGNAL(J)
ALPHA(J)=(SIGMAC(J)+SIGNAL(J))/ABTOT(J)
10 SNUBAR(J)=(ACONT(J)*SCONT(J)+ALINE(J)*SLINE(J))/
1 (ACONT(J)+ALINE(J))
RHOX0=RHOX(1)
RHOX(1)=0.
CALL INTEG(RHOX,ABTOT,TAUNU,NRHOX)
RHOX(1)=RHOX0
IF(IFS CAT.EQ.1)GO TO 30
DO 20 J=1,NRHOX
20 SNU(J)=SNUBAR(J)
IF(IFS JRF.EQ.2)GO TO 70
MAXJ=MAP1(TAUNU,SNU,NRHOX,XTAU,XS,NXTAU)
IF(IFS JRF.EQ.1)GO TO 60
DO 21 J=1,NRHOX
21 ALPHA(J)=0.
30 MAXJ=MAP1(TAUNU,SNUBAR,NRHOX,XTAU,XS,NXTAU)
MAXJ=MAP1(TAUNU,ALPHA,NRHOX,XTAU,XALPHA,NXTAU)
DO 31 L=1,NXTAU
C   IN CASE OF BAD INTERPOLATION

```



```

      IF(XALPHA(L).LT.0.)XALPHA(L)=0.
      XS(L)=XSBAR(L)
      DIAS(L)=1.-XALPHA(L)*COEFJ(L,L)
31  XSBAR(L)=(1.-XALPHA(L))*XSBAR(L)
C   THE LIMIT ON DO 34, THE MAXIMUM NUMBER OF ITERATIONS, IS ARBITRARY
      DO 34 L=1,NXTAU
      IFERR=0
      K=NXTAU+1
      DO 33 KK=1,NXTAU
      K=K-1
      DELXS=C1(K)*XS(1)+C2(K)*XS(2)+C3(K)*XS(3)+C4(K)*XS(4)+C5(K)*XS(5)+
      1C6(K)*XS(6)+C7(K)*XS(7)+C8(K)*XS(8)+C9(K)*XS(9)+C10(K)*XS(10)+
      2C11(K)*XS(11)+C12(K)*XS(12)+C13(K)*XS(13)+C14(K)*XS(14)+
      3C15(K)*XS(15)+C16(K)*XS(16)+C17(K)*XS(17)+C18(K)*XS(18)+
      4C19(K)*XS(19)+C20(K)*XS(20)+C21(K)*XS(21)+C22(K)*XS(22)+
      5C23(K)*XS(23)+C24(K)*XS(24)+C25(K)*XS(25)+C26(K)*XS(26)+
      6C27(K)*XS(27)+C28(K)*XS(28)+C29(K)*XS(29)+C30(K)*XS(30)+
      7C31(K)*XS(31)+C32(K)*XS(32)+C33(K)*XS(33)+C34(K)*XS(34)+
      8C35(K)*XS(35)+C36(K)*XS(36)+C37(K)*XS(37)+C38(K)*XS(38)+
      9C39(K)*XS(39)+C40(K)*XS(40)+C41(K)*XS(41)+C42(K)*XS(42)+
      TC43(K)*XS(43)
C   DELXS=0.
C   DO 32 M=1,NXTAU
C 32  DELXS=DELXS+COEFJ(K,M)*XS(M)
      DELXS=(DELXS*XALPHA(K)+XSBAR(K)-XS(K))/DIAG(K)
      ERROR=ABS(DELXS/XS(K))
      IF(ERROR.GT..00001)IFERR=1
33  XS(K)=XS(K)+DELXS
39  IF(IFERR.EQ.0)GO TO 35
34  CONTINUE
C
35  IF(IFSURF.EQ.1)GO TO 60
      MDUMMY=MAP1(XTAU,XS,NXTAU,TAJNU,SNU,MAXJ)
      IF(MAXJ.EQ.NRHOX)GO TO 46
      MAXJ1=MAXJ+1
      DO 40 J=MAXJ1,NRHOX
40  SNU(J)=SNUBAR(J)
      M=MAX0(MAXJ-1,1)
      NM1=NRHOX-M+1
      NMJ=NRHOX-MAXJ+1
C   THE LIMIT ON DO 45 IS ARBITRARY
      DO 45 L=1,NXTAU
      ERROR=0.
      CALL DERIV(TAUNU(M),SNU(M),HNU(M),NM1)
      DO 41 J=M,NRHOX
41  HNU(J)=HNU(J)/3.
      CALL DERIV(TAUNU(MAXJ),HNU(MAXJ),JMINS(MAXJ),NMJ)
      DO 43 J=MAXJ1,NRHOX
      JNU(J)=JMINS(J)+SNU(J)
      SNEW=(1.-ALPHA(J))*SNUBAR(J)+ALPHA(J)*JNU(J)
      ERROR=ABS(SNEW-SNU(J))/SNEW+ERROR
43  SNU(J)=SNEW
      IF(ERROR.LT..00001)GO TO 46
45  CONTINUE
46  IF(IFSURF.EQ.2)GO TO 70
C
C 50  DO 51 L=1,NXTAU
C      XJS(L)=-XS(L)
C      XH(L)=0.
C 51  M=1,NXTAU

```

```

C      XJS(L)=XJS(L)+COEFJ(L,M)*XS(M)
C 51 XH(L)=XH(L)+COEFH(L,M)*XS(M)
50 DO 51 K=1,NXTAU
    XJ =C1(K)*XS(1)+C2(K)*XS(2)+C3(K)*XS(3)+C4(K)*XS(4)+C5(K)*XS(5)+
    1C6(K)*XS(6)+C7(K)*XS(7)+C8(K)*XS(8)+C9(K)*XS(9)+C10(K)*XS(10)+
    2C11(K)*XS(11)+C12(K)*XS(12)+C13(K)*XS(13)+C14(K)*XS(14)+
    3C15(K)*XS(15)+C16(K)*XS(16)+C17(K)*XS(17)+C18(K)*XS(18)+
    4C19(K)*XS(19)+C20(K)*XS(20)+C21(K)*XS(21)+C22(K)*XS(22)+
    5C23(K)*XS(23)+C24(K)*XS(24)+C25(K)*XS(25)+C26(K)*XS(26)+
    6C27(K)*XS(27)+C28(K)*XS(28)+C29(K)*XS(29)+C30(K)*XS(30)+
    7C31(K)*XS(31)+C32(K)*XS(32)+C33(K)*XS(33)+C34(K)*XS(34)+
    8C35(K)*XS(35)+C36(K)*XS(36)+C37(K)*XS(37)+C38(K)*XS(38)+
    9C39(K)*XS(39)+C40(K)*XS(40)+C41(K)*XS(41)+C42(K)*XS(42)+
    TC43(K)*XS(43)
    XJS(K)=XJ-XS(K)
    XH(K)=D1(K)*XS(1)+D2(K)*XS(2)+D3(K)*XS(3)+D4(K)*XS(4)+D5(K)*XS(5)+
    1D6(K)*XS(6)+D7(K)*XS(7)+D8(K)*XS(8)+D9(K)*XS(9)+D10(K)*XS(10)+
    2D11(K)*XS(11)+D12(K)*XS(12)+D13(K)*XS(13)+D14(K)*XS(14)+
    3D15(K)*XS(15)+D16(K)*XS(16)+D17(K)*XS(17)+D18(K)*XS(18)+
    4D19(K)*XS(19)+D20(K)*XS(20)+D21(K)*XS(21)+D22(K)*XS(22)+
    5D23(K)*XS(23)+D24(K)*XS(24)+D25(K)*XS(25)+D26(K)*XS(26)+
    6D27(K)*XS(27)+D28(K)*XS(28)+D29(K)*XS(29)+D30(K)*XS(30)+
    7D31(K)*XS(31)+D32(K)*XS(32)+D33(K)*XS(33)+D34(K)*XS(34)+
    8D35(K)*XS(35)+D36(K)*XS(36)+D37(K)*XS(37)+D38(K)*XS(38)+
    9D39(K)*XS(39)+D40(K)*XS(40)+D41(K)*XS(41)+D42(K)*XS(42)+
    TD43(K)*XS(43)
51 CONTINUE
    MDUMMY=MAP1(XTAU,XJS,NXTAU,TAUNU,JMINS,MAXJ)
    MDUMMY=MAP1(XTAU,XH,NXTAU,TAJNU,HNU,MAXJ)
    DO 52 J=1,MAXJ
52 JNU(J)=JMINS(J)+SNU(J)
    RETURN
C
60 HNU(1)=0.
    DO 61 M=1,NXTAU
61 HNU(1)=HNU(1)+COEFH(1,M)*XS(M)
    RETURN
70 CALL PARCOE(SNU,TAUNU,A,B,C,NRHOX)
    N1=NRHOX-1
    DO 74 MJ=1,NMU
    OLD=1.
    SUM=0.
    DO 73 J=1,N1
    NEW=0.
    TANGLE=TAUNU(J+1)/ANGLE(MU)
    IF(TANGLE.LT.50.)NEW=EXP(-TANGLE)
    D=TANGLE-TAUNU(J)/ANGLE(MU)
    IF(D.LE..03)GO TO 72
    SUM=SUM+OLD*(SNU(J)+((B(J)+2.*C(J)*TAJNU(J))+2.*C(J)*
    1ANGLE(MJ))*ANGLE(MU))-NEW*(SNU(J+1)+((B(J)+2.*C(J)*TAUNU(J+1))+
    2 2.*C(J)*ANGLE(MU))*ANGLE(MJ))
    GO TO 73
72 SUM=SUM+NEW*(SNU(J)+(SNU(J)+(B(J)+2.*C(J)*TAUNU(J))*ANGLE(MU)+
    1(SNJ(J)+(B(J)+2.*C(J)*TAUNU(J)+2.*C(J)*ANGLE(MJ))*ANGLE(MJ))*
    2(((D/9.+1.)*D/8.+1.)*D/7.+1.)*D/6.+1.)*D/5.+1.)*D/4.+1.)*
    3D/3.)*D/2.)*D
73 OLD=NEW
74 SURFI(MJ)=SUM+OLD*(SNU(NRHOX)+((B(NRHOX)+2.*C(NRHOX)*
    1TAUNU(NRHOX))+2.*C(NRHOX)*ANGLE(MU))*ANGLE(MU))
    RETURN
    END

```

