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RAYs: A Geometrical Optics
Code for EBT

D. B. Batchelor
R. C. Goldfinger

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DEPARTMENT OF ENERGY

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RAYS: A GEOMETRICAL OPTICS CODE FOR EBT

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ABSTRACT

A geometrical optics computer code RAYS has been developed to study the propagation and absorption of electromagnetic waves in an arbitrary, three-dimensional, magnetized plasma configuration. The RAYS code integrates the Hamiltonian form of the geometrical optics equations for position $\underline{r}$ and wave vector $\underline{k}$ from initial conditions $\underline{r}_0$, $\underline{k}_0$ with arc length along the ray S or time as the ray parameter. In addition, the local electric field polarization is evaluated and quantities such as the wave damping rate or the phase path length can be integrated along the ray. The code is written in modular form with subroutines specifying the plasma equilibrium magnetic field and density and subroutines specifying the wave dispersion relation being independent. In this way, various models for the plasma geometry and for the wave physics can be easily interchanged without disturbing the bulk of the program. The RAYS code has been used extensively in the theoretical study of microwave heating of the ELMO Bumpy Torus device at Oak Ridge National Laboratory. In this report the theory, structure, and operation of the code are described. Mathematical details of equilibrium subroutines for slab, bumpy torus, and tokamak plasma geometry are presented. Wave dispersion and absorption subroutines are presented for frequencies ranging from ion cyclotron frequency to electron cyclotron frequency. Graphics postprocessors for RAYS output data are also described.

1. INTRODUCTION

In this report we describe the structure and operation of the computer code RAYS, which does ray tracing of electromagnetic waves in an arbitrary magnetized plasma configuration. This code is being developed as a major part of the theoretical study of microwave heating of the ELMO Bumpy Torus (EBT) device at Oak Ridge National Laboratory (ORNL). As a result, the applications to date have emphasized magnetic mirror geometries, and the graphics capabilities have been tailored for this application. However, other geometries have been used (slab geometry, tandem mirror, and idealizations of tokamak geometry), and we feel that the code could be readily adapted to a wide variety of plasma configurations.

The RAYS code integrates the Hamiltonian form of the geometrical optics equations for position $\underline{r}$ and wave vector $\underline{k}$ from initial conditions $\underline{r}_0$ and $\underline{k}_0$, with arc length along the ray s or time t as the independent variable. In addition, the local electric field polarization is evaluated, and quantities such as the wave damping rate or the phase path length can be integrated along the ray. The code is written in modular form with subroutines specifying the plasma equilibrium magnetic field and density and specifying the wave dispersion relation as independent. In this way, various models for the plasma geometry and wave characteristics can be easily interchanged without disturbing the bulk of the program.

This report is not intended as a users' manual in the sense of a scientific subroutine package that is an immutable "black box." In fact, the RAYS code is continuously evolving, with each new application requiring modifications and additions. After more than four years of such evolution, the code has become a very flexible and thoroughly tested tool, and there has been considerable demand for this code to be published and documentation made available. Therefore, we have collected the most generally useful of the routines, "cleaned them up" by deleting vestiges from previous generations, and inserted sufficient comments to serve as a road map. In this report we present the relevant mathematical equations, give a brief description of the structure of the code, and provide some simple examples. It is hoped that this document contains sufficient information to assist those who might wish to adapt the RAYS code to their particular problems and to suggest possible additional applications.

We have chosen not to discuss in detail but merely to mention some of the more sophisticated routines we have developed. These codes are of specialized interest, or are somewhat tricky to use, and therefore require extensive documentation of their own. In this category are a dispersion relation package for a finite temperature plasma that includes all Bessel functions and all cyclotron harmonics, a nonrelativistic wave damping package that includes all Bessel functions and all cyclotron harmonics, a fully relativistic damping package, and an interpolative axisymmetric equilibrium package that can be used with numerically defined data on a grid.

Section 2 is a brief discussion of the ray tracing equations in Hamiltonian form. The structure of the RAYS code is outlined in Sect. 3, which includes the required input data, output format, program operation, as well as descriptions and calling sequences of the principal subroutine modules. Mathematical details of the various plasma dispersion relation modules, DERV, that have been developed for the RAYS code are given in Sect. 4, and in Sect. 5 mathematical details are given of the various equilibrium modules, EQUIB, that have been developed for the code. Descriptions are given in Sect. 6 of two of the wave damping models developed for RAYS, and the module used to calculate the electric field polarization, EPOLAR, is discussed in Sect. 7. The testing and diagnostic techniques for the code are discussed in Sect. 8. In Sect. 9 the RAYPLT program, a postprocessor for the RAYS code that produces graphical output, is described.

Appendix I contains a descriptive list of the input parameters, and Appendix II contains a description of the output files. Example cases of input and output data are presented in Appendix III. Appendix IV contains a listing of the RAYS code, the dispersion relation modules DERV, the equilibrium modules EQUIB, and the ray plotting program RAYPLT.

2. THE RAY TRACING EQUATIONS

The theory of geometrical optics¹⁻⁴ seeks to describe the propagation of waves in an inhomogeneous medium by expanding the wave equations in a parameter $\delta = \lambda/L$, assumed to be small. Here, λ is the wavelength and L is a characteristic scale length of variation of the medium. To zero order in δ , one obtains equations for the direction of energy flow (ray paths) and for changes in the wave number $\underline{k}$ as one moves along the ray path. In order to obtain information concerning the amplitude of the fields, it is necessary to go to first order in the formal δ expansion. (See Ref. 3 for a derivation relevant to plasmas.)

For general space- and time-varying media, the waves satisfy a local dispersion relation of the form

$$D(\underline{k}, \omega, \underline{r}, t) = \det(\underline{D}) = 0, \quad (1)$$

where $\underline{D}$ is the dielectric tensor, which is assumed to be Hermitian. Its anti-Hermitian part is taken as first order in δ and gives rise to a weak absorption of the waves. When solved for ω , with $\omega = \Omega(\underline{k}, \underline{r}, t)$, the dispersion relation plays the role of the Hamiltonian, defining the trajectories $\underline{r}(t)$ and $\underline{k}(t)$:

$$\frac{d\underline{r}}{dt} \equiv \underline{v}_g = \frac{\partial \Omega}{\partial \underline{k}} \quad \text{or} \quad \underline{v}_g = - \frac{\partial D / \partial \underline{k}}{\partial D / \partial \omega}, \quad (2)$$

and

$$\frac{dk}{dt} = -\frac{\partial \Omega}{\partial r} \quad \text{or} \quad \frac{dk}{dt} = \frac{\partial D / \partial r}{\partial D / \partial \omega} \quad (3)$$

A case of considerable importance that arises in the application of wave heating methods to plasmas is that of a ray passing through cyclotron resonance. At cyclotron resonance the anti-Hermitian (dissipative) part is large. Nevertheless, depending on the density, temperature, and angle of propagation, it is possible for waves to be only weakly damped at cyclotron resonance. It is shown in Ref. 4 that when the waves are weakly damped at cyclotron resonance, a consistent geometrical optics expansion is possible and the ray trajectories are given by the cold plasma dispersion relation.

For time-invariant media ($\partial/\partial t = 0$), the arc length along the ray s is a convenient parameter, and the above equations can be reduced to

$$\frac{dr}{ds} = \frac{1}{|v_g|} \frac{dr}{dt} = -\text{sgn}\left(\frac{\partial D}{\partial \omega}\right) \frac{\partial D / \partial k}{|\partial D / \partial k|} \quad (4)$$

and

$$\frac{dk}{ds} = \frac{1}{|v_g|} \frac{dk}{dt} = \text{sgn}\left(\frac{\partial D}{\partial \omega}\right) \frac{\partial D / \partial r}{|\partial D / \partial k|} \quad (5)$$

In most instances the RAYS code integrates the ray equations using s as the parameter [Eqs. (4) and (5)] although occasionally it proves convenient to use t [Eqs. (2) and (3)].

The right-hand sides of Eqs. (2) and (3) can be obtained by a straightforward but tedious differentiation of the dispersion relation [Eq. (1)]. If the local dispersion relation is written in the form

$$D(\underline{k}, \underline{r}) = D\left[\underline{k}, \frac{\omega_{pe}^2(\underline{r})}{\omega^2}, \frac{\Omega_e(\underline{r})}{\omega}, \omega\right] = 0, \quad (6)$$

where ω_{pe} is the local plasma frequency and Ω_e is the local electron cyclotron frequency, the details of variations of the plasma equilibrium can be separated from the plasma dispersion properties. In particular, we can write

$$\frac{\partial D}{\partial \underline{r}} = \frac{\partial D}{\partial \omega_{pe}^2} \underline{\nabla}(\omega_{pe}^2) + \frac{\partial D}{\partial \Omega_e} \underline{\nabla}(\Omega_e). \quad (7)$$

Throughout the RAYS code the density and magnetic field strength are dealt with by means of dimensionless parameters $\alpha = \Omega_{pe}^2/\omega^2$ and $\beta = \Omega_e^2/\omega^2$. In order to integrate the ray equations, it is necessary to calculate the following quantities related to the spatial variation of the plasma equilibrium:

$$n_e(\underline{r}), \underline{B}(\underline{r}), \underline{\nabla} n_e(\underline{r}), \text{ and } \underline{\nabla} B(\underline{r}).$$

In the RAYS code this information is provided by an equilibrium module, a subroutine called EQUIB. Examples of various equilibrium geometries are discussed in Sect. 5. It is also necessary to calculate the following quantities related to plasma dispersion:

$$\frac{\partial D}{\partial \underline{k}}, \frac{\partial D}{\partial \omega}, \frac{\partial D}{\partial \omega_{pe}^2}, \text{ and } \frac{\partial D}{\partial \Omega_e}.$$

In the RAYS code this information is provided by a dispersion module, a subroutine called DERV. Examples of several dispersion relations for waves in the electron cyclotron range of frequencies are given in Sect. 4.

The coupled set of ordinary differential equations (4) and (5) are integrated in Cartesian coordinates (x, y, z, k_x, k_y, k_z) from an initial value of $(x_0, y_0, z_0, k_{x0}, k_{y0}, k_{z0})$. The origin and orientation of the coordinate system are defined by the equilibrium model embodied in the EQUIB subroutine. The initial value of the wave vector $\underline{k}_0$ must of course be a solution of the local dispersion relation at the point $\underline{r}_0$.

The dispersion relation [Eq. (1)] may have multiple branches corresponding to different modes of propagation. For example, the cold plasma dispersion relation has ordinary mode and extraordinary mode branches. If $\underline{k}_0$ is properly initialized to be a solution of the local dispersion relation, $\underline{k}(s)$ will remain on this branch unless a point is reached where two roots of the local dispersion relation coincide. At

such a point the geometrical optics approximation breaks down, and coupling can occur between the two modes. In this situation the ray tracing code follows the particular root away from the coupling point which maintains continuity of the equations. Thus, one observes either zero or total mode conversion at a coupling point.

The field amplitude $\underline{E}$ can be obtained from a transport equation of the form:

$$\frac{\partial U}{\partial t} + \underline{\nabla} \cdot (\underline{v}_g U) + \underline{E}^* \cdot \underline{\tilde{g}}^H \cdot \underline{E} = 0 \quad , \quad (8)$$

where

$$U = \frac{1}{8\pi} \underline{E}^* \cdot \frac{\partial}{\partial \omega} (\omega \underline{\epsilon}) \cdot \underline{E} = \text{wave energy density} \quad ,$$

and

$$\underline{\tilde{g}}^H = \text{Hermitian part of the conductivity tensor} \quad .$$

No attempt has yet been made to include such an equation in the RAYS code. However, an indication of the wave absorption can be obtained by evaluating the imaginary part of the wave vector using a dispersion relation which includes the anti-Hermitian part of the dispersion tensor. Neglecting the effects of focusing and defocusing of the rays,

which come from the $\nabla \cdot \mathbf{v}_g$ in Eq. (8), one obtains for the power density along the ray $P(s)$:

$$P(s) = P_0 \exp\left\{-2 \int_0^s ds k_i(s) \cos[\phi(s)]\right\} \quad (9)$$

where

P_0 = initial power density ,

k_i = imaginary part of k ,

and

ϕ = angle between $\mathbf{k}_i$ and $\mathbf{v}_g$.

Calculations such as this have been done with the RAYS code using several models for the wave damping.

3. STRUCTURE OF THE RAYS CODE

3.1 INTRODUCTION

The RAYS code consists of a main program plus a collection of subroutines which integrate Eqs. (4) and (5) to give the trajectories of the rays and the wavevectors for points along these trajectories. In order to minimize memory overhead the computed ray data is not plotted immediately but is written in a disk file. After inspection by the user, graphics output may be obtained by means of a postprocessor called RAYPLT.RAY. RAYS is written in standard FORTRAN and uses the IMSL scientific subroutine library and the ODE differential equation package. The graphics postprocessor makes use of the DISSPLA graphics software. The RAYS code has been implemented for the DEC system 10 and for the CRAY 1 computer.

The main program controls the input/output, initializes quantities, drives routines which integrate the ray equations, calculates the electric field polarization vectors, and calculates the locations of B field lines and of resonance and cutoff surfaces. The actual integration of the ray equations is carried out by ODE, a very efficient software package written by L. F. Shampine and M. K. Gordon for integrating an arbitrary number of coupled ordinary differential equations. ODE, in turn, requires a subroutine to evaluate the derivatives of $\underline{r}(s)$ and $\underline{k}(s)$. This task is performed by subroutine DERV. The last principal module of RAYS is the subroutine EQUIB, which computes $\underline{B}$, $\underline{\nabla}B$, n_e , and $\underline{\nabla}n_e$.

3.2 INPUT AND OUTPUT

All input and output for RAYS is performed by the MAIN program. Input data is read from disk file RAYD.DAT, and output is written into two disk files having user-defined device numbers: IO1 and IO2. The IO2 file contains all the ray information plus the data needed to plot magnetic field lines, resonances, and cutoffs (if requested by the user). The IO1 file contains bookkeeping and diagnostic data.

The schematic flow chart in Fig. 1 illustrates the structure and operation of the RAYS code.

3.2.1 Input

All input information to the RAYS code enters through a namelist, DATA, which resides on a disk file RAYD.DAT. The input parameters can be classified as follows:

- (1) Parameters which specify the computer characteristics: CMPUTR, IO1, IO2.
- (2) Parameters which specify the kind of data to be calculated and limits on the rays: IEQ, IBUG, IDAMP, DS, SMAX, XMAX, YMAX, ZMAX, RELERR, ABSERR.
- (3) Parameters which specify the initial conditions and number of rays to be calculated: THETA0, NTHETA, DTHETA, PHIO, NPHI, DPHI, RZO, NRZ, DRZ, XO, DX, IXMX, YO, DY, IYMX, ZO, DZ, IZMX.

Fig. 1. Schematic flow chart of the RAYS code.

- (4) Parameters which specify the plasma equilibrium quantities and magnetic geometry: PFEO, CFEO, BETANN, TE, TEHOT, TI, ISLAB, RSLAB, NCOIL, SEP, RCOIL, RNOT, DELTA, DINF.
- (5) Parameters which specify the wave characteristics: FMU, SGN, IPARAM, ICONV.

Somewhat more detailed descriptions of these parameters can be found in Appendix I. The absolute plasma density and magnetic field strength are specified by the ratio of electron plasma frequency to wave frequency [$\omega_{pe}(0)/\omega = \text{PFEO}$] and the ratio of electron cyclotron frequency to wave frequency [$\Omega_e(0)/\omega = \text{CFEO}$] at some reference point, usually the origin ($x = y = z = 0$).

3.2.2 Output

The computed ray information is written in a disk file on unit IO2 (typically, IO2 = 21, filename = FOR21.DAT) at the end of each integration increment ΔS (see Fig. 1). The format is $S, \underline{V}$, where S is the ray parameter (typically arc length) and $\underline{V}$ is a ten-dimensional vector with

$$V(1) = x(s) \quad V(2) = y(s) \quad V(3) = z(s)$$

$$V(4) = k_x(s) \quad V(5) = k_y(s) \quad V(6) = k_z(s)$$

and V(7) through V(10) are used for multiple purposes. Frequently, V(7) is used to calculate the integrated power absorption, $1 - P(s)/P_0$ [Eq. (9)], or to calculate the path phase length $\int_0^s ds' \, k_i \cdot v_g/|v_g|$. The polarization eigenvector may be inserted in V(8) through V(10):

$$V(8) = |E_x| \quad V(9) = |E_y| \quad V(10) = |E_z| \quad .$$

In practice, we usually use V(8) through V(10) for diagnostic purposes: V(8) and V(9) give checks on the plasma equilibrium (see Sect. 8 for more information), and V(10) contains the local value of imaginary (k_i) as given by the damping module.

The parameter S is also used to pass information to the RAYPLT program; S is set to -1 at the end of each ray and to -10 to indicate the end of run. When plotting magnetic field lines or the locations of resonance or cutoff surfaces, S is set to 5000: the x, y, z coordinates of the field line are contained in V(1), V(2), V(3); and components V(4) through V(10) are unused. For ease in identifying output, the beginning of the FOR21.DAT contains the date and time of the run, a listing of the input file RAYD.DAT, and Hollerith characters indicating which of the interchangeable dispersion relation, plasma equilibrium, or damping models were actually used in the calculation.

A secondary output file is written on device IO1 (typically, IO1 = 20, filename = FOR20.DAT) containing diagnostic and bookkeeping information. At the beginning of execution, the time, date, and contents of the input file RAYD.DAT are listed. At the beginning of

each ray, the initial values of $|k|$ and θ (the angle between k and B) are printed. At the end of each ray, a flag, ISTOP, is printed that indicates the conditions under which the ray terminated (see Appendix I).

ISTOP = 1 The ray stepped out of bounds ($S > SMAX$ or $|x|, |y|, |z| > XMAX, YMAX, ZMAX$ or $Z < 0$).

ISTOP = 2 ODE has stepped the RAY into a cutoff region.

ISTOP = 3 The ray is approaching a resonance, and the refractive index is large (i.e., $n > 10^6$).

ISTOP = 7 Greater than 99% of the initial wave power has been absorbed, as indicated by subroutine DAMP.

ISTOP = 8 The criterion for conversion to a warm plasma mode has been satisfied. This test is done in subroutine CONVRT.

Additional flags which appear at the end of each ray are NDERV, which indicates the number of this subroutine DERV was called for the ray, and NDAMP, which gives the number of times the subroutine DAMP was called.

If the ODE package has numerical difficulty integrating the ray equation, a flag, IFLAG, indicating the nature of the difficulty (see

ODE documentation), and information concerning the location along the ray and error criteria are printed. If the IBUG parameter is chosen > 0 in the input data, additional diagnostic data is printed (see listing, Appendix IV, for details).

Examples of RAYS output files are given in Appendix III.

3.3 DESCRIPTION OF MAIN

The MAIN program communicates with its subroutines through the subroutines calling statements and through several common blocks. Unlabeled common contains most of the necessary input data from the DATA namelist. Common block /STP/ contains the flag ISTOP used to terminate a ray from the ODE routine, block /ZONES/ contains information required to plot the singular surfaces, and block /NAMES/ contains the Hollerith literal names of the modules which were used.

MAIN begins by reading the input data into the DATA namelist from the RAYD.DAT file (see block diagram). This namelist and the time and date of the run are then immediately written in the FOR20.DAT file and FOR21.DAT files.

Depending upon the value of IEQ, MAIN may then write the plotting information for the field lines and the singular surfaces in FOR21.DAT. A complex root-finding routine from the IMSL subroutine library, ZANLYT, is used by MAIN to locate the cyclotron resonance and the right-hand cutoff. ZANLYT uses the function ZONE, which defines the equations for the singular surfaces.

At this point the ray tracing begins. From the input parameters MAIN determines the initial starting position and either the angle of propagation or the value of $n_{\parallel}$ for the first ray. If DRZ is zero, the ray's initial direction is specified by the angles θ and ϕ , the conventional spherical angles specified in degrees. The corresponding variables in the RAYD.DAT file are THETA0 and PHIO, respectively. If the user wants the ray to be initialized with a given value of $n_{\parallel}$, then, initially, he must set DRZ unequal to zero, and RZ0 to the desired value for $n_{\parallel}$. DERV is called and the magnitude of $\underline{k}$ is normalized to satisfy the dispersion relation if the ray is initialized to a specified angle of propagation, or $n_{\perp}$ is normalized to satisfy the dispersion relation if the ray is initialized to a specified $n_{\parallel}$. The ODE differential equation package is initialized, and the arc length parameter S is set equal to zero. Then, ODE is called, and the ray equations are integrated from S to $S + DS$. If requested upon return from ODE, subroutine EPOLAR is then called to determine the electric polarization vector, and the magnitudes of the complex eigenvectors ($|E_x|$, $|E_y|$, $|E_z|$) are stored in $V(8)$, $V(9)$, and $V(10)$. S and V are then output to the FOR21.DAT file.

A check is made to see if any of the stop conditions are satisfied. If the tests fail, the program loops back and ODE integrates again over an interval ΔS . When a stop condition is finally met, the integration of that ray ceases, and a line is written out to the FOR21.DAT file with $S = -1$.

If additional rays are to be calculated, the program branches back and calculates the new starting position and direction of the wavevector. DERV is called to find the magnitude of k , and the sequence continues. The starting position and direction of k are controlled by a set of nested do loops whose parameters are set by the input data. The quantities vary from fastest to slowest in the following order: $n_{||}$, θ , ϕ , Z , Y , and X , where θ and ϕ are the usual angles in spherical coordinates defining the initial direction of k .

Successive values of THETA are defined by THETA0, THETA0 + DTHETA, ..., THETA0 + (NTHETA - 1) $\times$ DTHETA. The other five parameters are incremented in an analogous way.

When the last ray has been calculated, a line with $S = -10$ is written in the FOR21.DAT file and RAYS stops.

3.4 DESCRIPTION OF ODE

ODE is a suite of subroutines written by L. F. Shampine and M. K. Gordon that integrates a coupled system of first-order ordinary differential equations with specified initial values. We have been using ODE very effectively since the inception of the ray tracing problem to integrate the ray equations. ODE is also used to integrate the local wave damping rate if this option is desired. ODE is very well documented by comments in the subroutines although considerably more information can be found in Ref. 5.

ODE is actually the controlling subroutine which calls DE, STEP, and INTRP to solve the differential equations using a modified divided difference form of the Adams-PECE formulas and local extrapolation.

The calling sequence for ODE is as follows: CALL ODE (DERV, NDIM, V, S, SOUT, RELERR, ABSERR, IFLAG, IWORK). ODE integrates NDIM (typically NDIM = 9) differential equations simultaneously from the arc length parameter S to SOUT and gives the solution vector V at SOUT. The derivatives of V with respect to S are defined by an external subroutine, DERV. ODE automatically adjusts the order and step size to satisfy the error criterion: $| \text{Local error} | < | V(i) | \cdot \text{RELERR} + \text{ABSERR}$, $i = 1, \dots, \text{NDIM}$. The user must provide space in the calling program by dimensioning IWORK as 5 and dimensioning WORK as $100 + 21 \cdot \text{NDIM}$. WORK and IWORK contain internal information for ODE which is of no interest to the user.

IFLAG is used to initialize ODE at the beginning of each integration and to give information about the status of the integration upon return. If IFLAG $\neq$ 2 upon return, the ray is terminated.

3.5 SUBROUTINE DERV

The derivatives necessary for integration of the ray equation [Eqs. (4)-(5) or Eqs. (2)-(3), if time is used as the ray parameter] are calculated in the module DERV [see Fig. (1)]. The calling sequence is:

```
CALL DERV (S, V, DV) ,
```

where arguments S and V have been described previously (Sect. 3.3) and the computed derivatives are returned in DV:

$$DV(1) = \frac{dx}{ds} \quad DV(2) = \frac{dy}{ds} \quad DV(3) = \frac{dz}{ds}$$

$$DV(4) = \frac{dk_x}{ds} \quad DV(5) = \frac{dk_y}{ds} \quad DV(6) = \frac{dk_z}{ds}$$

If wave damping is being calculated, DV(7) contains the derivative of fraction of power absorbed [See Eq. (9)]:

$$V(7) = 1 - P(S)/P_0,$$

$$DV(7) = 2k_i \cos(\phi) [1 - V(7)] = \frac{d}{ds} V(7).$$

Before integration of the equations begins for each ray, the initial conditions for the ray $\underline{x}_0, \underline{k}_0$ must be established. If the ray is to be initialized with a specific direction for $\underline{k}_0$, DERV is called by MAIN with arguments $S = -1$, $V = (\underline{x}_0, \hat{\underline{k}}_0, 0 \dots)$, where $\underline{x}_0$ is the starting point of the ray and a unit vector $\hat{\underline{k}}_0$ is in the desired direction for the initial wave vector. When $S = -1$, the action of DERV is to normalize V(4) through V(6) to be a solution of the local wave dispersion relation in the direction of $\underline{k}_0$ for the desired mode. If

the ray is to be initialized with a specified value of $n_{\parallel}$, DERV is called by MAIN with arguments $S = -2$, $V = (x_0, 0, 0, n_{\parallel}, 0 \dots)$. When $S = -2$, the action of DERV is to normalize $V(4)$ through $V(6)$ to be a solution of the local wave dispersion relation having the given $n_{\parallel}$.

In order to evaluate the ray derivatives, DERV must have available the local values of the plasma density $n_e(x)$ and the magnetic field $B(x)$ and the derivatives of these quantities, ∇n_e and ∇B . It obtains these by calling a plasma equilibrium subroutine EQUIB. Thus, the plasma geometry model is completely separated from the wave physics model. The local value of $k_{\perp}$ necessary to calculate wave damping is obtained by calling a subroutine DAMP.

A number of different DERV modules describing different wave physics have been written and used with the RAYS code. A high frequency limit of the cold plasma dispersion relation in terms of $|n|$ and θ (Appleton-Hartree dispersion relation) and a cold plasma dispersion relation in terms of $n_{\parallel}$ and $n_{\perp}$ that includes an ion species are to be described in this report (Sect. 4). The Hollerith literal names for these modules, which appear in the FOR20.DAT and FOR21.DAT files, are APPLE and COLD, respectively.

3.6 SUBROUTINE DAMP

When wave absorption is being calculated in DERV using Eq. (9), the local value of $k_{\perp}$ is obtained from a model DAMP. The calling sequence is

CALL DAMP (ALFA, BETA, VTE, RXB, RXP, RXI)

where

$ALFA = \omega_{pe}^2(\underline{x})/\omega^2 = \text{normalized local electron plasma frequency}$,

$BETA = \Omega_e^2(\underline{x})/\omega^2 = \text{normalized local electron cyclotron frequency}$,

$VTE = (2T_e/m_e c^2)^{1/2} = \text{normalized electron thermal speed}$,

$RXB = n_{\parallel}(s) = \frac{c}{\omega} \underline{k}(s) \cdot \hat{\underline{B}} = \text{parallel refractive index}$,

and

$RXP = [n(s)^2 - n_{\parallel}(s)^2]^{1/2} = \text{perpendicular refractive index}$.

On return, RXI contains the imaginary part of the refractive index. The imaginary part of the wave vector $\underline{k}$ is taken to be in the same direction as the real part of $\underline{k}$. A number of DAMP subroutines have been written using various methods to evaluate cyclotron, cyclotron harmonic damping, and Landau damping.

3.7 SUBROUTINE EQUIB

The magnetic geometry and plasma density properties are defined in the module EQUIB. The calling sequence is

```
CALL EQUIB (V, B, GRB, D, GRD) ,
```

where the argument V has been discussed previously, output B is a three-dimensional vector containing Cartesian components of the normalized magnetic field (B_x, B_y, B_z), output GRB is a 3×3 matrix containing ∇B , output D is a scalar containing the normalized plasma density n_e , and output GRD is a three-vector containing ∇n_e . The output of EQUIB is normalized such that $|B|$ and D are unity at some prescribed point $\underline{x}_0$ (typically, $x_0 = y_0 = z_0 = 0$). The absolute magnetic field strength and absolute density are introduced through the parameters CFEO and PFEO, where $CFEO = \Omega_e(\underline{x}_0)/\omega$ and $PFEO = \omega_{pe}(\underline{x}_0)/\omega$. The local values of the previously defined quantities α and β are therefore given by $\alpha(\underline{x}) = (PFEO ** 2) D$ and $\beta(\underline{x}) = (CFEO * |B| ** 2)$. In addition to the local position information entering through V(1)-V(3), EQUIB receives parameters defining the equilibrium geometry and scaling from common blocks /SLAB/ and /EQBC/.

Various EQUIB packages have been written for the RAYS code including slabs, cylinders, mirrors, and assorted idealizations of tokamaks. Details of slab, bumpy cylinder, and tokamak models will be given in Sect. 5.

4. DISPERSION RELATION MODULES, DERV

The plasma physics enters the calculation of ray paths by means of the local dispersion relation $D(\underline{k}, \omega, \underline{r})$ and its derivative. A number of different dispersion relations have been used with the RAYS code, three of which will be discussed in this section.

4.1 COLD PLASMA DISPERSION RELATION IN TERMS OF $n_{\parallel}, n_{\perp}$

The dispersion relation for a cold magnetized plasma is in general a quartic equation in the components of the refractive index $\underline{n}$. When expressed in terms of $n_{\parallel}$ (the component of $\underline{n}$ parallel to $\underline{B}$) and $n_{\perp}$ (the magnitude of the component of $\underline{n}$ perpendicular to $\underline{B}$), the dispersion relation reduces to a biquadratic of the form:

$$D(n_{\parallel}, n_{\perp}, \omega, \underline{r}) = A(n_{\perp}^2, \underline{r})n_{\parallel}^4 + B(n_{\perp}^2, \underline{r})n_{\parallel}^2 + C(n_{\perp}^2, \underline{r}) = 0, \quad (10)$$

where

$$\underline{n} = \frac{c\underline{k}}{\omega} \quad n_{\parallel} = \frac{\underline{n} \cdot \underline{B}}{B} \quad n_{\perp}^2 = n^2 - \left(\frac{\underline{n} \cdot \underline{B}}{B}\right)^2.$$

In the electron cyclotron range of frequencies ($\omega \gg \Omega_i, \omega_{pi}$), the coefficients reduce to

$$A = (1 - \alpha)(1 - \beta),$$

$$B = -2(1 - \alpha)(1 - \alpha - \beta) + [(1 - \alpha)(1 - \alpha - \beta) + (1 - \alpha)^2 - \beta]n_{\perp}^2, \quad (11)$$

and

$$C = (1 - \alpha - \beta)n_{\perp}^4 - [(1 - \alpha)(1 - \alpha - \beta) + (1 - \alpha)^2 - \beta]n_{\perp}^2 + (1 - \alpha)[(1 - \alpha)^2 - \beta].$$

The derivatives necessary for Eqs. (4) and (5) are

$$\begin{aligned} \frac{\partial D}{\partial k} &= (4An_{\parallel}^2 + 2B)n_{\parallel} \frac{\partial n_{\parallel}}{\partial k} + \left(\frac{\partial A}{\partial n_{\perp}^2} n_{\parallel}^4 + \frac{\partial B}{\partial n_{\perp}^2} n_{\parallel}^2 + \frac{\partial C}{\partial n_{\perp}^2} \right) \frac{\partial n_{\perp}^2}{\partial k}, \\ \frac{\partial D}{\partial r} &= \left(\frac{\partial A}{\partial \alpha} n_{\parallel}^4 + \frac{\partial B}{\partial \alpha} n_{\parallel}^2 + \frac{\partial C}{\partial \alpha} \right) \frac{\partial \alpha}{\partial r} + \left(\frac{\partial A}{\partial \beta} n_{\parallel}^4 + \frac{\partial B}{\partial \beta} n_{\parallel}^2 + \frac{\partial C}{\partial \beta} \right) \frac{\partial \beta}{\partial r} \\ &\quad + (4An_{\parallel}^2 + 2Bn_{\parallel}) \frac{\partial n_{\parallel}}{\partial r} + \left(\frac{\partial A}{\partial n_{\perp}^2} n_{\parallel}^4 + \frac{\partial B}{\partial n_{\perp}^2} n_{\parallel}^2 + \frac{\partial C}{\partial n_{\perp}^2} \right) \frac{\partial n_{\perp}^2}{\partial r}, \end{aligned} \quad (12)$$

and

$$\begin{aligned} \frac{\partial D}{\partial \omega} &= \left(\frac{\partial A}{\partial \alpha} n_{\parallel}^4 + \frac{\partial B}{\partial \alpha} n_{\parallel}^2 + \frac{\partial C}{\partial \alpha} \right) \frac{\partial \alpha}{\partial \omega} + \left(\frac{\partial A}{\partial \beta} n_{\parallel}^4 + \frac{\partial B}{\partial \beta} n_{\parallel}^2 + \frac{\partial C}{\partial \beta} \right) \frac{\partial \beta}{\partial \omega} \\ &\quad + \left(\frac{\partial A}{\partial n_{\perp}^2} n_{\parallel}^4 + \frac{\partial B}{\partial n_{\perp}^2} n_{\parallel}^2 + \frac{\partial C}{\partial n_{\perp}^2} \right) \frac{\partial n_{\perp}^2}{\partial \omega} + (4An_{\parallel}^2 + 2B)n_{\parallel} \frac{\partial n_{\parallel}}{\partial \omega}, \end{aligned}$$

where

$$\frac{\partial n_{\parallel}}{\partial \tilde{k}} = \frac{c}{\omega} \frac{\tilde{B}}{B}, \quad \frac{\partial n_{\perp}^2}{\partial \tilde{k}} = 2 \frac{c}{\omega} \left(\tilde{n} - n_{\parallel} \frac{\tilde{B}}{B} \right),$$

$$\frac{\partial \alpha}{\partial \tilde{r}} = \alpha \frac{\tilde{\nabla} n_e}{n_e}, \quad \frac{\partial \beta}{\partial \tilde{r}} = 2\beta \frac{\tilde{\nabla} B}{B}, \quad \frac{\partial \alpha}{\partial \omega} = -\frac{2}{\omega} \alpha, \quad \frac{\partial \beta}{\partial \omega} = -\frac{2}{\omega} \beta,$$

$$\frac{\partial n_{\parallel}}{\partial \tilde{r}} = \tilde{n} \cdot \tilde{\nabla} \left(\frac{B}{B} \right), \quad \frac{\partial n_{\perp}^2}{\partial \tilde{r}} = -2n_{\parallel} \frac{\partial n_{\parallel}}{\partial \tilde{r}},$$

$$\frac{\partial n_{\perp}^2}{\partial \omega} = -\frac{2}{\omega} n_{\perp}^2, \quad \text{and} \quad \frac{\partial n_{\parallel}}{\partial \omega} = -\frac{n_{\parallel}}{\omega}.$$

The derivatives of A, B, and C with respect to α, β are easily obtained from Eq. (11).

At a given point in the plasma with fixed $\alpha, \beta, n_{\perp}$, there are two roots to Eq. (10):

$$(n_{\parallel}^{\pm})^2 = \frac{-B \pm \sqrt{\Delta}}{2A}, \quad (13)$$

where $\Delta = B^2 - 4AC = \alpha^2\{\beta[2(1 - \alpha) - n_{\perp}^2] - (1 - \beta)n_{\perp}^4\}$. For exactly parallel propagation ($n_{\perp} \rightarrow 0$), Eq. (13) reduces to

$$(n_{\parallel}^{\pm})^2 = 1 - \frac{\alpha}{1 \pm \sqrt{\beta}} \quad , \quad (14)$$

where the upper sign corresponds to ordinary mode propagation and the lower sign is extraordinary mode. Provided $\alpha, \beta < 1$, the $(\pm)$ signs in Eq. (13) remain associated with these modes for nonzero $n_{\perp}$. However, for higher density or field strength the associated signs can reverse or both roots of Eq. (13) can correspond to the same mode at different angles of propagation.⁶ As a result, some care is required in initializing $\underline{n}$ to the proper sign root of Eq. (13) when $\alpha > 1$ or $\beta > 1$. Also, as the ray propagates through the plasma, it is possible for $\underline{n}$ to jump from one branch of Eq. (13) to the other. For a detailed discussion of this phenomenon with examples see Ref. 6.

With the dispersion relation in the form of Eq. (10), it is comparatively easy to include multiple plasma species and therefore extend its range of validity to lower frequencies. The cold plasma dispersion relation for a general multicomponent plasma can be written

$$D(n_{\parallel}, n_{\perp}) = n^2(n_{\parallel}^2 P + n_{\perp}^2 S) - (n_{\parallel}^2 + n_{\perp}^2)PS - n_{\perp}^2 RL + PRL = 0 \quad , \quad (15)$$

where in Stix's notation²

$$P = 1 - \sum_j \frac{\omega_{pj}^2}{\omega^2}, \quad R = 1 - \sum_j \frac{\omega_{pj}^2}{\omega(\omega + \Omega_j)}, \quad L = 1 - \sum_j \frac{\omega_{pj}^2}{\omega(\omega - \Omega_j)},$$

and

$$S = \frac{1}{2}(R + L) = 1 - \sum_j \frac{\omega_{pj}^2}{\omega^2 - \Omega_j^2}.$$

For ray tracing it is convenient to remove the singular denominators by multiplying by $T \equiv \prod_j (\omega + \Omega_j)(\omega - \Omega_j)$. Once this is done, the dispersion relation can be written in the form of Eq. (10) with coefficients given by

$$A = TP,$$

$$B = -2TSP + [TP + TS]n_{\perp}^2, \quad (16)$$

and

$$C = (P - n_{\perp}^2)(TRL - n_{\perp}^2 TS).$$

For a two-component plasma of electrons and singly charged ions we have in terms of the previously defined dimensionless density and magnetic field variables α, β :

$$P = 1 - \left(1 + \frac{m_e}{m_i}\right)\alpha ,$$

$$T = 1 - \left(1 + \frac{m_e}{m_i}\right)\beta + \frac{m_e^2}{m_i^2}\beta^2 , \quad (17)$$

$$TS = T - \left(1 + \frac{m_e}{m_i}\right)\alpha + \left(1 + \frac{m_e}{m_i}\right)\frac{m_e}{m_i}\alpha\beta ,$$

and

$$Q \equiv TRL = T - 2\left(1 + \frac{m_e}{m_i}\right)\alpha + 2\frac{m_e}{m_i}\left(1 + \frac{m_e}{m_i}\right)\alpha\beta + \left(1 + \frac{m_e}{m_i}\right)^2\alpha^2 .$$

A DERV module based on Eqs. (10)-(12) and Eqs. (16)-(17) essentially has become our standard operating package. The Hollerith name is COLD. Calculations have been made throughout the lower hybrid to electron cyclotron range of frequencies with this single routine. The exact results of the Appleton-Hartree dispersion relation are recovered by letting $m_i \rightarrow \infty$. In addition to the usual mode of initializing $|n|$ as a solution of the dispersion relation for specified θ , in COLD we have provided for $n_\perp$ to be initialized to the proper value for specified $n_\parallel$. If $S = -2$ on the first call to DERV, the input value of $V(6)$ is taken

as $n_{\parallel}$, and the appropriate local value of $n_{\perp}$ is obtained from the dispersion relation. The wave vector is then initialized according to $[V(4), V(5), V(6)] = k_0 \underline{\underline{R}} \cdot (n_{\perp}, 0, n_{\parallel})$ where k_0 is the free space wavenumber and $\underline{\underline{R}}$ is a rotation matrix which takes into account the angle between $\underline{\underline{B}}$ and the z axis. This mode of initialization is very useful for lower hybrid studies where the angle of injection is nearly perpendicular but where the wave damping is quite sensitive to $n_{\parallel}$. A FORTRAN listing of the module COLD is presented in Appendix IV.