```

SUBROUTINE BLOCKJ
C CAN BE BLOCK DATA INSTEAD OF SUBROUTINE
COMMON /MATX/CJ(1849),CH(1849),XTAU(43),NXTAU
DIMENSION CJ 1(36),CJ 2(36),CJ 3(36),CJ 4(36),CJ 5(36)
DIMENSION CJ 6(36),CJ 7(36),CJ 8(36),CJ 9(36),CJ 10(36)
DIMENSION CJ 11(36),CJ 12(36),CJ 13(36),CJ 14(36),CJ 15(36)
DIMENSION CJ 16(36),CJ 17(36),CJ 18(36),CJ 19(36),CJ 20(36)
DIMENSION CJ 21(36),CJ 22(36),CJ 23(36),CJ 24(36),CJ 25(36)
DIMENSION CJ 26(36),CJ 27(36),CJ 28(36),CJ 29(36),CJ 30(36)
DIMENSION CJ 31(36),CJ 32(36),CJ 33(36),CJ 34(36),CJ 35(36)
DIMENSION CJ 36(36),CJ 37(36),CJ 38(36),CJ 39(36),CJ 40(36)
DIMENSION CJ 41(36),CJ 42(36),CJ 43(36),CJ 44(36),CJ 45(36)
DIMENSION CJ 46(36),CJ 47(36),CJ 48(36),CJ 49(36),CJ 50(36)
DIMENSION CJ 51(36),CJ 52(13)
EQUIVALENCE (CJ 1(1),CJ ( 1)),(CJ 2(1),CJ ( 37))
EQUIVALENCE (CJ 3(1),CJ ( 73)),(CJ 4(1),CJ ( 109))
EQUIVALENCE (CJ 5(1),CJ ( 145)),(CJ 6(1),CJ ( 181))
EQUIVALENCE (CJ 7(1),CJ ( 217)),(CJ 8(1),CJ ( 253))
EQUIVALENCE (CJ 9(1),CJ ( 289)),(CJ 10(1),CJ ( 325))
EQUIVALENCE (CJ 11(1),CJ ( 361)),(CJ 12(1),CJ ( 397))
EQUIVALENCE (CJ 13(1),CJ ( 433)),(CJ 14(1),CJ ( 469))
EQUIVALENCE (CJ 15(1),CJ ( 505)),(CJ 16(1),CJ ( 541))
EQUIVALENCE (CJ 17(1),CJ ( 577)),(CJ 18(1),CJ ( 613))
EQUIVALENCE (CJ 19(1),CJ ( 649)),(CJ 20(1),CJ ( 685))
EQUIVALENCE (CJ 21(1),CJ ( 721)),(CJ 22(1),CJ ( 757))
EQUIVALENCE (CJ 23(1),CJ ( 793)),(CJ 24(1),CJ ( 829))
EQUIVALENCE (CJ 25(1),CJ ( 865)),(CJ 26(1),CJ ( 901))
EQUIVALENCE (CJ 27(1),CJ ( 937)),(CJ 28(1),CJ ( 973))
EQUIVALENCE (CJ 29(1),CJ (1009)),(CJ 30(1),CJ (1045))
EQUIVALENCE (CJ 31(1),CJ (1081)),(CJ 32(1),CJ (1117))
EQUIVALENCE (CJ 33(1),CJ (1153)),(CJ 34(1),CJ (1189))
EQUIVALENCE (CJ 35(1),CJ (1225)),(CJ 36(1),CJ (1261))
EQUIVALENCE (CJ 37(1),CJ (1297)),(CJ 38(1),CJ (1333))
EQUIVALENCE (CJ 39(1),CJ (1369)),(CJ 40(1),CJ (1405))
EQUIVALENCE (CJ 41(1),CJ (1441)),(CJ 42(1),CJ (1477))
EQUIVALENCE (CJ 43(1),CJ (1513)),(CJ 44(1),CJ (1549))
EQUIVALENCE (CJ 45(1),CJ (1585)),(CJ 46(1),CJ (1621))
EQUIVALENCE (CJ 47(1),CJ (1657)),(CJ 48(1),CJ (1693))
EQUIVALENCE (CJ 49(1),CJ (1729)),(CJ 50(1),CJ (1765))
EQUIVALENCE (CJ 51(1),CJ (1801)),(CJ 52(1),CJ (1837))
DATA CJ 1/
1 8.14986025E-05, 7.31538254E-05, 6.71178656E-05, 6.24581491E-05,
2 5.79414138E-05, 5.36599004E-05, 4.95677731E-05, 4.53702132E-05,
3 4.11409031E-05, 3.70180419E-05, 3.30221502E-05, 2.88995437E-05,
4 2.55766809E-05, 2.24455861E-05, 1.88519709E-05, 1.58867744E-05,
5 1.33092440E-05, 1.09509308E-05, 8.86744834E-06, 6.98752785E-06,
6 5.33944478E-06, 4.00549621E-06, 3.06255733E-06, 2.30471158E-06,
7 1.70829464E-06, 1.22756917E-06, 8.97423163E-07, 6.17580912E-07,
8 4.31441568E-07, 2.84814120E-07, 1.90447891E-07, 1.28648434E-07,
9 7.72171575E-08, 4.14502255E-08, 2.00042982E-08, 8.21662923E-09/
DATA CJ 2/
1 2.04916539E-09, 3.36821047E-10, 2.97451696E-11, 1.98489427E-12,
2 1.37287283E-13, 9.73803273E-15, 7.03780218E-16, 1.50153547E-04,
3 1.69998410E-04, 1.49551568E-04, 1.33114548E-04, 1.22341492E-04,
4 1.12691930E-04, 1.03789120E-04, 9.48288272E-05, 8.58965958E-05,
5 7.72399845E-05, 6.88765300E-05, 6.02632697E-05, 5.33275330E-05,
6 4.67953579E-05, 3.93007243E-05, 3.31179453E-05, 2.77440975E-05,
7 2.28276312E-05, 1.84843096E-05, 1.45654595E-05, 1.11299644E-05,
8 8.34933442E-06, 6.38378621E-06, 4.80407272E-06, 3.56085984E-06,
9 2.55880582E-06, 1.87063082E-06, 1.28731302E-06, 8.99315117E-07/

```

DATA CJ 3/

1 5.93678149E-07, 3.96977081E-07, 2.68159722E-07, 1.60954311E-07,
 2 8.64003431E-08, 4.16976593E-08, 1.71270216E-08, 4.27134786E-09,
 3 7.02080564E-10, 6.20017576E-11, 4.13737418E-12, 2.86165744E-13,
 4 2.02982455E-14, 1.46698029E-15, 1.38762226E-04, 1.52892603E-04,
 5 1.73973599E-04, 1.48361768E-04, 1.27782783E-04, 1.16648599E-04,
 6 1.06792177E-04, 9.72270010E-05, 8.78857753E-05, 7.89334108E-05,
 7 7.03363020E-05, 6.15124360E-05, 5.44199981E-05, 4.77466096E-05,
 8 4.00947229E-05, 3.37846547E-05, 2.83013360E-05, 2.32853712E-05,
 9 1.88545261E-05, 1.48569320E-05, 1.13525420E-05, 8.51622518E-06/

DATA CJ 4/

1 6.51134817E-06, 4.90004469E-06, 3.63198185E-06, 2.60990507E-06,
 2 1.90798268E-06, 1.31301454E-06, 9.17268607E-07, 6.05529102E-07,
 3 4.04901009E-07, 2.73512100E-07, 1.64166733E-07, 8.81246833E-08,
 4 4.25298033E-08, 1.74688037E-08, 4.35658139E-09, 7.16089755E-10,
 5 6.32388810E-11, 4.21992498E-12, 2.91875343E-13, 2.07032318E-14,
 6 1.49624885E-15, 2.56894537E-04, 2.68265016E-04, 2.82680119E-04,
 7 3.20147632E-04, 2.71320447E-04, 2.33081797E-04, 2.11908717E-04,
 8 1.91950967E-04, 1.73009337E-04, 1.55132197E-04, 1.38103891E-04,
 9 1.20705419E-04, 1.06754481E-04, 9.36443364E-05, 7.86242175E-05/

DATA CJ 5/

1 6.62442877E-05, 5.54893860E-05, 4.56528336E-05, 3.69646972E-05,
 2 2.91266743E-05, 2.22560211E-05, 1.66953761E-05, 1.27648716E-05,
 3 9.60600474E-06, 7.12006931E-06, 5.11638732E-06, 3.74034592E-06,
 4 2.57398256E-06, 1.79817365E-06, 1.18705058E-06, 7.93747494E-07,
 5 5.36178620E-07, 3.21823317E-07, 1.72754489E-07, 8.33728443E-08,
 6 3.42447430E-08, 8.54035678E-09, 1.40377384E-09, 1.23969092E-10,
 7 8.27244054E-12, 5.72171358E-13, 4.05851067E-14, 2.93313638E-15,
 8 4.28478661E-04, 4.38774832E-04, 4.48007290E-04, 4.74192405E-04,
 9 5.41887599E-04, 4.55714232E-04, 3.88809427E-04, 3.48834558E-04/

DATA CJ 6/

1 3.12498628E-04, 2.79274670E-04, 2.48145814E-04, 2.16625539E-04,
 2 1.91470492E-04, 1.67889720E-04, 1.40916781E-04, 1.18707073E-04,
 3 9.94231585E-05, 8.17917639E-05, 6.62222043E-05, 5.21781154E-05,
 4 3.98685750E-05, 2.99067370E-05, 2.28655892E-05, 1.72069282E-05,
 5 1.27538260E-05, 9.16465428E-06, 6.69979937E-06, 4.61055441E-06,
 6 3.22090046E-06, 2.12624430E-06, 1.42175560E-06, 9.60397422E-07,
 7 5.76444952E-07, 3.09434371E-07, 1.49335410E-07, 6.13382136E-08,
 8 1.52972066E-08, 2.51438798E-09, 2.22048435E-10, 1.48172404E-11,
 9 1.02484777E-12, 7.26941783E-14, 5.25369629E-15, 6.81346357E-04/

DATA CJ 7/

1 6.90881617E-04, 6.98754282E-04, 7.15098172E-04, 7.61797143E-04,
 2 8.79148724E-04, 7.30251690E-04, 6.11067387E-04, 5.42551009E-04,
 3 4.82001904E-04, 4.26857352E-04, 3.71876580E-04, 3.28350939E-04,
 4 2.87718988E-04, 2.41367155E-04, 2.03264175E-04, 1.70210809E-04,
 5 1.40006824E-04, 1.13344596E-04, 8.93004808E-05, 6.82295010E-05,
 6 5.11791622E-05, 3.91286652E-05, 2.94446879E-05, 2.18241298E-05,
 7 1.56821832E-05, 1.14643071E-05, 7.88923736E-06, 5.51132513E-06,
 8 3.63822025E-06, 2.43275575E-06, 1.64332221E-06, 9.86342258E-07,
 9 5.29464043E-07, 2.55522410E-07, 1.04953205E-07, 2.61742883E-08/

DATA CJ 8/

1 4.30222799E-09, 3.79933350E-10, 2.53528033E-11, 1.75354660E-12,
 2 1.24381866E-13, 8.98921998E-15, 1.11484772E-03, 1.12418194E-03,
 3 1.13155813E-03, 1.14602725E-03, 1.17595604E-03, 1.25851232E-03,
 4 1.46433576E-03, 1.19777794E-03, 9.84898020E-04, 8.67486791E-04,
 5 7.63496969E-04, 6.62669551E-04, 5.84007292E-04, 5.11122829E-04,
 6 4.28377739E-04, 3.60559179E-04, 3.01823315E-04, 2.48203963E-04,
 7 2.00902454E-04, 1.58263961E-04, 1.20908862E-04, 9.06877167E-05,
 8 6.93314047E-05, 5.21706171E-05, 3.86672514E-05, 2.77844799E-05,
 9 2.03112075E-05, 1.39770538E-05, 9.76407481E-06, 6.44553426E-06/

DATA CJ 9/

1 4.30987268E-06, 2.91128982E-06, 1.74737828E-06, 9.37977549E-07,
 2 4.52670223E-07, 1.85928420E-07, 4.63683585E-08, 7.62144641E-09,
 3 6.73052396E-10, 4.49123318E-11, 3.10638784E-12, 2.20340597E-13,
 4 1.59242422E-14, 1.87645118E-03, 1.88596108E-03, 1.89330275E-03,
 5 1.90726204E-03, 1.93448596E-03, 1.98883780E-03, 2.13292357E-03,
 6 2.50895650E-03, 2.02160072E-03, 1.64022653E-03, 1.42967762E-03,
 7 1.23180309E-03, 1.08166934E-03, 9.44527713E-04, 7.90233024E-04,
 8 6.64466714E-04, 5.55869126E-04, 4.56912546E-04, 3.69718850E-04,
 9 2.91182454E-04, 2.22414806E-04, 1.66800680E-04, 1.27509362E-04/

DATA CJ 10/

1 9.59420089E-05, 7.11054588E-05, 5.10907704E-05, 3.73475053E-05,
 2 2.56997018E-05, 1.79528489E-05, 1.18509126E-05, 7.92410065E-06,
 3 5.35260374E-06, 3.21262703E-06, 1.72448625E-06, 8.32230538E-07,
 4 3.41823776E-07, 8.52456611E-08, 1.40114383E-08, 1.23734148E-09,
 5 8.25663209E-11, 5.71071794E-12, 4.05067958E-13, 2.92745938E-14,
 6 3.05596719E-03, 3.06538575E-03, 3.07256282E-03, 3.08598245E-03,
 7 3.11130067E-03, 3.15877521E-03, 3.25098448E-03, 3.51262193E-03,
 8 4.18929514E-03, 3.32802567E-03, 2.66019873E-03, 2.26255825E-03,
 9 1.97241133E-03, 1.71470116E-03, 1.42979273E-03, 1.19998887E-03/

DATA CJ 11/

1 1.00267078E-03, 8.23483583E-04, 6.65943148E-04, 5.24251321E-04,
 2 4.00308105E-04, 3.00140478E-04, 2.29403448E-04, 1.72588821E-04,
 3 1.27898063E-04, 9.18898504E-05, 6.71676646E-05, 4.62170248E-05,
 4 3.22840871E-05, 2.13103008E-05, 1.42486670E-05, 9.62450663E-06,
 5 5.77646456E-06, 3.10063265E-06, 1.49631817E-06, 6.14572206E-07,
 6 1.53261121E-07, 2.51902665E-08, 2.22449327E-09, 1.48435657E-10,
 7 1.02664851E-11, 7.28208746E-13, 5.26279611E-14, 4.58905399E-03,
 8 4.59800329E-03, 4.60477562E-03, 4.61732873E-03, 4.64062203E-03,
 9 4.68292875E-03, 4.76051134E-03, 4.92176307E-03, 5.38442458E-03/

DATA CJ 12/

1 6.54922376E-03, 5.03719066E-03, 3.84919968E-03, 3.34188459E-03,
 2 2.88688750E-03, 2.39518284E-03, 2.00456361E-03, 1.67194936E-03,
 3 1.37143155E-03, 1.10808371E-03, 8.71743749E-04, 6.65317431E-04,
 4 4.98659080E-04, 3.81044905E-04, 2.86621113E-04, 2.12371138E-04,
 5 1.52561656E-04, 1.11506092E-04, 7.67190760E-05, 5.35872980E-05,
 6 3.53701589E-05, 2.36483834E-05, 1.59731092E-05, 9.58640571E-06,
 7 5.14549598E-06, 2.48305034E-06, 1.01981189E-06, 2.54309643E-07,
 8 4.17973884E-08, 3.69092105E-09, 2.46281967E-10, 1.70337329E-11,
 9 1.20820145E-12, 8.73165412E-14, 7.63344239E-03, 7.64265143E-03/

DATA CJ 13/

1 7.64959272E-03, 7.66239614E-03, 7.68593738E-03, 7.72797518E-03,
 2 7.80267307E-03, 7.94918588E-03, 8.25219168E-03, 9.08595967E-03,
 3 1.11718179E-02, 8.50948584E-03, 6.67067668E-03, 5.66624413E-03,
 4 4.63749691E-03, 3.85370081E-03, 3.20032500E-03, 2.61728999E-03,
 5 2.11034644E-03, 1.65770792E-03, 1.26373000E-03, 9.46397409E-04,
 6 7.22788157E-04, 5.43449520E-04, 4.02532513E-04, 2.89087221E-04,
 7 2.11247909E-04, 1.45315957E-04, 1.01486491E-04, 6.69768382E-05,
 8 4.47757942E-05, 3.02408867E-05, 1.81477045E-05, 9.73991532E-06,
 9 4.69979281E-06, 1.93010363E-06, 4.81267394E-07, 7.90933701E-08/

DATA CJ 14/

1 6.98388223E-09, 4.65986964E-10, 3.22282472E-11, 2.28589265E-12,
 2 1.65198131E-13, 1.06716479E-02, 1.06801444E-02, 1.06865355E-02,
 3 1.06982944E-02, 1.07198145E-02, 1.07579188E-02, 1.08245983E-02,
 4 1.09515714E-02, 1.11999257E-02, 1.16984658E-02, 1.30537716E-02,
 5 1.64947744E-02, 1.24602153E-02, 9.56746194E-03, 7.64827637E-03,
 6 6.27825452E-03, 5.17676322E-03, 4.21361197E-03, 3.38651398E-03,
 7 2.65388823E-03, 2.01962478E-03, 1.51059058E-03, 1.15272726E-03,
 8 8.66154710E-04, 6.41233882E-04, 4.60319778E-04, 3.36269473E-04,
 9 2.31249862E-04, 1.61465725E-04, 1.06538851E-04, 7.12127109E-05/

DATA CJ 15/

1 4.80898278E-05, 2.88550145E-05, 1.54845115E-05, 7.47082608E-06,
 2 3.06775966E-06, 7.64841497E-07, 1.25682795E-07, 1.10965833E-08,
 3 7.40345596E-10, 5.12006967E-11, 3.63144429E-12, 2.62432019E-13,
 4 1.24208536E-02, 1.24277306E-02, 1.24328975E-02, 1.24423905E-02,
 5 1.24597184E-02, 1.24902550E-02, 1.25432456E-02, 1.26425720E-02,
 6 1.28308312E-02, 1.31867664E-02, 1.38836281E-02, 1.61371087E-02,
 7 2.09342998E-02, 1.50640284E-02, 1.04396460E-02, 8.52366488E-03,
 8 6.96923411E-03, 5.63914478E-03, 4.51383247E-03, 3.52682352E-03,
 9 2.67803436E-03, 1.99989867E-03, 1.52453504E-03, 1.14460280E-03/

DATA CJ 16/

1 8.46833440E-04, 6.07587365E-04, 4.43675885E-04, 3.05000337E-04,
 2 2.12901324E-04, 1.40441165E-04, 9.38549059E-05, 6.33698772E-05,
 3 3.80168928E-05, 2.03976823E-05, 9.83979455E-06, 4.03995811E-06,
 4 1.00706369E-06, 1.65462426E-07, 1.46069081E-08, 9.74459366E-10,
 5 6.73872941E-11, 4.77927345E-12, 3.45369833E-13, 1.94810935E-02,
 6 1.94886657E-02, 1.94943513E-02, 1.95047890E-02, 1.95238140E-02,
 7 1.95572554E-02, 1.96150267E-02, 1.97224258E-02, 1.99228219E-02,
 8 2.02906364E-02, 2.09790973E-02, 2.24766315E-02, 2.59060675E-02,
 9 3.37894606E-02, 2.36650522E-02, 1.67865205E-02, 1.34852146E-02/

DATA CJ 17/

1 1.07554640E-02, 8.52894896E-03, 6.62031125E-03, 5.00327821E-03,
 2 3.72392321E-03, 2.83262704E-03, 2.12313739E-03, 1.56873156E-03,
 3 1.12430016E-03, 8.20332823E-04, 5.63506593E-04, 3.93125304E-04,
 4 2.59191151E-04, 1.73143499E-04, 1.16866620E-04, 7.00863842E-05,
 5 3.75917115E-05, 1.81285895E-05, 7.44097441E-06, 1.85425078E-06,
 6 3.04569192E-07, 2.68803496E-08, 1.79291701E-09, 1.23970942E-10,
 7 8.79152445E-12, 6.35267562E-13, 2.68144794E-02, 2.68220282E-02,
 8 2.68276939E-02, 2.68380900E-02, 2.68570222E-02, 2.68902478E-02,
 9 2.69474868E-02, 2.70533594E-02, 2.72490323E-02, 2.76017887E-02/

DATA CJ 18/

1 2.82397420E-02, 2.95368461E-02, 3.16415686E-02, 3.66967999E-02,
 2 4.98810707E-02, 3.43114781E-02, 2.40016204E-02, 1.87161429E-02,
 3 1.45996143E-02, 1.12081149E-02, 8.40567489E-03, 6.22335553E-03,
 4 4.71782027E-03, 3.52695811E-03, 2.60069160E-03, 1.86076446E-03,
 5 1.35601978E-03, 9.30420718E-04, 6.48541490E-04, 4.27250986E-04,
 6 2.85234445E-04, 1.92429775E-04, 1.15342167E-04, 6.18339132E-05,
 7 2.98055973E-05, 1.22285626E-05, 3.04580008E-06, 5.00070384E-07,
 8 4.41179135E-08, 2.94184605E-09, 2.03375111E-10, 1.44205805E-11,
 9 1.04191002E-12, 2.93105845E-02, 2.93166665E-02, 2.93212301E-02/

DATA CJ 19/

1 2.93296012E-02, 2.93448369E-02, 2.93715472E-02, 2.94174786E-02,
 2 2.95021568E-02, 2.96577012E-02, 2.99349550E-02, 3.04259264E-02,
 3 3.13820917E-02, 3.28196439E-02, 3.52993354E-02, 4.37293513E-02,
 4 6.16813834E-02, 4.10710605E-02, 2.73272861E-02, 2.08412122E-02,
 5 1.57078159E-02, 1.16349995E-02, 8.54306269E-03, 6.44256291E-03,
 6 4.79727031E-03, 3.52654009E-03, 2.51682379E-03, 1.83075442E-03,
 7 1.25402197E-03, 8.72988704E-04, 5.74439671E-04, 3.63149531E-04,
 8 2.58298944E-04, 1.54704606E-04, 8.28739739E-05, 3.99203092E-05,
 9 1.63679751E-05, 4.07388548E-06, 6.68441342E-07, 5.89393441E-08/

DATA CJ 20/

1 3.92856743E-09, 2.71514068E-10, 1.92482164E-11, 1.39050368E-12,
 2 3.38719415E-02, 3.38774427E-02, 3.38815700E-02, 3.38891395E-02,
 3 3.39029120E-02, 3.39270440E-02, 3.39685030E-02, 3.40448073E-02,
 4 3.41845344E-02, 3.44321947E-02, 3.48663543E-02, 3.56957363E-02,
 5 3.69034406E-02, 3.89082216E-02, 4.34786937E-02, 5.48837934E-02,
 6 7.92311401E-02, 5.11201902E-02, 3.29130965E-02, 2.41709942E-02,
 7 1.75449024E-02, 1.27168996E-02, 9.51480609E-03, 7.04353074E-03,
 8 5.15471899E-03, 3.66546818E-03, 2.65931636E-03, 1.81718603E-03,
 9 1.26276077E-03, 8.29549046E-04, 5.52603530E-04, 3.72158022E-04/

DATA CJ 21/

1 2.22659715E-04, 1.19153630E-04, 5.73421433E-05, 2.34905250E-05,
 2 5.84084847E-06, 9.57527717E-07, 8.43647141E-08, 5.62015093E-09,
 3 3.88277143E-10, 2.75182611E-11, 1.98752421E-12, 3.78705822E-02,
 4 3.78755493E-02, 3.78792755E-02, 3.78861088E-02, 3.78985392E-02,
 5 3.79203122E-02, 3.79576958E-02, 3.80264251E-02, 3.81520308E-02,
 6 3.83738644E-02, 3.87602803E-02, 3.94896661E-02, 4.05309718E-02,
 7 4.22050142E-02, 4.58079989E-02, 5.18680175E-02, 6.69949177E-02,
 8 9.99650283E-02, 6.22151021E-02, 3.79264661E-02, 2.68360813E-02,
 9 1.90636001E-02, 1.40947336E-02, 1.03444628E-02, 7.52188726E-03/

DATA CJ 22/

1 5.32118372E-03, 3.84637814E-03, 2.61953759E-03, 1.81578530E-03,
 2 1.19014956E-03, 7.91436695E-04, 5.32265138E-04, 3.17985329E-04,
 3 1.69927045E-04, 8.16723406E-05, 3.34177509E-05, 8.29812235E-06,
 4 1.35876813E-06, 1.19593740E-07, 7.96107135E-09, 5.49724892E-10,
 5 3.89462240E-11, 2.81213504E-12, 4.07045732E-02, 4.07089796E-02,
 6 4.07122849E-02, 4.07183460E-02, 4.07293704E-02, 4.07486759E-02,
 7 4.07818096E-02, 4.08426810E-02, 4.09537773E-02, 4.11495151E-02,
 8 4.14890357E-02, 4.21248963E-02, 4.30212543E-02, 4.44338295E-02,
 9 4.73542676E-02, 5.19486346E-02, 5.96595030E-02, 8.00440021E-02/

DATA CJ 23/

1 1.23805652E-01, 7.36099127E-02, 4.22094370E-02, 2.93020252E-02,
 2 2.12632345E-02, 1.53999160E-02, 1.10899988E-02, 7.78581980E-03,
 3 5.59792888E-03, 3.79408528E-03, 2.62063726E-03, 1.71219569E-03,
 4 1.13580719E-03, 7.62385553E-04, 4.54536615E-04, 2.42425104E-04,
 5 1.16311835E-04, 4.75131868E-05, 1.17765788E-05, 1.92524640E-06,
 6 1.69215319E-07, 1.12528107E-08, 7.76489372E-10, 5.49843371E-11,
 7 3.96867843E-12, 4.32342833E-02, 4.32382374E-02, 4.32412033E-02,
 8 4.32466417E-02, 4.32565325E-02, 4.32738504E-02, 4.33035646E-02,
 9 4.33581273E-02, 4.34576211E-02, 4.36326376E-02, 4.39353696E-02/

DATA CJ 24/

1 4.44994366E-02, 4.52881489E-02, 4.65156962E-02, 4.89934064E-02,
 2 5.27270383E-02, 5.86246340E-02, 6.89792766E-02, 9.55178919E-02,
 3 1.53805931E-01, 8.72665990E-02, 4.81287151E-02, 3.42518696E-02,
 4 2.42867642E-02, 1.72256496E-02, 1.19534085E-02, 8.52602534E-03,
 5 5.73789848E-03, 3.94296355E-03, 2.56435298E-03, 1.69519482E-03,
 6 1.13475697E-03, 6.74616532E-04, 3.58827677E-04, 1.71739540E-04,
 7 6.99968308E-05, 1.73056589E-05, 2.82293429E-06, 2.47641764E-07,
 8 1.64454429E-08, 1.13374274E-09, 8.02278537E-11, 5.78776151E-12,
 9 4.32087632E-02, 4.32121598E-02, 4.32147075E-02, 4.32193789E-02/

DATA CJ 25/

1 4.32278743E-02, 4.32427472E-02, 4.32682614E-02, 4.33150958E-02,
 2 4.34004438E-02, 4.35504092E-02, 4.38093044E-02, 4.42899816E-02,
 3 4.49583505E-02, 4.59898809E-02, 4.80394281E-02, 5.10451508E-02,
 4 5.55906118E-02, 6.30744680E-02, 7.57836932E-02, 1.10123496E-01,
 5 1.85653774E-01, 1.03646665E-01, 5.94714146E-02, 4.05637117E-02,
 6 2.79429568E-02, 1.89929637E-02, 1.33657202E-02, 8.89196126E-03,
 7 6.06091784E-03, 3.91386910E-03, 2.57362900E-03, 1.71569689E-03,
 8 1.01565207E-03, 5.38061069E-04, 2.56602824E-04, 1.04242060E-04,
 9 2.56787686E-05, 4.17562098E-06, 3.65311742E-07, 2.42123395E-08/

DATA CJ 26/

1 1.66699275E-09, 1.17850743E-10, 8.49584676E-12, 3.61991027E-02,
 2 3.62016216E-02, 3.62035109E-02, 3.62069750E-02, 3.62132746E-02,
 3 3.62243025E-02, 3.62432184E-02, 3.62779330E-02, 3.63411687E-02,
 4 3.64521995E-02, 3.66436361E-02, 3.69982490E-02, 3.74895600E-02,
 5 3.82437785E-02, 3.97276968E-02, 4.18684883E-02, 4.50254746E-02,
 6 5.00133841E-02, 5.80103385E-02, 7.21340556E-02, 1.13025502E-01,
 7 1.99418938E-01, 1.09586908E-01, 5.94793914E-02, 3.95984015E-02,
 8 2.61425920E-02, 1.80656790E-02, 1.18401639E-02, 7.98800065E-03,
 9 5.11311185E-03, 3.34058255E-03, 2.21597730E-03, 1.30517128E-03/

DATA CJ 27/

1 6.88176910E-04, 3.26823531E-04, 1.32263645E-04, 3.24455102E-05,
 2 5.25702999E-06, 4.58502450E-07, 3.03218082E-08, 2.08452552E-09,
 3 1.47211698E-10, 1.06039398E-11, 2.93072216E-02, 2.93090679E-02,
 4 2.93104528E-02, 2.93129919E-02, 2.93176092E-02, 2.93256917E-02,
 5 2.93395542E-02, 2.93649910E-02, 2.94113137E-02, 2.94926082E-02,
 6 2.96326546E-02, 2.98916735E-02, 3.02496816E-02, 3.07973230E-02,
 7 3.18679302E-02, 3.33963795E-02, 3.56156824E-02, 3.90380654E-02,
 8 4.43148129E-02, 5.31920594E-02, 6.91640591E-02, 1.16575775E-01,
 9 2.09934433E-01, 1.12013093E-01, 5.82642687E-02, 3.70523334E-02/

DATA CJ 28/

1 2.49076025E-02, 1.59750451E-02, 1.06254412E-02, 6.72152469E-03,
 2 4.35445309E-03, 2.87016476E-03, 1.67963537E-03, 8.80394242E-04,
 3 4.15953076E-04, 1.67551113E-04, 4.08940875E-05, 6.59741042E-06,
 4 5.73294937E-07, 3.78143135E-08, 2.59506766E-09, 1.83037178E-10,
 5 1.31720886E-11, 2.56383409E-02, 2.56398398E-02, 2.56409641E-02,
 6 2.56430254E-02, 2.56467737E-02, 2.56533350E-02, 2.56645878E-02,
 7 2.56852340E-02, 2.57228259E-02, 2.57887774E-02, 2.59023307E-02,
 8 2.61121441E-02, 2.64017019E-02, 2.68436483E-02, 2.77041846E-02,
 9 2.89248481E-02, 3.06808077E-02, 3.33507344E-02, 3.73782881E-02/

DATA CJ 29/

1 4.39205671E-02, 5.52858594E-02, 7.56826005E-02, 1.25832006E-01,
 2 2.30642137E-01, 1.18332498E-01, 5.71643469E-02, 3.76047112E-02,
 3 2.34557191E-02, 1.53226318E-02, 9.55330997E-03, 6.12663729E-03,
 4 4.00811123E-03, 2.32818065E-03, 1.21213576E-03, 5.69369511E-04,
 5 2.28164697E-04, 5.53788075E-05, 8.89242600E-06, 7.69668743E-07,
 6 5.06251462E-08, 3.46775995E-09, 2.44264908E-10, 1.75607129E-11,
 7 2.22761665E-02, 2.22773802E-02, 2.22782905E-02, 2.22799595E-02,
 8 2.22829944E-02, 2.22883068E-02, 2.22974173E-02, 2.23141315E-02,
 9 2.23445596E-02, 2.23979289E-02, 2.24897765E-02, 2.26593445E-02/

DATA CJ 30/

1 2.28930634E-02, 2.32491203E-02, 2.39401206E-02, 2.49151104E-02,
 2 2.63070342E-02, 2.83995587E-02, 3.15019911E-02, 3.64043040E-02,
 3 4.45264732E-02, 5.81378958E-02, 7.88629990E-02, 1.36137259E-01,
 4 2.57211631E-01, 1.30192772E-01, 6.63608831E-02, 3.93311909E-02,
 5 2.48502333E-02, 1.51148435E-02, 9.53662310E-03, 6.16693160E-03,
 6 3.54233209E-03, 1.82616568E-03, 8.50690362E-04, 3.38428996E-04,
 7 8.15126391E-05, 1.30057303E-05, 1.11972018E-06, 7.33764515E-08,
 8 5.01384071E-09, 3.52551166E-10, 2.53124541E-11, 1.72345593E-02,
 9 1.72354470E-02, 1.72361127E-02, 1.72373334E-02, 1.72395531E-02/

DATA CJ 31/

1 1.72434383E-02, 1.72501011E-02, 1.72623239E-02, 1.72845732E-02,
 2 1.73235899E-02, 1.73907151E-02, 1.75145682E-02, 1.76851231E-02,
 3 1.79446101E-02, 1.84470178E-02, 1.91532719E-02, 2.01562308E-02,
 4 2.16523609E-02, 2.38450945E-02, 2.72488293E-02, 3.27267114E-02,
 5 4.14736368E-02, 5.40800824E-02, 7.55433816E-02, 1.36071502E-01,
 6 2.66937747E-01, 1.30878244E-01, 5.70704857E-02, 3.54810703E-02,
 7 2.10071223E-02, 1.30176391E-02, 8.31203265E-03, 4.71755468E-03,
 8 2.40684877E-03, 1.11154500E-03, 4.38918146E-04, 1.04896063E-04,
 9 1.66302014E-05, 1.42423313E-06, 9.29901017E-08, 6.33873136E-09/

DATA CJ 32/

1 4.44949458E-10, 3.19056755E-11, 1.37799601E-02, 1.37806330E-02,
 2 1.37811376E-02, 1.37820629E-02, 1.37837454E-02, 1.37866904E-02,
 3 1.37917405E-02, 1.38010045E-02, 1.38178664E-02, 1.38474308E-02,
 4 1.38982799E-02, 1.39920548E-02, 1.41210902E-02, 1.43171872E-02,
 5 1.46961074E-02, 1.52270987E-02, 1.59778404E-02, 1.70905750E-02,
 6 1.87061758E-02, 2.11789725E-02, 2.50716330E-02, 3.10732443E-02,
 7 3.92866830E-02, 5.24646620E-02, 7.45948113E-02, 1.44921051E-01,
 8 2.88593785E-01, 1.37313825E-01, 6.35764233E-02, 3.58313861E-02,
 9 2.14391887E-02, 1.33813743E-02, 7.44208358E-03, 3.73383866E-03/

DATA CJ 33/

1 1.70148693E-03, 6.64396181E-04, 1.56988946E-04, 2.46638190E-05,
 2 2.09672615E-06, 1.36208322E-07, 9.25417471E-09, 6.48092636E-10,
 3 4.63921497E-11, 1.10836014E-02, 1.10841214E-02, 1.10845115E-02,
 4 1.10852267E-02, 1.10865271E-02, 1.10888033E-02, 1.10927065E-02,
 5 1.10998664E-02, 1.11128976E-02, 1.11357432E-02, 1.11750288E-02,
 6 1.12474539E-02, 1.13470595E-02, 1.14983165E-02, 1.17902001E-02,
 7 1.21983629E-02, 1.27737467E-02, 1.36229698E-02, 1.48484789E-02,
 8 1.67074935E-02, 1.95944437E-02, 2.39552086E-02, 2.97559740E-02,
 9 3.86981296E-02, 5.32679383E-02, 8.05305435E-02, 1.50256705E-01/

DATA CJ 34/

1 3.10028330E-01, 1.43359269E-01, 5.79514507E-02, 3.41359790E-02,
 2 2.07888262E-02, 1.13072749E-02, 5.57200234E-03, 2.50380051E-03,
 3 9.66527996E-04, 2.25785061E-04, 3.51550992E-05, 2.96723592E-06,
 4 1.91823036E-07, 1.29916830E-08, 9.07829318E-10, 6.48783939E-11,
 5 8.05345169E-03, 8.05381410E-03, 8.05408592E-03, 8.05458428E-03,
 6 8.05549048E-03, 8.05707659E-03, 8.05979643E-03, 8.06478541E-03,
 7 8.07386492E-03, 8.08978091E-03, 8.11714522E-03, 8.16757597E-03,
 8 8.23689741E-03, 8.34208772E-03, 8.54480995E-03, 8.82771009E-03,
 9 9.22537505E-03, 9.80990903E-03, 1.06485399E-02, 1.19099547E-02/

DATA CJ 35/

1 1.38442261E-02, 1.67118796E-02, 2.04310483E-02, 2.59634497E-02,
 2 3.44927631E-02, 4.92459652E-02, 7.17143792E-02, 1.53427244E-01,
 3 3.26514616E-01, 1.45742764E-01, 6.13074379E-02, 3.60649980E-02,
 4 1.88174151E-02, 8.98850140E-03, 3.94809638E-03, 1.49719844E-03,
 5 3.43850572E-04, 5.28497905E-05, 4.41591581E-06, 2.83561601E-07,
 6 1.91222769E-08, 1.33221545E-09, 9.49969176E-11, 6.23899214E-03,
 7 6.23926423E-03, 6.23946831E-03, 6.23984247E-03, 6.24052283E-03,
 8 6.24171365E-03, 6.24375562E-03, 6.24750111E-03, 6.25431728E-03,
 9 6.26626487E-03, 6.28680368E-03, 6.32464677E-03, 6.37664705E-03/

DATA CJ 36/

1 6.45551338E-03, 6.60736780E-03, 6.81898452E-03, 7.11587158E-03,
 2 7.55107120E-03, 8.17302480E-03, 9.10333057E-03, 1.05183121E-02,
 3 1.25918504E-02, 1.52408962E-02, 1.91039365E-02, 2.48947623E-02,
 4 3.45085256E-02, 4.88880645E-02, 7.83625393E-02, 1.60081234E-01,
 5 3.50633150E-01, 1.58268933E-01, 6.90948156E-02, 3.39747806E-02,
 6 1.55020551E-02, 6.60454805E-03, 2.44930269E-03, 5.51214534E-04,
 7 8.34758490E-05, 6.89702873E-06, 4.39648683E-07, 2.95110464E-08,
 8 2.04941162E-09, 1.45796071E-10, 3.86282087E-03, 3.86298440E-03,
 9 3.86310704E-03, 3.86333191E-03, 3.86374079E-03, 3.86445644E-03/

DATA CJ 37/

1 3.86568359E-03, 3.86793446E-03, 3.87203051E-03, 3.87920970E-03,
 2 3.89154986E-03, 3.91428208E-03, 3.94550854E-03, 3.99284634E-03,
 3 4.08391991E-03, 4.21067527E-03, 4.38819654E-03, 4.64778015E-03,
 4 5.01747072E-03, 5.56772337E-03, 6.39868712E-03, 7.60416847E-03,
 5 9.12449772E-03, 1.13047814E-02, 1.44977905E-02, 1.96168808E-02,
 6 2.68935185E-02, 4.08571483E-02, 6.32813848E-02, 1.50625472E-01,
 7 3.39572661E-01, 1.48214255E-01, 4.93249265E-02, 2.20913623E-02,
 8 9.10755191E-03, 3.29653797E-03, 7.26006984E-04, 1.08260881E-04,
 9 8.84251505E-06, 5.59498831E-07, 3.73815783E-08, 2.58770380E-09/

DATA CJ 38/

1 1.83661677E-10, 2.98227701E-03, 2.98240025E-03, 2.98249267E-03,
 2 2.98266213E-03, 2.98297027E-03, 2.98350958E-03, 2.98443436E-03,
 3 2.98613057E-03, 2.98921719E-03, 2.99462686E-03, 3.00392462E-03,
 4 3.02104965E-03, 3.04456802E-03, 3.08020825E-03, 3.14873479E-03,
 5 3.24401847E-03, 3.37728863E-03, 3.57180598E-03, 3.84811665E-03,
 6 4.25788866E-03, 4.87350005E-03, 5.76017191E-03, 6.86845602E-03,
 7 8.44008711E-03, 1.07075673E-02, 1.42674113E-02, 1.91878660E-02,
 8 2.82561307E-02, 4.26527329E-02, 7.23734657E-02, 1.66053959E-01,
 9 3.70990169E-01, 1.46316337E-01, 4.02698622E-02, 1.66654154E-02/

DATA CJ 39/

1 5.85171602E-03, 1.25355455E-03, 1.83368213E-04, 1.47698909E-05,
 2 9.26359877E-07, 6.15562975E-08, 4.24539926E-09, 3.00506659E-10,
 3 2.45811060E-03, 2.45820983E-03, 2.45828425E-03, 2.45842070E-03,
 4 2.45866882E-03, 2.45910309E-03, 2.45984773E-03, 2.46121352E-03,
 5 2.46369880E-03, 2.46805437E-03, 2.47553979E-03, 2.48932478E-03,
 6 2.50825196E-03, 2.53692541E-03, 2.59202576E-03, 2.66857395E-03,
 7 2.77551117E-03, 2.93133156E-03, 3.15215542E-03, 3.47856747E-03,
 8 3.96667106E-03, 4.66523184E-03, 5.53158490E-03, 6.74834637E-03,
 9 8.48186839E-03, 1.11569348E-02, 1.47721717E-02, 2.12195479E-02/

DATA CJ 40/

1 3.09773686E-02, 5.02403557E-02, 8.47913144E-02, 1.81191796E-01,
 2 4.35742447E-01, 1.57375913E-01, 3.77857605E-02, 1.33290042E-02,
 3 2.74149053E-03, 3.89957840E-04, 3.08028604E-05, 1.90892638E-06,
 4 1.25926537E-07, 8.64237466E-09, 6.09587246E-10, 1.59785166E-03,
 5 1.59791453E-03, 1.59796168E-03, 1.59804813E-03, 1.59820532E-03,
 6 1.59848045E-03, 1.59895221E-03, 1.59981747E-03, 1.60139193E-03,
 7 1.60415109E-03, 1.60889254E-03, 1.61762298E-03, 1.62960733E-03,
 8 1.64775671E-03, 1.68261296E-03, 1.73099274E-03, 1.79849426E-03,
 9 1.89667977E-03, 2.03548663E-03, 2.23996953E-03, 2.54428747E-03/

DATA CJ 41/

1 2.97700375E-03, 3.50944290E-03, 4.25010023E-03, 5.29241140E-03,
 2 6.87457470E-03, 8.96846856E-03, 1.25938324E-02, 1.78542716E-02,
 3 2.75754555E-02, 4.35335831E-02, 6.96112838E-02, 1.80490484E-01,
 4 4.82704032E-01, 1.61597899E-01, 3.14210153E-02, 6.39612290E-03,
 5 8.71749067E-04, 6.68968138E-05, 4.07529713E-06, 2.66109955E-07,
 6 1.81401024E-08, 1.27335576E-09, 9.13895040E-04, 9.13930152E-04,
 7 9.13956486E-04, 9.14004768E-04, 9.14092560E-04, 9.14246216E-04,
 8 9.14509689E-04, 9.14992926E-04, 9.15872212E-04, 9.17413055E-04,
 9 9.20060708E-04, 9.24935178E-04, 9.31625042E-04, 9.41753339E-04/

DATA CJ 42/

1 9.61194906E-04, 9.88157859E-04, 1.02573661E-03, 1.08031414E-03,
 2 1.15730888E-03, 1.27040239E-03, 1.43802604E-03, 1.67507093E-03,
 3 1.96483346E-03, 2.36475676E-03, 2.92202864E-03, 3.75712891E-03,
 4 4.84501549E-03, 6.68905982E-03, 9.29025396E-03, 1.39090077E-02,
 5 2.10834728E-02, 3.24306164E-02, 5.78278590E-02, 1.79391487E-01,
 6 5.25453937E-01, 1.48969451E-01, 7.12696350E-03, 1.60875816E-03,
 7 1.26599544E-04, 7.71608101E-06, 5.02732802E-07, 3.41952527E-08,
 8 2.39594123E-09, 5.13463168E-04, 5.13482434E-04, 5.13496884E-04,
 9 5.13523377E-04, 5.13571550E-04, 5.13655863E-04, 5.13800434E-04/

DATA CJ 43/

1 5.14065587E-04, 5.14548042E-04, 5.15393454E-04, 5.16846035E-04,
 2 5.19519981E-04, 5.23189081E-04, 5.28742473E-04, 5.39397236E-04,
 3 5.54162986E-04, 5.74721309E-04, 6.04536894E-04, 6.46516805E-04,
 4 7.08013039E-04, 7.98821169E-04, 9.26601769E-04, 1.08188455E-03,
 5 1.29472397E-03, 1.58878219E-03, 2.02468563E-03, 2.58522337E-03,
 6 3.51958611E-03, 4.80979190E-03, 7.03675174E-03, 1.03698638E-02,
 7 1.54127709E-02, 2.65454282E-02, 5.23789497E-02, 1.85114913E-01,
 8 6.14272689E-01, 1.31788475E-01, -5.07506631E-04, 3.56621382E-04,
 9 2.34332842E-05, 1.54943305E-06, 1.05811807E-07, 7.42101112E-09/

DATA CJ 44/

1 2.16926351E-04, 2.16934307E-04, 2.16940274E-04, 2.16951215E-04,
 2 2.16971108E-04, 2.17005925E-04, 2.17065625E-04, 2.17175119E-04,
 3 2.17374342E-04, 2.17723430E-04, 2.18323192E-04, 2.19427122E-04,
 4 2.20941634E-04, 2.23233355E-04, 2.27628323E-04, 2.33714877E-04,
 5 2.42181308E-04, 2.54444296E-04, 2.71679859E-04, 2.96866923E-04,
 6 3.33935009E-04, 3.85865648E-04, 4.48647359E-04, 5.34182709E-04,
 7 6.51494899E-04, 8.23810075E-04, 1.04303235E-03, 1.40355998E-03,
 8 1.89317411E-03, 2.72049733E-03, 3.92601880E-03, 5.69311432E-03,
 9 9.42482602E-03, 1.79699471E-02, 3.85691187E-02, 1.65305886E-01/

DATA CJ 45/
1 7.12586173E-01, 1.16125715E-01,-9.27852038E-03,-9.73364283E-05,
2-2.51140046E-06,-7.08946092E-08,-1.33934783E-09, 4.27934297E-05,
3 4.27949511E-05, 4.27960923E-05, 4.27981844E-05, 4.28019886E-05,
4 4.28086468E-05, 4.28200632E-05, 4.28410013E-05, 4.28790970E-05,
5 4.29458468E-05, 4.30605192E-05, 4.32715551E-05, 4.35610149E-05,
6 4.39988735E-05, 4.48380984E-05, 4.59993015E-05, 4.76125895E-05,
7 4.99454029E-05, 5.32166317E-05, 5.79820100E-05, 6.49650582E-05,
8 7.46927056E-05, 8.63754826E-05, 1.02171264E-04, 1.23636362E-04,
9 1.54807865E-04, 1.93944281E-04, 2.57259964E-04, 3.41546842E-04/
DATA CJ 46/
1 4.80449068E-04, 6.76662483E-04, 9.54036876E-04, 1.51001582E-03,
2 2.67871203E-03, 5.24401095E-03, 8.97290116E-03, 1.37035572E-01,
3 7.78656505E-01, 9.70826118E-02,-1.09162957E-02,-1.94896605E-04,
4-8.21793338E-06,-4.33354674E-07, 4.89268618E-06, 4.89285502E-06,
5 4.89298166E-06, 4.89321384E-06, 4.89363601E-06, 4.89437490E-06,
6 4.89564182E-06, 4.89796538E-06, 4.90219285E-06, 4.90959974E-06,
7 4.92232340E-06, 4.94573611E-06, 4.97784272E-06, 5.02639520E-06,
8 5.11940569E-06, 5.24799833E-06, 5.42646214E-06, 5.68413513E-06,
9 6.04472391E-06, 6.56855330E-06, 7.33324810E-06, 8.39324366E-06/
DATA CJ 47/
1 9.65903481E-06, 1.13593361E-05, 1.36520370E-05, 1.69502309E-05,
2 2.10471150E-05, 2.75900014E-05, 3.61682422E-05, 5.00482191E-05,
3 6.92366305E-05, 9.57300603E-05, 1.47227509E-04, 2.50957171E-04,
4 4.68850060E-04, 9.60463772E-04,-9.41162570E-04, 1.12442752E-01,
5 8.27483107E-01, 9.33399010E-02,-9.78021236E-03,-1.66965841E-04,
6-6.80403754E-06,-9.83932073E-08,-9.83972297E-08,-9.84002466E-08,
7-9.84057778E-08,-9.84158354E-08,-9.84334386E-08,-9.84636229E-08,
8-9.85189850E-08,-9.86197236E-08,-9.87962657E-08,-9.90996497E-08,
9-9.96582912E-08,-1.00425187E-07,-1.01586683E-07,-1.03817643E-07/
DATA CJ 48/
1-1.06914718E-07,-1.11236740E-07,-1.17524632E-07,-1.26415013E-07,
2-1.39510428E-07,-1.58986850E-07,-1.86634126E-07,-2.20547285E-07,
3-2.67482937E-07,-3.32996473E-07,-4.31152233E-07,-5.58626117E-07,
4-7.73022042E-07,-1.07106748E-06,-1.58698806E-06,-2.35671087E-06,
5-3.50854578E-06,-5.99057583E-06,-1.17888809E-05,-2.69569256E-05,
6-7.80646056E-05,-4.75675364E-04,-9.85302696E-03, 9.52489529E-02,
7 8.34819192E-01, 9.40538961E-02,-9.75525756E-03,-1.65569752E-04,
8-2.60590716E-08,-2.60600024E-08,-2.60607006E-08,-2.60619806E-08,
9-2.60643080E-08,-2.60683814E-08,-2.60753660E-08,-2.60881760E-08/
DATA CJ 49/
1-2.61114830E-08,-2.61523210E-08,-2.62224788E-08,-2.63515949E-08,
2-2.65286963E-08,-2.67966019E-08,-2.73101140E-08,-2.80207022E-08,
3-2.90080546E-08,-3.04359910E-08,-3.24387637E-08,-3.53571296E-08,
4-3.96351931E-08,-4.55974177E-08,-5.27615474E-08,-6.24530616E-08,
5-7.56309112E-08,-9.47808894E-08,-1.18841964E-07,-1.57802846E-07,
6-2.09723976E-07,-2.95412476E-07,-4.16711397E-07,-5.88720583E-07,
7-9.35676036E-07,-1.67732628E-06,-3.40469579E-06,-8.36208766E-06,
8-3.66735772E-05,-2.97280704E-04,-1.09915858E-02, 9.27463390E-02,
9 8.31874183E-01, 7.39772247E-02,-9.75916655E-03,-1.21433306E-09/
DATA CJ 50/
1-1.21437592E-09,-1.21440807E-09,-1.21446701E-09,-1.21457418E-09,
2-1.21476176E-09,-1.21508339E-09,-1.21567326E-09,-1.21674650E-09,
3-1.21862695E-09,-1.22185740E-09,-1.22780229E-09,-1.23595589E-09,
4-1.24828859E-09,-1.27192260E-09,-1.30461649E-09,-1.35002457E-09,
5-1.41565584E-09,-1.50763296E-09,-1.64151023E-09,-1.83746665E-09,
6-2.11003211E-09,-2.43680651E-09,-2.87773197E-09,-3.47545902E-09,
7-4.34090389E-09,-5.42383519E-09,-7.16876756E-09,-9.48085809E-09,
8-1.32707815E-08,-1.85935498E-08,-2.60775219E-08,-4.10071712E-08,
9-7.24179015E-08,-1.43956009E-07,-3.42506712E-07,-1.40134936E-06/