4.2 APPLETON-HARTREE DISPERSION RELATION

Most of the early calculations in the microwave heating study for EBT used the Appleton-Hartree dispersion relation,^{2,7} a high frequency limit ($\omega \gg \Omega_i$) of the cold plasma dispersion relation,

$$D(k, \theta, \omega, \underline{\underline{r}}) = 1 - \frac{c^2 k^2}{\omega^2} - \frac{2\alpha(1 - \alpha)}{2(1 - \alpha) - \beta \sin^2 \theta \pm \Gamma(\theta, \underline{\underline{r}})} \quad , \quad (18)$$

where

$$k^2 = \underline{\underline{k}} \cdot \underline{\underline{k}} \quad ,$$

$$\Gamma(\omega, \theta, \underline{\underline{r}}) = [\beta^2 \sin^4 \theta + 4\beta(1 - \alpha)^2 \cos^2 \theta]^{1/2} \quad ,$$

$$\alpha(\omega, \underline{r}) = \frac{\omega_{pe}^2(\underline{r})}{\omega^2} ,$$

$$\beta(\omega, \underline{r}) = \frac{\Omega_e^2(\underline{r})}{\omega^2} ,$$

and

$$\cos \theta = \underline{k} \cdot \frac{\underline{B}}{|\underline{k}| |\underline{B}|} .$$

An advantage of this form for the dispersion relation is that the ordinary and extraordinary modes are separated and determined explicitly by the sign in Eq. (18). The $+$ ($-$) sign corresponds to the ordinary mode (extraordinary mode) of propagation.

With this form for the dispersion relation, it is convenient to resolve the group velocity into components along $\hat{k} = \underline{k}/|\underline{k}|$ and $\hat{\theta}$ (Fig. 2):

$$\underline{v}_g = - \frac{\frac{\partial D}{\partial \underline{k}} \hat{k} + \frac{1}{k} \frac{\partial D}{\partial \theta} \hat{\theta}}{\frac{\partial D}{\partial \omega}} , \quad (19)$$

where

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Fig. 2. Local coordinate system for ray tracing using the Appleton-Hartree dispersion relation.

$$\hat{\theta} = \frac{\underline{k} \times (\underline{k} \times \underline{B})}{|\underline{k} \times (\underline{k} \times \underline{B})|} \quad (20)$$

The ray equations [Eqs. (4) and (5)] take the form

$$\frac{d\underline{r}}{ds} = -\text{sgn} \left(\frac{\partial D}{\partial \omega} \right) \frac{\frac{\partial D}{\partial \underline{k}} \hat{\underline{k}} + \frac{1}{k} \frac{\partial D}{\partial \theta} \hat{\theta}}{\left[\left(\frac{\partial D}{\partial \underline{k}} \right)^2 + \left(\frac{1}{k} \frac{\partial D}{\partial \theta} \right)^2 \right]^{1/2}} \quad (21)$$

and

$$\frac{d\underline{k}}{ds} = \text{sgn} \left(\frac{\partial D}{\partial \omega} \right) \frac{\frac{\partial D}{\partial \alpha} \underline{\nabla} \alpha + \frac{\partial D}{\partial \beta} \underline{\nabla} \beta + \frac{\partial D}{\partial \theta} \underline{\nabla} \theta}{\left[\left(\frac{\partial D}{\partial \underline{k}} \right)^2 + \frac{1}{k} \left(\frac{\partial D}{\partial \theta} \right)^2 \right]^{1/2}} \quad (22)$$

The right-hand sides of Eqs. (21) and (22) are obtained by repeated application of the chain rule. Defining

$$D(k, \theta, \alpha, \beta, \omega) = 1 - \frac{k^2 c^2}{\omega^2} - G(\alpha, \beta, \theta) = 1 - \frac{k^2 c^2}{\omega^2} - \frac{N(\alpha)}{D_{\pm}(\alpha, \beta, \theta)} \quad (23)$$

where

$$G(\alpha, \beta, \Gamma, \theta) \equiv \frac{N(\alpha)}{D_{\pm}(\alpha, \beta, \Gamma, \theta)} \equiv \frac{2\alpha(1 - \alpha)}{2(1 - \alpha) - \beta \sin^2 \theta \pm \Gamma(\alpha, \beta, \theta)} \quad (24)$$

we have

$$\frac{\partial D}{\partial k} = -\frac{2kc^2}{\omega^2} , \quad (25)$$

$$\frac{\partial D}{\partial \theta} = \frac{N}{D_{\pm}^2} \frac{\partial D_{\pm}}{\partial \theta} = -\frac{2 \sin \theta \cos \theta}{D_{\pm}^2} \left[\beta \pm \frac{\beta^2 \sin^2 \theta - 2\beta(1-\alpha)^2}{\Gamma} \right] ,$$

$$\frac{\partial D}{\partial \omega} = \frac{2k^2 c^2}{\omega^3} + \frac{2\alpha}{\omega} \left(\frac{\partial G}{\partial \alpha} + \frac{\partial G}{\partial r} \frac{\partial r}{\partial \alpha} \right) + \frac{2\beta}{\omega} \left(\frac{\partial G}{\partial \beta} + \frac{\partial G}{\partial \Gamma} \frac{\partial \Gamma}{\partial \beta} \right) ,$$

$$\frac{\partial D}{\partial \tilde{r}} = -\left(\frac{\partial G}{\partial \alpha} + \frac{\partial G}{\partial \theta} \frac{\partial \Gamma}{\partial \alpha} \right) \tilde{\nabla} \alpha - \left(\frac{\partial G}{\partial \beta} + \frac{\partial G}{\partial \Gamma} \frac{\partial \Gamma}{\partial \beta} \right) \tilde{\nabla} \beta ,$$

$$\frac{\partial G}{\partial \alpha} + \frac{\partial G}{\partial \Gamma} \frac{\partial \Gamma}{\partial \alpha} = \frac{1}{D_{\pm}^2} \left[2(1-2\alpha)D_{\pm} + 2N + N \frac{4\beta(1-\alpha)}{\Gamma} \cos^2 \theta \right] ,$$

$$\frac{\partial G}{\partial \beta} + \frac{\partial G}{\partial \Gamma} \frac{\partial \Gamma}{\partial \beta} = \frac{N}{D_{\pm}^2} \left[\sin^2 \theta \pm \frac{\beta \sin^4 \theta + 2(1-\alpha)^2 \cos^2 \theta}{\Gamma} \right] ,$$

$$\tilde{\nabla} \alpha = \alpha \frac{\tilde{\nabla} n_e}{n_e} ,$$

$$\nabla\beta = 2\beta \frac{\nabla|B|}{|B|} ,$$

and

$$\nabla\theta = - \frac{1}{k \sin \theta} \nabla(\hat{k} \cdot \frac{\underline{B}}{|B|}) .$$

A FORTRAN listing of the DERV module, which has the Hollerith literal name APPLE and which evaluates the right-hand sides of Eqs. (21) and (22) using Eq. (25), is presented in Appendix V.

4.3 FINITE TEMPERATURE DISPERSION RELATION

Recently, we have developed a module of subroutines to calculate the derivatives of the full finite temperature dispersion relation. This dispersion relation takes the form

$$D = \det(\underline{\underline{\epsilon}}^H) = 0$$

and

$$\epsilon^H = \frac{1}{2}(\underline{\underline{\epsilon}} + \underline{\underline{\epsilon}}^+) ,$$

where $\underline{\underline{\epsilon}}$ is the dispersion tensor for a nonrelativistic, isotropic

Maxwellian plasma. The plasma dispersion functions $Z(\xi_n)$ and modified Bessel functions $I_n(k_{\perp}^2 \rho_e^2/2)$ can be included for an arbitrary number of cyclotron harmonics, $\xi_n = (\omega - n\Omega_e)/k_{\parallel} v_e$. Details will not be presented because the expressions are extremely complicated and the results are preliminary. This formulation is not valid near the fundamental cyclotron resonance because the anti-Hermitian part of ξ is dominant there. This routine can, however, be used near the upper hybrid resonance, and we have, for example, observed the conversion of the extraordinary mode to a finite temperature electrostatic mode near the upper hybrid resonance [see Ref. G].

5. EQUILIBRIUM MODULES

The plasma geometry is introduced by means of analytic models for $B(\underline{r})$, $n_e(\underline{r})$, ∇B , ∇n_e as a function of position $\underline{r}$. In the RAYS code these quantities are obtained by calling a subroutine EQUIB, whose calling sequence was described in Sect. 3.6. The profiles of B and n_e are normalized such that $|B|$ and n_e are unity at some specified position $\underline{r}_0$ (e.g., on-axis at the midplane of a mirror, $\underline{r}_0 = 0$). The absolute magnetic field strength and the absolute density are then specified by the ratios $\Omega_e(\underline{r}_0)/\omega$ (denoted CFEO in the code), and $\omega_{pe}(\underline{r}_0)/\omega$ (denoted PFEO in the code), respectively.

A number of equilibrium models have been used in the RAYS code, including slab models, bumpy cylinder models, and various idealized models for tandem mirrors and tokamaks. In this section we present mathematical details of three EQUIB subroutines which have been extensively used in our studies: a simple 1-D slab model, a 2-D analytic bumpy cylinder model, and an analytic tokamak model.

5.1 SLAB MODEL

Considerable simplification in the wave propagation problem occurs if the medium is plane stratified; i.e., all gradients in $n_e(\underline{x})$ and $B(\underline{x})$ lie in a single fixed direction. In this case the refractive index in any direction perpendicular to the gradient is constant in consequence of Snell's law. The component of the refractive index along the gradient is determined by the local dispersion relation so the location of ray turning points (cutoffs) and resonances can be

found without the necessity of integrating the ray equations. As a result considerable ray tracing has been done in slab geometry for the purpose of testing the RAYS code (Sect. 8).

Two particular examples of plane stratification useful in magnetized plasmas are: (1) perpendicular stratification in which all gradients are perpendicular to a straight parallel magnetic field (Fig. 3a) and (2) parallel stratification in which all gradients are along the magnetic field (Fig. 3b). In both cases, the cold plasma dispersion relation reduces from a quartic to a biquadratic [Eq. (10)] so that the behavior of the nonconserved component of the refractive index can be determined algebraically.

In the EQUIB subroutine with the Hollerith name SLAB, the magnetic field is chosen to lie along z . An integer ISLAB selects one of four configurations:

$$\text{ISLAB} = 1 \quad n_e = 1, \quad \nabla n_e = 0, \quad B_z = 1 + \frac{z}{\text{RSLAB}}, \quad \frac{\partial B_z}{\partial z} = \frac{1}{\text{RSLAB}},$$

$$\text{ISLAB} = 2 \quad n_e = 1, \quad \nabla n_e = 0, \quad B_z = 1 + \frac{x}{\text{RSLAB}}, \quad \frac{\partial B_z}{\partial x} = \frac{1}{\text{RSLAB}},$$

$$\text{ISLAB} = 3 \quad n_e = 1 + \frac{z}{\text{RSLAB}}, \quad \nabla n_e = (0, 0, \frac{1}{\text{RSLAB}}), \quad \underline{B} = (0, 0, 1), \quad \underline{\nabla} B = 0,$$

Fig. 3. Geometry for plane-stratified plasma: (a) perpendicular stratification and (b) parallel stratification.

$$\text{ISLAB} = 4 \quad n_e = 1 + \frac{x}{\text{RSLAB}}, \quad \nabla n_e = \left(\frac{1}{\text{RSLAB}}, 0, 0 \right), \quad \mathbf{B} = (0, 0, 1), \quad \nabla \mathbf{B} = 0.$$

EQUIB obtains the parameters ISLAB and RSLAB from labeled common /SLAB/.

The parallel stratified magnetic field case, ISLAB = 1, is an idealization of the situation near the axis of a mirror. It is true that $\nabla \cdot \mathbf{B} = 0$ is violated in this model, but wave propagation is not sensitive to this feature.

5.2 BUMPY CYLINDER MODEL

For our investigation of wave propagation and absorption in EBT, a bumpy cylinder equilibrium routine (with the Hollerith name EQBC) has been developed in which the magnetic field is the vacuum field due to a set of coaxial current loops spaced along the z axis (Fig. 4). The density is taken to be a function of the axial magnetic flux.

The magnetic field due to the j th current loop can be expressed in the mks system of units using cylindrical coordinates as⁸

$$\mathbf{B}_j(\rho, z) = B_{j\rho} \hat{\rho} + B_{jz} \hat{z}, \quad (26)$$

$$B_{j\rho} = \frac{\mu_0 I}{2\pi} \frac{z_j}{\rho [(a + \rho)^2 + z_j^2]^{1/2}} \left[\frac{a^2 + \rho^2 + z_j^2}{(a - \rho)^2 + z_j^2} E(m_j) - K(m_j) \right], \quad (27)$$

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Fig. 4. Geometry for bumpy cylinder plasma equilibrium.

and

$$B_{jz} = \frac{\mu_0 I}{2\pi} \frac{1}{[(a + \rho)^2 + z_j^2]^{1/2}} \left[\frac{a^2 - \rho^2 - z_j^2}{(a - \rho)^2 + z_j^2} E(m_j) + K(m_j) \right] , \quad (28)$$

where $K(m)$ and $E(m)$ are the complete elliptic integrals of the first and second kind,

$$m_j = \frac{4a\rho}{(a + \rho)^2 + z_j^2} ,$$

I = current in the loop ,

a = radius of the loop ,

and

z_j = axial location of the jth loop .

The four derivatives of B_ρ and B_z can be calculated by differentiating Eqs. (27) and (28) directly. Actually, only two of the derivatives are independent since $\nabla \cdot \underline{B} = 0$ and $\nabla \times \underline{B} = 0$. Making use of these two equations and dropping the index j referring to the number of the current loop, we have

$$\frac{dB_\rho}{d\rho} = -\frac{B_\rho}{\rho} - \frac{dB_z}{dz} \quad (29a)$$

and

$$\frac{dB_\rho}{dz} = \frac{dB_z}{d\rho} \quad (29b)$$

The computational technique is to differentiate Eq. (28) for B_z and solve for $dB_\rho/d\rho$ and dB_ρ/dz from Eqs. (29a) and (29b). The derivatives of B_z turn out to be⁹

$$\begin{aligned} \frac{\partial B_z}{\partial z} = & \frac{-\mu_0 I Z}{2\pi[(a+\rho)^2 + z^2]^{3/2}} \left\{ \left[\frac{1}{1-m} + \frac{m(a-\rho)}{(1-m)^2 \rho} + \frac{m(a+\rho)-2\rho}{(1-m)\rho} \right] E(m) \right. \\ & \left. - \left[\frac{m(a+\rho)-2\rho}{2(1-m)\rho} \right] K(m) \right\} \end{aligned} \quad (30)$$

and

$$\begin{aligned} \frac{\partial B_z}{\partial \rho} = & \frac{\mu_0 I a}{2\pi[(a+\rho)^2 + z^2]^{3/2}} \left(\left\{ - \left[\frac{m(a+\rho)-2\rho}{2a\rho(1-m)} (a+\rho) \right] + \frac{m(a^2 + \rho^2) - 2a\rho}{a\rho(1-m)^2} \right. \right. \end{aligned}$$

$$\begin{aligned}
& + \frac{m(a + \rho) - 2\rho}{2a\rho(1 - m)} \cdot \frac{2a - m(a + \rho)}{m} + \frac{2a - m(a + \rho)}{am(1 - m)} \} E(m) \\
& - \left[\frac{a + \rho}{a} + \frac{2a - m(a + \rho)}{am} \cdot \frac{m(a + \rho) - 2\rho}{2\rho(1 - m)} + \frac{2a - m(a + \rho)}{am} \right] K(m) \} .
\end{aligned}
\tag{31}$$

The axial magnetic flux ψ is defined as

$$\psi(\rho, z) = \int_0^\rho \rho' d\rho' B_z(\rho', z) . \tag{32}$$

It is easily shown that ψ is constant along magnetic field lines. The density defined as a function of ψ is therefore constant along field lines. The exact expression for the contribution ψ_j of the j th current loop is given by

$$\psi_j(\rho, z) = \frac{2\mu_0 a I \rho}{\pi m_j [(a + \rho)^2 + z_j^2]^{1/2}} \left[\left(1 - \frac{m_j}{2}\right) K(m_j) - E(m_j) \right] . \tag{33}$$

A number of warnings are in order concerning the numerical evaluation of the fields and derivatives using the above equations. It is obvious that Eq. (27) cannot be computed when the field point lies on the axis of the loop ($\rho = 0$) because of the inverse dependence on radius. This problem is widely recognized. However, there is an additional problem with Eq. (27) in that there must be cancellation in the numerator to make the expression for B_ρ go to zero as m approaches zero. This

results from the facts that $E(m)$ and $K(m)$ both become $\pi/2$ as m approaches zero and that the coefficient of $E(m)$ approaches unity. Even though the absolute error in B_ρ for this case may be small, the relative error will be very large due to cancellation between terms of order one. This can cause numerical havoc if B_ρ is divided by the radial coordinate, as is often the case. Note that the inaccuracy occurs when ρ is not small if z is sufficiently large. The solution to this problem is to use explicit small argument formulas for B_ρ . The criterion for using these small argument formulas is that m , rather than ρ , must be small. Similar difficulties arise in the computation of $dB_z/d\rho$ and ψ for small m . A complete discussion of these problems, as well as the correct expressions to use for small m , is presented in Ref. 10.

For purposes of modeling EBT we choose the density to have the specific form

$$D[\psi(\rho, z)] = \frac{1 + A - \tanh\left[\frac{\psi(\rho, z) - \psi(r_0, 0)}{\delta^2}\right]}{1 + A + \tanh\left[\frac{\psi(r_0, 0)}{\delta^2}\right]}, \quad (34)$$

where

$$A = \frac{1 + \tanh\left[\frac{\psi(r_0, 0)}{\delta^2}\right]}{1 - D_\infty} D_\infty,$$

with r_0 , δ , and D_∞ as constants appropriate for the problem. This functional form gives a density illustrated by Fig. (5) which shows the radial profile of D at the midplane $z = 0$ at $z = 5$ cm and at $z = 10$ cm. Note that $D(\rho = 0, z = 0)$ is normalized to unity and that D at large radii is D_∞ : D_∞ was taken to be 0.1 in this problem to model the cold background plasma in EBT. The density is approximately one-half at $(\rho, z) = (r_0, 0)$, and the width of the shoulder is controlled by δ .

The gradient of the density follows immediately and is

$$\nabla D = \frac{dD(\psi)}{d\psi} \nabla \psi, \quad (35)$$

where

$$\frac{dD(\psi)}{d\psi} = - \frac{\frac{1}{\delta^2} \operatorname{sech}^2 \left[\frac{\psi - \psi(r_0, 0)}{\delta^2} \right]}{1 + A + \tanh \left[\frac{\psi(r_0, 0)}{\delta^2} \right]}. \quad (36)$$

The gradient of ψ is obtained from the definition of ψ , Eq. (32):

$$\nabla \psi = \rho B_z \hat{\rho} - \rho B_\rho \hat{z}. \quad (37)$$

Provided the field point does not lie on the loop axis, $\rho = 0$, the Cartesian components of B and ∇B needed in the RAYS code can be

Fig. 5. Density is minor radius at various z positions for EBT-I.

obtained by taking trigonometric projections. When $\rho = 0$, the angle θ is undefined and must be dealt with as a special case. For $\rho > 0$,

$$B_x = B_\rho \cos \theta \quad B_y = B_\rho \sin \theta$$

$$\frac{dB_x}{dx} = \frac{dB_\rho}{d\rho} \cos^2 \theta + \frac{B_\rho}{\rho} \sin^2 \theta \quad \frac{dB_x}{dy} = \left(\frac{dB_\rho}{d\rho} - \frac{B_\rho}{\rho} \right) \sin \theta \cos \theta$$

$$\frac{dB_x}{dz} = \frac{dB_\rho}{dz} \cos \theta \quad (38)$$

$$\frac{dB_x}{dy} = \frac{dB_y}{dx} \quad \frac{dB_y}{dy} = \frac{dB_\rho}{d\rho} \sin^2 \theta + \frac{B_\rho}{\rho} \cos^2 \theta \quad \frac{dB_y}{dz} = \frac{dB_\rho}{dz} \sin \theta$$

$$\frac{dB_z}{dx} = \frac{dB_x}{dz} \quad \frac{dB_z}{dy} = \frac{dB_y}{dz}$$

Since the z axis is the same in the cylindrical and the Cartesian systems, B_z and dB_z/dz are the same in both systems.

When ρ is nearly equal to zero, B_ρ/ρ is mathematically well defined but θ is undefined. The solution to this singularity is to recognize that

$$\lim_{\rho \rightarrow 0} B_\rho(\rho) = B_\rho(0) + \rho \frac{dB_\rho}{d\rho} = \rho \frac{dB}{d\rho} \quad (39)$$

Thus,

$$\lim_{\rho \rightarrow 0} \frac{dB}{d\rho} = \frac{B}{\rho}.$$

Using this result, the above quantities can be reduced to

$$B_x = \left(\frac{B}{\rho}\right)x$$

$$B_y = \left(\frac{B}{\rho}\right)y$$

$$\frac{dB_x}{dx} = \frac{dB}{d\rho} \quad \frac{dB_x}{dy} = 0 \quad \frac{dB_x}{dz} = 0 \quad (40)$$

$$\frac{dB_y}{dx} = 0 \quad \frac{dB_y}{dy} = \frac{dB}{d\rho} \quad \frac{dB_y}{dz} = 0$$

$$\frac{dB_z}{dx} = 0 \quad \frac{dB_z}{dy} = 0.$$

In our numerical work, Eq. (40) is used when ρ is smaller than 10^{-17} , since the approximations will then be excellent and computer overflow is avoided.

A FORTRAN EQUIB module named EQBC has been written to evaluate $\underline{B}$, $\underline{\nabla}B$, ψ , D , and $\underline{\nabla}D$ according to the equations in this subsection. For small values of ρ and m , the small argument expansions described in Ref. 10 are used.

The user specifies the current sources and the density profile by means of the parameters NCOIL, SEP, RCOIL, RNOT, DELTA, and DINF. These quantities are defined in the input RAYD.DAT file and pass to EQUIB through common block /EQBC/. NCOIL sets the number of coils and may be unity or any even number less than one hundred. When the user sets NCOIL equal to one, the origin of the coordinate system lies at the center of the loop, as in Fig. 4. For NCOIL greater than one, the origin lies on the axis midway between the innermost pair of coils. SEP, RCOIL, and CURREN are the separation between adjacent coils, the coil radius, and the current flowing in each coil, respectively. The parameters of the density profile are defined following Eq. (34): $r_0 = RNOT$, $\delta = DELTA$, and $D_\infty = DINF$.

Upon first entry into EQUIB the subroutine NORM is called, which serves to normalize the magnitude of the magnetic field and the density to be exactly unity at the origin of the coordinate system. The normalization of the magnetic field is accomplished by adjusting the value of CURREN. The density is normalized by calculating $\psi(r_0, 0)$. The actual calculation of the magnetic field is carried out by subroutine BCOIL, which returns B_ρ , B_z , $\partial B_\rho / \partial \rho$, $\partial B_\rho / \partial z$, $\partial B_z / \partial z$, and ψ as functions of ρ, z . Additional subroutines required are TRANS, which transforms the output of BCOIL in cylindrical coordinates to Cartesian

coordinates, and ELLIP, which evaluates the required complete elliptic integrals by the very efficient method of the arithmetic-geometric mean. A FORTRAN listing of the module EQBC is presented in Appendix IV.

In Figs. (5) and (6) we show density and magnetic field calculations made with EQUIB for EBT-I geometry. In this example $N_{COIL} = 4$, $SEP = 20$ cm, and the coil radius $R_{COIL} = 10$ cm. For the density model we have taken $R_{NOT} = 8$ cm, $DELTA = 4$ cm, and $DINF = 0.1$.

Fig. 6. Magnetic field lines for EBT-I geomtry.

5.3 TOKAMAK MODEL

The RAYS code has also been used to study electron cyclotron wave propagation in the PDX tokamak. For this purpose an EQUIB module has been developed using a simple analytical model of an axisymmetric, circular cross-section tokamak. To date the $q(r)$ profile has been taken to be parabolic and the density profile to be a polynomial with peak on the magnetic axis. However, these models are easily modified.

The equilibrium is most easily described in terms of the conventional tokamak coordinate system r, θ, ϕ (Fig. 7). The major and minor radius of the tokamak are R and a , respectively. The origin of the Cartesian system required by the RAYS code is on the equatorial plane of the tokamak with the z axis coinciding with the symmetry axis. The transformation between these two systems is given by

$$\begin{aligned} x &= (R + r \cos \theta) \cos \phi , \\ y &= (R + r \cos \theta) \sin \phi , \\ z &= r \sin \theta . \end{aligned} \tag{41}$$

The general form of the magnetic field produced by the subroutines has a toroidal component, $B_\phi(r, \theta)$, and a poloidal component, $B_\theta(r, \theta)$:

$$\underline{B} = B_\phi(r, \theta) \hat{\phi} + B_\theta(r, \theta) \hat{\theta} . \tag{42}$$

The Cartesian components of B are then

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Fig. 7. Geometry for tokamak equilibrium.

$$\begin{aligned}
B_x(r, \theta, \phi) &= -B_\phi \sin \phi - B_\theta \sin \theta \cos \phi \\
B_y(r, \theta, \phi) &= B_\phi \cos \phi - B_\theta \sin \theta \sin \phi \\
B_z(r, \theta) &= B_\theta \cos \theta .
\end{aligned} \tag{43}$$

The Cartesian components of ∇B follow from a straightforward, but tedious, application of the chain rule

$$\frac{dB_{x_i}}{dx_j} = \sum_{k=1}^3 \frac{dB_{x_i}}{d\xi_k} \frac{d\xi_k}{dx_j} , \tag{44}$$

where $x_i = x, y, z$ and $\xi_k = r, \phi, \theta$. The $d\xi_k/dx_j$ Jacobian matrix is obtained by differentiating Eqs. (41):

$$\begin{aligned}
\frac{\partial r}{\partial x} &= \cos \theta \cos \phi & \frac{\partial r}{\partial y} &= \cos \theta \sin \phi & \frac{\partial r}{\partial z} &= \frac{z}{r} \\
\frac{\partial \theta}{\partial x} &= -\frac{z \cos \phi}{r^2} & \frac{\partial \theta}{\partial y} &= -\frac{z \sin \phi}{r^2} & \frac{\partial \theta}{\partial z} &= \frac{\cos \theta}{r} \\
\frac{\partial \phi}{\partial x} &= -\frac{y}{(x^2 + y^2)} & \frac{\partial \phi}{\partial y} &= \frac{x}{(x^2 + y^2)} & \frac{\partial \phi}{\partial z} &= 0 .
\end{aligned} \tag{45}$$

The $\partial B_{x_i}/\partial \xi_k$ matrix is obtained by differentiating Eqs. (43):

$$\frac{\partial B_x}{\partial r} = -\sin \phi \frac{\partial B_\phi}{\partial r} - \sin \theta \cos \phi \frac{\partial B_\theta}{\partial r}$$

$$\begin{aligned}
\frac{\partial B_x}{\partial \theta} &= -\sin \phi \frac{\partial B_\phi}{\partial \theta} - \sin \theta \cos \phi \frac{\partial B_\theta}{\partial \theta} - B_\theta \cos \theta \cos \phi \\
\frac{\partial B_x}{\partial \phi} &= -\cos \phi B_\phi + \sin \theta \sin \phi B_\theta \\
\frac{\partial B_y}{\partial r} &= \cos \phi \frac{\partial B_\phi}{\partial r} - \sin \theta \sin \phi \frac{\partial B_\theta}{\partial r} \\
\frac{\partial B_y}{\partial \theta} &= \cos \phi \frac{\partial B_\phi}{\partial \theta} - \cos \theta \sin \phi B_\theta - \sin \theta \sin \phi \frac{\partial B_\theta}{\partial \theta} \\
\frac{\partial B_y}{\partial \phi} &= -\sin \phi B_\phi - \cos \phi \sin \theta B_\theta \\
\frac{\partial B_z}{\partial r} &= \cos \theta \frac{\partial B_\theta}{\partial r} \\
\frac{\partial B_z}{\partial \theta} &= -\sin \theta B_\theta + \cos \theta \frac{\partial B_\theta}{\partial \theta} \\
\frac{\partial B_z}{\partial \phi} &= 0
\end{aligned} \tag{46}$$

Some of the above equations are undefined for $r = 0$ producing a similar difficulty to the $\rho = 0$ limit in the bumpy cylinder model. The limiting expressions for $\nabla \tilde{B}$ must be obtained by explicit differentiation of $\tilde{B}$ for the particular field model chosen.

Up to this point the toroidal and poloidal field models $B_\phi(r, \theta)$, $B_\theta(r, \theta)$ have been arbitrary. Appropriate profiles to describe a tokamak device are of the form:

$$B_{\phi} = \frac{R}{R + r \cos \theta} \quad (47)$$

and

$$B_{\theta} = \frac{r B_{\phi}}{R q(r)} \quad (48)$$

The derivatives required to compute $\nabla \underline{B}$ are

$$\begin{aligned} \frac{\partial B_{\phi}}{\partial r} &= \frac{-R}{(R + r \cos \theta)^2} \cos \theta \\ \frac{\partial B_{\phi}}{\partial \theta} &= \frac{R}{(R + r \cos \theta)^2} r \sin \theta \\ \frac{\partial B_{\theta}}{\partial r} &= \frac{1}{R} \left[\frac{B_{\phi}}{q(r)} - \frac{r B_{\phi}}{q^2(r)} \frac{dq(r)}{dr} + \frac{r}{q(r)} \frac{\partial B_{\phi}}{\partial r} \right] \end{aligned} \quad (49)$$

and

$$\frac{\partial B_{\theta}}{\partial \theta} = \frac{r}{R q(r)} \frac{\partial B_{\phi}}{\partial \theta}$$

which combine with Eqs. (44)-(46) to give $\nabla \underline{B}$. In the limit as r approaches zero, the model defined by Eqs. (47) and (48) gives the following expression for $\nabla \underline{B}$:

$$\frac{dB_x}{dx} = \frac{2 \cos \phi \sin \phi}{R} \quad \frac{dB_x}{dy} = \frac{\sin^2 \phi}{R} \quad \frac{-\cos^2 \phi}{R} \quad \frac{dB_x}{dz} = \frac{-\cos \phi}{R q_0}$$

$$\frac{dB_y}{dx} = \frac{dB_x}{dy} \quad \frac{dB_y}{dy} = \frac{-2 \cos \phi \sin \phi}{R} \quad \frac{dB_y}{dz} = \frac{-\sin \phi}{Rq_0} \quad (50)$$

$$\frac{dB_z}{dx} = \frac{\cos \phi}{Rq_0} \quad \frac{dB_z}{dy} = \frac{\sin \phi}{Rq_0} \quad \frac{dB_z}{dz} = 0 .$$

These expressions are used in our subroutines when $r/R \leq 10^{-9}$.

The preceding analysis is valid for arbitrary $q(r)$ profile. For our calculations we have adopted a parabolic profile

$$q(r) = q_0 + (q_a - q_0) \frac{r^2}{a^2} ,$$

where q_0 and q_a are specified constants. The density profile we have adopted is of the form

$$n_e(r) = \left[1 - \left(\frac{r}{a} \right)^j \right]^m ,$$

where j and m are constants.

A FORTRAN subroutine EQUIB with Hollerith label "TOKAM" has been written to evaluate B , ∇B , n , and ∇n according to the equations in this section. Upon first entry into EQUIB, normalization constants are calculated which fit the magnitude of the magnetic field and density to unity along the toroidal axis, $r = 0$. The constants defining the equilibrium enter EQUIB through common block TOKA. These constants are R , A , $Q\phi$, QA , $P1$, and $P2$, which are the major radius, the minor radius, q_0 , q_a , j , and m , respectively.

EQUIB calls the associated subroutines TRANS, BDERV, and DENS. Since the transformation between the Cartesian system used by the RAYS code and the toroidal system used by this version of EQUIB must be done so often, a separate subroutine TRANS has been written that transforms the (x,y,z) system to the (r,θ,ϕ) system. TRANS is careful to ensure both the continuity and positivity of the angles θ and ϕ , making them consistent with their definitions in Fig. (7). For $r > 0$ BDERV calculates $B_\theta(r,\theta)$, $B_\phi(r,\theta)$, dB_θ/dr , $dB_\theta/d\theta$, dB_ϕ/dr , and $dB_\phi/d\theta$ while DENS calculates $n(r)$ and dn/dr . FORTRAN listings of these subroutines are presented in Appendix IV.

6. WAVE DAMPING MODULES

Wave absorption processes are taken into account by integrating the imaginary part of the refractive index n_i along the ray path. A necessary condition for the geometrical optics approximation to be valid is that the waves be weakly damped, i.e., $|k_i| \ll |k_r|$. When this condition is satisfied k_i can be readily obtained by expansion of the dispersion relation about k_r . In this section we describe two simple DAMP modules based on such an expansion: DAMPEC, which calculates electron cyclotron damping near the fundamental resonance, and DAMPLH, which calculates electron Landau damping near the lower-hybrid frequency. In addition to these routines a number of other damping packages have been developed, including a numerical solution of the full dispersion relation which calculates the cyclotron harmonics with no assumption of weak damping and a fully relativistic package based on Poynting's theorem. Unless the user has chosen to overwrite the electric field polarization components contained in V(8)-V(10) of the FOR21.DAT file, V(10) contains the local value of $|k_i|$ as defined by the damping module. This information is often very useful as the ray propagates through the damping region.

6.1 DAMPEC

To calculate n_i we employ a weak damping approximation similar to that given by Akhiezer et al.¹¹ For our application, however, we expand around the local value of $n_{\parallel}, n_{\perp}$ as given by the RAYS code rather than the value of $n(\theta)$ evaluated at the resonance point, $\Omega_e(r) = \omega$. This

approach gives more accurate results on the wings of the absorption lines, and it eliminates the necessity of keeping track of the branch of the dispersion relation being followed by the ray.

Assuming $k_{\perp}^2 \rho_e^2 \ll 1$, the warm plasma dispersion relation for a Maxwellian distribution can be written in the form

$$D(n_{\parallel}, n_{\perp}, \omega) = \frac{\omega_{pe}^2}{2\omega} \frac{c}{n_{\parallel} v_e} Z(\xi) D_0 + D_1 + \left(D_2 + \frac{N_1^2}{2n_{\parallel}^2} \frac{\omega^2}{\Omega_e^2} \xi D_3 \right) [1 + \xi Z(\xi)] = 0, \quad (51)$$

where

$$D_0 = n^2 n_{\perp}^2 - (1 - P)(n^2 + n_{\parallel}^2) - 2(1 - 2q)n_{\perp}^2 + 2(1 - P)(1 - 2q),$$

$$D_1 = (1 - q)n^2 n_{\perp}^2 + (1 - P)n^2 n_{\parallel}^2 - (1 - q)(1 - P)(n^2 + n_{\parallel}^2) - (1 - 2q)n_{\perp}^2 \\ + (1 - 2q)(1 - P),$$

$$D_2 = P \frac{\omega}{|\Omega_e|} [n^2 n_{\perp}^2 - (1 - 2q)n_{\perp}^2] + P^2 \frac{\omega}{4\Omega_e^2} \left[\frac{n_{\perp}^2}{n_{\parallel}^2} (n^2 + n_{\parallel}^2) - 2(1 - 2q) \frac{n_{\perp}^2}{n_{\parallel}^2} \right],$$

$$D_3 = P [n^2 n_{\parallel}^2 - (1 - q)(n^2 + n_{\parallel}^2) + (1 - 2q)],$$

$$P = \frac{\omega_{pe}^2}{\omega^2}, \quad q = \frac{\omega_{pe}^2}{2\omega(\omega + |\Omega_e|)}, \quad \xi = \frac{\omega - |\Omega_e|}{k_{\parallel} v_e}, \quad v_e = \left(\frac{2T_e}{m_e} \right)^{1/2},$$

and $Z(\xi)$ is the plasma dispersion function.

If Eq. (51) is multiplied by $(\omega + \Omega_e)/\omega^2 \times [k_{\parallel} v_e/Z(\xi)]$, the result can be separated into

$$D' = D^C + D^W = 0, \quad (52)$$

where D^C is the cold plasma dispersion relation, Eq. (10), and D^W is a warm plasma correction of the form

$$D^W = -\frac{\omega + \Omega_e}{\omega} n_{\parallel} \frac{v_e}{c} \left(D_1 + D_2 + \frac{n_{\perp}^2}{2n_{\parallel}} \frac{\omega^2}{\Omega_e^2} \frac{v_e}{c} \xi \right) \left[\xi + \frac{1}{Z(\xi)} \right]. \quad (53)$$

Note that for nonrelativistic plasmas ($v_e/c \ll 1$), D^W is uniformly small ($\sim v_e/c$) both near the resonance and in the cold plasma regime ($|\xi| \rightarrow \infty$).

Expanding D' about the roots $\underline{n}^0$ of $D^C(\underline{n}^0) = 0$ gives

$$D'(\underline{n}) = D'(\underline{n}^0 + \underline{n}^1) \approx D^C(\underline{n}^0) + D^W(\underline{n}^0) + \underline{n}^1 \cdot \frac{\partial D^C}{\partial \underline{n}^0} = 0. \quad (54)$$

Choosing $\underline{n}^1$ parallel to $\underline{n}^0$, we obtain

$$n_i = \text{Im} \left\{ -\frac{D^W(\underline{n}^0)}{\hat{n}^0 \cdot \frac{\partial D^C}{\partial \underline{n}^0}} \right\} = \text{Im} \left\{ -\frac{D^W(\underline{n}^0)}{\frac{n_x^0}{|\underline{n}^0|} \frac{\partial D^C}{\partial n_x^0} + \frac{n_z^0}{|\underline{n}^0|} \frac{\partial D^C}{\partial n_z^0}} \right\}. \quad (55)$$

The zero-order refractive indices $n_{\parallel}^0, n_{\perp}^0$ are obtained directly from the integration of the ray equations.

6.2 DAMPLH

For lower hybrid wave studies a frequency range of interest is near the gyroresonance frequency $\omega \sim (\Omega_e \Omega_i)^{1/2}$. We assume that $\Omega_i \ll \omega \ll |\Omega_e|$ and take

$$\left| \frac{\omega - \Omega_e}{k_{\parallel} v_e} \right| \sim \left| \frac{\Omega_e}{k_{\parallel} v_e} \right| \gg 1,$$

and

$$\left| \frac{\omega - \Omega_i}{k_{\parallel} v_i} \right| \sim \left| \frac{\omega}{k_{\parallel} v_i} \right| \gg 1.$$

In this case the ion response is just the cold plasma response and the only finite temperature effect in the electrons is electron Landau damping. Assuming that $k_{\perp}^2 \rho_e^2 \ll 1$ and $\xi_0 = \omega/k_{\parallel} v_e \gg 1$, we find the only modification to the electron response is a finite-temperature correction to ϵ_{33} :

$$\epsilon_{33}^H = i\sqrt{\pi} \frac{\omega_{pe}^2}{\omega^2} \xi_0^3 e^{-\xi_0^2}. \quad (56)$$

The corrected dispersion relation can be written

$$\Lambda = \Lambda^C + \Lambda^H = 0 \quad , \quad (57)$$

where for a two-component plasma the cold plasma contribution Λ^C is given in Eq. (10) and the hot plasma contribution Λ^H is

$$\Lambda^H = i\sqrt{\pi} \frac{\omega_{pe}^2}{\omega^2} \epsilon_0^3 \Lambda_1(n^0) \quad (58)$$

and

$$\Lambda_1(n) = n^{02} n_{\parallel}^{02} T - (n^{02} + n_{\parallel}^{02}) TS + Q \quad .$$

The quantities T , S , and Q are defined in Sect. 4.1. Expanding Eq. (57) near the cold plasma refractive index n^0 gives for n_i

$$n_i = \sqrt{\pi} \frac{\omega_{pe}^2}{\omega^2} \epsilon_0^3 e^{-\epsilon_0^2} \frac{\Lambda_1(n^0)}{\partial \Lambda^C / \partial n^0} \quad . \quad (59)$$

7. POLARIZATION MODULE, EPOLAR

The electric field polarization of a given mode is a local vector quantity which is determined by the local dispersion tensor $\underline{\underline{D}}(\underline{k}, \underline{r})$. In particular, if $\underline{k}^j$ is the solution of $\det(\underline{\underline{D}}) = 0$, corresponding to the j th mode, the polarization vector $\underline{E}^j$ is given by

$$\underline{\underline{D}}(\underline{k}^j, \underline{r}) \cdot \underline{E}^j(\underline{r}) = 0. \quad (60)$$

In the EPOLAR subroutine this equation is solved in a local magnetic coordinate system $\hat{e}_1, \hat{e}_2, \hat{e}_3$. The 3 axis is taken along $\underline{B}$ and the 1 axis is taken perpendicular to $\underline{B}$ in the $\underline{B}, \underline{k}$ plane:

$$\hat{e}_3 = \frac{\underline{B}}{|\underline{B}|},$$

$$\hat{e}_1 = \frac{\underline{B} \times (\underline{k} \times \underline{B})}{|\underline{B} \times (\underline{k} \times \underline{B})|}, \quad (61)$$

and

$$\hat{e}_2 = \hat{e}_3 \times \hat{e}_1,$$

where the components of the unit vectors $(\hat{e}_1, \hat{e}_2, \hat{e}_3)$ are expressed in the fixed coordinate system. After solving Eq. (60) in the local

coordinate system, the components of $\underline{E}^j$ in the fixed Cartesian coordinate system can be written

$$(\underline{E}^j)_x = [E_1^j \hat{e}_1 + E_2^j \hat{e}_2 + E_3^j \hat{e}_3] \cdot \hat{x} \quad (62)$$

with similar equations for E_1 and E_2 . If $\underline{k}$ is parallel to $\underline{B}$, then $\hat{e}_x$ as given by Eq. (61) is undefined. In that case $\hat{e}_x$ is taken in an arbitrary direction perpendicular to $\underline{B}$. The components of $\underline{E}^j$ are complex quantities in general; however, for graphics purposes, the phase information is discarded and only $|E_x^j|$, $|E_y^j|$, and $|E_z^j|$ are stored.