```

DATA CJ 51/
1-9.70094682E-06,-1.65409793E-04,-9.75158564E-03, 9.41592324E-02,
2 8.42018552E-01, 2.00443013E-02,-9.09966467E-11,-9.09998056E-11,
3-9.10021749E-11,-9.10065186E-11,-9.10144169E-11,-9.10282406E-11,
4-9.10519432E-11,-9.10954140E-11,-9.11745054E-11,-9.13130813E-11,
5-9.15511324E-11,-9.19891800E-11,-9.25899129E-11,-9.34984102E-11,
6-9.52389670E-11,-9.76457687E-11,-1.00986696E-10,-1.05811883E-10,
7-1.12567016E-10,-1.22385705E-10,-1.36730202E-10,-1.56634264E-10,
8-1.80431063E-10,-2.12441329E-10,-2.55678370E-10,-3.18012771E-10,
9-3.95642810E-10,-5.20035550E-10,-6.83820118E-10,-9.50336363E-10/
DATA CJ 52/
1-1.32157045E-09,-1.83904531E-09,-2.86022274E-09,-4.97692943E-09,
2-9.70293516E-09,-2.24631475E-08,-8.71919425E-08,-5.48748367E-07,
3-7.48344600E-06,-1.80376685E-04,-1.01123390E-02, 7.39345544E-02,
4 9.89887661E-01/
DATA XTAU/0,, .000032,,.000056,,.0001,,.00018,,.00032,
1.00056,,.001,,.0018,,.0032,,.0056,,.01,,.016,,.025,,.042,,.065,
2.096,,.139,,.196,,.273,,.375,,.5,,.63,,.78,,.95,,.1.15,,.1.35,,.1.6,,.1.85,,.2.15,
32.45,,.2.75,,.3.15,,.3.65,,.4.25,,.5.0,,.6.2,,.7.8,,.10,,.12.5,,.15,,.17.5,,.20./
DATA NXTAU/43/
END

```