For a cold plasma the dispersion equation in the magnetic coordinate system is

$$\begin{bmatrix} \epsilon_1 - n_j^2 \cos^2 \theta & -i\epsilon_2 & n_j^2 \sin \theta \cos \theta \\ i\epsilon_2 & \epsilon_1 - n_j^2 & 0 \\ n_j^2 \sin \theta \cos \theta & 0 & \epsilon_3 - n_j^2 \sin^2 \theta \end{bmatrix} \begin{bmatrix} E_1^j \\ E_2^j \\ E_3^j \end{bmatrix} = 0, \quad (63)$$

where $\epsilon_1 = 1 - \alpha/(1 - \beta)$, $\epsilon_2 = \alpha\sqrt{\beta}(1 - \beta)$, $\epsilon_3 = 1 - \alpha$, and n_j is a solution of the dispersion relation. This can be solved to give eigenvectors of the form

$$\mathbf{E}^j = \left(1, \frac{i\epsilon_2}{n_j^2 - \epsilon}, \frac{n_z^j \sin \theta \cos \theta}{n_j^2 \sin^2 \theta - \epsilon_3} \right) \quad \theta \neq \frac{\pi}{2}, \quad (64)$$

$$\mathbf{E} = \begin{cases} (0, 0, 1) & \text{ordinary mode, } \theta = \frac{\pi}{2} \\ (i\epsilon_2, -\epsilon_1, 0) & \text{extraordinary mode, } \theta = \frac{\pi}{2} \end{cases}.$$

If the dispersion tensor is more complicated, such as with finite temperature effects, it is more efficient to solve Eq. (60) numerically using Gaussian elimination or another technique.

8. TESTING AND DIAGNOSING THE RAYS CODE

Considerable effort has been expended validating the various dispersion relation modules, equilibrium modules, damping modules, and the ODE solver developed for the RAYS code. An important method of testing the dispersion relation and damping models is to consider simple plasma geometries, such as slabs, for which the local refractive indices can be determined algebraically. In a plane-stratified plasma, ray tracing is considerably simplified in that only the component of the wave vector $\underline{k}$ which is in the direction of the gradients can vary; the components of $\underline{k}$ perpendicular to the gradients are constant as a consequence of Snell's law. The location of cutoffs, resonances, and mode conversion points and to a great extent the behavior of the ray trajectory itself can be determined directly from the dispersion relation without actually tracing rays. An extensive discussion of wave propagation near the electron cyclotron frequency in plane-stratified plasmas is contained in Ref. 6. Ray-tracing examples are also presented which illustrate in the simplest possible geometry many of the interesting properties of wave propagation in inhomogeneous plasmas.

In higher dimensions analytic solutions of the geometrical optics equations are rarely obtainable. However, Kriegsmann¹¹ has obtained a solution for ordinary mode propagation perpendicular to a circular cylindrical plasma with a parabolic density profile. Exact agreement was found between his results and the RAYS code.

Once a wave dispersion module has been tested, a very useful technique of testing complicated plasma equilibrium routines is to integrate ∇n_e and $\nabla |B|$ along the ray trajectory. The RAYS code is currently set up so that a consistency check between n_e and ∇n_e appears in column V(8) of the FOR21.DAT file and a check of $|B|$ with $\nabla |B|$ appears in V(9). These checks are printed out for each value of S as the ray propagates:

$$V(8) = \frac{n_e(s) - \int_0^s ds' \nabla n_e(s') \cdot \hat{v}_g}{n_e(s)},$$

and

$$V(9) = \frac{|B(s)| - \int_0^s ds' \nabla |B(s')| \cdot \hat{v}_g}{|B(s)|},$$

where $\hat{v}_g$ is a unit vector in the direction of the group velocity. If the equilibrium $|B|$ and n_e are consistent with their respective gradients, V(8) and V(9) should have absolute magnitudes no larger than the error criteria set for ODE (i.e., RELERR and ABSERR).

9. RAYPLT

Graphics output is obtained by running the RAYPLT postprocessor. This program reads data from the disk file on unit IO2 written by the RAYS code (typically FOR21.DAT). It plots magnetic field lines, resonance/cutoff surfaces, ray paths, and, at the discretion of the user, wavevectors and electric field polarization vectors. When wave damping has been calculated, symbols are plotted along the ray at specified decrements in wave power. This code has been implemented using machine dependent interactive I/O and therefore is currently limited to use on the DEC system 10. Use is made of the proprietary DISSPLA graphics package which allows output to be obtained on a graphics terminal, a printer with graphics capability (such as VERSATEC), or on a CALCOMP-type plotter. Because of our interest in EBT, the graphics produced by RAYPLT has been tailored for magnetic mirror geometry. Each execution of RAYPLT produces two plot frames. The first is a projection of the quantities of interest onto the x-z plane for $-x_{\max} < x < x_{\max}$ and $0 < z < z_{\max}$. There is a provision for magnetic field lines and resonance/cutoff surfaces to be plotted in this frame. The second is a projection onto the x-y plane for $-x_{\max} < x < x_{\max}$ and $-y_{\max} < y < y_{\max}$.

Upon execution, the program interactively asks the user whether $\underline{k}$ vectors and/or $\underline{E}$ vectors are to be plotted. It also permits the user to type in a label of up to 75 characters that subsequently appears at the bottom of each plot frame. The disk file FOR21.DAT is opened and the input information to the RAYS code in namelist /DATA/ (as well as

the Hollerith names of the routines used) is read. The values of $x_{\max}$, $y_{\max}$, and $z_{\max}$ obtained from /DATA/ are used to scale the plot axes, and plotting begins. Successive reads from FOR21.DAT provide the data points $[S, V(1), \dots, V(10)]$ required for curve plotting. If $S = 5000$ the data in $[V(1), V(2), V(3)]$ are regarded as a field line or resonance/cutoff data point and plotted with dotted lines. For $0 \leq S < 5000$ the V vector is considered a ray data point and is plotted as a solid line. The quantities $V(4), V(5), V(6)$ are interpreted as the Cartesian components of $\underline{k}$, $V(7)$ is taken to be the fraction of power absorbed from the ray, and, if electric field vectors are to be plotted, $V(8), V(9), V(10)$ must contain the components of $\underline{E}$. The end of any plot curve (field line or ray) is designated by $S = -1$.

After all field lines and rays have been plotted (as indicated by $S = -10$), certain of the plasma equilibrium data (PFEO, CFEO, FMU, TE) and the Hollerith routine names are listed to the left of the ray plot. This completes the first plot frame. The FOR21.DAT file is closed, then reopened, and plotting proceeds on the second frame, the x-y projection.

The only fully toroidal equilibrium currently in use is the tokamak model. To accommodate the needs of toroidal geometry, the required plotting program RAYPLT has had to be considerably modified from the version used for the cylindrical and slab equilibria. For this reason, we have written a separate version of RAYPLT which creates three plots appropriate to the tokamak problem. The first graph traces the ray trajectory on a CMA diagram with ordinate and abscissa ω_{pe}^2/ω^2

and ω_{ce}/ω , respectively. The second and third plots trace the ray in real space. The second plot is a projection of the ray onto the $[(r,\theta), \text{poloidal}]$ plane. The last plot is a "top view" of the tokamak with the ray projected onto the x-y plane. This version of RAYPLT is still under development and is not documented in detail here.

REFERENCES

1. L. D. Landau and E. M. Lifshitz, The Classical Theory of Fields, 3rd ed., Chap. 7, Pergamon, Oxford, 1971.
2. T. H. Stix, The Theory of Plasma Waves, McGraw-Hill, New York, 1962.
3. I. B. Bernstein, Phys. Fluids 18, 320 (1975).
4. H. Weitzner and D. B. Batchelor, Phys. Fluids 23, 1359 (1980).
5. L. F. Shampine and M. K. Gordon, Computer Solutions of Ordinary Differential Equation: The Initial Value Problem.
6. D. B. Batchelor, R. C. Goldfinger, and H. Weitzner, IEEE Trans. Plasma Sci. PS-8, 78 (1980).
7. K. G. Budden, Radio Waves in the Ionosphere, Cambridge University Press, Cambridge, 1961.
8. W. R. Smythe, Static and Dynamic Electricity, 3rd. ed., p. 291, McGraw Hill, New York, 1968.
9. "Guiding Center Motion and Plasma Behavior in the Bumpy Torus," Appendix III and IV, University of California Research Laboratory Report UCRL 7246 (1963). M. Abramowitz and I. A. Stegun, Handbook of Mathematical Functions, p. 591, National Bureau of Standards, AMS 55, U.S. Government Printing Office, Washington, D.C.
10. R. C. Goldfinger, "Formulas and Subroutines for B , ∇B and ψ of a Current Loop with Applications to Magnetic Fusion Experiments," Oak Ridge National Laboratory Report ORNL/TM-7636 (1981).
11. G. A. Kriegsmann, J. Math. Phys. (Cambridge, Mass.) 17, 112 (1976).

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Appendix I: DESCRIPTION OF INPUT FILE RAYD.DAT

- IO1 Integer unit number for the output file which contains diagnostics and plasma parameters along ray trajectories. Typically, we choose IO1 = 20 on our PDP-10, which creates an output file named "FOR20.DAT".
- IO2 Integer unit number for output file which contains s and V along rays. This is the file which RAYPLT.RAY reads to produce plots. Typically, we choose IO2 = 21, which creates an output file "FOR21.DAT."
- CMPUTR A flag which tells the user the type of computer used. When CMPUTR has the value 10, 1, or 7600 a message appears on the output files saying that the PDP-10, CRAY1, or 7600 computer was used for the run. The value of CMPUTR has no effect on the calculations.
- IBUG A flag which causes various quantities to be printed out in output files for debugging purposes.
- IPARAM A flag which indicates whether arc length or time is the running variable along the ray trajectory. When IPARAM = 0 (1) time (arc length) parameterization is chosen.
- IDAMP A flag which determines whether damping is to be calculated along ray. IDAMP = 0(1) indicates no damping (damping).
- ICONV A flag which determines whether the criterion for mode conversion to a warm plasma mode is to be calculated. When ICONV = 1 subroutine CONVRT is called to check whether local ray parameters satisfy the criterion. ICONV = 0 causes CONVRT to not be called.
- IEQ A flag which controls plotting of field lines, rays, and resonance zones. When IEQ < 0 only the ray trajectories are plotted by RAYPLT.RAY. For IEQ = 0 eight magnetic field lines and the rays are plotted. IEQ = 1 plots field lines, rays, the first and second electron cyclotron harmonic surfaces, and the right-hand cutoff layer. IEQ > 1 is the same as IEQ = 1 but without the rays.
- RELERR, ABSERR Error criteria which ODE integrator uses to satisfy: $|LOCAL\ ERROR| < |V(i)| RELERR + ABSERR$ for $i = 1, NDIM$. (NDIM is number of equations to be integrated.)
- DS, SMAX Information about ray is printed out in intervals of DS for $S = 0$ to $S = SMAX$. S is either arc length or time depending

on whether IPARAM = 1. or 0. Since the ODE integrator automatically adjusts the step size internally to satisfy error criteria specified by RELERR and ABSERR, the value of DS does not affect the calculation. One rare exception occurs when ODE integrates a very sharply peaked function, e.g., in calculating cyclotron damping with $n \approx 0$. In this case a smaller value of DS ensures trapping the peak.

- X0, Y0, Z0 Initial position of ray in Cartesian coordinate system.
- PHIO, THETA0 Initial direction of $\underline{k}$ expressed in units of degrees. These are the conventional spherical angles.
- RZO Initial $n_{\parallel}$ of ray. A choice must be made by the user whether he wants to specify θ_0 and ϕ_0 of the ray or $n_{\parallel 0}$. Ray will be initialized using RZO if DRZ $\neq$ 0 and will be initialized using THETA0 and PHIO if DRZ = 0.
- DX, IXMX, DY, IYMX, DZ, IZMX, DPHI, NPHI, DTHETA, NTHETA, DRZ, NRZ
The above quantities which determine $\underline{r}_0$ and $\underline{k}_0$ occur in a set of nested do-loops so that multiple rays can be calculated during the same run. The quantities vary from slowest to fastest in the following order: X,Y,Z, ϕ , θ , $n_{\parallel}$. The various quantities are incremented as follows:
X =	X0,	X0+DX, ...,	X0+(IXMX-1)DX
Y =	Y0,	Y0+DY, ...,	Y0+(IYMX-1)DY
Z =	Z0,	Z0+DZ, ...,	Z0+(IZMX-1)DZ
ϕ =	PHIO,	PHIO+DPHI, ...,	PHIO+(NPHI-1)DPHI
θ =	THETA0,	THETA0+DTHETA, ...,	THETA0+(NTHETA-1)DTHETA
$n_{\parallel}$ =	RZO,	RZO+DRZ, ...,	RZO+(NRZ-1)DRZ
- SGN Determines which branch of cold plasma dispersion relation is used to initialize ray. SGN = +1(-1) corresponds to the ordinary (extraordinary) mode, but note relevant comment in Sect. 4.1.
- FMU The wave frequency, in GHz.
- PFE0 The ratio of the plasma frequency to the wave frequency at the origin of the coordinate system, $PFE0 \equiv \omega_{pe}(\underline{r} = 0)/\omega$.
- CFE0 The ratio of the electron cyclotron frequency to the wave frequency at the origin, $CFE0 \equiv \Omega_e(\underline{r} = 0)/\omega$.
- BETANN Annulus beta. For EBT calculations we have a hot electron annulus component which is used to calculate the damping there. This does not affect the ray tracing or the damping as calculated by DAMP1 or DAMPLH, and it may be set to zero.

TEHOT Temperature of annulus electrons in eV units. Comment for BETANN applies here.

TI Temperature of ions in eV. This is used by subroutine CONVRT to determine if warm plasma mode conversion criterion is satisfied. Does not affect the ray-tracing or damping calculations.

TE Temperature of electrons in eV. This is used by damping subroutines. Ray tracing is done using cold plasma dispersion relation so TE does not affect ray trajectories.

XMAX, X, Y, and Z limits, respectively, for ray trajectory. For
YMAX, $|X| > XMAX$, $|Y| > YMAX$ $Z < 0$, or $Z > ZMAX$ the ray calculation
ZMAX stops and moves on to the next ray, if any. RAYPLT also uses these parameters in setting the axis limits during plotting.

ISLAB, The type of stratification and the scale length when using
RSLAB slab model equilibrium "SLAB". These quantities are defined in Sect. 5.1.

NCOIL, The geometry of the current loop configuration and parameters
SEP, of the density model when using the bumpy cylinder
RCOIL, equilibrium "EQBC." These are defined in Sect. 5.2.
RNOT1
DELTA,
DINF

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Appendix II: DESCRIPTION OF OUTPUT FILES

FOR20.DAT

After the time, date, and input namelist /DATA/ have been printed, Hollerith names are listed which give more information about the run. In the first example these names are COLD, SLAB, PDP10, DMPEC, and ARCL. COLD refers to the fact that the two-component cold plasma dispersion relation described in Sect. 4.1 has been used. SLAB indicates that the slab model described in Sect. 5.1 has been used. DMPEC refers to the electron cyclotron damping module of Sect. 6.1. PDP10 indicates a DEC PDP-10 computer was used, and ARCL indicates arc length parameterization has been chosen.

Following this are column headings defining quantities which appear in the succeeding rows of numbers. Each row contains the integrated value of S , followed by ten quantities which are evaluated for that particular value of S . These quantities are:

NZRAY, The parallel and perpendicular components of the index of the
NXRAY refraction of the ray.

$$NZRAY \equiv \frac{n_{ray} \cdot B}{|B|}$$

$$NXRAY = (n_{ray}^2 - NZRAY^2)^{1/2}$$

NX2C+, The roots of the cold plasma dispersion relation (Sect. 4.1)
NX2C- when $n_{\perp}$ is solved as a function of NZRAY. Thus, if the ray
has remained on a branch of the dispersion relation, NX2C±
should be equal to NXRAY depending on which sign was used to
initialize the ray. Besides being a check on the
calculation, NX2C± also can show when the ray switches
branches of the dispersion relation. In this case, NXRAY
will first be equal to NX2C- and then NX2C+ (or vice versa)
after the coupling point.

If one of the modes is cut off (i.e., NX2C+ or NX2C- is
complex), then -1×10^{38} is printed out.

NZ2C+, Analogous to NX2C+ and NX2C-. NZ2C± are the roots of the
 NZ2C- dispersion relation when $n_{\parallel}$ is solved as a function of NXRAY.
 Note that this rearrangement of terms in the quadratic
 equation (13) means that the branch of NZ2C± does not
 necessarily match up with the same branch of NX2C±.

RESID Diagnostic indicating how well the ray satisfies the
 dispersion relation, Eq. (10).

$$\text{RESID} \equiv \frac{A \cdot \text{NZRAY}^4 + B \cdot \text{NZRAY}^2 + C}{|A \cdot \text{NZRAY}^4| + |B \cdot \text{NZRAY}^2| + |C|}.$$

(RESID should be a small number on the order of RELERR,
 ABSERR, or the "machine epsilon.")

ALFA Normalized electron plasma frequency ω_{pe}^2/ω^2 .

ALHOT Related to hot electron annulus component used in EBT
 studies. This does not affect ray tracing or damping and can
 be replaced.

BETA Normalized electron cyclotron frequency Ω_e^2/ω^2 .

At the end of each ray several counters and flags appear. NDERV and
 NDAMP tell the number of times modules DERV and DAMP were called.
 ISTOP gives the condition which caused the ray to terminate (see Sect.
 6.3). IFLAG tells the status of the ODE integrator (IFLAG = 2 is
 normal).

FOR21.DAT

The format of FOR21.DAT is very similar to that of FOR20.DAT. The
 quantities appearing in each row are s followed by an array, V(i), with
 dimension ten (see Sect. 6.3):

V(1) = X(S) V(2) = Y(S) V(3) = Z(S)
 V(4) = K_x (S) V(5) = K_y (S) v(6) = K_z (S)
 V(7) = Integrated fractional power absorption, f, indicated
 by DAMP modules.

$$f(s) = 1 - \exp\left[-2 \left(\int_0^s k_i \cdot \frac{v_g}{|v_g|} ds\right)\right]$$

V(8), V(9) = Diagnostics for the plasma equilibrium module,
EQUIB (see Section 8).

V(10) = Local value of k_i from DAMP.

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Appendix III: EXAMPLE RUNS OF THE RAYS CODE

Example 1. Extraordinary ray propagating toward upper
hybrid resonance in a perpendicularly
stratified plasma.