```

C SUBROUTINE BLOCKH
CAN BE BLOCK DATA INSTEAD OF SUBROUTINE
COMMON /MATX/CJ(1849),CH(1849),XTAU(43),NXTAU
DIMENSION CH 1(36),CH 2(36),CH 3(36),CH 4(36),CH 5(36)
DIMENSION CH 6(36),CH 7(36),CH 8(36),CH 9(36),CH 10(36)
DIMENSION CH 11(36),CH 12(36),CH 13(36),CH 14(36),CH 15(36)
DIMENSION CH 16(36),CH 17(36),CH 18(36),CH 19(36),CH 20(36)
DIMENSION CH 21(36),CH 22(36),CH 23(36),CH 24(36),CH 25(36)
DIMENSION CH 26(36),CH 27(36),CH 28(36),CH 29(36),CH 30(36)
DIMENSION CH 31(36),CH 32(36),CH 33(36),CH 34(36),CH 35(36)
DIMENSION CH 36(36),CH 37(36),CH 38(36),CH 39(36),CH 40(36)
DIMENSION CH 41(36),CH 42(36),CH 43(36),CH 44(36),CH 45(36)
DIMENSION CH 46(36),CH 47(36),CH 48(36),CH 49(36),CH 50(36)
DIMENSION CH 51(36),CH 52(13)
EQUIVALENCE (CH 1(1),CH ( 1)),(CH 2(1),CH ( 37))
EQUIVALENCE (CH 3(1),CH ( 73)),(CH 4(1),CH ( 109))
EQUIVALENCE (CH 5(1),CH ( 145)),(CH 6(1),CH ( 181))
EQUIVALENCE (CH 7(1),CH ( 217)),(CH 8(1),CH ( 253))
EQUIVALENCE (CH 9(1),CH ( 289)),(CH 10(1),CH ( 325))
EQUIVALENCE (CH 11(1),CH ( 361)),(CH 12(1),CH ( 397))
EQUIVALENCE (CH 13(1),CH ( 433)),(CH 14(1),CH ( 469))
EQUIVALENCE (CH 15(1),CH ( 505)),(CH 16(1),CH ( 541))
EQUIVALENCE (CH 17(1),CH ( 577)),(CH 18(1),CH ( 613))
EQUIVALENCE (CH 19(1),CH ( 649)),(CH 20(1),CH ( 685))
EQUIVALENCE (CH 21(1),CH ( 721)),(CH 22(1),CH ( 757))
EQUIVALENCE (CH 23(1),CH ( 793)),(CH 24(1),CH ( 829))
EQUIVALENCE (CH 25(1),CH ( 865)),(CH 26(1),CH ( 901))
EQUIVALENCE (CH 27(1),CH ( 937)),(CH 28(1),CH ( 973))
EQUIVALENCE (CH 29(1),CH (1009)),(CH 30(1),CH (1045))
EQUIVALENCE (CH 31(1),CH (1081)),(CH 32(1),CH (1117))

```

EQUIVALENCE (CH 33(1),CH (1153)),(CH 34(1),CH (1189))
 EQUIVALENCE (CH 35(1),CH (1225)),(CH 36(1),CH (1261))
 EQUIVALENCE (CH 37(1),CH (1297)),(CH 38(1),CH (1333))
 EQUIVALENCE (CH 39(1),CH (1369)),(CH 40(1),CH (1405))
 EQUIVALENCE (CH 41(1),CH (1441)),(CH 42(1),CH (1477))
 EQUIVALENCE (CH 43(1),CH (1513)),(CH 44(1),CH (1549))
 EQUIVALENCE (CH 45(1),CH (1585)),(CH 46(1),CH (1621))
 EQUIVALENCE (CH 47(1),CH (1657)),(CH 48(1),CH (1693))
 EQUIVALENCE (CH 49(1),CH (1729)),(CH 50(1),CH (1765))
 EQUIVALENCE (CH 51(1),CH (1801)),(CH 52(1),CH (1837))

DATA CH 1/

1 7.15468111E-06,-7.63518254E-06,-7.15194190E-06,-7.14908817E-06,
 2-7.14434126E-06,-7.13655915E-06,-7.12412582E-06,-7.10337944E-06,
 3-7.06894113E-06,-7.01450683E-06,-6.93090638E-06,-6.79555793E-06,
 4-6.63291776E-06,-6.41788366E-06,-6.06957067E-06,-5.67267991E-06,
 5-5.22293773E-06,-4.70482715E-06,-4.14396013E-06,-3.53845938E-06,
 6-2.91564752E-06,-2.33731168E-06,-1.88157141E-06,-1.48246502E-06,
 7-1.14445670E-06,-8.53997483E-07,-6.43477679E-07,-4.56544435E-07,
 8-3.26945808E-07,-2.21153320E-07,-1.50877193E-07,-1.03653072E-07,
 9-6.33945709E-08,-3.46862852E-08,-1.70494808E-08,-7.13023297E-09/

DATA CH 2/

1-1.81676142E-09,-3.04652954E-10,-2.74072641E-11,-1.85486483E-12,
 2-1.29572640E-13,-9.25877958E-15,-6.72963730E-16, 1.49104109E-05,
 3-3.90201199E-06,-1.61388810E-05,-1.49037775E-05,-1.48935421E-05,
 4-1.48771099E-05,-1.48514527E-05,-1.48079226E-05,-1.47359130E-05,
 5-1.46223031E-05,-1.44479043E-05,-1.41656379E-05,-1.38265136E-05,
 6-1.33781866E-05,-1.26520376E-05,-1.18246559E-05,-1.08871250E-05,
 7-9.80709529E-06,-8.63795420E-06,-7.37578617E-06,-6.07754325E-06,
 8-4.87201699E-06,-3.92204193E-06,-3.09012066E-06,-2.38555751E-06,
 9-1.78010945E-06,-1.34129184E-06,-9.51639673E-07,-6.81498671E-07/

DATA CH 3/

1-4.60980408E-07,-3.14494034E-07,-2.16058241E-07,-1.32141902E-07,
 2-7.23012998E-08,-3.55385179E-08,-1.48624949E-08,-3.78691638E-09,
 3-6.35028248E-10,-5.71285479E-11,-3.86633654E-12,-2.70085094E-13,
 4-1.92992751E-14,-1.40274544E-15, 1.52026574E-05, 1.68173785E-05,
 5 4.09890951E-06,-1.75587254E-05,-1.51942778E-05,-1.51773709E-05,
 6-1.51506530E-05,-1.51059123E-05,-1.50322201E-05,-1.49160857E-05,
 7-1.47379368E-05,-1.44497640E-05,-1.41036562E-05,-1.36461842E-05,
 8-1.29053252E-05,-1.20612605E-05,-1.11048794E-05,-1.00031765E-05,
 9-8.81060628E-06,-7.52317033E-06,-6.19895694E-06,-4.96932846E-06/

DATA CH 4/

1-4.00036789E-06,-3.15182512E-06,-2.43318816E-06,-1.81564832E-06,
 2-1.36806808E-06,-9.70635957E-07,-6.95101755E-07,-4.70181345E-07,
 3-3.20770911E-07,-2.20370321E-07,-1.34779083E-07,-7.37441757E-08,
 4-3.62477144E-08,-1.51590763E-08,-3.86248133E-09,-6.47699272E-10,
 5-5.82684230E-11,-3.94347888E-12,-2.75473821E-13,-1.96843285E-14,
 6-1.43073233E-15, 2.97896810E-05, 2.97980436E-05, 3.02862105E-05,
 7 5.50647710E-06,-3.39987917E-05,-2.97607355E-05,-2.97074452E-05,
 8-2.96191403E-05,-2.94741216E-05,-2.92456743E-05,-2.88957424E-05,
 9-2.83301186E-05,-2.76510734E-05,-2.67537628E-05,-2.53008644E-05/

DATA CH 5/

1-2.36457701E-05,-2.17705777E-05,-1.96105587E-05,-1.72724667E-05,
 2-1.47484513E-05,-1.21523844E-05,-9.74178213E-06,-7.84222059E-06,
 3-6.17873953E-06,-4.76993351E-06,-3.55932255E-06,-2.68189971E-06,
 4-1.90278810E-06,-1.36264217E-06,-9.21718380E-07,-6.28821467E-07,
 5-4.32001343E-07,-2.64212927E-07,-1.44563571E-07,-7.10577364E-08,
 6-2.97168721E-08,-7.57175055E-09,-1.26970521E-09,-1.14225320E-10,
 7-7.73051375E-12,-5.40018920E-13,-3.85877188E-14,-2.80470236E-15,
 8 5.33166565E-05, 5.33305336E-05, 5.33411719E-05, 5.45903541E-05,
 9 9.45344282E-06,-5.98750876E-05,-5.32380787E-05,-5.30767814E-05/

DATA CH 6/

1-5.28138232E-05,-5.24019312E-05,-5.17726512E-05,-5.07570460E-05,
 2-4.95388096E-05,-4.79297869E-05,-4.53254263E-05,-4.23593245E-05,
 3-3.89992680E-05,-3.51292236E-05,-3.09404208E-05,-2.64187551E-05,
 4-2.17681883E-05,-1.74499821E-05,-1.40472898E-05,-1.10675313E-05,
 5-8.54399479E-06,-6.37549656E-06,-4.80383043E-06,-3.40827054E-06,
 6-2.44075547E-06,-1.65097143E-06,-1.12633544E-06,-7.73792885E-07,
 7-4.73252449E-07,-2.58938632E-07,-1.27276602E-07,-5.32279265E-08,
 8-1.35622540E-08,-2.27424725E-09,-2.04595667E-10,-1.38465591E-11,
 9-9.67257493E-13,-6.91165342E-14,-5.02365045E-15, 9.11154271E-05/

DATA CH 7/

1 9.11373857E-05, 9.11540613E-05, 9.11851613E-05, 9.35475905E-05,
 2 1.47063981E-05,-1.03462545E-04,-9.08852056E-05,-9.04268240E-05,
 3-8.97143108E-05,-8.86303376E-05,-8.68853571E-05,-8.47952605E-05,
 4-8.20369956E-05,-7.75751291E-05,-7.24955321E-05,-6.67426582E-05,
 5-6.01176981E-05,-5.29478997E-05,-4.52090066E-05,-3.72500018E-05,
 6-2.98601473E-05,-2.40372258E-05,-1.89381774E-05,-1.46199094E-05,
 7-1.09092379E-05,-8.21988044E-06,-5.83189075E-06,-4.17635691E-06,
 8-2.82495145E-06,-1.92724820E-06,-1.32401640E-06,-8.09767079E-07,
 9-4.43060175E-07,-2.1777566E-07,-9.10757716E-08,-2.32056491E-08/

DATA CH 8/

1-3.89133110E-09,-3.50070669E-10,-2.36919192E-11,-1.65500706E-12,
 2-1.18260370E-13,-8.59560278E-15, 1.61084638E-04, 1.61120455E-04,
 3 1.61147523E-04, 1.61197627E-04, 1.61290471E-04, 1.65663480E-04,
 4 3.12833419E-05,-1.84767459E-04,-1.60383513E-04,-1.59095624E-04,
 5-1.57151776E-04,-1.54037375E-04,-1.50316852E-04,-1.45414273E-04,
 6-1.37492118E-04,-1.28479528E-04,-1.18276734E-04,-1.06530685E-04,
 7-9.38212441E-05,-8.01050512E-05,-6.60003185E-05,-5.29053047E-05,
 8-4.25875346E-05,-3.35527875E-05,-2.59017163E-05,-1.93273550E-05,
 9-1.45626021E-05,-1.03318579E-05,-7.39883160E-06,-5.00464369E-06/

DATA CH 9/

1-3.41426413E-06,-2.34558186E-06,-1.43454739E-06,-7.84901321E-07,
 2-3.85800856E-07,-1.61343209E-07,-4.11091944E-08,-6.89352042E-09,
 3-6.20149585E-10,-4.19700385E-11,-2.93182374E-12,-2.09496329E-13,
 4-1.52269488E-14, 2.95118055E-04, 2.95178254E-04, 2.95223603E-04,
 5 2.95307214E-04, 2.95460869E-04, 2.95735398E-04, 3.02765668E-04,
 6 5.58676946E-05,-3.37573853E-04,-2.93054976E-04,-2.89397455E-04,
 7-2.83590510E-04,-2.76688690E-04,-2.67619892E-04,-2.52994639E-04,
 8-2.36378122E-04,-2.17582125E-04,-1.95954621E-04,-1.72562085E-04,
 9-1.47323476E-04,-1.21375266E-04,-9.72882826E-05,-7.83117813E-05/

DATA CH 10/

1-6.16962878E-05,-4.76263106E-05,-3.55369461E-05,-2.67755473E-05,
 2-1.89963282E-05,-1.36034154E-05,-9.20135573E-06,-6.27727001E-06,
 3-4.31241145E-06,-2.63742438E-06,-1.44303115E-06,-7.09283125E-07,
 4-2.96621802E-07,-7.55764702E-08,-1.26731441E-08,-1.14008132E-09,
 5-7.71570818E-11,-5.38979485E-12,-3.85131719E-13,-2.79926878E-14,
 6 5.27450267E-04, 5.27548209E-04, 5.27621866E-04, 5.27757352E-04,
 7 5.28005236E-04, 5.28444092E-04, 5.29212980E-04, 5.42982886E-04,
 8 9.43257262E-05,-5.94289095E-04,-5.21949858E-04,-5.11218869E-04,
 9-4.98593743E-04,-4.82097986E-04,-4.55597512E-04,-4.25563821E-04/

DATA CH 11/

1-3.91641331E-04,-3.52647471E-04,-3.10500866E-04,-2.65051281E-04,
 2-2.18341644E-04,-1.74994619E-04,-1.40851146E-04,-1.10959921E-04,
 3-8.56508809E-05,-6.39065263E-05,-4.81490961E-05,-3.41589441E-05,
 4-2.44608124E-05,-1.65448705E-05,-1.12868617E-05,-7.75380763E-06,
 5-4.74205493E-06,-2.59450211E-06,-1.27523489E-06,-5.33293310E-07,
 6-1.35875428E-07,-2.27840386E-08,-2.04962735E-09,-1.38710531E-10,
 7-9.68951630E-12,-6.92367014E-13,-5.03233504E-14, 8.67939527E-04,
 8 8.68086519E-04, 8.68196952E-04, 8.68399838E-04, 8.68770151E-04,
 9 8.69422777E-04, 8.70555854E-04, 8.72685043E-04, 9.00316827E-04/

DATA CH 12/

1 1.18726820E-04,-1.05068040E-03,-8.51640282E-04,-8.30180001E-04,
2-8.02328557E-04,-7.57838031E-04,-7.07603820E-04,-6.50991942E-04,
3-5.86013815E-04,-5.15855799E-04,-4.40257134E-04,-3.62606802E-04,
4-2.90576808E-04,-2.33857067E-04,-1.84211669E-04,-1.42183646E-04,
5-1.06079989E-04,-7.99196360E-05,-5.66953416E-05,-4.05972023E-05,
6-2.74581721E-05,-1.87312937E-05,-1.28676222E-05,-7.86932554E-06,
7-4.30539149E-06,-2.11610499E-06,-8.84915842E-07,-2.25456988E-07,
8-3.78043305E-08,-3.40075163E-09,-2.30144881E-10,-1.60763829E-11,
9-1.14873131E-12,-8.34926889E-14, 1.61498414E-03, 1.61522856E-03/

DATA CH 13/

1 1.61541206E-03, 1.61574893E-03, 1.61636286E-03, 1.61744182E-03,
2 1.61930543E-03, 1.62277036E-03, 1.62924770E-03, 1.68333458E-03,
3 3.60899757E-04,-1.82730765E-03,-1.58410667E-03,-1.52899488E-03,
4-1.44234855E-03,-1.34546950E-03,-1.23689296E-03,-1.11271628E-03,
5-9.78971597E-04,-8.35109934E-04,-6.87538020E-04,-5.50779439E-04,
6-4.43161682E-04,-3.49011624E-04,-2.69337615E-04,-2.00915634E-04,
7-1.51349791E-04,-1.07355641E-04,-7.68658545E-05,-5.19840976E-05,
8-3.54597507E-05,-2.43579442E-05,-1.48953901E-05,-8.14890300E-06,
9-4.00495346E-06,-1.67469957E-06,-4.26647390E-07,-7.15352259E-08/

DATA CH 14/

1-6.43470743E-09,-4.35448549E-10,-3.04166311E-11,-2.17336083E-12,
2-1.57962724E-13, 2.50720905E-03, 2.50755068E-03, 2.50780708E-03,
3 2.50827754E-03, 2.50913426E-03, 2.51063770E-03, 2.51322757E-03,
4 2.51801809E-03, 2.52687709E-03, 2.54289614E-03, 2.63774332E-03,
5 1.76260416E-04,-2.78126196E-03,-2.45704320E-03,-2.31262955E-03,
6-2.15394575E-03,-1.97774832E-03,-1.77739883E-03,-1.56245308E-03,
7-1.33188374E-03,-1.09584644E-03,-8.77427902E-04,-7.05726344E-04,
8-5.55621605E-04,-4.28668973E-04,-3.19696027E-04,-2.40783539E-04,
9-1.70762699E-04,-1.22247776E-04,-8.26646695E-05,-5.63817215E-05/

DATA CH 15/

1-3.87261829E-05,-2.36795672E-05,-1.29532571E-05,-6.36557648E-06,
2-2.66157673E-06,-6.77995222E-07,-1.13667632E-07,-1.02237148E-08,
3-6.91813611E-10,-4.83219157E-11,-3.45263538E-12,-2.50935807E-13,
4 3.20994276E-03, 3.21034034E-03, 3.21063867E-03, 3.21118592E-03,
5 3.21218201E-03, 3.21392850E-03, 3.21693250E-03, 3.22247328E-03,
6 3.23266196E-03, 3.25087011E-03, 3.28333413E-03, 3.52680121E-03,
7 2.90599435E-04,-3.99201557E-03,-3.07880403E-03,-2.86239707E-03,
8-2.62426711E-03,-2.35540482E-03,-2.06836350E-03,-1.76152461E-03,
9-1.44821000E-03,-1.15882208E-03,-9.31623746E-04,-7.33184814E-04/

DATA CH 16/

1-5.65473991E-04,-4.21599458E-04,-3.17461291E-04,-2.25092147E-04,
2-1.61113538E-04,-1.08927603E-04,-7.42843836E-05,-5.10170507E-05,
3-3.11911486E-05,-1.70601847E-05,-8.38286988E-06,-3.50466057E-06,
4-8.92642574E-07,-1.49636185E-07,-1.34574290E-08,-9.10558142E-10,
5-6.35972818E-11,-4.54388504E-12,-3.30236900E-13, 5.61912502E-03,
6 5.61974854E-03, 5.62021633E-03, 5.62107432E-03, 5.62263546E-03,
7 5.62537113E-03, 5.63007179E-03, 5.63872596E-03, 5.65458361E-03,
8 5.68273038E-03, 5.73223829E-03, 5.82772200E-03, 6.17039808E-03,
9 1.43639190E-03,-6.68103918E-03,-5.37711410E-03,-4.91201049E-03/

DATA CH 17/

1-4.39582996E-03,-3.85110758E-03,-3.27335460E-03,-2.68668446E-03,
2-2.14696473E-03,-1.72437761E-03,-1.35598680E-03,-1.04510471E-03,
3-7.78728323E-04,-5.86104634E-04,-4.15382293E-04,-2.97210854E-04,
4-2.00873337E-04,-1.36950183E-04,-9.40333957E-05,-5.74765590E-05,
5-3.14294076E-05,-1.54399049E-05,-6.45358275E-06,-1.64330990E-06,
6-2.75407226E-07,-2.47632234E-08,-1.67526173E-09,-1.16994342E-10,
7-8.35829727E-12,-6.07419294E-13, 8.60872637E-03, 8.60958456E-03,
8 8.61022836E-03, 8.61140900E-03, 8.61355681E-03, 8.61731911E-03,
9 8.62377964E-03, 8.63565978E-03, 8.65738046E-03, 8.69577446E-03/

DATA CH 18/

1 8.76277550E-03, 8.88981793E-03, 9.07314195E-03, 9.60580772E-03,
2 5.68967448E-04, -1.02680807E-02, -8.28490183E-03, -7.37632354E-03,
3 -6.43680809E-03, -5.45363991E-03, -4.46443150E-03, -3.56017279E-03,
4 -2.85517842E-03, -2.24242398E-03, -1.72651510E-03, -1.28528029E-03,
5 -9.66674652E-04, -6.84627687E-04, -4.89594200E-04, -3.30726916E-04,
6 -2.25387410E-04, -1.54703712E-04, -9.45251600E-05, -5.16691993E-05,
7 -2.53739882E-05, -1.06022757E-05, -2.69865726E-06, -4.52114678E-07,
8 -4.06387087E-08, -2.74859164E-09, -1.91919631E-10, -1.37094058E-11,
9 -9.96203776E-13, 1.04706488E-02, 1.04715868E-02, 1.04722905E-02/

DATA CH 19/

1 1.04735808E-02, 1.04759277E-02, 1.04800379E-02, 1.04870926E-02,
2 1.05000549E-02, 1.05237187E-02, 1.05654328E-02, 1.06378618E-02,
3 1.07738115E-02, 1.09663337E-02, 1.12726017E-02, 1.26399636E-02,
4 1.00257118E-03, -1.32448573E-02, -1.02003884E-02, -8.84301595E-03,
5 -7.45329555E-03, -6.07603132E-03, -4.82977801E-03, -3.86459789E-03,
6 -3.02952045E-03, -2.32888278E-03, -1.73132600E-03, -1.30078168E-03,
7 -9.20311543E-04, -6.57610360E-04, -4.43884672E-04, -3.02318135E-04,
8 -2.07403662E-04, -1.26655650E-04, -6.91945397E-05, -3.39630183E-05,
9 -1.41841204E-05, -3.60829257E-06, -6.04192720E-07, -5.42826409E-08/

DATA CH 20/

1 -3.67009568E-09, -2.56200381E-10, -1.82978663E-11, -1.32944308E-12,
2 1.33110352E-02, 1.33121192E-02, 1.33129323E-02, 1.33144233E-02,
3 1.33171350E-02, 1.33218831E-02, 1.33300305E-02, 1.33449935E-02,
4 1.33722851E-02, 1.34203163E-02, 1.35034721E-02, 1.36586923E-02,
5 1.38764431E-02, 1.42174069E-02, 1.49161828E-02, 1.68840513E-02,
6 1.68049676E-03, -1.75585958E-02, -1.31968210E-02, -1.10288702E-02,
7 -8.93226417E-03, -7.06568073E-03, -5.63477235E-03, -4.40515439E-03,
8 -3.37877289E-03, -2.50692076E-03, -1.88069912E-03, -1.32869378E-03,
9 -9.48354161E-04, -6.39452497E-04, -4.35142460E-04, -2.98317864E-04/

DATA CH 21/

1 -1.82035567E-04, -9.93745215E-05, -4.87418148E-05, -2.03423910E-05,
2 -5.17079894E-06, -8.65204519E-07, -7.76821776E-08, -5.24960379E-09,
3 -3.66338380E-10, -2.61574502E-11, -1.90012484E-12, 1.62635669E-02,
4 1.62647788E-02, 1.62656879E-02, 1.62673547E-02, 1.62703861E-02,
5 1.62756934E-02, 1.62847988E-02, 1.63015153E-02, 1.63319866E-02,
6 1.63855544E-02, 1.64781138E-02, 1.66502535E-02, 1.68902874E-02,
7 1.72624926E-02, 1.80097009E-02, 1.91301740E-02, 2.20507234E-02,
8 1.60598467E-03, -2.29301685E-02, -1.64041170E-02, -1.31520191E-02,
9 -1.03269818E-02, -8.19508155E-03, -6.38158993E-03, -4.87910449E-03/

DATA CH 22/

1 -3.61017455E-03, -2.70275023E-03, -1.90566618E-03, -1.35806528E-03,
2 -9.14371740E-04, -6.21497638E-04, -4.25669633E-04, -2.59477519E-04,
3 -1.41505510E-04, -6.93399826E-05, -2.89124421E-05, -7.34137704E-06,
4 -1.22720877E-06, -1.10088386E-07, -7.43470144E-09, -5.18589035E-10,
5 -3.70162362E-11, -2.68824340E-12, 1.90288838E-02, 1.90301864E-02,
6 1.90311635E-02, 1.90329549E-02, 1.90362129E-02, 1.90419163E-02,
7 1.90517000E-02, 1.90696574E-02, 1.91023759E-02, 1.91598480E-02,
8 1.92590133E-02, 1.94429574E-02, 1.96983785E-02, 2.00918628E-02,
9 2.08715613E-02, 2.20119512E-02, 2.37371486E-02, 2.83114149E-02/

DATA CH 23/

1 2.46456465E-03, -2.93002107E-02, -1.96758212E-02, -1.52741478E-02,
2 -1.20287271E-02, -9.31144019E-03, -7.08564280E-03, -5.22193919E-03,
3 -3.89775767E-03, -2.74046750E-03, -1.94871813E-03, -1.30935747E-03,
4 -8.88519151E-04, -6.07746487E-04, -3.69934554E-04, -2.01457063E-04,
5 -9.85867634E-05, -4.10554077E-05, -1.04094561E-05, -1.73777685E-06,
6 -1.55703706E-07, -1.05059482E-08, -7.32366100E-10, -5.22518089E-11,
7 -3.79339169E-12, 2.18877223E-02, 2.18891059E-02, 2.18901436E-02,
8 2.18920464E-02, 2.18955065E-02, 2.19015636E-02, 2.19119529E-02,
9 2.19310185E-02, 2.19657448E-02, 2.20267078E-02, 2.21317887E-02/

DATA CH 24/

1 2.23263409E-02, 2.25956922E-02, 2.30087684E-02, 2.38202866E-02,
 2 2.49891583E-02, 2.67122164E-02, 2.94459970E-02, 3.60952709E-02,
 3 2.92743075E-03, -3.73647840E-02, -2.38681375E-02, -1.85748279E-02,
 4 -1.42447859E-02, -1.07616185E-02, -7.88376564E-03, -5.85888497E-03,
 5 -4.10243568E-03, -2.90808105E-03, -1.94826632E-03, -1.31904346E-03,
 6 -9.00545180E-04, -5.47062546E-04, -2.97330725E-04, -1.45238774E-04,
 7 -6.03779764E-05, -1.52779792E-05, -2.54593371E-06, -2.27744155E-07,
 8 -1.53482999E-08, -1.06903513E-09, -7.62254979E-11, -5.53125955E-12,
 9 2.36015431E-02, 2.36029258E-02, 2.36039630E-02, 2.36058645E-02/

DATA CH 25/

1 2.36093224E-02, 2.36153754E-02, 2.36257567E-02, 2.36448050E-02,
 2 2.36794912E-02, 2.37403567E-02, 2.38451879E-02, 2.40390035E-02,
 3 2.43067409E-02, 2.47159813E-02, 2.55150365E-02, 2.66539649E-02,
 4 2.83052241E-02, 3.08509749E-02, 3.47923899E-02, 4.46119530E-02,
 5 3.20503910E-03, -4.47187614E-02, -2.99247790E-02, -2.25420281E-02,
 6 -1.68110438E-02, -1.21916112E-02, -8.99598614E-03, -6.25826949E-03,
 7 -4.41481615E-03, -2.94457279E-03, -1.98669550E-03, -1.35260584E-03,
 8 -8.19247514E-04, -4.43981117E-04, -2.16298007E-04, -8.96923905E-05,
 9 -2.26304235E-05, -3.76143506E-06, -3.35701359E-07, -2.25853298E-08/

DATA CH 26/

1 -1.57126337E-09, -1.11939888E-10, -8.11753486E-12, 2.10819534E-02,
 2 2.10831118E-02, 2.10839807E-02, 2.10855737E-02, 2.10884705E-02,
 3 2.10935411E-02, 2.11022372E-02, 2.11181919E-02, 2.11472395E-02,
 4 2.11981948E-02, 2.12859096E-02, 2.14479200E-02, 2.16713789E-02,
 5 2.20121631E-02, 2.26748079E-02, 2.36128573E-02, 2.49588564E-02,
 6 2.69994181E-02, 3.00695593E-02, 3.50546660E-02, 4.82036877E-02,
 7 -7.97111783E-04, -4.87438566E-02, -3.09328678E-02, -2.26544845E-02,
 8 -1.62047269E-02, -1.18463299E-02, -8.17351975E-03, -5.73132332E-03,
 9 -3.80196984E-03, -2.55452966E-03, -1.73345966E-03, -1.04625341E-03/

DATA CH 27/

1 -5.65090551E-04, -2.74450106E-04, -1.13476006E-04, -2.85368603E-05,
 2 -4.72921747E-06, -4.20972316E-07, -2.82677419E-08, -1.96399356E-09,
 3 -1.39783925E-10, -1.01292468E-11, 1.80345087E-02, 1.80354466E-02,
 4 1.80361500E-02, 1.80374397E-02, 1.80397849E-02, 1.80438900E-02,
 5 1.80509298E-02, 1.80638448E-02, 1.80873553E-02, 1.81285880E-02,
 6 1.81995382E-02, 1.83304906E-02, 1.85109119E-02, 1.87856137E-02,
 7 1.93181999E-02, 2.00685569E-02, 2.11377479E-02, 2.27412677E-02,
 8 2.51123942E-02, 2.88515368E-02, 3.50495187E-02, 5.16632021E-02,
 9 3.00500586E-03, -5.10502016E-02, -3.11834652E-02, -2.18472301E-02/

DATA CH 28/

1 -1.57558003E-02, -1.07467788E-02, -7.47494351E-03, -4.92345064E-03,
 2 -3.29037961E-03, -2.22343494E-03, -1.33610350E-03, -7.18622045E-04,
 3 -3.47694325E-04, -1.43252461E-04, -3.58817234E-05, -5.92553698E-06,
 4 -5.25827462E-07, -3.52284403E-08, -2.44380886E-09, -1.73737228E-10,
 5 -1.25787831E-11, 1.64786075E-02, 1.64794279E-02, 1.64800433E-02,
 6 1.64811715E-02, 1.64832231E-02, 1.64868141E-02, 1.64929723E-02,
 7 1.65042692E-02, 1.65248325E-02, 1.65608906E-02, 1.66229198E-02,
 8 1.67373508E-02, 1.68948904E-02, 1.71344875E-02, 1.75980955E-02,
 9 1.82492013E-02, 1.91727468E-02, 2.05483911E-02, 2.25612944E-02/

DATA CH 29/

1 2.56821454E-02, 3.07104584E-02, 3.88090757E-02, 5.60828824E-02,
 2 1.38016993E-03, -5.70339351E-02, -3.20806211E-02, -2.27479574E-02,
 3 -1.52901387E-02, -1.05291477E-02, -6.87599889E-03, -4.56641458E-03,
 4 -3.07072472E-03, -1.83601908E-03, -9.82842417E-04, -4.73524685E-04,
 5 -1.94334826E-04, -4.84650274E-05, -7.97307566E-06, -7.05164855E-07,
 6 -4.71286473E-08, -3.26392278E-09, -2.31762737E-10, -1.67645871E-11,
 7 1.49382707E-02, 1.49389835E-02, 1.49395182E-02, 1.49404985E-02,
 8 1.49422810E-02, 1.49454010E-02, 1.49507513E-02, 1.49605658E-02,
 9 1.49784293E-02, 1.50097490E-02, 1.50636142E-02, 1.51629417E-02/

DATA CH 30/

1 1.52995974E-02, 1.55072323E-02, 1.59083061E-02, 1.64700506E-02,
 2 1.72637549E-02, 1.84392393E-02, 2.01445276E-02, 2.27531418E-02,
 3 2.68624659E-02, 3.32277631E-02, 4.20505558E-02, 6.32993021E-02,
 4 4.77638112E-03, -6.19856622E-02, -3.71436880E-02, -2.42903955E-02,
 5 -1.64402688E-02, -1.05882308E-02, -6.96335960E-03, -4.64839913E-03,
 6 -2.75889880E-03, -1.46685643E-03, -7.02504829E-04, -2.86746026E-04,
 7 -7.10852755E-05, -1.16341887E-05, -1.02437882E-06, -6.82424944E-08,
 8 -4.71587304E-09, -3.34334041E-10, -2.41552083E-11, 1.19676523E-02,
 9 1.19682039E-02, 1.19686175E-02, 1.19693759E-02, 1.19707550E-02/

DATA CH 31/

1 1.19731688E-02, 1.19773080E-02, 1.19849008E-02, 1.19987195E-02,
 2 1.20229452E-02, 1.20646023E-02, 1.21413936E-02, 1.22469917E-02,
 3 1.24073222E-02, 1.27166280E-02, 1.31489715E-02, 1.37581127E-02,
 4 1.46565416E-02, 1.59520156E-02, 1.79155963E-02, 2.09638003E-02,
 5 2.55738576E-02, 3.17370854E-02, 4.13539855E-02, 6.47330583E-02,
 6 -3.13002439E-03, -6.64300268E-02, -3.38972397E-02, -2.25383908E-02,
 7 -1.42927434E-02, -9.29930308E-03, -6.15889710E-03, -3.62688409E-03,
 8 -1.91468013E-03, -9.11336795E-04, -3.69930636E-04, -9.11557818E-05,
 9 -1.48423565E-05, -1.30108568E-06, -8.64017699E-08, -5.95801290E-09/

DATA CH 32/

1 -4.21745668E-10, -3.04351150E-11, 9.90213654E-03, 9.90257751E-03,
 2 9.90290825E-03, 9.90351464E-03, 9.90461728E-03, 9.90654721E-03,
 3 9.90985662E-03, 9.91592702E-03, 9.92697457E-03, 9.94634027E-03,
 4 9.97963508E-03, 1.00409936E-02, 1.01253323E-02, 1.02533023E-02,
 5 1.04998993E-02, 1.08439750E-02, 1.13275447E-02, 1.20382071E-02,
 6 1.30576130E-02, 1.45908932E-02, 1.69430759E-02, 2.04359677E-02,
 7 2.49835860E-02, 3.18044908E-02, 4.24883980E-02, 7.17810122E-02,
 8 8.67332704E-03, -6.89895852E-02, -3.75877207E-02, -2.31267135E-02,
 9 -1.47569239E-02, -9.64269831E-03, -5.60654549E-03, -2.92702753E-03/

DATA CH 33/

1 -1.38022587E-03, -5.55694562E-04, -1.35743764E-04, -2.19418569E-05,
 2 -1.91162598E-06, -1.26393983E-07, -8.69039953E-09, -6.13877527E-10,
 3 -4.42306311E-11, 8.17766125E-03, 8.17801593E-03, 8.17828196E-03,
 4 8.17876969E-03, 8.17965656E-03, 8.18120883E-03, 8.18387062E-03,
 5 8.18875298E-03, 8.19763809E-03, 8.21321213E-03, 8.23998502E-03,
 6 8.28931430E-03, 8.35709735E-03, 8.45989986E-03, 8.65784069E-03,
 7 8.93367940E-03, 9.32067034E-03, 9.88797957E-03, 1.06988496E-02,
 8 1.19121548E-02, 1.37590627E-02, 1.64702835E-02, 1.99453256E-02,
 9 2.50435890E-02, 3.27774721E-02, 4.59347375E-02, 7.42013248E-02/

DATA CH 34/

1 -3.84440691E-03, -7.61316789E-02, -3.61005009E-02, -2.25876634E-02,
 2 -1.45415779E-02, -8.33864216E-03, -4.30235527E-03, -2.00920297E-03,
 3 -8.02224334E-04, -1.94269373E-04, -3.11778855E-05, -2.70011013E-06,
 4 -1.77780823E-07, -1.21896014E-08, -8.59347250E-10, -6.18247844E-11,
 5 6.11252521E-03, 6.11278293E-03, 6.11297622E-03, 6.11333061E-03,
 6 6.11397502E-03, 6.11510290E-03, 6.11703692E-03, 6.12058433E-03,
 7 6.12703979E-03, 6.13835434E-03, 6.15780263E-03, 6.19362889E-03,
 8 6.24284199E-03, 6.31744633E-03, 6.46097742E-03, 6.66074206E-03,
 9 6.94051524E-03, 7.34963242E-03, 7.93233789E-03, 8.79983611E-03/

DATA CH 35/

1 1.01105399E-02, 1.20139653E-02, 1.44190263E-02, 1.78794221E-02,
 2 2.29776191E-02, 3.12457639E-02, 4.32092822E-02, 8.03682628E-02,
 3 7.96504037E-03, -7.77435659E-02, -3.82082769E-02, -2.39372959E-02,
 4 -1.33928966E-02, -6.77602270E-03, -3.11640595E-03, -1.22867876E-03,
 5 -2.93764570E-04, -4.66654415E-05, -4.00773967E-06, -2.62358411E-07,
 6 -1.79205213E-08, -1.25997124E-09, -9.04651546E-11, 4.84035718E-03,
 7 4.84055683E-03, 4.84070657E-03, 4.84098112E-03, 4.84148033E-03,
 8 4.84235409E-03, 4.84385235E-03, 4.84660042E-03, 4.85160115E-03,
 9 4.86036555E-03, 4.87542922E-03, 4.90317432E-03, 4.94127798E-03/

DATA CH 36/

1 4.99902191E-03, 5.11005101E-03, 5.26444026E-03, 5.48039520E-03,
 2 5.79563422E-03, 6.24351713E-03, 6.90795579E-03, 7.90675700E-03,
 3 9.34685632E-03, 1.11498855E-02, 1.37134602E-02, 1.74284831E-02,
 4 2.33075143E-02, 3.15464164E-02, 4.71303961E-02, 8.31860584E-02,
 5 -1.39809080E-03, -8.27387920E-02, -4.26914313E-02, -2.30114305E-02,
 6 -1.13291684E-02, -5.10872289E-03, -1.98326793E-03, -4.67128039E-04,
 7 -7.33488891E-05, -6.24146834E-06, -4.06032922E-07, -2.76215859E-08,
 8 -1.93648608E-09, -1.38742936E-10, 3.06078216E-03, 3.06090577E-03,
 9 3.06099849E-03, 3.06116847E-03, 3.06147755E-03, 3.06201853E-03/

DATA CH 37/

1 3.06294614E-03, 3.06464754E-03, 3.06774352E-03, 3.07316939E-03,
 2 3.08249429E-03, 3.09966707E-03, 3.12324631E-03, 3.15896846E-03,
 3 3.22761787E-03, 3.32299780E-03, 3.45626012E-03, 3.65047653E-03,
 4 3.92579238E-03, 4.33292826E-03, 4.94215751E-03, 5.81499105E-03,
 5 6.89908541E-03, 8.42487188E-03, 1.06056083E-02, 1.39880458E-02,
 6 1.85952310E-02, 2.69222098E-02, 3.97570231E-02, 8.17551485E-02,
 7 -2.09131453E-03, -8.11066235E-02, -3.25775813E-02, -1.56223141E-02,
 8 -6.89366661E-03, -2.63175306E-03, -6.10107245E-04, -9.46532067E-05,
 9 -7.97870666E-06, -5.15774840E-07, -3.49442591E-08, -2.44287458E-09/

DATA CH 38/

1 -1.74654400E-10, 2.40512571E-03, 2.40522114E-03, 2.40529272E-03,
 2 2.40542396E-03, 2.40566258E-03, 2.40608023E-03, 2.40679639E-03,
 3 2.40810991E-03, 2.41050005E-03, 2.41468874E-03, 2.42188700E-03,
 4 2.43514190E-03, 2.45333866E-03, 2.48089982E-03, 2.53384359E-03,
 5 2.60735450E-03, 2.70997012E-03, 2.85933438E-03, 3.07069863E-03,
 6 3.38249757E-03, 3.84744668E-03, 4.51040248E-03, 5.32899596E-03,
 7 6.47276667E-03, 8.09200038E-03, 1.05707708E-02, 1.38891885E-02,
 8 1.97365176E-02, 2.84560234E-02, 4.53047976E-02, 8.93548007E-02,
 9 1.14633644E-02, -8.50321604E-02, -2.84309792E-02, -1.22811274E-02/

DATA CH 39/

1 -4.58861788E-03, -1.04252349E-03, -1.59353873E-04, -1.32809492E-05,
 2 -8.52138923E-07, -5.74588777E-08, -4.00355036E-09, -2.85539274E-10,
 3 2.01712685E-03, 2.01720552E-03, 2.01726451E-03, 2.01737268E-03,
 4 2.01756936E-03, 2.01791361E-03, 2.01850388E-03, 2.01958652E-03,
 5 2.02155648E-03, 2.02500871E-03, 2.03094102E-03, 2.04186369E-03,
 6 2.05685634E-03, 2.07955939E-03, 2.12315372E-03, 2.18364614E-03,
 7 2.26801810E-03, 2.39068326E-03, 2.56398272E-03, 2.81904874E-03,
 8 3.19818241E-03, 3.73643021E-03, 4.39752935E-03, 5.31530603E-03,
 9 6.60386497E-03, 8.55456517E-03, 1.11290500E-02, 1.55742879E-02/

DATA CH 40/

1 2.20122110E-02, 3.39250844E-02, 5.36878777E-02, 9.95979074E-02,
 2 7.38783044E-03, -9.50072179E-02, -2.79356771E-02, -1.01851683E-02,
 3 -2.24587849E-03, -3.36029960E-04, -2.75671564E-05, -1.75095562E-06,
 4 -1.17317849E-07, -8.13872981E-09, -5.78618369E-10, 1.33691378E-03,
 5 1.33696491E-03, 1.33700326E-03, 1.33707358E-03, 1.33720143E-03,
 6 1.33742520E-03, 1.33780889E-03, 1.33851262E-03, 1.33979310E-03,
 7 1.34203698E-03, 1.34589263E-03, 1.35299095E-03, 1.36273259E-03,
 8 1.37748057E-03, 1.40578764E-03, 1.44504138E-03, 1.49974151E-03,
 9 1.57916833E-03, 1.69118670E-03, 1.85566113E-03, 2.09931507E-03/

DATA CH 41/

1 2.44365704E-03, 2.86428333E-03, 3.44438938E-03, 4.25209311E-03,
 2 5.46149607E-03, 7.03592367E-03, 9.70370806E-03, 1.34682349E-02,
 3 2.01665716E-02, 3.06303250E-02, 4.73318755E-02, 1.06574541E-01,
 4 6.58083280E-03, -9.85451697E-02, -2.41064074E-02, -5.12218188E-03,
 5 -7.41842410E-04, -5.94664130E-05, -3.72309705E-06, -2.47259455E-07,
 6 -1.70506064E-08, -1.20694890E-09, 7.78854591E-04, 7.78883836E-04,
 7 7.78905770E-04, 7.78945986E-04, 7.79019109E-04, 7.79147093E-04,
 8 7.79366544E-04, 7.79769034E-04, 7.80501380E-04, 7.81784680E-04,
 9 7.83989647E-04, 7.88048628E-04, 7.93618284E-04, 8.02048402E-04/

DATA CH 42/

1 8.18222883E-04, 8.40638968E-04, 8.71850601E-04, 9.17120249E-04,
 2 9.80866557E-04, 1.07426366E-03, 1.21221123E-03, 1.40639039E-03,
 3 1.64246567E-03, 1.96622437E-03, 2.41386451E-03, 3.07813259E-03,
 4 3.93352139E-03, 5.36225587E-03, 7.34083699E-03, 1.07710625E-02,
 5 1.59396774E-02, 2.38349433E-02, 4.14797560E-02, 1.10667846E-01,
 6 6.69476806E-03, -1.00490686E-01, -8.34055502E-03, -1.38819796E-03,
 7 -1.12607643E-04, -7.04375324E-06, -4.66733399E-07, -3.21186259E-08,
 8 -2.26965265E-09, 4.45876399E-04, 4.45892830E-04, 4.45905154E-04,
 9 4.45927749E-04, 4.45968832E-04, 4.46040738E-04, 4.46164033E-04/

DATA CH 43/

1 4.46390164E-04, 4.46801609E-04, 4.47522568E-04, 4.48761254E-04,
 2 4.51041255E-04, 4.54169369E-04, 4.58903016E-04, 4.67981895E-04,
 3 4.80557056E-04, 4.98052784E-04, 5.23401307E-04, 5.59042637E-04,
 4 6.11155327E-04, 6.87908451E-04, 7.95544891E-04, 9.25829005E-04,
 5 1.10358370E-03, 1.34780443E-03, 1.70733573E-03, 2.16596771E-03,
 6 2.92284891E-03, 3.95529451E-03, 5.71016659E-03, 8.28724061E-03,
 7 1.21018809E-02, 2.02805452E-02, 3.94082016E-02, 1.19326015E-01,
 8 2.58470846E-02, -9.46027264E-02, -2.39823456E-03, -3.28979558E-04,
 9 -2.15337590E-05, -1.44104765E-06, -9.94313398E-08, -7.02990926E-09/

DATA CH 44/

1 1.91892428E-04, 1.91899370E-04, 1.91904577E-04, 1.91914122E-04,
 2 1.91931479E-04, 1.91961858E-04, 1.92013946E-04, 1.92109479E-04,
 3 1.92283299E-04, 1.92587867E-04, 1.93111123E-04, 1.94074172E-04,
 4 1.95395272E-04, 1.97394042E-04, 2.01226243E-04, 2.06531377E-04,
 5 2.13906976E-04, 2.24582219E-04, 2.39571298E-04, 2.61445769E-04,
 6 2.93578931E-04, 3.38486848E-04, 3.92625716E-04, 4.66147726E-04,
 7 5.66593618E-04, 7.13435719E-04, 8.99238192E-04, 1.20277877E-03,
 8 1.61173826E-03, 2.29607918E-03, 3.28165543E-03, 4.70753692E-03,
 9 7.66612215E-03, 1.42774187E-02, 3.06073228E-02, 1.11348077E-01/

DATA CH 45/

1 9.05174743E-03, -9.10890130E-02, 4.23839019E-03, 6.52943626E-05,
 2 1.76371806E-06, 4.67683038E-08, 4.29648844E-10, 3.88348135E-05,
 3 3.88361829E-05, 3.88372100E-05, 3.88390931E-05, 3.88425171E-05,
 4 3.88485098E-05, 3.88587853E-05, 3.88776307E-05, 3.89119188E-05,
 5 3.89719962E-05, 3.90752038E-05, 3.92651340E-05, 3.95256307E-05,
 6 3.99196469E-05, 4.06747385E-05, 4.17193111E-05, 4.31701504E-05,
 7 4.52672436E-05, 4.82063665E-05, 5.24848668E-05, 5.87483530E-05,
 8 6.74626885E-05, 7.79135491E-05, 9.20210692E-05, 1.11156157E-04,
 9 1.38882621E-04, 1.73609351E-04, 2.29633624E-04, 3.03982032E-04/

DATA CH 46/

1 4.26086041E-04, 5.97959532E-04, 8.40167451E-04, 1.32446578E-03,
 2 2.34418068E-03, 4.64229330E-03, 1.03060732E-02, 1.02579871E-01,
 3 1.40535965E-02, -8.03045607E-02, 5.76840587E-03, 1.50710934E-04,
 4 6.92153933E-06, 3.81045304E-07, 4.55312566E-06, 4.55328223E-06,
 5 4.55339966E-06, 4.55361495E-06, 4.55400643E-06, 4.55469159E-06,
 6 4.55586639E-06, 4.55802098E-06, 4.56194105E-06, 4.56880930E-06,
 7 4.58060760E-06, 4.60231729E-06, 4.63208792E-06, 4.67710664E-06,
 8 4.76334352E-06, 4.88256254E-06, 5.04800120E-06, 5.28683607E-06,
 9 5.62100286E-06, 6.10633382E-06, 6.81460776E-06, 7.79601868E-06/

DATA CH 47/

1 8.96748562E-06, 1.05404093E-05, 1.26603932E-05, 1.57087088E-05,
 2 1.94936487E-05, 2.55363991E-05, 3.34578555E-05, 4.62779780E-05,
 3 6.40158596E-05, 8.85481005E-05, 1.36412175E-04, 2.33722148E-04,
 4 4.43310225E-04, 9.62549398E-04, 2.23092560E-03, 8.73151804E-02,
 5 2.71444166E-03, -7.68157795E-02, 5.10252445E-03, 1.27671125E-04,
 6 5.67396829E-06, -7.73402679E-08, -7.73434165E-08, -7.73457781E-08,
 7 -7.73501078E-08, -7.73579807E-08, -7.73717602E-08, -7.73953878E-08,
 8 -7.74387240E-08, -7.75175795E-08, -7.76557706E-08, -7.78932455E-08,
 9 -7.83305118E-08, -7.89307593E-08, -7.98398026E-08, -8.15856703E-08/

DATA CH 48/
1-8.40089168E-08,-8.73898190E-08,-9.23069411E-08,-9.92561203E-08,
2-1.09485909E-07,-1.24687480E-07,-1.46242275E-07,-1.72647247E-07,
3-2.09135396E-07,-2.59971094E-07,-3.35959627E-07,-4.34381901E-07,
4-5.99372871E-07,-8.27837373E-07,-1.22141783E-06,-1.80526801E-06,
5-2.67343677E-06,-4.52838449E-06,-8.80740898E-06,-1.47946979E-05,
6-5.57319213E-05,-3.16220538E-04,-4.67708855E-03, 7.98809888E-02,
7-1.74624993E-03,-7.73015278E-02, 5.08110768E-03, 1.26415472E-04,
8-2.35229915E-08,-2.35238254E-08,-2.35244508E-08,-2.35255975E-08,
9-2.35276826E-08,-2.35313319E-08,-2.35375891E-08,-2.35490651E-08/
DATA CH 49/
1-2.35699450E-08,-2.36065296E-08,-2.36693794E-08,-2.37850421E-08,
2-2.39436824E-08,-2.41836442E-08,-2.46435373E-08,-2.52798064E-08,
3-2.61636631E-08,-2.74414620E-08,-2.92327810E-08,-3.18412956E-08,
4-3.56617144E-08,-4.09799727E-08,-4.73618779E-08,-5.59823597E-08,
5-6.76834284E-08,-8.46519064E-08,-1.05922602E-07,-1.40270863E-07,
6-1.85900967E-07,-2.60930271E-07,-3.66694583E-07,-5.16006631E-07,
7-8.15470672E-07,-1.45050597E-06,-2.91340829E-06,-7.04558759E-06,
8-2.99192566E-05,-2.26323937E-04,-5.82515447E-03, 7.79801956E-02,
9 2.64981937E-05,-7.72380706E-02, 5.08455687E-03,-1.10721562E-09/
DATA CH 50/
1-1.10725448E-09,-1.10728363E-09,-1.10733706E-09,-1.10743423E-09,
2-1.10760428E-09,-1.10789586E-09,-1.10843063E-09,-1.10940360E-09,
3-1.11110836E-09,-1.11403694E-09,-1.11942618E-09,-1.12681742E-09,
4-1.13799643E-09,-1.15941759E-09,-1.18904619E-09,-1.23018909E-09,
5-1.28963998E-09,-1.37292604E-09,-1.49409450E-09,-1.67133328E-09,
6-1.91765674E-09,-2.21268824E-09,-2.61035604E-09,-3.14876883E-09,
7-3.92717721E-09,-4.89960462E-09,-6.46347526E-09,-8.53112373E-09,
8-1.19118032E-08,-1.66462726E-08,-2.32831944E-08,-3.64734820E-08,
9-6.40818411E-08,-1.26528298E-07,-2.98194168E-07,-1.19785294E-06/
DATA CH 51/
1-8.01992633E-06,-1.26283859E-04,-5.07820452E-03, 7.73783206E-02,
2 5.35582696E-03,-1.43906176E-01,-8.42356555E-11,-8.42385674E-11,
3-8.42407515E-11,-8.42447557E-11,-8.42520365E-11,-8.42647795E-11,
4-8.42866291E-11,-8.43267015E-11,-8.43996095E-11,-8.45273508E-11,
5-8.47467877E-11,-8.51505756E-11,-8.57043109E-11,-8.65417017E-11,
6-8.81459237E-11,-9.03639825E-11,-9.34424940E-11,-9.78878527E-11,
7-1.04109656E-10,-1.13150043E-10,-1.26351379E-10,-1.44658354E-10,
8-1.66530972E-10,-1.95930758E-10,-2.35606951E-10,-2.92748415E-10,
9-3.63830105E-10,-4.77578458E-10,-6.27122117E-10,-8.70043981E-10/
DATA CH 52/
1-1.20775676E-09,-1.67755564E-09,-2.60232678E-09,-4.51267404E-09,
2-8.75886974E-09,-2.01539927E-08,-7.73451278E-08,-4.77509588E-07,
3-6.26368061E-06,-1.38811220E-04,-5.35582696E-03, 6.66666667E-02,
4 1.38689160E-01/
END