DDP10 COMPUTER USED FOR THIS RUN
SUBROUTINES LINKED IN:

COLD
SLAB
DMPEC

ARCL

*
*
*
*
*

RAY = 1 INITIALIZATION WITH SPECIFIED (N-PARALLEL)**2
KX0 = -1.589E+01 KY0 = 0.000E+00 KZ0 = 2.765E+01
N-PARA**2 = 1.210E+00 N-PER**2 = 3.997E-01 N**2 = 1.610E+00
ALFA = 5.000E-01 BETA = 2.000E+00 THETA = 2.989E+01

RESIDUAL OF DISPERSION RELATION -0.1100E-08

FIRST CALL TO DAMPING SUBROUTINE.

K-REAL = 3.50632E+01 K-IMAG = 5.36207E-08
AT X,Y,Z 5.63673E+00 0.00000E+00 4.99355E+00

S X XKIM V(7)	5.0000	0.5605070300E+01	0.5999370000E-07	0.5924261200E-09
S X XKIM V(7)	5.5000	0.5206691000E+01	0.2396235700E-03	0.1589323600E-04
S X XKIM V(7)	6.0000	0.4720425400E+01	0.2609451200E+00	0.3514850000E-01
S X XKIM V(7)	6.5000	0.4227404800E+01	0.1303262000E+01	0.4700469000E+03
S X XKIM V(7)	7.0000	0.3729507400E+01	0.7814622700E+00	0.8014613500E+05
S X XKIM V(7)	7.5000	0.3229631500E+01	0.5534564600E-02	0.0399776400E+00
S X XKIM V(7)	8.0000	0.2732419300E+01	0.2311644200E-06	0.0400015900E+00

ISTOP FLAG HAS BEEN SET IN DERV2C ISTOP= 3

ALFA BETA SEN RS RXS RZS (ALL FROM TWOIMP)

0.49999040E+00 0.4999737E+00 -0.1000000E+01
0.1644735E+07 0.1644734E+07 0.1210000E+01

RXS X AND Z FROM RAYS CODE 0.1150235E+07 -0.1167155E-02 0.2445542E+01
ISTOP, IFLAG 3 2 AT 0.1953E-01 0.0000E+00 0.2776E+01

PRECISE VALUES FOR V VECTOR AT END

0.195311310E-01	0.000000000E+00	0.277647650E+01	-0.410472940E+03	0.000000000E+00
0.276460150E+02	0.040091590E+00	0.100090000E+01	0.100195310E+01	0.000000000E+00

Output to terminal (Example I)

Output to file FOR20.DAT (Example I)

[illegible]

87

21-Aug-81 15:13

\$DATA
 IEQ= -1, IO1= 20, IO2= 21, IBUG= 0, IDAMP= 1, DS= 0.5000000
 SMAX= 100000.0 , PHI0= 0.000000E+00, NPHI= 1, DPHI= 0.1070000E-02, THETA0= 30.00000 ,
 NTHETA= 1, DTHETA= 25.00000 , IYMX= 1, IYDM= 1, IZMX= 1, IZDM= 1,
 DX= -5.000000 , DY= 0.1500000 , DZ= 5.000000 , X0= 10.00000 , Y0= 0.000000E+00, Z0= 2.500000
 SGN= -1.000000 , PFE0= 0.7071000 , BETANN= 0.1600000 , CFEO= 0.7071000 , FNU= 120.0000 , TE= 100.0000
 TEHOT= 1000000. , TI= 500.0000 , XIAX= 10.00000 , YMAX= 25.00000 , ZMAX= 7.000000 , RZ0= 1.100000
 NRZ= 1, DRZ= 0.5000000 , ISLAB= 2, RSLAB= 10.00000 , NCOIL= 4,
 SEP= 25.00000 , RCOIL= 10.00000 , RNOT= 6.000000 , DELTA= 2.500000 , IINF= 0.1000000E+00, IPARAM=
 1,
 ICONV= 0, RELERR= 0.6000000E-06, ABSERR= 0.6000000E-06, CMPTUR= 10.00000 , \$
 COLD
 SLAD
 PDP10
 DMPEC
 ARCL

	NZRAY	NXRAY	NX2C+	NX2C-	RESID	NZ2C+	NZ2C-	ALFA	ALHOT	BETA
0.5000	1.100E+00	6.499E-01	-1.000E+30	6.499E-01	4.920E-09	3.855E-01	1.100E+00	5.000E-01	0.000E+00	1.922E+00
1.0000	1.100E+00	6.689E-01	-1.000E+30	6.689E-01	-2.506E-08	3.189E-01	1.100E+00	5.000E-01	0.000E+00	1.843E+00
1.5000	1.100E+00	6.895E-01	-1.000E+30	6.895E-01	-4.470E-08	2.192E-01	1.100E+00	5.000E-01	0.000E+00	1.766E+00
2.0000	1.100E+00	7.118E-01	-1.000E+30	7.118E-01	-8.513E-09	-1.000E+30	1.100E+00	5.000E-01	0.000E+00	1.680E+00
2.5000	1.100E+00	7.362E-01	-1.000E+30	7.362E-01	-2.844E-07	-1.000E+30	1.100E+00	5.000E-01	0.000E+00	1.618E+00
3.0000	1.100E+00	7.629E-01	-1.000E+30	7.629E-01	-3.199E-07	-1.000E+30	1.100E+00	5.000E-01	0.000E+00	1.533E+00
3.5000	1.100E+00	7.925E-01	-1.000E+30	7.925E-01	-6.022E-07	-1.000E+30	1.100E+00	5.000E-01	0.000E+00	1.457E+00
4.0000	1.100E+00	8.255E-01	-1.000E+30	8.255E-01	-9.937E-07	-1.000E+30	1.100E+00	5.000E-01	0.000E+00	1.380E+00
4.5000	1.100E+00	8.625E-01	-1.000E+30	8.625E-01	-1.570E-06	-1.000E+30	1.100E+00	5.000E-01	0.000E+00	1.305E+00
5.0000	1.100E+00	9.044E-01	-1.000E+30	9.044E-01	-2.703E-06	-1.000E+30	1.100E+00	5.000E-01	0.000E+00	1.230E+00
5.5000	1.100E+00	9.524E-01	-1.000E+30	9.524E-01	-3.776E-06	-1.000E+30	1.100E+00	5.000E-01	0.000E+00	1.155E+00
6.0000	1.100E+00	1.000E+00	-1.000E+30	1.000E+00	-3.963E-06	-1.000E+30	1.100E+00	5.000E-01	0.000E+00	1.083E+00
6.5000	1.100E+00	1.074E+00	-1.000E+30	1.074E+00	-4.310E-06	-1.000E+30	1.100E+00	5.000E-01	0.000E+00	1.012E+00
7.0000	1.100E+00	1.152E+00	-1.000E+30	1.152E+00	-3.810E-06	1.501E+00	1.100E+00	5.000E-01	0.000E+00	9.425E-01
7.5000	1.100E+00	1.247E+00	-1.000E+30	1.247E+00	-3.615E-06	1.100E+00	7.599E-01	5.000E-01	0.000E+00	8.751E-01
8.0000	1.100E+00	1.366E+00	-1.000E+30	1.366E+00	-3.564E-06	1.100E+00	-1.000E+30	5.000E-01	0.000E+00	8.186E-01
8.5000	1.100E+00	1.519E+00	-1.000E+30	1.519E+00	-3.555E-06	1.100E+00	-1.000E+30	5.000E-01	0.000E+00	7.496E-01
9.0000	1.100E+00	1.720E+00	-1.000E+30	1.720E+00	-2.147E-06	1.100E+00	-1.000E+30	5.000E-01	0.000E+00	6.931E-01
9.5000	1.100E+00	1.997E+00	-1.000E+30	1.997E+00	-2.410E-06	1.100E+00	-1.000E+30	5.000E-01	0.000E+00	6.421E-01
10.0000	1.100E+00	2.399E+00	-1.000E+30	2.399E+00	-2.101E-06	1.100E+00	-1.000E+30	5.000E-01	0.000E+00	5.977E-01
10.5000	1.100E+00	3.028E+00	-1.000E+30	3.028E+00	-2.139E-06	1.100E+00	-1.000E+30	5.000E-01	0.000E+00	5.609E-01
11.0000	1.100E+00	4.137E+00	-1.000E+30	4.137E+00	-3.059E-06	1.100E+00	-1.000E+30	5.000E-01	0.000E+00	5.324E-01
11.5000	1.100E+00	6.586E+00	-1.000E+30	6.586E+00	-3.356E-06	1.100E+00	-1.000E+30	5.000E-01	0.000E+00	5.126E-01
12.0000	1.100E+00	1.633E+01	-1.000E+30	1.633E+01	-1.370E-06	1.100E+00	-1.000E+30	5.000E-01	0.000E+00	5.019E-01
12.5000	1.100E+00	1.633E+01	-1.000E+30	1.633E+01	-1.370E-06	1.100E+00	-1.000E+30	5.000E-01	0.000E+00	5.019E-01

NBFRV 452
 NDCVF 270

1STOP 3
JFLAG 2
-1.000 1.953E-02 0.000E+00 2.776E+00 -4.105E+02 0.000E+00 2.765E+01 8.491E-01 1.000E+00 1.002E+00 0.000E+00

Output to file FOR21.DAT (Example I)

21-Aug-31 15:13

\$DATA
IER= -1, IO1= 20, IO2= 21, IOUG= 0, IDAMP= 1, DS= 0.5000000
SNAX= 100000.0 , PHI0= 0.0000000E+00, NPHI= 1, DPHI= 0.1070000E-02, THETA0= 30.00000 ,
NTHETA= 1, DTHETA= 25.00000 , IMX= 1, IYMX= 1, IZMX= 1,
DX= -5.000000 , DY= 0.1500000 , DZ= 5.000000 , X0= 10.00000 , Y0= 0.0000000E+00, Z0= 2.500000 ,
SGN= -1.000000 , PFE0= 0.7071000 , BETANN= 0.1600000 , CFE0= 0.7071000 , FMU= 120.0000 , TE= 100.0000
TENOT= 1000000. , TI= 500.0000 , XMAX= 10.00000 , YMAX= 25.00000 , ZMAX= 7.000000 , RZ0= 1.100000
NRZ= 1, DRZ= 0.5000000 , ISLAB= 2, RSLAB= 10.00000 , NCOIL= 4,
SEP= 25.00000 , RCOIL= 10.00000 , RNOT= 6.000000 , DELTA= 2.500000 , DINF= 0.1000000E+00, IPARAM=
1,
ICONV= 0, RELERR= 0.6000000E-06, ABSERR= 0.6000000E-06, CMPTUR= 10.00000 , \$
COL D
SLAB
FDP10
DMPEC

ARCL

0.0000	1.000E+01	0.000E+00	2.500E+00	-1.509E+01	0.000E+00	2.765E+01	0.000E+00	1.000E+00	2.000E+00	0.000E+00
0.5000	9.604E+00	0.000E+00	2.806E+00	-1.633E+01	0.000E+00	2.765E+01	0.000E+00	0.000E+00	0.000E+00	0.000E+00
1.0000	9.202E+00	0.000E+00	3.102E+00	-1.681E+01	0.000E+00	2.765E+01	0.000E+00	0.000E+00	7.760E-09	0.000E+00
1.5000	8.791E+00	0.000E+00	3.388E+00	-1.733E+01	0.000E+00	2.765E+01	0.000E+00	0.000E+00	7.930E-09	0.000E+00
2.0000	8.373E+00	0.000E+00	3.661E+00	-1.709E+01	0.000E+00	2.765E+01	0.000E+00	0.000E+00	0.000E+00	0.000E+00
2.5000	7.948E+00	0.000E+00	3.932E+00	-1.050E+01	0.000E+00	2.765E+01	0.000E+00	0.000E+00	0.000E+00	0.000E+00
3.0000	7.512E+00	0.000E+00	4.169E+00	-1.917E+01	0.000E+00	2.765E+01	0.000E+00	0.000E+00	0.000E+00	0.000E+00
3.5000	7.060E+00	0.000E+00	4.400E+00	-1.992E+01	0.000E+00	2.765E+01	0.000E+00	0.000E+00	0.000E+00	0.000E+00
4.0000	6.616E+00	0.000E+00	4.613E+00	-2.075E+01	0.000E+00	2.765E+01	0.000E+00	0.000E+00	0.000E+00	0.000E+00
4.5000	6.155E+00	0.000E+00	4.807E+00	-2.168E+01	0.000E+00	2.765E+01	0.000E+00	0.000E+00	0.000E+00	0.000E+00
5.0000	5.685E+00	0.000E+00	4.978E+00	-2.273E+01	0.000E+00	2.765E+01	5.924E-09	0.000E+00	-9.500E-09	5.999E-09
5.5000	5.207E+00	0.000E+00	5.123E+00	-2.394E+01	0.000E+00	2.765E+01	1.589E-05	0.000E+00	0.000E+00	2.396E-04
6.0000	4.720E+00	0.000E+00	5.239E+00	-2.533E+01	0.000E+00	2.765E+01	3.515E-02	0.000E+00	0.000E+00	2.600E-01
6.5000	4.227E+00	0.000E+00	5.321E+00	-2.690E+01	0.000E+00	2.765E+01	4.780E-01	0.000E+00	0.000E+00	1.303E+00
7.0000	3.734E+00	0.000E+00	5.366E+00	-2.095E+01	0.000E+00	2.765E+01	8.015E-01	0.000E+00	1.005E-00	7.015E-01
7.5000	3.230E+00	0.000E+00	5.366E+00	-3.135E+01	0.000E+00	2.765E+01	8.400E-01	0.000E+00	1.126E-00	5.535E-03
8.0000	2.732E+00	0.000E+00	5.316E+00	-3.434E+01	0.000E+00	2.765E+01	8.401E-01	0.000E+00	1.170E-00	2.312E-07
8.5000	2.244E+00	0.000E+00	5.210E+00	-3.017E+01	0.000E+00	2.765E+01	8.401E-01	0.000E+00	0.000E+00	0.000E+00
9.0000	1.774E+00	0.000E+00	5.042E+00	-4.323E+01	0.000E+00	2.765E+01	8.401E-01	0.000E+00	1.266E-00	0.000E+00
9.5000	1.332E+00	0.000E+00	4.800E+00	-5.019E+01	0.000E+00	2.765E+01	8.401E-01	0.000E+00	1.315E-00	0.000E+00
10.0000	9.337E-01	0.000E+00	4.507E+00	-6.029E+01	0.000E+00	2.765E+01	8.401E-01	0.000E+00	0.000E+00	0.000E+00
10.5000	5.915E-01	0.000E+00	4.143E+00	-7.610E+01	0.000E+00	2.765E+01	8.401E-01	0.000E+00	1.407E-00	0.000E+00
11.0000	3.187E-01	0.000E+00	3.725E+00	-1.040E+02	0.000E+00	2.765E+01	8.401E-01	0.000E+00	1.444E-00	0.000E+00
11.5000	1.257E-01	0.000E+00	3.264E+00	-1.655E+02	0.000E+00	2.765E+01	8.401E-01	0.000E+00	0.000E+00	0.000E+00
12.0000	1.953E-02	0.000E+00	2.776E+00	-4.105E+02	0.000E+00	2.765E+01	8.401E-01	0.000E+00	0.000E+00	0.000E+00
12.5000	1.953E-02	0.000E+00	2.776E+00	-4.105E+02	0.000E+00	2.765E+01	8.401E-01	0.000E+00	0.000E+00	0.000E+00
-1.0000	1.953E-02	0.000E+00	2.776E+00	-4.105E+02	0.000E+00	2.765E+01	8.401E-01	1.000E+00	1.002E+00	0.000E+00
-10.0000	1.953E-02	0.000E+00	2.776E+00	-4.105E+02	0.000E+00	2.765E+01	8.401E-01	1.000E+00	1.002E+00	0.000E+00

PRECISE VALUES FOR V VECTOR AT END

0.15311710E-01	0.00000000E+00	0.277647650E+01	-0.410472940E+03	0.000000000E+00
0.00000000E+00	0.00000000E+00	0.100000000E+01	0.100195310E+01	0.000000000E+00

NDERV 452
NDAMP 239
ISTOP 3
IFLAG 2

RAYPLT plot (Example 1)

MINUS BRANCH PROPAGATION

Example II. Extraordinary rays in bumpy cylinder geometry
with field lines, resonance surfaces,
and cutoff surfaces plotted.

PDP10 COMPUTER USED FOR THIS RUN
SUBROUTINES LINKED IN:

COLD
EQBC
DMPEC

ARCL

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RAY * 1 INITIALIZATION WITH SPECIFIED ANGLE FOR K
KX0 = 1.076E+01 KY0 = 6.213E+00 KZ0 = 2.152E+01
N-PARA**2 = 7.332E-01 N-PERP**2 = 2.444E-01 N**2 = 9.776E-01
ALFA = 1.619E-02 BETA = 9.257E-02 THETA = 3.000E+01

ISTOP, IFLAG 1 2 AT -0.5671E+01 0.5656E+01 -0.1536E+00

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RAY * 2 INITIALIZATION WITH SPECIFIED ANGLE FOR K
KX0 = 1.765E+01 KY0 = 1.019E+01 KZ0 = 1.427E+01
N-PARA**2 = 3.223E-01 N-PERP**2 = 6.573E-01 N**2 = 9.795E-01
ALFA = 1.619E-02 BETA = 9.257E-02 THETA = 5.500E+01

ISTOP FLAG HAS BEEN SET IN DERV2C ISTOP= 2
ALFA BETA SGN RS RXS RZS (ALL FROM TWOCMP)
0.1600001E-01 0.4005943E-04 -0.1000000E+01
-0.1000000E+39 -0.1000000E+39 0.7457946E+00
RXS X AND Z FROM RAYS CODE 0.2381280E+00 0.2680100E+01 0.0086457E+00
ISTOP FLAG HAS BEEN SET IN DERV2C ISTOP= 3
ALFA BETA SGN RS RXS RZS (ALL FROM TWOCMP)
0.1600001E-01 0.4005943E-04 -0.1000000E+01
-0.1000000E+39 -0.1000000E+39 0.7457946E+00
RXS X AND Z FROM RAYS CODE 0.2381280E+00 0.2680100E+01 0.0086457E+00
ISTOP, IFLAG 3 2 AT 0.2509E+01 0.2241E+02 0.1009E+01

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RAY * 3 INITIALIZATION WITH SPECIFIED ANGLE FOR K
KX0 = 2.124E+01 KY0 = 1.226E+01 KZ0 = 4.324E+00
N-PARA**2 = 2.960E-02 N-PERP**2 = 9.521E-01 N**2 = 9.817E-01
ALFA = 1.619E-02 BETA = 9.257E-02 THETA = 0.000E+01

ISTOP, IFLAG 1 2 AT 0.1012E+02 0.2041E+02 0.5689E+01
PRECISE VALUES FOR V VECTOR AT END
0.10120040E+02 0.20400270E+02 0.56893370E+01 0.154305440E+02 0.190013690E+02
0.47002240E+01 0.00000000E+00 0.100000380E+00 0.362000340E-01 0.00000000E+00

Output to terminal (Example II)

Output file FOR20.DAT (Example II)

21-Aug-01 14:52

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$DATA
IEQ=      1, IO1=      20, IO2=      21, IBUG=      0, IDAMP=      0, DS= 0.2500000
SMAX= 100000.0 , PHI0= 30.00000 , NPHI=      1, DPHI= 0.1070000E-02, THETA0= 30.00000 ,
NTHETA=      3, DTHETA= 25.00000 , IYMX=      1, IYMX=      1, IZMX=      1,
DX= -5.000000 , DY= 0.1500000 , DZ= 5.000000 , X0= -10.00000 , Y0= 0.000000E+00, Z0= 0.000000E+00,
SGN= -1.000000 , PFE0= 0.4000000 , BETAHN= 0.1600000 , CFE0= 0.6000000 , FMU= 120.0000 , TE= 100.0000
TEHOT= 1000000. , T1= 500.0000 , XMAX= 10.00000 , YMAX= 25.00000 , ZMAX= 12.50000 , RZ0= 1.100000
NRZ=      1, DRZ= 0.000000E+00, ISLAB=      2, RSLAB= 10.00000 , NCOIL=      4,
SEP= 25.00000 , RCOIL= 10.00000 , RNOT= 6.000000 , DELTA= 2.500000 , DINF= 0.1000000E+00, IPARAM=
1,
ICONV=      0, RCLERR= 0.6000000E-06, ABSERR= 0.6000000E-06, CPUTR= 10.00000 , $
COLD
EOBC
PDP10
DMPEC
ARCCL