```

SUBROUTINE CONVEC
COMMON /ABROSS/ABROSS(40),TAJROS(40)
COMMON /CONV/DLTDLF(40),HEATCP(40),DLRDLT(40),VELSND(40),
1      GRDALR(40),HSCALE(40),FLXCNV(40),VCNV(40),MIXLTH,
      IFCNV
      REAL MIXLTH
COMMON /IF/IFCORR,IFPRES,IFSURF,IFSCAT,IFMOL
COMMON /IONS/XNFPH(40,2),XNFPHE(40,3)
COMMON /PTOTAL/PTOTAL(40)
COMMON /RAD/ACCRAD(40),PRAD(40)
COMMON /RHUX/RHUX(40),NRHUX
COMMON /STATL/P(40),XNE(40),XNATOM(40),RHO(40)
COMMON /TEMP/T(40),TKEV(40),TK(40),HKT(40),TLOG(40),ITEMP
COMMON /TEFF/TEFF,GRAV,GLUG
COMMON /TURBPR/VTURB(40),PTURB(40),TRBFDG,TRBCON,TRBPOW,TRBSND,
1      IFTURB
COMMON /XABUND/XABUND(99),WTMOLE
DIMENSION EQ(4),DEQ(4,4),DUMMY(4)
DIMENSION TNEW(4),PNEW(4),ENERGY(4),RHON(4)
DIMENSION DTDRHX(40)
EQUIVALENCE (DTDRHX(1),DLTDLF(1))
CALL DERIV(RHUX,T,DTDRHX,NRHUX)
C      CALCULATE DERIVATIVES BY EVALUATING FUNCTIONS AT + AND - .001
C      FIRST GUESSES
XH=AMAX1(XABUND(1),1.E-20)
XHE=AMAX1(XABUND(2),1.E-20)
XNHE1=XNATOM(1)*XHE
XNH1=XNFPH(1,1)*2.
XNAT=XNATOM(1)
XNEL=XNE(1)
DO 30 J=1,NRHUX
TNEW(1)=T(J)*1.001
PNEW(1)=P(J)
TNEW(2)=T(J)*.999
PNEW(2)=P(J)
TNEW(3)=T(J)
PNEW(3)=P(J)*1.001
TNEW(4)=T(J)
PNEW(4)=P(J)*.999
DO 15 I=1,4
TN=TNEW(I)
TKN=TN*1.3804E-16
TKEVN=TN*8.6171E-5
XNTOT=PNEW(I)/TKN
CT32=2.4148E15*TN*SQRT(TN)
CEQH2=CT32*EXP(-13.595/TKEVN)
CEQH4=0.
IF(TN.LT.10000.)CEQHH=EXP(4.477/TKEVN-4.6628E1+(1.8031E-3+
1(-5.0239E-7+(8.1424E-11-5.0501E-15*TN)*TN)*TN)*TN-1.5*ALOG(TN))
C      THE AMIN IS FOR ANY UNFORTUNATE WHO HAS A 360
CEQHE2=4.*CT32*EXP(-AMIN1(24.580/TKEVN,150.))
CEQHE3=4.*CT32**2*EXP(-AMIN1(78.983/TKEVN,150.))
DO 13 K=1,100
XNH2=XNH1*CEQH2/XNEL
XNH4=XNH1**2*CEQHH
XNHE2=XNHE1*CEQHE2/XNEL
XNHE3=XNHE1*CEQHE3/XNEL**2
EQ(1)=XNH1+XNH2+2.*XNH4-XH*XNAT
EQ(2)=XNHE1+XNHE2+XNHE3-XHE*XNAT
EQ(3)=XNH2+XNHE2+2.*XNHE3-XNEL
EQ(4)=XNH1+XNH2+XNH4+XNHE1+XNHE2+XNHE3+XNEL-XNTOT

```

```

DEQ(1,1)=(XNH1+XNH2+4.*XNHH)/XNH1
DEQ(1,2)=0.
DEQ(1,3)=-XH
DEQ(1,4)=-XNH2/XNEL
DEQ(2,1)=0.
DEQ(2,2)=(XNHE1+XNHE2+XNHE3)/XNHE1
DEQ(2,3)=-XHE
DEQ(2,4)=(-XNHE2-2.*XNHE3)/XNEL
DEQ(3,1)=XNH2/XNH1
DEQ(3,2)=(XNHE2+XNHE3)/XNHE1
DEQ(3,3)=0.
DEQ(3,4)=(-XNH2-XNHE2-4.*XNHE3-XNEL)/XNEL
DEQ(4,1)=(XNH1+XNH2+2.*XNHH)/XNH1
DEQ(4,2)=(XNHE1+XNHE2+XNHE3)/XNHE1
DEQ(4,3)=0.
DEQ(4,4)=(-XNH2-XNHE2-2.*XNHE3+XNEL)/XNEL
C CALL SOLVIT(DEQ,4,EQ,DUMMY)
Q1311=DEQ(1,3)/DEQ(1,1)
Q1411=DEQ(1,4)/DEQ(1,1)
E111=EQ(1)/DEQ(1,1)
Q2322=DEQ(2,3)/DEQ(2,2)
Q2422=DEQ(2,4)/DEQ(2,2)
E222=EQ(2)/DEQ(2,2)
Q3431=DEQ(3,4)/DEQ(3,1)
Q3231=DEQ(3,2)/DEQ(3,1)
E331=EQ(3)/DEQ(3,1)
Q4441=DEQ(4,4)/DEQ(4,1)
Q4241=DEQ(4,2)/DEQ(4,1)
E441=EQ(4)/DEQ(4,1)
Q003=Q1311+Q2322*Q3231
Q004=Q1311+Q2322*Q4241
Q0003=(Q1411+Q2422*Q3231-Q3431)/Q003
EQ003=(E111+E222*Q3231-E331)/Q003
Q0004=(Q1411+Q2422*Q4241-Q4441)/Q004
EQ004=(E111+E222*Q4241-E441)/Q004
EQ(4)=(EQ004-E0003)/(Q0004-Q0003)
EQ(3)=EQ003-Q0003*EQ(4)
EQ(2)=E222-Q2422*EQ(4)-Q2322*EQ(3)
EQ(1)=E111-Q1411*EQ(4)-Q1311*EQ(3)
ERROR=ABS(EQ(1)/XNH1)+ABS(EQ(2)/XNHE1)+ABS(EQ(3)/XNAT)+
1 ABS(EQ(4)/XNEL)
XNH1=XNH1-EQ(1)
XNHE1=XNHE1-EQ(2)
XNAT=XNAT-EQ(3)
XNEL=XNEL-EQ(4)
IF(ERROR.LT..00001)GO TO 14
13 CONTINUE
CALL EXIT
14 XNH2=XNH1*CEQH2/XNEL
XNHH=XNH1**2*CEQHH
XNHE2=XNHE1*CEQHE2/XNEL
XNHE3=XNHE1*CEQHE3/XNEL**2
EHH=-4.476/TKEVN+(1.*(1.8031E-3)+(2.*(-5.0739E-7)+(3.*(8.1424E-11)
1 +4.*(-5.0501E-15)*TN)*TN)*TN)*TN
RHON(I)=XNAT*WTMOLE*1.660E-24
15 ENERGY(I)=((1.5*XNTOT+13.595/TKEVN*XNH2+EHH*XNHH+
1 24.580/TKEVN*XNHE2+78.983/TKEVN*XNHE3)*TKN+
2 3.*PRAD(J)*(TN/T(J))**4)/RHON(I)
DEDT=(ENERGY(1)-ENERGY(2))/T(J)*500.
DRDT=(RHON(1)-RHON(2))/T(J)*500.

```

```

DEDPG=(ENERGY(3)-ENERGY(4))/P(J)*500.
DRDPG=(RHON(3)-RHON(4))/P(J)*500.
C
C CALCULATE THERMODYNAMIC QUANTITIES AND CONVECTIVE FLUX
C IGNORING PTURB AND ASSUMING PRAL PROPORTIONAL TO T**4
DPDPG=1.
DPDT=4.*PRAD(J)/T(J)
DLTDLP(J)=PTOTAL(J)/T(J)/GRAV*DTDRHX(J)
HEATCV=DEDT-DEDPG*DRDT/DKDPG
HEATCP(J)=DEDT-DEDPG*DPDT/DPDPG-PTOTAL(J)/RHO(J)**2*(DRDT-
1 DRDPG*DPDT/DPDPG)
VELSND(J)=SQRT(HEATCP(J)/HEATCV*DPDPG/DRDPG)
DLRDLT(J)=T(J)/RHO(J)*(DRDT-DRDPG*DPDT/DPDPG)
GRDADB(J)=-PTOTAL(J)/RHO(J)/T(J)*DLRDLT(J)/HEATCP(J)
HSCALE(J)=PTOTAL(J)/RHO(J)/GRAV
VCONV(J)=0.
FLXCNV(J)=0.
IF(MIXLTH.EQ.0.)GO TO 30
DEL=DLTDLP(J)-GRDADB(J)
IF(DEL.LT.0.)GO TO 30
VCO=.5*MIXLTH*SQRT(-.5*PTOTAL(J)/RHO(J)*DLRDLT(J))
FLUXCO=.5*RHO(J)*HEATCP(J)*T(J)*MIXLTH/12.5664
D=8.*5.6697E-5*T(J)**4/(ABROSS(J)*HSCALE(J)*RHO(J))/
1 (FLUXCO*12.5664)/VCO
D=D**2/2.
DDD=(DEL/(D+DEL))**2
IF(DDD.LT..5)GO TO 24
DELTA=(1.-SQRT(1.-DDD))/DDD
GO TO 26
24 DELTA=.5
TERM=.5
JP=-1.
DOWN=2.
25 JP=JP+2.
DOWN=DOWN+2.
TERM=UP/DOWN*DDD*TERM
DELTA=DELTA+TERM
IF(TERM.GT.1.E-6)GO TO 25
26 DELTA=DELTA*DEL**2/(D+DEL)
VCONV(J)=VCO*SQRT(DELTA)
FLXCNV(J)=FLUXCO*VCONV(J)*DELTA
30 CONTINUE
RETURN
END

```



```

SUBROUTINE HIGH
COMMON /ABTOT/ABTOT(40),ALPHA(40)
COMMON /HEIGHT/HEIGHT(40)
COMMON /RHOX/RHOX(40),NRHOX
COMMON /STATE/P(40),XNE(40),XNATOM(40),RHO(40)
DIMENSION RHOINV(40)
EQUIVALENCE (RHOINV(1),ABTOT(1))
DO 1 J=1,NRHOX
1 RHOINV(J)=1.E-5/RHO(J)
CALL INTEG(RHOX,RHOINV,HEIGHT,NRHOX)
RETJRN
END

```

```

SUBROUTINE TURB
COMMON /CONV/DLTDLP(40),HEATCP(40),DLRDLT(40),VELSND(40),
1 GRDADB(40),HSCALE(40),FLXCNV(40),VCONV(40),MIXLTH,
2 IFCONV
REAL MIXLTH
COMMON /RHOX/RHOX(40),NRHOX
COMMON /STATE/P(40),XNE(40),XNATOM(40),RHO(40)
COMMON /TURBPR/VTURB(40),PTJRB(40),TRBFDG,TRBCON,TRBPOW,TRBSND,
1 IFTURB
DO 10 J=1,NRHOX
VTURB(J)=(TRBFDG*RHO(J)**TRBPOW+TRBSND*VELSND(J)/1.E5+TRBCON)*1.E5
10 PTURB(J)=RHO(J)*VTURB(J)**2*0.5
RETJRN
END

```

9. UTILITY PROGRAMS

9.1 FRESET

Given a list of frequencies, FRESET (pages 1 to 3 in the listing in Section 9.5) computes least-squares parabolic integration coefficients, which are defined in Section 2.6. FRESET punches the frequencies and integration coefficients in a format that can be read by READIN.

Below we list a sample input deck for FRESET. First comes the name of the frequency set and then the list of frequencies or wavelengths that FRESET reads using subroutines FREEFR and FREEFF from ATLAS5. Negative numbers represent discontinuities, which FRESET divides into two, one frequency on each side of the discontinuity. The end of the data is marked with a 0.

```
COOL
H -3.28805E15,-.8220125E15,-3.6533889E14,-.205503125E15,-.131522E15,
  -9.1334722E13,-6.7103061E13,-5.1375781E13,-4.0593210E13,-3.28805E13
HMINJS -1641.9
C -2.7254E15,-2.4196E15,-2.0761E15
AL -1.443E15
MG -1.8488510E15,-1.1925797E15,-7.9804046E14
SI -1.9723165E15,-1.7879689E15,-1.5152920E15
.195E15,.23E15,.26E15,.30E15,.33E15,.4E15,.45E15,.5E15,.55E15,
.6E15,.65E15,.7E15,.75E15,.85E15,.9E15,
.95E15,1.E15,1.05E15,1.1E15,1.15E15,
1.25E15,1.3E15,1.35E15,1.4E15,1.55E15,1.6E15,1.65E15,1.75E15,
1.82E15,1.9E15,2.02E15
2.2E15,2.3E15,2.5E15,2.6E15,2.8E15,3.E15
0.
```

The easiest way to use FRESET is to start by reading in all the discontinuities required. FRESET will print them out in order with integration weights indicative of their spacing. With this information, intermediate frequencies can be chosen easily.

9.2 PRETAB

PRETAB (pages 4 to 10) computes integration matrices for the radiation field as described in Section 2.6. The dimensions are set for a maximum of 80 τ 's, which are listed in the statement DATA TAU. Instructions are given by defining the variables NTAU, IFJ, IFH, and IFPUN. PRETAB also requires subroutine EXPI from ATLAS5.

9.3 ATLAS5 for TTAUP

This is a modified version of ATLAS5 (pages 11 and 12) that produces an opacity table for TTAUP. It is run just as if ATLAS5 were computing a model.

9.4 REDIME

REDIME redimensions all the arrays in ATLAS5 that are dimensioned 40 to any dimension up to 99. A card with the new dimension precedes the deck to be converted. The deck is followed by a card with 0 in column 1.

9.5 Listing of Programs

```

PROGRAM FRESET(INPUT,OUTPUT,PUNCH,TAPE5=INPUT,TAPE6=OUTPUT,
1TAPE7=PUNCH)
  DIMENSION FREQIN(1000),FREQ(1000),RCO(1000)
  DIMENSION A(1000)
  COMMON /FREE/WORD(6),NUMCOL,LETCOL,LAST,MORE,IFFAIL,MAXPOW
  DIMENSION CARD(81)
  DATA CARD/81*1H /
  MAXPOW=99
  LAST=81
  NUMCOL=1
90 DO 1 I=1,1000
  1 RCO(I)=0.
  READ (5,2)ALABEL
  2 FORMAT(A6)
  WRITE(6,80)
80 FORMAT(1H1)
C
  IN=1
10 FREQIN(IN)=FREEFR(CARD)
  IF(FREQIN(IN).EQ.0.)GO TO 11
  IF(ABS(FREQIN(IN)).LT.1.E6)FREQIN(IN)=2.997925E17/FREQIN(IN)
  IN=IN+1
  GO TO 10
11 DO 12 I=1,IN
  A(I)=ABS(FREQIN(I))
12 WRITE(6,70)I,FREQIN(I),A(I)
70 FORMAT(I5,2E20.8)
C
  DO 16 LAST=2,IN
  LAST1=IN-LAST+2
  DO 15 I=2,LAST1
  IF(A(I).GE.A(I-1))GO TO 15
  SAVE=A(I-1)
  A(I-1)=A(I)
  A(I)=SAVE
  SAVE=FREQIN(I-1)
  FREQIN(I-1)=FREQIN(I)
  FREQIN(I)=SAVE
15 CONTINUE
16 CONTINUE
  WRITE(6,80)
  DO 17 I=1,IN
17 WRITE(6,70)I,FREQIN(I),A(I)
C
  WRITE(6,80)
  J=1
  DO 22 I=1,IN
  FREQ(J)=A(I)
  J=J+1
  IF(FREQIN(I).GE.0.)GO TO 22
  IF(I.EQ.IN)GO TO 22
  FREQ(J)=A(I)
  J=J+1
22 CONTINUE
  NJ=J-1
  DO 23 J=1,NJ
23 WRITE(6,70)J,FREQ(J)
C
  K1=1
  DO 39 J=1,NJ

```

```

      IF(J.EQ.NJ)GO TO 32
      IF(FREQ(J+1).NE.FREQ(J))GO TO 39
32  K2=J
      NUM=K2-K1+1
      IF(NUM.GT.2)GO TO 33
      W=(FREQ(J)-FREQ(J-1))/2.
      RCO(J)=W
      RCO(J-1)=W
      K1=K2+1
      GO TO 39
33  K21=K2-1
      DO 35 K=K1,K21
      M=K-K1+1
      DO 34 L=K1,K2
      N=L-K1+1
      RCO(L)=RCO(L)+(FREQ(K+1)-FREQ(K))*PARCO(M,1,N,FREQ(K1),NUM)+
      1(FREQ(K+1)**2-FREQ(K)**2)/2.*PARCO(M,2,N,FREQ(K1),NUM)+
      2(FREQ(K+1)**3-FREQ(K)**3)/3.*PARCO(M,3,N,FREQ(K1),NUM)
34  CONTINUE
35  CONTINUE
      K1=K2+1
39  CONTINUE
C
      NJ1=NJ-1
      DO 45 J=1,NJ1
      IF(FREQ(J+1).NE.FREQ(J))GO TO 45
      FREQ(J)=FREQ(J)*.999999
      FREQ(J+1)=FREQ(J+1)*1.000001
45  CONTINUE
      IF(FREQ(IN).LT.0.)FREQ(NJ)=FREQ(NJ)*.999999
      WRITE(6,80)
      WRITE(6,77)NJ1,NJ1,ALABEL
      WRITE(7,77)NJ1,NJ1,ALABEL
77  FORMAT(17H READ FREQUENCIES,15,29H VALUES. INTEGRATE FROM 1 TO,
      115, 3H, A6,11H IS THE ID.)
      DO 41 J=2,NJ
      J1=J-1
      WRITE(7,70)J1,FREQ(J),RCO(J)
41  WRITE(6,70)J1,FREQ(J),RCO(J)
      CALL EXIT
      END

```

```

FUNCTION PARCO(J,K,I,TAU,NTAU)
DIMENSION TAU(1)
PARCO=0.
JI2=I-J+2
IF(JI2.LT.1.OR.JI2.GT.4)RETURN
IF(J.EQ.1)GO TO 100
IF(J.EQ. NTAU-1)GO TO 200
X1=TAU(J-1)
X2=TAU(J)
X3=TAU(J+1)
X4=TAU(J+2)
D=X1**2+X4**2-(X2+X3)*(X1+X4)+2.*X2*X3
XXD=(X2-X3)*D

```

```

      GO TO (10,20,30,40),J12
10  GO TO (11,12,13),K
11  PARCO=X2*X3/D
      RETJRN
12  PARCO=-(X2+X3)/D
      RETJRN
13  PARCO=1./D
      RETURN
20  GO TO (21,22,23),K
21  PARCO=X3*(-X1**2-X4**2+X3*X1+X3*X4)/XXD
      RETJRN
22  PARCO=(X1**2-2.*X3**2+X4**2)/XXD
      RETJRN
23  PARCO=(-X1+2.*X3-X4)/XXD
      RETJRN
30  GO TO (31,32,33),K
31  PARCO=X2*(X1**2+X4**2-X2*X1-X2*X4)/XXD
      RETJRN
32  PARCO=(-X1**2+2.*X2**2-X4**2)/XXD
      RETJRN
33  PARCO=(X1-2.*X2+X4)/XXD
      RETJRN
40  GO TO (41,42,43),K
41  PARCO=X2*X3/D
      RETJRN
42  PARCO=-(X2+X3)/D
      RETURN
43  PARCO=1./D
      RETURN
100 X1=TAU(1)
     X2=TAU(2)
     X3=TAU(3)
     GO TO (110,120,130),I
110 GO TO (111,112,113),K
111 PARCO=X2*X3/(X1-X2)/(X1-X3)
     RETJRN
112 PARCO=-(X2+X3)/(X1-X2)/(X1-X3)
     RETJRN
113 PARCO=1./(X1-X2)/(X1-X3)
     RETJRN
120 GO TO(121,122,123),K
121 PARCO=X1*X3/(X2-X1)/(X2-X3)
     RETJRN
122 PARCO=-(X1+X3)/(X2-X1)/(X2-X3)
     RETURN
123 PARCO=1./(X2-X1)/(X2-X3)
     RETURN
130 GO TO(131,132,133),K
131 PARCO=X1*X2/(X3-X1)/(X3-X2)
     RETJRN
132 PARCO=-(X1+X2)/(X3-X1)/(X3-X2)
     RETJRN
133 PARCO=1./(X3-X1)/(X3-X2)
     RETURN
200 X1=TAU(NTAU-2)
     X2=TAU(NTAU-1)
     X3=TAU(NTAU)
     I3=I-NTAU+3
     GO TO (110,120,130),I3
     END

```

```

PROGRAM PRETAB(OUTPUT,PUNCH,TAPE6=OUTPUT,TAPE7=PUNCH)
COMMON COEF(80,80)
DIMENSION CO(6400),S(80),TAJ(81),F(80),EXACT(80),ERROR(80)
EQUIVALENCE(COEF,CO)
DIMENSION LABEL(2)
DIMENSION A(4),B(4),C(4),D(4)
DATA TAJ/0.,.000032,.000056,.0001,.00018,.00032,
1.00056,.001,.0018,.0032,.0056,.01,.016,.025,.042,.065,
2.096,.139,.196,.273,.375,.5,.63,.78,.95,1.15,1.35,1.6,1.85,2.15,
32.45,2.75,3.15,3.65,4.25,5.0,6.2,7.8,10.,12.5,15.,17.5,20./
DATA LABEL/3HCH ,3HCH /
DATA A,B,C,D/1.,0.,0.,1.,0.,1.,0.,1.,0.,0.,1.,0.,0.,1.,0.,0.,0.,0.,1./
NTAU=43
IFJ=1
IFJ=0
IFH=0
IFH=1
IFPJN=0
IFPJN=1
TAU(NTAJ+1)=TAU(NTAU)+1000.
NFIRST=1
NLASt=2
IF(IFJ.EQ.0)NFIRST=2
IF(IFH.EQ.0)NLASt=1
DO 50 N=NFIRST,NLASt
CALL INTCO(COEF,TAU,NTAU,N)
WRITE(6,200)
200 FORMAT(1H1)
DO 201 L=1,NTAU
201 WRITE(6,202)(COEF(L,J),J=1,NTAU)
202 FORMAT(/(X10E13.5))
DO 70 M=1,4
DO 3 L=1,NTAU
CALL ANALYT(TAU(L),S(L),EJ,EH,A(M),B(M),C(M),D(M))
EXACT(L)=EJ
IF(N.EQ.2)EXACT(L)=EH
3 CONTINUE
DO 9 L=1,NTAU
F(L)=0.
DO 1 J=1,NTAU
1 F(L)=F(L)+COEF(L,J)*S(J)
9 ERROR(L)=(F(L)-EXACT(L))/EXACT(L)
N1=A(M)
N2=B(M)
N3=C(M)
N4=D(M)
WRITE(6,29)N1,N2,N3,N4
29 FORMAT(19H1ANALYTIC TEST S=,I1,1H+,I1,4HTAU+,I1,7HTAU**2-,I1,
A9HEXP(-TAU)//
15X,9X3HTAU9X,10X1H510X,5X11HFUNCTION N=I1,4X,8X5HEXACT8X,
28X5HERROR)
WRITE(6,30)(L,TAU(L),S(L),F(L),EXACT(L),ERROR(L),L=1,NTAU)
30 FORMAT(15,5E21.14)
70 CONTINUE
IF(IFPJN.EQ.0)GO TO 50
I=0
DO 4 J=1,NTAU
DO 4 L=1,NTAU
I=I+1
4 CO(I)=COEF(L,J)

```



```

CALL PJNDAT(CO,NTAU**2,LABEL(N))
50 CONTINUE
CALL EXIT
END

```

```

FUNCTION EXPIDI(TAUL,TAUJ,TAUJ1,K,KK,N)
DIMENSION FACT(11),PSI(6)
DATA ALOGD,ALOGD1/0.,0./
DATA FACT/1.,1.,2.,6.,24.,120.,720.,5040.,40320.,362880.,3628800./
DATA PSI/-.577215664901533.,.422784335098467.,.922784335098467,
11.256117668431800,1.506117668431800,1.706117668431800/
DATA SAVED,SAVED1/1.E30,1.E30/
D=ABS(TAUL-TAUJ)
D1=ABS(TAUL-TAUJ1)
IF(D.EQ.SAVED.AND.D1.EQ.SAVED1)GO TO 1
IF(D.GT.0.)ALOGD=ALOG(D)
IF(D1.GT.0.)ALOGD1=ALOG(D1)
SAVED=D
SAVED1=D1
1 D=-D
D1=-D1
NKK=N+KK
<KK=K-<<
TERM=0.
IF(TAUJ.GT.0.)TERM=TAUJ**KK<
IF(TAUJ.EQ.0..AND.KKK.EQ.0)TERM=1.
TERM1=TAUJ1**KKK
C=PSI(NKK)-ALOGD
C1=PSI(NKK)-ALOGD1
SUM=(TERM-TERM1)/FLOAT(NKK-1)
DO 5 MM=2,11
TERM=TERM*D
TERM1=TERM1*D1
IF(MM.EQ.NKK)GO TO 3
SUM=SUM-(TERM-TERM1)/FLOAT(MM-NKK)/FACT(MM)
GO TO 5
3 SUM=SUM+(TERM*C-TERM1*C1)/FACT(NKK)
5 CONTINUE
EXPIDI=SUM
RETURN
END

```

```

SUBROUTINE INTCD(COINT,TAU,NTAU,N)
DIMENSION COINT(80,80)
DO 1 L=1,NTAU
DO 1 J=1,NTAU
SUM=0.
DO 2 K=1,3
DO 2 I=1,NTAU
P=PARCO(I,K,J,TAU,NTAU)
IF(P.EQ.0.)GO TO 2
E=ETA(N,K,I,L,TAU,NTAU)
SUM=SUM+E*P
2 CONTINUE
1 COINT(L,J)=SUM
RETURN
END

```

```

FUNCTION ETA(N,K,I,L,TAU,NTAU)
DIMENSION TAU(1)
IF(I.GT.NTAU)GO TO 1
IF(I.EQ.0)GO TO 1
TI=TAU(I)
TI1=TAU(I+1)
TL=TAU(L)
Z=SIGN(1.,TI-TL)**(N-1)
S=ISIGN(1,I-L)
TIL=ABS(TI-TL)
TI1L=ABS(TI1-TL)
<1=K-1
<2=K-2
<3=<-3
X1=K1
X2=K2
N1=N+1
N2=N+2
N3=N+3
TT=TI
IF(TI.EQ.0.)TT=1.E-40
IF(TI1.GT.1.)GO TO 7
IF(TL.LE.20..AND.TI1.LT.TL/10.)GO TO 9
IF(TL.GT.20..AND.TI1.LT..0001)GO TO 1
7 IF(TIL.LT..16..AND.TI1L.LT..16)GO TO 2
C1=TT**K1*EXPI(N1,TIL)
C2=S*X1*TT**K2*EXPI(N2,TIL)
C3=X1*X2*TT**K3*EXPI(N3,TIL)
D1=TI1**K1*EXPI(N1,TI1L)
D2=S*X1*TI1**K2*EXPI(N2,TI1L)
D3=X1*X2*TI1**K3*EXPI(N3,TI1L)
GO TO 8
9 C1=TT**K1*EXPIS(TL,TI,N,1)
C2=S*X1*TT**K2*EXPIS(TL,TI,N,2)
C3=X1*X2*TT**K3*EXPIS(TL,TI,N,3)
D1=TI1**K1*EXPIS(TL,TI1,N,1)
D2=S*X1*TI1**K2*EXPIS(TL,TI1,N,2)
D3=X1*X2*TI1**K3*EXPIS(TL,TI1,N,3)
8 ETA=Z/2.*ABS(C1+C2+C3-D1-D2-D3)
RETURN
2 ETA=Z/2.*ABS(EXPIDI(TL,TI,TI1,K,1,N)+S*X1*EXPIDI(TL,TI,TI1,K,2,N)+
1 X1*X2*EXPIDI(TL,TI,TI1,K,3,N))
RETURN
1 ETA=0.
RETURN
END

```

```

FUNCTION EXPIS(X,Y,N,NN)
DIMENSION E(10)
DATA X1/-1./
IF(X.EQ.X1)GO TO 2
X1=X
EX=EXP(-X)
DO 1 I=1,6
1 E(I)=EXPI(I,X)
2 IF(Y.EQ.0.)GO TO 10
SUM=0.
TERM=Y**(NN-1)
IF(NN.EQ.3)TERM=TERM/2.
DO 3 I=1,N
TERM=TERM*Y/FLOAT(NN+I-1)
NI1=N-I+1
3 SUM=SUM+TERM*E(NI1)
TERM=TERM*EX*Y/FLOAT(NN+N)/X
SUM=SUM+TERM
DO 4 M=1,100
TERM=TERM*FLOAT(M)/FLOAT(NN+N*M)*Y/X
S=1.
T=1.
DO 5 MM=1,M
T=T*X/FLOAT(MM)
5 S=S+T
SUM1=SUM+S*TERM
IF(SUM.EQ.SUM1)GO TO 9
4 SUM=SUM1
9 EXPIS=SUM1
RETURN
10 EXPIS=0.
RETURN
END

```

```

SUBROUTINE ANALYT(X,S,AJ,H,A,B,C,D)
S=A+B*X+C*X**2+D*EXP(-X)
E1=EXPI(1,X)
E2=EXPI(2,X)
E3=EXPI(3,X)
E4=EXPI(4,X)
E5=EXPI(5,X)
AJ=A*(1.-E2/2.)+B*(X+E3/2.)+C*(2./3.+X**2-E4)
H=A*E3/2.+B*(1./3.-E4/2.)+C*(2./3.*X+E5)
IF(X.GT.0) GO TO 3
AJ=ALOG(2.)/2.*D+AJ
H=(1.-ALOG(2.))/2.*D+H
RETURN
3 AJ=AJ+D*(EXP(-X)/2.*(ALOG(2.*X)+.577215664901533)+E1/2.)
H=H+D*(EXP(-X)/2.*(2.-.577215664901533-ALOG(2.*X))-(E2+E1)/2.)
RETURN
END

```

```

      FUNCTION PARCO(J,K,I,TAU,NTAU)
      DIMENSION TAU(1)
      PARCO=0.
      JI2=I-J+2
      IF (JI2.LT.1.OR.JI2.GT.4) RETJRN
      IF (J.EQ.1) GO TO 100
      IF (J.EQ.2) GO TO 200
      IF (J.EQ.3) GO TO 300
      X1=TAU(J-1)
      X2=TAU(J)
      X3=TAU(J+1)
      X4=TAU(J+2)
      D=X1**2+X4**2-(X2+X3)*(X1+X4)+2.*X2*X3
      XXD=(X2-X3)*D
      GO TO (10,20,30,40),JI2
10    GO TO (11,12,13),K
11    PARCO=X2*X3/D
      RETJRN
12    PARCO=-(X2+X3)/D
      RETJRN
13    PARCO=1./D
      RETJRN
20    GO TO (21,22,23),K
21    PARCO=X3*(-X1**2-X4**2+X3*X1+X3*X4)/XXD
      RETJRN
22    PARCO=(X1**2-2.*X3**2+X4**2)/XXD
      RETJRN
23    PARCO=(-X1+2.*X3-X4)/XXD
      RETJRN
30    GO TO (31,32,33),K
31    PARCO=X2*(X1**2+X4**2-X2*X1-X2*X4)/XXD
      RETJRN
32    PARCO=(-X1**2+2.*X2**2-X4**2)/XXD
      RETJRN
33    PARCO=(X1-2.*X2+X4)/XXD
      RETJRN
40    GO TO (41,42,43),K
41    PARCO=X2*X3/D
      RETJRN
42    PARCO=-(X2+X3)/D
      RETJRN
43    PARCO=1./D
      RETJRN
100   X1=TAU(J-1)
      X2=TAU(J)
      X3=TAU(J+1)
      X4=2.*TAU(J+1)-TAU(J)
      D=X1**2+X4**2-(X2+X3)*(X1+X4)+2.*X2*X3
      XXD=(X2-X3)*D
      GO TO (10,120,130,333),JI2
120   GO TO (121,122,123),K
121   PARCO=X3*(-X1**2-X4**2+X3*X1+X3*X4)/XXD-X2*X3/D
      RETJRN
122   PARCO=(X1**2-2.*X3**2+X4**2)/XXD+(X2+X3)/D
      RETJRN
123   PARCO=(-X1+2.*X3-X4)/XXD-1./D
      RETJRN
130   GO TO (131,132,133),K
131   PARCO=X2*(X1**2+X4**2-X2*X1-X2*X4)/XXD+2.*X2*X3/D

```