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INITIAL ANGLE OF K WRT LOCAL B 3.000E+01 INITIAL K= 2.485E+01

	NZRAY	NXRAY	NY2C+	NX2C-	RESID	NZ2C+	NZ2C-	ALFA	ALHOT	BETA
0.2500	8.696E-01	4.703E-01	4.806E-01	4.703E-01	-7.277E-09	8.752E-01	8.696E-01	1.623E-02	0.000E+00	9.577E-02
0.5000	8.815E-01	4.472E-01	4.584E-01	4.472E-01	3.459E-09	8.872E-01	8.815E-01	1.627E-02	0.000E+00	9.934E-02
0.7500	8.921E-01	4.254E-01	4.376E-01	4.254E-01	-6.626E-09	8.980E-01	8.921E-01	1.631E-02	0.000E+00	1.033E-01
1.0000	9.014E-01	4.048E-01	4.182E-01	4.048E-01	0.000E+00	9.074E-01	9.014E-01	1.636E-02	0.000E+00	1.077E-01
1.2500	9.094E-01	3.858E-01	4.003E-01	3.858E-01	-3.098E-09	9.157E-01	9.094E-01	1.640E-02	0.000E+00	1.126E-01
1.5000	9.164E-01	3.685E-01	3.843E-01	3.685E-01	-9.071E-09	9.228E-01	9.164E-01	1.645E-02	0.000E+00	1.180E-01
1.7500	9.222E-01	3.530E-01	3.701E-01	3.530E-01	-1.187E-08	9.289E-01	9.222E-01	1.651E-02	0.000E+00	1.240E-01
2.0000	9.271E-01	3.393E-01	3.578E-01	3.393E-01	0.000E+00	9.340E-01	9.271E-01	1.656E-02	0.000E+00	1.305E-01
2.2500	9.310E-01	3.277E-01	3.476E-01	3.277E-01	-2.901E-09	9.382E-01	9.310E-01	1.661E-02	0.000E+00	1.377E-01
2.5000	9.341E-01	3.180E-01	3.394E-01	3.180E-01	0.000E+00	9.416E-01	9.341E-01	1.665E-02	0.000E+00	1.456E-01
2.7500	9.363E-01	3.103E-01	3.332E-01	3.103E-01	5.760E-09	9.442E-01	9.363E-01	1.670E-02	0.000E+00	1.543E-01
3.0000	9.379E-01	3.046E-01	3.289E-01	3.046E-01	0.000E+00	9.461E-01	9.379E-01	1.674E-02	0.000E+00	1.639E-01
3.2500	9.389E-01	3.007E-01	3.265E-01	3.007E-01	-5.854E-09	9.473E-01	9.389E-01	1.678E-02	0.000E+00	1.743E-01
3.5000	9.391E-01	2.985E-01	3.257E-01	2.985E-01	2.963E-09	9.481E-01	9.391E-01	1.681E-02	0.000E+00	1.858E-01
3.7500	9.389E-01	2.968E-01	3.265E-01	2.968E-01	0.000E+00	9.483E-01	9.389E-01	1.684E-02	0.000E+00	1.984E-01
4.0000	9.382E-01	2.987E-01	3.266E-01	2.987E-01	-3.872E-09	9.481E-01	9.382E-01	1.686E-02	0.000E+00	2.122E-01
4.2500	9.378E-01	3.037E-01	3.319E-01	3.037E-01	-3.145E-09	9.476E-01	9.378E-01	1.687E-02	0.000E+00	2.273E-01
4.5000	9.355E-01	3.036E-01	3.363E-01	3.036E-01	0.000E+00	9.467E-01	9.355E-01	1.688E-02	0.000E+00	2.439E-01
4.7500	9.337E-01	3.073E-01	3.415E-01	3.073E-01	0.000E+00	9.450E-01	9.337E-01	1.688E-02	0.000E+00	2.620E-01
5.0000	9.310E-01	3.116E-01	3.475E-01	3.116E-01	0.000E+00	9.442E-01	9.310E-01	1.687E-02	0.000E+00	2.819E-01
5.2500	9.282E-01	3.164E-01	3.540E-01	3.164E-01	7.195E-09	9.427E-01	9.282E-01	1.685E-02	0.000E+00	3.037E-01
5.5000	9.265E-01	3.216E-01	3.612E-01	3.216E-01	0.000E+00	9.410E-01	9.265E-01	1.683E-02	0.000E+00	3.275E-01

5.7500	9.236E-01	3.269E-01	3.688E-01	3.269E-01	-3.961E-09	9.393E-01	9.236E-01	1.681E-02	0.000E+00	3.537E-01
6.0000	9.204E-01	3.324E-01	3.768E-01	3.324E-01	8.390E-09	9.374E-01	9.204E-01	1.678E-02	0.000E+00	3.822E-01
6.2500	9.169E-01	3.370E-01	3.854E-01	3.370E-01	4.478E-09	9.356E-01	9.169E-01	1.675E-02	0.000E+00	4.135E-01
6.5000	9.131E-01	3.432E-01	3.945E-01	3.432E-01	1.447E-08	9.337E-01	9.131E-01	1.671E-02	0.000E+00	4.476E-01
6.7500	9.088E-01	3.486E-01	4.044E-01	3.486E-01	2.103E-08	9.318E-01	9.088E-01	1.667E-02	0.000E+00	4.849E-01
7.0000	9.040E-01	3.537E-01	4.153E-01	3.537E-01	3.106E-08	9.299E-01	9.040E-01	1.663E-02	0.000E+00	5.257E-01
7.2500	8.983E-01	3.586E-01	4.276E-01	3.586E-01	4.580E-08	9.281E-01	8.983E-01	1.659E-02	0.000E+00	5.700E-01
7.5000	8.914E-01	3.633E-01	4.419E-01	3.633E-01	5.289E-08	9.264E-01	8.914E-01	1.656E-02	0.000E+00	6.183E-01
7.7500	8.824E-01	3.677E-01	4.597E-01	3.677E-01	8.616E-08	9.247E-01	8.824E-01	1.652E-02	0.000E+00	6.707E-01
8.0000	8.690E-01	3.717E-01	4.833E-01	3.717E-01	1.771E-07	9.232E-01	8.699E-01	1.648E-02	0.000E+00	7.276E-01
8.2500	8.494E-01	3.751E-01	5.183E-01	3.751E-01	2.969E-07	9.219E-01	8.494E-01	1.644E-02	0.000E+00	7.890E-01
8.5000	8.099E-01	3.773E-01	5.794E-01	3.773E-01	6.153E-07	9.211E-01	8.088E-01	1.641E-02	0.000E+00	8.552E-01
8.7500	6.750E-01	3.756E-01	7.301E-01	3.756E-01	2.581E-06	9.219E-01	6.750E-01	1.639E-02	0.000E+00	9.258E-01
9.0000	-5.595E-01	4.865E-01	8.212E-01	4.865E-01	6.319E-06	9.263E-01	5.595E-01	1.644E-02	0.000E+00	9.365E-01
9.2500	-7.206E-01	5.099E-01	6.769E-01	5.099E-01	1.585E-06	8.545E-01	7.286E-01	1.668E-02	0.000E+00	8.658E-01
9.5000	-7.739E-01	5.102E-01	6.247E-01	5.103E-01	0.431E-07	8.542E-01	7.739E-01	1.679E-02	0.000E+00	8.009E-01
9.7500	-7.968E-01	5.062E-01	5.951E-01	5.062E-01	5.994E-07	8.564E-01	7.968E-01	1.704E-02	0.000E+00	7.416E-01
10.0000	-8.118E-01	5.003E-01	5.744E-01	5.003E-01	4.576E-07	8.597E-01	8.118E-01	1.734E-02	0.000E+00	6.875E-01
10.2500	-8.231E-01	4.933E-01	5.578E-01	4.933E-01	3.723E-07	8.636E-01	8.231E-01	1.759E-02	0.000E+00	6.382E-01
10.5000	-8.324E-01	4.854E-01	5.435E-01	4.854E-01	3.373E-07	8.678E-01	8.325E-01	1.811E-02	0.000E+00	5.931E-01
10.7500	-8.406E-01	4.769E-01	5.305E-01	4.769E-01	2.900E-07	8.723E-01	8.406E-01	1.859E-02	0.000E+00	5.519E-01
11.0000	-8.480E-01	4.677E-01	5.182E-01	4.677E-01	2.667E-07	8.770E-01	8.480E-01	1.913E-02	0.000E+00	5.143E-01
11.2500	-8.548E-01	4.581E-01	5.064E-01	4.581E-01	2.320E-07	8.818E-01	8.548E-01	1.973E-02	0.000E+00	4.799E-01
11.5000	-8.613E-01	4.481E-01	4.948E-01	4.481E-01	2.312E-07	8.866E-01	8.613E-01	2.038E-02	0.000E+00	4.485E-01
11.7500	-8.674E-01	4.378E-01	4.835E-01	4.378E-01	2.056E-07	8.914E-01	8.674E-01	2.106E-02	0.000E+00	4.197E-01
12.0000	-8.732E-01	4.273E-01	4.723E-01	4.273E-01	1.946E-07	8.962E-01	8.732E-01	2.177E-02	0.000E+00	3.934E-01
12.2500	-8.788E-01	4.166E-01	4.613E-01	4.166E-01	1.754E-07	9.009E-01	8.788E-01	2.249E-02	0.000E+00	3.694E-01
12.5000	-8.840E-01	4.060E-01	4.505E-01	4.061E-01	1.793E-07	9.054E-01	8.840E-01	2.320E-02	0.000E+00	3.473E-01
12.7500	-8.890E-01	3.956E-01	4.400E-01	3.956E-01	1.553E-07	9.097E-01	8.890E-01	2.309E-02	0.000E+00	3.272E-01
13.0000	-8.936E-01	3.855E-01	4.299E-01	3.855E-01	1.483E-07	9.137E-01	8.936E-01	2.453E-02	0.000E+00	3.087E-01
13.2500	-8.979E-01	3.759E-01	4.203E-01	3.760E-01	1.422E-07	9.174E-01	8.979E-01	2.512E-02	0.000E+00	2.919E-01
13.5000	-9.018E-01	3.670E-01	4.113E-01	3.670E-01	1.447E-07	9.208E-01	9.018E-01	2.563E-02	0.000E+00	2.764E-01
13.7500	-9.057E-01	3.590E-01	4.030E-01	3.590E-01	1.324E-07	9.237E-01	9.053E-01	2.606E-02	0.000E+00	2.623E-01
14.0000	-9.093E-01	3.521E-01	3.957E-01	3.521E-01	1.350E-07	9.262E-01	9.093E-01	2.638E-02	0.000E+00	2.494E-01
14.2500	-9.109E-01	3.464E-01	3.895E-01	3.464E-01	1.208E-07	9.282E-01	9.109E-01	2.668E-02	0.000E+00	2.376E-01
14.5000	-9.129E-01	3.422E-01	3.845E-01	3.423E-01	1.225E-07	9.296E-01	9.129E-01	2.671E-02	0.000E+00	2.260E-01
14.7500	-9.143E-01	3.390E-01	3.810E-01	3.398E-01	1.271E-07	9.305E-01	9.143E-01	2.671E-02	0.000E+00	2.170E-01
15.0000	-9.151E-01	3.391E-01	3.790E-01	3.391E-01	1.186E-07	9.307E-01	9.151E-01	2.659E-02	0.000E+00	2.081E-01
15.2500	-9.153E-01	3.404E-01	3.787E-01	3.404E-01	1.207E-07	9.303E-01	9.153E-01	2.636E-02	0.000E+00	2.000E-01
15.5000	-9.147E-01	3.437E-01	3.802E-01	3.437E-01	1.099E-07	9.291E-01	9.147E-01	2.603E-02	0.000E+00	1.927E-01
15.7500	-9.134E-01	3.491E-01	3.836E-01	3.491E-01	1.230E-07	9.272E-01	9.134E-01	2.561E-02	0.000E+00	1.861E-01
16.0000	-9.113E-01	3.565E-01	3.899E-01	3.565E-01	1.166E-07	9.245E-01	9.113E-01	2.511E-02	0.000E+00	1.802E-01
16.2500	-9.084E-01	3.650E-01	3.961E-01	3.659E-01	1.274E-07	9.218E-01	9.084E-01	2.454E-02	0.000E+00	1.749E-01
16.5000	-9.046E-01	3.771E-01	4.051E-01	3.771E-01	1.152E-07	9.167E-01	9.046E-01	2.392E-02	0.000E+00	1.702E-01
16.7500	-8.999E-01	3.908E-01	4.159E-01	3.908E-01	1.308E-07	9.115E-01	8.999E-01	2.326E-02	0.000E+00	1.661E-01
17.0000	-8.943E-01	4.045E-01	4.283E-01	4.045E-01	1.238E-07	9.054E-01	8.943E-01	2.258E-02	0.000E+00	1.626E-01
17.2500	-8.878E-01	4.204E-01	4.422E-01	4.204E-01	1.298E-07	8.983E-01	8.878E-01	2.198E-02	0.000E+00	1.595E-01
17.5000	-8.802E-01	4.375E-01	4.575E-01	4.376E-01	1.330E-07	8.903E-01	8.802E-01	2.122E-02	0.000E+00	1.570E-01
NDERV	410									
NLAMP	0									
ISTOP	1									
IFLAG	2									
-1.0000	-5.671E+00	5.656E+00	-1.538E-01	2.333E-01	1.072E+01	-2.226E+01	0.000E+00	1.326E-01	6.603E-01	0.000E+00

INITIAL ANGLE OF K WRT LOCAL B 5.500E+01 INITIAL K= 2.487E+01

	NZRAY	NXRAY	NX2C+	NX2C-	RESID	NZ2C+	NZ2C-	ALFA	ALHOT	BETA
0.2500	5.823E-01	0.000E-01	0.042E-01	0.000E-01	-2.259E-09	5.861E-01	5.823E-01	1.626E-02	0.000E+00	9.766E-02
0.5000	5.958E-01	7.898E-01	7.943E-01	7.898E-01	-3.109E-09	6.018E-01	5.958E-01	1.634E-02	0.000E+00	1.030E-01
0.7500	6.003E-01	7.800E-01	7.640E-01	7.800E-01	0.000E+00	6.145E-01	6.003E-01	1.645E-02	0.000E+00	1.007E-01
1.0000	6.196E-01	7.707E-01	7.759E-01	7.707E-01	0.000E+00	6.261E-01	6.196E-01	1.659E-02	0.000E+00	1.146E-01
1.2500	6.300E-01	7.619E-01	7.675E-01	7.619E-01	-1.632E-00	6.367E-01	6.300E-01	1.677E-02	0.000E+00	1.208E-01
1.5000	6.393E-01	7.537E-01	7.597E-01	7.537E-01	-2.250E-00	6.464E-01	6.393E-01	1.699E-02	0.000E+00	1.274E-01
1.7500	6.476E-01	7.460E-01	7.525E-01	7.460E-01	-9.229E-09	6.551E-01	6.476E-01	1.720E-02	0.000E+00	1.343E-01
2.0000	6.550E-01	7.389E-01	7.459E-01	7.389E-01	-1.402E-00	6.629E-01	6.550E-01	1.765E-02	0.000E+00	1.415E-01
2.2500	6.615E-01	7.324E-01	7.400E-01	7.324E-01	-1.150E-00	6.699E-01	6.615E-01	1.810E-02	0.000E+00	1.491E-01
2.5000	6.670E-01	7.265E-01	7.347E-01	7.265E-01	0.000E+00	6.760E-01	6.670E-01	1.866E-02	0.000E+00	1.570E-01
2.7500	6.718E-01	7.211E-01	7.301E-01	7.211E-01	1.652E-00	6.814E-01	6.718E-01	1.935E-02	0.000E+00	1.653E-01
3.0000	6.756E-01	7.163E-01	7.261E-01	7.163E-01	-0.156E-09	6.861E-01	6.756E-01	2.019E-02	0.000E+00	1.740E-01
3.2500	6.787E-01	7.119E-01	7.227E-01	7.119E-01	-2.659E-09	6.901E-01	6.787E-01	2.120E-02	0.000E+00	1.831E-01
3.5000	6.810E-01	7.079E-01	7.199E-01	7.079E-01	-1.077E-00	6.936E-01	6.810E-01	2.240E-02	0.000E+00	1.926E-01
3.7500	6.826E-01	7.044E-01	7.178E-01	7.044E-01	-1.620E-00	6.964E-01	6.826E-01	2.382E-02	0.000E+00	2.025E-01
4.0000	6.834E-01	7.012E-01	7.161E-01	7.012E-01	-5.442E-09	6.988E-01	6.834E-01	2.546E-02	0.000E+00	2.128E-01
4.2500	6.835E-01	6.983E-01	7.151E-01	6.983E-01	-1.102E-00	7.007E-01	6.835E-01	2.735E-02	0.000E+00	2.235E-01
4.5000	6.829E-01	6.957E-01	7.145E-01	6.957E-01	-1.401E-00	7.022E-01	6.829E-01	2.947E-02	0.000E+00	2.347E-01
4.7500	6.816E-01	6.973E-01	7.146E-01	6.933E-01	-1.719E-00	7.034E-01	6.816E-01	3.183E-02	0.000E+00	2.463E-01
5.0000	6.796E-01	6.912E-01	7.152E-01	6.912E-01	-1.704E-00	7.042E-01	6.796E-01	3.439E-02	0.000E+00	2.583E-01
5.2500	6.769E-01	6.893E-01	7.163E-01	6.893E-01	-3.033E-09	7.046E-01	6.769E-01	3.711E-02	0.000E+00	2.708E-01
5.5000	6.735E-01	6.877E-01	7.180E-01	6.877E-01	3.142E-09	7.049E-01	6.735E-01	3.994E-02	0.000E+00	2.830E-01
5.7500	6.695E-01	6.861E-01	7.202E-01	6.861E-01	-3.270E-09	7.046E-01	6.695E-01	4.281E-02	0.000E+00	2.972E-01
6.0000	6.648E-01	6.856E-01	7.231E-01	6.856E-01	-1.710E-00	7.040E-01	6.648E-01	4.564E-02	0.000E+00	3.112E-01
6.2500	6.594E-01	6.853E-01	7.267E-01	6.853E-01	-7.197E-09	7.029E-01	6.594E-01	4.834E-02	0.000E+00	3.256E-01
6.5000	6.532E-01	6.856E-01	7.309E-01	6.856E-01	-7.593E-09	7.014E-01	6.532E-01	5.081E-02	0.000E+00	3.406E-01
6.7500	6.463E-01	6.868E-01	7.359E-01	6.860E-01	-2.823E-00	6.992E-01	6.463E-01	5.297E-02	0.000E+00	3.561E-01
7.0000	6.387E-01	6.889E-01	7.416E-01	6.869E-01	-4.369E-09	6.962E-01	6.387E-01	5.472E-02	0.000E+00	3.722E-01
7.2500	6.303E-01	6.921E-01	7.480E-01	6.921E-01	1.159E-00	6.924E-01	6.303E-01	5.599E-02	0.000E+00	3.888E-01
7.5000	6.211E-01	6.965E-01	7.553E-01	6.965E-01	0.000E+00	6.877E-01	6.211E-01	5.669E-02	0.000E+00	4.061E-01
7.7500	6.111E-01	7.023E-01	7.633E-01	7.023E-01	2.739E-09	6.817E-01	6.111E-01	5.678E-02	0.000E+00	4.240E-01
8.0000	6.002E-01	7.096E-01	7.721E-01	7.096E-01	2.411E-00	6.740E-01	6.002E-01	5.620E-02	0.000E+00	4.426E-01
8.2500	5.885E-01	7.183E-01	7.815E-01	7.183E-01	6.697E-09	6.650E-01	5.885E-01	5.494E-02	0.000E+00	4.618E-01
8.5000	5.759E-01	7.286E-01	7.917E-01	7.206E-01	-4.134E-00	6.555E-01	5.759E-01	5.298E-02	0.000E+00	4.817E-01
8.7500	5.624E-01	7.404E-01	8.024E-01	7.404E-01	-3.199E-00	6.435E-01	5.624E-01	5.038E-02	0.000E+00	5.024E-01
9.0000	5.481E-01	7.535E-01	8.136E-01	7.535E-01	-3.185E-00	6.299E-01	5.481E-01	4.721E-02	0.000E+00	5.238E-01
9.2500	5.330E-01	7.676E-01	8.252E-01	7.676E-01	2.052E-09	6.146E-01	5.330E-01	4.358E-02	0.000E+00	5.460E-01
9.5000	5.170E-01	7.825E-01	8.376E-01	7.825E-01	-1.584E-00	5.977E-01	5.170E-01	3.966E-02	0.000E+00	5.685E-01
9.7500	5.003E-01	7.977E-01	8.485E-01	7.977E-01	-2.020E-00	5.797E-01	5.003E-01	3.566E-02	0.000E+00	5.928E-01
10.0000	4.827E-01	8.128E-01	8.607E-01	8.128E-01	-6.407E-00	5.600E-01	4.827E-01	3.179E-02	0.000E+00	6.175E-01
10.2500	4.642E-01	8.273E-01	8.723E-01	8.273E-01	-4.208E-00	5.410E-01	4.642E-01	2.823E-02	0.000E+00	6.433E-01
10.5000	4.447E-01	8.408E-01	8.837E-01	8.408E-01	-1.167E-07	5.224E-01	4.447E-01	2.512E-02	0.000E+00	6.701E-01
10.7500	4.239E-01	8.532E-01	8.950E-01	8.532E-01	-7.692E-00	5.037E-01	4.239E-01	2.255E-02	0.000E+00	6.981E-01
11.0000	4.013E-01	8.642E-01	9.062E-01	8.642E-01	-1.363E-07	4.861E-01	4.013E-01	2.053E-02	0.000E+00	7.274E-01
11.2500	3.762E-01	8.737E-01	9.175E-01	8.737E-01	-2.751E-07	4.700E-01	3.762E-01	1.901E-02	0.000E+00	7.582E-01
11.5000	3.471E-01	8.814E-01	9.292E-01	8.814E-01	-2.392E-07	4.562E-01	3.471E-01	1.792E-02	0.000E+00	7.903E-01
11.7500	3.113E-01	8.879E-01	9.420E-01	8.879E-01	-4.105E-00	4.460E-01	3.113E-01	1.718E-02	0.000E+00	8.239E-01
12.0000	2.630E-01	8.950E-01	9.567E-01	8.950E-01	2.196E-07	4.423E-01	2.630E-01	1.670E-02	0.000E+00	8.584E-01
12.2500	1.871E-01	8.842E-01	9.742E-01	8.842E-01	9.156E-07	4.523E-01	1.871E-01	1.639E-02	0.000E+00	8.925E-01
12.5000	4.129E-02	8.617E-01	9.910E-01	8.617E-01	-2.114E-04	4.944E-01	4.129E-02	1.621E-02	0.000E+00	9.213E-01
12.7500	-2.220E-01	8.073E-01	9.671E-01	8.073E-01	-2.513E-06	5.790E-01	2.220E-01	1.611E-02	0.000E+00	9.283E-01
13.0000	-4.366E-01	7.567E-01	8.921E-01	7.567E-01	-3.406E-07	6.450E-01	4.366E-01	1.607E-02	0.000E+00	9.046E-01
13.2500	-5.474E-01	7.251E-01	8.294E-01	7.251E-01	-1.599E-07	6.005E-01	5.474E-01	1.604E-02	0.000E+00	8.672E-01
13.5000	-6.118E-01	7.017E-01	7.841E-01	7.017E-01	-0.311E-00	7.047E-01	6.118E-01	1.603E-02	0.000E+00	8.247E-01
13.7500	-6.538E-01	6.816E-01	7.496E-01	6.816E-01	-3.960E-09	7.243E-01	6.538E-01	1.602E-02	0.000E+00	7.798E-01
14.0000	-6.091E-01	6.629E-01	7.198E-01	6.629E-01	-2.221E-00	7.415E-01	6.091E-01	1.601E-02	0.000E+00	7.338E-01