```

      RETJRN
132 PARCO=(-X1**2+2.*X2**2-X4**2)/XXD-2.*(X2+X3)/D
      RETJRN
133 PARCO=(X1-2.*X2+X4)/XXD+2./D
      RETJRN
200 X1=2.*TAU(J)-TAU(J+1)
      X2=TAJ(J)
      X3=TAJ(J+1)
      X4=TAJ(J+2)
      D=X1**2+X4**2-(X2+X3)*(X1+X4)+2.*X2*X3
      XXD=(X2-X3)*D
      GO TO(333,220,230,40),JI2
220 GO TO(221,222,223),K
221 PARCO=X3*(-X1**2-X4**2+X3*X1+X3*X4)/XXD+2.*X2*X3/D
      RETJRN
222 PARCO=(X1**2-2.*X3**2+X4**2)/XXD-2.*(X2+X3)/D
      RETJRN
223 PARCO=(-X1+2.*X3-X4)/XXD+2./D
      RETJRN
230 GO TO (231,232,233),K
231 PARCO=X2*(X1**2+X4**2-X2*X1-X2*X4)/XXD-X2*X3/D
      RETJRN
232 PARCO=(-X1**2+2.*X2**2-X4**2)/XXD+(X3+X2)/D
      RETJRN
233 PARCO=(X1-2.*X2+X4)/XXD-1./D
      RETJRN
300 X1=TAU(J-1)
      X2=TAJ(J)
      GO TO (310,320,333,333),JI2
310 GO TO(311,312,333),K
311 PARCO=X2/(X2-X1)
      RETJRN
312 PARCO=1./(X1-X2)
      RETURN
320 GO TO(321,322,333),K
321 PARCO=X1/(X1-X2)
      RETJRN
322 PARCO=1./(X2-X1)
333 RETJRN
      END

```

```

SUBROUTINE PUNDAT(X,NUMB,TITLE)
C   X IS AN ARRAY TO BE PUNCHED IN DATA STATEMENTS
C   NUMB IS ITS LENGTH
C   TITLE IS A 3 LETTER DUMMY NAME FOR THE OUTPUT ARRAYS
  DIMENSION X(1)
  DIMENSION IDIM(300),COMMAS(300),A(81),B(81)
  DATA B/1H1.8*1H.,1H2.8*1H.,1H3.8*1H.,1H4.8*1H.,1H5.8*1H.,
1 1H6.8*1H.,1H7.8*1H.,1H8.8*1H.,1H9.8*1H./
  DATA QCOMMA,QBLANK,QSLASH,QPAREN/1H.,1H. 1H/.,1H(/
  NARRAY=(NUMB+35)/36
  LAST=NUMB-NARRAY*36+36
C   DIMENSIONS
  DO 10 I=1,NARRAY
    IDIM(I)=36
10  COMMAS(I)=QCOMMA
  DO 11 I=5,NARRAY,5
11  COMMAS(I)=QBLANK
  COMMAS(NARRAY)=QBLANK
  IDIM(NARRAY)=LAST
  WRITE(6,12)(TITLE,I,IDIM(I),COMMAS(I),I=1,NARRAY)
  WRITE(7,12)(TITLE,I,IDIM(I),COMMAS(I),I=1,NARRAY)
12  FORMAT(6X,10HDIMENSION ,5(A3,I3,1H(,I2,1H),A1))
C   EQUIVALENCES
  DO 20 I=1,NARRAY
    IDIM(I)=(I-1)*36+1
20  COMMAS(I)=QCOMMA
  DO 21 I=2,NARRAY,2
21  COMMAS(I)=QBLANK
  COMMAS(NARRAY)=QBLANK
  WRITE(6,22)(QPAREN,TITLE,I,TITLE,IDIM(I),COMMAS(I),I=1,NARRAY)
  WRITE(7,22)(QPAREN,TITLE,I,TITLE,IDIM(I),COMMAS(I),I=1,NARRAY)
22  FORMAT(6X,12HEQUIVALENCE ,2(A1,A3,I3,4H(1),A3,1H(,I4,2H),A1))
C   DATA STATEMENTS
  L=0
  DO 33 ISTART=1,NUMB,36
    L=L+1
    IEND=MINO(NUMB,ISTART+35)
    DO 30 K=1,81
30  A(K)=B(K)
    K=1
    DO 31 I=ISTART,IEND
      IF(I-I/4*4.EQ.1)K=K+1
      A(K)=X(I)
31  K=K+2
    K=K-1
    A(K)=QSLASH
    WRITE(7,32)TITLE,L,(A(J),J=1,K)
33  WRITE(6,32)TITLE,L,(A(J),J=1,K)
32  FORMAT(6X,5HDATA ,A3,I3,1H// (5XA1,4(E15.8,A1)))
  RETURN
  END

```

```

PROGRAM ATLAS5(INPUT=513,OUTPUT=513,PUNCH=513,TAPE5=INPUT,
1 TAPE6=OUTPUT,TAPE7=PUNCH)
COMMON /ABROSS/ABROSS(40),TAUROS(40)
COMMON /ABTOT/ABTOT(40),ALPHA(40)
COMMON /CONV/DLTDL(40),HEATCP(40),DLRDLT(40),VELSND(40),
1 GRDADB(40),HSCALE(40),FLXCNV(40),VCONV(40),MIXLTH,
2 IFCONV
REAL MIXLTH
COMMON /DEPART/BHYD(40,6),BMIN(40),NLTEON
COMMON /ELEM/ABUND(99),ATMASS(99),ELEM(99)
COMMON /FLUX/ FLUX,FLXERR(40),FLXDRV(40),FLXRAD(40)
COMMON /FREQ/FREQ,FREQLG,EHVKT(40),STIM(40),BNJ(40)
COMMON /FRESE/FRESE(500),RCOSET(500),NULO,NUHI,NUMNU
COMMON /HEIGHT/HEIGHT(40)
COMMON /IF/IFCORR,IFPRES,IFSURF,IFSCAT,IFMOL
COMMON /IFOP/IFOP(20)
COMMON /IONS/XNFP(40,2),XNFPHE(40,3)
COMMON /ITER/ ITER,IFPRNT(15),IFPNC(15),NUMITS
COMMON /JUNK/TITLE(74),FREQID(6),WLTE,XSCALE
COMMON /MUS/ANGLE(20),SURFI(20),NMU
COMMON /OPS/AHYD(40),AH2P(40),AHMIN(40),SIGH(40),AHE1(40),
1 AHE2(40),AHEMIN(40),SIGHE(40),ACOO(40),ALUKE(40),AHOT(40),
2 SIGEL(40),SIGH2(40),AHLIN(40),ALINES(40),SIGLIN(40),
3 AXLIN(40),SIGXL(40),AXCONT(40),SIGX(40),SHYD(40),
4 SHMIN(40),SHLIN(40),SXLIN(40),SXCONT(40)
COMMON /OPTOT/ACONT(40),SCONT(40),ALINE(40),SLINE(40),SIGMAC(40),
1 SIGMAL(40)
COMMON /PTOTAL/PTOTAL(40)
COMMON /PUT/PUT,IPUT
COMMON /RAD/ ACCRAD(40),PRAD(40)
COMMON /RHOX/RHOX(40),NRHOX
COMMON /STATE/P(40),XNE(40),XNATOM(40),RHO(40)
COMMON /TAUSHJ/TAUNU(40),SNJ(40),HNU(40),JNU(40),JMIN(40)
REAL JNJ,JMIN
COMMON /TEFF/TEFF,GRAV,GLOG
COMMON /TEMP/T(40),TKEV(40),TK(40),HKT(40),TLOG(40),ITEMP
COMMON /TURBPR/VTURB(40),PTURB(40),TR3FDG,TRBCON,TRBPOW,TRBSND,
1 IFTURB
COMMON /WAVEY/WBEGIN,DELTAW,IFWAVE
COMMON /XABUND/XABUND(99),WTMOLE
DIMENSION ABNORM(40)
DIMENSION KABROS(40)
EQUIVALENCE (ABROSS(1),KABROS(1))
DIMENSION TABT(30),TABP(30)
DATA NT,NP/30,30/
DATA TABT/3.5,3.525,3.55,3.575,3.6,3.625,3.65,3.675,3.7,3.725,
1 3.75,3.775,3.8,3.825,3.85,3.875,3.9,3.925,3.95,3.975,4.,4.05,4.1,
2 4.15,4.2,4.25,4.3,4.35,4.4,4.45/
DATA TABP/-2.,-1.5,-1.,-.5,0.,.5,1.,1.25,1.5,1.75,2.,2.25,2.5,
1 2.75,3.,3.2,3.4,3.6,3.8,4.,4.2,4.4,4.6,4.8,5.,5.2,5.4,5.6,5.8,6./
EXP10(X)=EXP(X*2.302585092994E0)
CALL READIN(1)
WRITE(6,75)TABT,TABP
WRITE(7,75)TABT,TABP
75 FORMAT(6X10HDATA TABT/4X,7(F6.3,1H,)/5X1H1,9(F6.3,1H,)/
1 5X1H2,9(F6.3,1H,)/5X1H3,4(F6.3,1H,),F6.3,1H//
2 6X10HDATA TABP/4X,7(F6.3,1H,)/5X1H1,9(F6.3,1H,)/
3 5X1H2,9(F6.3,1H,)/5X1H3,4(F6.3,1H,),F6.3,1H/)
NRHOX=NT
ITER=1

```

```

DO 1 J=1,NRHOX
  T(J)=EXP10(TABT(J))
  TK(J)=1.38054E-16*T(J)
  HKT(J)=6.6256E-27/TK(J)
  TKEV(J)=8.6171E-5*T(J)
1  TLOG(J)=ALOG(T(J))
  ITEMP=0
  DO 100 K=1,NP
    ITEMP=ITEMP+K
    DO 2 J=1,30
      ABNORM(J)=0.
      ABROSS(J)=0.
2  P(J)=EXP10(TABP(K))
  CALL POPS(0.,1,XNE)
C
C  FREQUENCY INTEGRATION SECTION
DO 25 NJ=NULO,NUHI
  IF(IFWAVE.EQ.0)GO TO 21
  WAVE=WBEGIN+FLOAT(NU-NULO)*DELTAW
  FREQ=2.997925E17/WAVE
  RCO=ABS(DELTAW/WAVE*FREQ)
  GO TO 22
21 FREQ=FRESET(NU)
  RCO=RCOSET(NU)
22 FREQLG=ALOG(FREQ)
  DO 20 J=1,NRHOX
    EHVKT(J)=EXP(-FREQ*HKT(J))
    STIM(J)=1.-EHVKT(J)
20 BNU(J)=1.47439E-47*FREQ**3*EHVKT(J)/STIM(J)
  N=0
24 N=N+1
  CALL KAPP(N,NSTEPS,STEPWT)
  RCOWT=RCO*STEPWT
  DO 23 J=1,NRHOX
    ABTOT(J)=ACONT(J)+ALINE(J)+SIGMAC(J)+SIGMAL(J)
    DBDT=BNJ(J)*FREQ*HKT(J)/T(J)/STIM(J)
    ABNORM(J)=ABNORM(J)+DBDT*RCOWT
23 ABROSS(J)=ABROSS(J)+DBDT/ABTOT(J)*RCOWT
  IF(N.LT.NSTEPS)GO TO 24
25 CONTINUE
  DO 29 J=1,NRHOX
C  NORMALIZATION IS PERFORMED WITH AN INTEGRAL SO THAT A
C  MONOCHROMATIC OPACITY CAN BE FOUND BY INTEGRATING OVER ONLY ONE
C  FREQUENCY
  ABROSS(J)=ABNORM(J)/ABROSS(J)
29 KABROS(J)=ALOG10(ABROSS(J))*1000.
  K1=K/10
  K2=K-K1*10
  WRITE(6,77)K1,K2,TABP(K),(KABROS(J),J=1,10),TABP(K),
1(KABROS(J),J=11,20),TABP(K),(KABROS(J),J=21,30),TABP(K)
  WRITE(7,77)K1,K2,TABP(K),(KABROS(J),J=1,10),TABP(K),
1(KABROS(J),J=11,20),TABP(K),(KABROS(J),J=21,30),TABP(K)
77 FORMAT(6X9HDATA K TAB,2I1,1H/,54X,F6.3/5X1H1,10(I5,1H.),6XF6.3/
1 5X1H2,10(I5,1H.),6XF6.3/5X1H3,9(I5,1H.),15,1H/,6XF6.3)
100 CONTINUE
  CALL EXIT
  END

```



```

PROGRAM REDIME(INPUT,OUTPUT,PUNCH,TAPES=INPUT,TAPE6=OUTPUT,
1TAPE7=PUNCH)
C DIMENSION A(80)
BCD CHARACTERS
DATA JA,QB,QC,QD,QE,QF,QG,QH,QI,QJ,QK,QL,QM,QN,QO,QP,QQ,QR,QS,
1QT,QU,QV,QW,QX,QY,QZ,Q0,Q1,Q2,Q3,Q4,Q5,Q6,Q7,Q8,Q9,QPLUS,QMINUS,
2QSTAR,QSLASH,QPARL,QPARR,QDOLL,QEQUAL,QBLANK,QCOMMA,QPOINT/
3 1HA,1HB,1HC,1HD,1HE,1HF,1HG,1HH,1HI,1HJ,1HK,1HL,1HM,1HN,1HO,1HP,
4 1HQ,1HR,1HS,1HT,1HU,1HV,1HW,1HX,1HY,1HZ,1H0,1H1,1H2,1H3,1H4,1H5,
5 1H6,1H7,1H8,1H9,1H+,1H-,1H*,1H/,1H(.1H),1H$,1H%=1H ,1H.,1H./
IFCONT=0
READ(5,11)QDIM1,QDIM2
11 FORMAT(80A1)
10 READ(5,11)A
IF(A(1).EQ.Q0)CALL EXIT
IF(A(1).NE.QBLANK)GO TO 100
IF(A(6).NE.QBLANK.AND.IFCONT.NE.0)GO TO 25
IFCONT=0
IF(A(7).EQ.QC)GO TO 20
IF(A(7).EQ.QD)GO TO 21
GO TO 100
20 IF(A(8).NE.Q0)GO TO 100
IF(A(9).NE.QM)GO TO 100
IF(A(10).NE.QM)GO TO 100
IF(A(11).NE.Q0)GO TO 100
IF(A(12).NE.QN)GO TO 100
N=13
IFCONT=1
GO TO 30
21 IF(A(8).NE.QI)GO TO 22
IF(A(9).NE.QM)GO TO 100
IF(A(10).NE.QE)GO TO 100
IF(A(11).NE.QN)GO TO 100
IF(A(12).NE.QS)GO TO 100
IF(A(13).NE.QI)GO TO 100
IF(A(14).NE.Q0)GO TO 100
IF(A(15).NE.QN)GO TO 100
N=16
IFCONT=1
GO TO 30
22 IF(A(8).NE.QA)GO TO 100
IF(A(9).NE.QT)GO TO 100
IF(A(10).NE.QA)GO TO 100
N=11
IFCONT=2
GO TO 40
25 GO TO (30,40),IFCONT
29 N=N-1
30 DO 31 I=N,69
IF(A(I).EQ.QPARL.OR.A(I).EQ.QCOMMA)GO TO 35
31 CONTINUE
N=7
GO TO 100
35 N=I+1
IF(A(N).NE.Q4)GO TO 30
N=N+1
IF(A(N).NE.Q0)GO TO 29
N=N+1
IF(A(N).NE.QPARR.AND.A(N).NE.QCOMMA)GO TO 29

```

```
A(I+1)=QDIM1
A(I+2)=QDIM2
GO TO 29
39 N=N-1
40 DO 41 I=N,69
   IF(A(I).EQ.Q4)GO TO 45
41 CONTINUE
   N=7
   GO TO 100
45 N=N+1
   IF(A(N).NE.Q0)GO TO 40
   N=N+1
   IF(A(N).NE.QSTAR)GO TO 39
   A(I)=QDIM1
   A(I+1)=QDIM2
   GO TO 39
100 WRITE(6,101)A
101 FORMAT(1X,80A1)
   WRITE(7,11)A
   GO TO 10
END
```

10. REFERENCES

AVRETT, E. H., and KROOK, M.

1963. The temperature distribution in a stellar atmosphere. *Astrophys. Journ.*, vol. 137, pp. 874-881.

DÖHM-VITENSE, E.

1964. An integral equation for the temperature correction in a nongray atmosphere. In Proceedings First Harvard-Smithsonian Conference on Stellar Atmospheres, Smithsonian Astrophys. Obs. Spec. Rep. No. 167, pp. 99-107.

BROWNE, J. C., and DALGARNO, A.

1969. Detachment in collisions of H and H^- . *Journ. Phys. B (Atom. Molec. Phys.)*, vol. 2, pp. 885-889.

CARBON, D., GINGERICH, O., and LATHAM, D.

1969. Model atmospheres for cool dwarf stars. In Low-Luminosity Stars, ed. by S. S. Kumar, Gordon and Breach, New York, pp. 435-455.

CARNAHAN, B., LUTHER, H. A., and WILKES, J. O.

1969. Applied Numerical Methods. J. Wiley & Sons, Inc., New York, 604 pp.

COX, J. P., and GUILL, R. T.

1968. Principles of Stellar Structure. Gordon and Breach, New York, 1327 pp.

DALGARNO, A.

1962. Spectral reflectivity of the earth's atmosphere. III: The scattering of light by atomic systems. Geophys. Corp. of America, GCA Tech Rep. #62-28-A.

DRAWIN, H. R., and FELENBOK, P.

1965. Data for Plasmas in Local Thermodynamic Equilibrium. Gautier-Villars, Paris, 503 pp.

FLOWER, D. R.

1968. The ionization equilibrium for heavy elements. In Planetary Nebulae, ed. by D. E. Osterbrock and C. R. O'Dell, IAU Symp. No. 34, D. Reidel Publ. Co., Dordrecht, Holland, pp. 205-208.

GELTMAN, S.

1962. The bound-free absorption coefficient of the hydrogen negative ion. *Astrophys. Journ.*, vol. 136, pp. 935-945.

GINGERICH, O.

1964. Review of opacity calculations. In Proceedings First Harvard-Smithsonian Conference on Stellar Atmospheres, Smithsonian Astrophys. Obs. Spec. Rep. No. 167, pp. 17-41.
1969. Theory and Observation of Normal Stellar Atmospheres (editor). The M.I.T. Press, Cambridge, Mass., 399 pp.

GRIEM, H. R.

1960. Stark broadening of higher hydrogen and hydrogen-like lines by electrons and ions. *Astrophys. Journ.*, vol. 132, pp. 883-893.
1964. Plasma Spectroscopy. McGraw-Hill Book Co., New York, 580 pp.
1967. Corrections to the asymptotic Holtsmark formula for hydrogen lines broadened by electrons and ions in a plasma. *Astrophys. Journ.*, vol. 147, pp. 1092-1099.

HENRY, R. J. W.

1970. Photoionization cross-sections for atoms and ions of carbon, nitrogen, oxygen, and neon. *Astrophys. Journ.*, vol. 161, pp. 1153-1155.

HILDAGO, M. B.

1968. Photoionization cross-sections for ions of carbon, nitrogen, oxygen, and neon. *Astrophys. Journ.*, vol. 153, pp. 981-985.
1969. Erratum. *Astrophys. Journ.*, vol. 157, p. 479.

HUNGER, K., and VAN BLERKOM, D.

1967. A pure helium model stellar atmosphere. *Zeits. für Astrophys.*, vol. 66, pp. 185-199.

JOHN, T. L.

1968. The free-free transitions of He^{III} . *Monthly Notices, Roy. Astron. Soc.*, vol. 138, pp. 137-141.

KARSAS, W. J., and LATTER, R.

1961. Electron radiative transitions in a Coulomb field. *Astrophys. Journ. Suppl.*, vol. 6, pp. 167-212.

KURUCZ, R. L.

1969. A matrix method for calculating the source function, mean intensity, and flux in a model atmosphere. *Astrophys. Journ.*, vol. 156, pp. 235-240.

LAMBERT, D. L., and PAGEL, B. E. J.

1968. The dissociation equilibrium of H^- in stellar atmospheres. *Monthly Notices, Roy. Astron. Soc.*, vol. 141, pp. 299-315.

McBRIDE, B. J., HEIMEL, S., EHLERS, J. G., and GORDON, S.

1963. Thermodynamic properties to 6000 °K for 210 substances involving the first 18 elements. NASA SP-3001.

MENZEL, D. H., and PEKERIS, C. L.

1935. Absorption coefficients and hydrogen line intensities. *Monthly Notices, Roy. Astron. Soc.*, vol. 96, pp. 77-111.

MOORE, C. E.

1949. Atomic energy levels. NBS Circ. 467, U.S. Govt. Printing Office, Washington, D.C. Vol. I, 1949; vol. II, 1952; vol. III, 1958.

PEACH, G.

1967. Free-free absorption coefficients for non-hydrogenic atoms. *Mem. Roy. Astron. Soc.*, vol. 71, pp. 1-11.
1970. Continuous absorption coefficients for non-hydrogenic atoms. *Mem. Roy. Astron. Soc.*, vol. 73, pp. 1-123.

PETERSON, D. M.

1969. The Balmer lines in early type stars. *Smithsonian Astrophys. Obs. Spec. Rep. No. 293*, 199 pp.

STILLY, J. L., and CALLAWAY, J.

1970. Free-free absorption coefficient of the negative hydrogen ion. *Astrophys. Journ.*, vol. 160, pp. 245-260.

TRAVIS, L. D., and MATSUSHIMA, S.

1968. Radiative opacity in stellar atmospheres. I. Metal absorption coefficients. *Astrophys. Journ.*, vol. 154, pp. 689-713.

UNDERHILL, A. B., and WADDELL, J. H.

1959. Stark broadening functions for the hydrogen lines. NBS Circ. 603, U.S. Govt. Printing Office, Washington, D.C., 94 pp.

BIOGRAPHICAL NOTE

ROBERT L. KURUCZ received his A.B. degree in astronomy from Harvard College in 1966. He is currently a candidate for the Ph.D. in astronomy from Harvard University.

Mr. Kurucz has been a Predoctoral Research Fellow of the Smithsonian Research Foundation since 1968. His principal fields of investigation concern radiative transfer and stellar atmospheres.