14.2500	-7.122E-01	6.449E-01	6.941E-01	6.449E-01	-1.931E-00	7.573E-01	7.122E-01	1.601E-02	0.000E+00	6.075E-01
14.5000	-7.344E-01	6.273E-01	6.706E-01	6.273E-01	-2.804E-00	7.719E-01	7.344E-01	1.601E-02	0.000E+00	6.414E-01
14.7500	-7.530E-01	6.100E-01	6.407E-01	6.100E-01	-1.043E-00	7.857E-01	7.530E-01	1.600E-02	0.000E+00	5.959E-01
15.0000	-7.712E-01	5.929E-01	6.290E-01	5.929E-01	-8.635E-01	7.986E-01	7.712E-01	1.600E-02	0.000E+00	5.516E-01
15.2500	-7.000E-01	5.762E-01	6.063E-01	5.762E-01	-9.750E-01	8.107E-01	7.000E-01	1.600E-02	0.000E+00	5.086E-01
15.5000	-8.011E-01	5.598E-01	5.894E-01	5.598E-01	-2.101E-00	8.221E-01	8.011E-01	1.600E-02	0.000E+00	4.673E-01
15.7500	-8.140E-01	5.430E-01	5.714E-01	5.430E-01	-3.602E-00	8.327E-01	8.140E-01	1.600E-02	0.000E+00	4.279E-01
16.0000	-8.250E-01	5.283E-01	5.544E-01	5.283E-01	-6.541E-00	8.420E-01	8.250E-01	1.600E-02	0.000E+00	3.905E-01
16.2500	-8.368E-01	5.133E-01	5.374E-01	5.133E-01	-2.941E-00	8.510E-01	8.368E-01	1.600E-02	0.000E+00	3.553E-01
16.5000	-8.467E-01	4.980E-01	5.216E-01	4.980E-01	5.349E-00	8.603E-01	8.467E-01	1.600E-02	0.000E+00	3.224E-01
16.7500	-8.557E-01	4.850E-01	5.064E-01	4.850E-01	-2.456E-00	8.681E-01	8.557E-01	1.600E-02	0.000E+00	2.917E-01
17.0000	-8.646E-01	4.718E-01	4.921E-01	4.718E-01	-2.275E-00	8.753E-01	8.640E-01	1.600E-02	0.000E+00	2.633E-01
17.2500	-8.716E-01	4.592E-01	4.785E-01	4.592E-01	2.125E-00	8.819E-01	8.716E-01	1.600E-02	0.000E+00	2.371E-01
17.5000	-8.784E-01	4.473E-01	4.650E-01	4.473E-01	7.992E-00	8.879E-01	8.784E-01	1.600E-02	0.000E+00	2.131E-01
17.7500	-8.847E-01	4.360E-01	4.534E-01	4.360E-01	-1.135E-00	8.934E-01	8.847E-01	1.600E-02	0.000E+00	1.911E-01
18.0000	-8.904E-01	4.254E-01	4.420E-01	4.254E-01	3.601E-00	8.984E-01	8.904E-01	1.600E-02	0.000E+00	1.711E-01
18.2500	-8.955E-01	4.155E-01	4.313E-01	4.155E-01	-3.440E-00	9.030E-01	8.955E-01	1.600E-02	0.000E+00	1.529E-01
18.5000	-9.002E-01	4.063E-01	4.213E-01	4.063E-01	-3.313E-00	9.071E-01	9.002E-01	1.600E-02	0.000E+00	1.364E-01
18.7500	-9.044E-01	3.977E-01	4.120E-01	3.977E-01	0.000E+00	9.108E-01	9.044E-01	1.600E-02	0.000E+00	1.216E-01
19.0000	-9.082E-01	3.897E-01	4.034E-01	3.897E-01	-3.099E-00	9.142E-01	9.082E-01	1.600E-02	0.000E+00	1.082E-01
19.2500	-9.117E-01	3.823E-01	3.953E-01	3.823E-01	6.027E-00	9.172E-01	9.117E-01	1.600E-02	0.000E+00	9.622E-02
19.5000	-9.149E-01	3.756E-01	3.890E-01	3.756E-01	0.000E+00	9.199E-01	9.149E-01	1.600E-02	0.000E+00	8.545E-02
19.7500	-9.175E-01	3.694E-01	3.812E-01	3.694E-01	-2.075E-00	9.224E-01	9.175E-01	1.600E-02	0.000E+00	7.581E-02
20.0000	-9.200E-01	3.630E-01	3.750E-01	3.630E-01	0.000E+00	9.245E-01	9.200E-01	1.600E-02	0.000E+00	6.719E-02
20.2500	-9.222E-01	3.580E-01	3.694E-01	3.580E-01	-5.540E-00	9.264E-01	9.222E-01	1.600E-02	0.000E+00	5.950E-02
20.5000	-9.241E-01	3.543E-01	3.644E-01	3.543E-01	2.720E-00	9.280E-01	9.241E-01	1.600E-02	0.000E+00	5.265E-02
20.7500	-9.259E-01	3.504E-01	3.599E-01	3.504E-01	2.692E-00	9.295E-01	9.259E-01	1.600E-02	0.000E+00	4.654E-02
21.0000	-9.272E-01	3.470E-01	3.560E-01	3.470E-01	-2.661E-00	9.306E-01	9.272E-01	1.600E-02	0.000E+00	4.111E-02
21.2500	-9.284E-01	3.442E-01	3.527E-01	3.442E-01	2.634E-00	9.316E-01	9.284E-01	1.600E-02	0.000E+00	3.629E-02
21.5000	-9.294E-01	3.419E-01	3.495E-01	3.419E-01	-2.612E-00	9.324E-01	9.294E-01	1.600E-02	0.000E+00	3.200E-02
21.7500	-9.302E-01	3.402E-01	3.477E-01	3.402E-01	2.594E-00	9.330E-01	9.302E-01	1.600E-02	0.000E+00	2.820E-02
22.0000	-9.307E-01	3.390E-01	3.461E-01	3.390E-01	2.580E-00	9.333E-01	9.307E-01	1.600E-02	0.000E+00	2.483E-02
22.2500	-9.311E-01	3.384E-01	3.450E-01	3.384E-01	0.000E+00	9.335E-01	9.311E-01	1.600E-02	0.000E+00	2.185E-02
22.5000	-9.312E-01	3.383E-01	3.445E-01	3.383E-01	2.561E-00	9.335E-01	9.312E-01	1.600E-02	0.000E+00	1.920E-02
22.7500	-9.311E-01	3.380E-01	3.440E-01	3.380E-01	-2.556E-00	9.332E-01	9.311E-01	1.600E-02	0.000E+00	1.686E-02
23.0000	-9.308E-01	3.399E-01	3.455E-01	3.399E-01	-2.554E-00	9.328E-01	9.308E-01	1.600E-02	4.005E-05	1.480E-02
23.2500	-9.303E-01	3.415E-01	3.465E-01	3.415E-01	0.000E+00	9.322E-01	9.303E-01	1.600E-02	8.762E-04	1.297E-02
23.5000	-9.295E-01	3.431E-01	3.483E-01	3.436E-01	2.555E-00	9.313E-01	9.295E-01	1.600E-02	2.096E-03	1.136E-02
23.7500	-9.287E-01	3.463E-01	3.500E-01	3.463E-01	-5.132E-00	9.303E-01	9.287E-01	1.600E-02	3.087E-03	9.931E-03
24.0000	-9.275E-01	3.495E-01	3.535E-01	3.495E-01	2.576E-00	9.290E-01	9.275E-01	1.600E-02	3.431E-03	8.675E-03
24.2500	-9.262E-01	3.532E-01	3.563E-01	3.532E-01	0.000E+00	9.276E-01	9.262E-01	1.600E-02	2.874E-03	7.569E-03
24.5000	-9.246E-01	3.574E-01	3.600E-01	3.574E-01	0.000E+00	9.260E-01	9.246E-01	1.600E-02	1.201E-03	6.593E-03
24.7500	-9.229E-01	3.620E-01	3.651E-01	3.620E-01	-7.063E-00	9.241E-01	9.229E-01	1.600E-02	0.000E+00	5.735E-03
25.0000	-9.209E-01	3.671E-01	3.700E-01	3.671E-01	0.000E+00	9.221E-01	9.209E-01	1.600E-02	0.000E+00	4.981E-03
25.2500	-9.183E-01	3.726E-01	3.752E-01	3.726E-01	-1.333E-00	9.190E-01	9.180E-01	1.600E-02	0.000E+00	4.318E-03
25.5000	-9.164E-01	3.765E-01	3.809E-01	3.765E-01	-2.691E-00	9.174E-01	9.164E-01	1.600E-02	0.000E+00	3.737E-03
25.7500	-9.138E-01	3.847E-01	3.869E-01	3.847E-01	-0.161E-00	9.148E-01	9.138E-01	1.600E-02	0.000E+00	3.227E-03
26.0000	-9.111E-01	3.913E-01	3.932E-01	3.913E-01	-5.505E-00	9.119E-01	9.111E-01	1.600E-02	0.000E+00	2.781E-03
26.2500	-9.082E-01	3.991E-01	3.999E-01	3.981E-01	2.707E-00	9.090E-01	9.082E-01	1.600E-02	0.000E+00	2.391E-03
26.5000	-9.051E-01	4.051E-01	4.062E-01	4.052E-01	2.825E-00	9.059E-01	9.051E-01	1.600E-02	0.000E+00	2.050E-03
26.7500	-9.016E-01	4.124E-01	4.139E-01	4.124E-01	0.594E-00	9.025E-01	9.016E-01	1.600E-02	0.000E+00	1.753E-03
27.0000	-8.984E-01	4.193E-01	4.211E-01	4.190E-01	2.900E-00	8.990E-01	8.984E-01	1.600E-02	0.000E+00	1.484E-03
27.2500	-8.949E-01	4.273E-01	4.285E-01	4.273E-01	0.000E+00	8.955E-01	8.949E-01	1.600E-02	0.000E+00	1.269E-03
27.5000	-8.913E-01	4.345E-01	4.354E-01	4.349E-01	-3.001E-00	8.918E-01	8.913E-01	1.600E-02	0.000E+00	1.074E-03
27.7500	-8.876E-01	4.424E-01	4.434E-01	4.424E-01	-6.102E-00	8.876E-01	8.876E-01	1.600E-02	0.000E+00	9.050E-04
28.0000	-8.830E-01	4.499E-01	4.500E-01	4.499E-01	-3.103E-00	8.843E-01	8.830E-01	1.600E-02	0.000E+00	7.591E-04
28.2500	-8.801E-01	4.573E-01	4.581E-01	4.573E-01	0.000E+00	8.805E-01	8.801E-01	1.600E-02	0.000E+00	6.335E-04
28.5000	-8.767E-01	4.645E-01	4.652E-01	4.645E-01	-3.210E-00	8.767E-01	8.763E-01	1.600E-02	0.000E+00	5.255E-04
28.7500	-8.726E-01	4.714E-01	4.720E-01	4.713E-01	-6.529E-00	8.730E-01	8.726E-01	1.600E-02	0.000E+00	4.332E-04

29.0000	-0.691E-01	4.779E-01	4.785E-01	4.779E-01	-5.636E-09	0.694E-01	0.691E-01	1.600E-02	0.000E+00	3.543E-04
29.2500	-0.650E-01	4.039E-01	4.644E-01	4.839E-01	-6.730E-09	0.660E-01	0.659E-01	1.600E-02	0.000E+00	2.874E-04
29.5000	-0.626E-01	4.893E-01	4.897E-01	4.893E-01	-6.833E-09	0.630E-01	0.627E-01	1.600E-02	0.000E+00	2.309E-04
29.7500	-0.602E-01	4.939E-01	4.943E-01	4.939E-01	-3.450E-09	0.604E-01	0.602E-01	1.600E-02	0.000E+00	1.833E-04
30.0000	-0.592E-01	4.974E-01	4.977E-01	4.973E-01	-6.900E-09	0.584E-01	0.582E-01	1.600E-02	0.000E+00	1.436E-04
30.2500	-0.570E-01	4.994E-01	4.997E-01	4.994E-01	-7.018E-09	0.571E-01	0.570E-01	1.600E-02	0.000E+00	1.107E-04
30.5000	-0.569E-01	4.995E-01	4.996E-01	4.996E-01	0.000E+00	0.571E-01	0.569E-01	1.600E-02	0.000E+00	8.372E-05
30.7500	-0.504E-01	4.970E-01	4.972E-01	4.970E-01	0.000E+00	0.585E-01	0.584E-01	1.600E-02	0.000E+00	6.181E-05
30.7500	-0.504E-01	4.970E-01	4.972E-01	4.970E-01	0.000E+00	0.585E-01	0.584E-01	1.600E-02	0.000E+00	6.181E-05
NDEKV	366									
NDAIP	0									
ISTUP	3									
IFLAG	2									
-1.0000	2.589E+00	2.241E+01	1.009E+00	7.096E+00	2.198E+01	-9.399E+00	0.000E+00	1.000E-01	1.310E-02	0.000E+00

INITIAL ANGLE OF K WRT LOCAL B 0.000E+01 INITIAL K= 2.490E+01

	NZRAY	NXRAY	NX2C+	NX2C-	RESID	NZ2C+	NZ2C-	ALFA	ALHOT	BETA
0.2500	1.774E-01	9.747E-01	9.760E-01	9.747E-01	-6.075E-07	1.049E-01	1.774E-01	1.627E-02	0.000E+00	9.864E-02
0.5000	1.824E-01	9.736E-01	9.751E-01	9.736E-01	-1.914E-06	1.902E-01	1.824E-01	1.639E-02	0.000E+00	1.049E-01
0.7500	1.870E-01	9.725E-01	9.741E-01	9.725E-01	-2.202E-06	1.952E-01	1.869E-01	1.655E-02	0.000E+00	1.113E-01
1.0000	1.912E-01	9.715E-01	9.732E-01	9.715E-01	-4.203E-07	1.998E-01	1.912E-01	1.677E-02	0.000E+00	1.179E-01
1.2500	1.950E-01	9.705E-01	9.723E-01	9.705E-01	-6.391E-07	2.041E-01	1.950E-01	1.708E-02	0.000E+00	1.246E-01
1.5000	1.964E-01	9.694E-01	9.714E-01	9.694E-01	-1.071E-06	2.082E-01	1.984E-01	1.751E-02	0.000E+00	1.314E-01
1.7500	2.015E-01	9.683E-01	9.705E-01	9.683E-01	-1.590E-06	2.120E-01	2.015E-01	1.811E-02	0.000E+00	1.383E-01
2.0000	2.043E-01	9.671E-01	9.695E-01	9.671E-01	-2.433E-06	2.156E-01	2.043E-01	1.893E-02	0.000E+00	1.453E-01
2.2500	2.067E-01	9.650E-01	9.685E-01	9.650E-01	-1.110E-05	2.191E-01	2.057E-01	2.004E-02	0.000E+00	1.523E-01
2.5000	2.087E-01	9.642E-01	9.673E-01	9.642E-01	-2.731E-06	2.226E-01	2.087E-01	2.152E-02	0.000E+00	1.594E-01
2.7500	2.104E-01	9.625E-01	9.668E-01	9.625E-01	-2.322E-06	2.251E-01	2.104E-01	2.347E-02	0.000E+00	1.665E-01
3.0000	2.118E-01	9.604E-01	9.644E-01	9.604E-01	-6.377E-07	2.290E-01	2.118E-01	2.599E-02	0.000E+00	1.735E-01
3.2500	2.128E-01	9.578E-01	9.626E-01	9.578E-01	-0.725E-07	2.330E-01	2.129E-01	2.919E-02	0.000E+00	1.806E-01
3.5000	2.136E-01	9.540E-01	9.605E-01	9.540E-01	-1.044E-06	2.382E-01	2.156E-01	3.314E-02	0.000E+00	1.875E-01
3.7500	2.140E-01	9.512E-01	9.580E-01	9.512E-01	-4.065E-07	2.431E-01	2.140E-01	3.789E-02	0.000E+00	1.943E-01
4.0000	2.141E-01	9.471E-01	9.552E-01	9.471E-01	-5.713E-07	2.485E-01	2.141E-01	4.343E-02	0.000E+00	2.010E-01
4.2500	2.139E-01	9.424E-01	9.521E-01	9.424E-01	-3.897E-07	2.545E-01	2.139E-01	4.969E-02	0.000E+00	2.075E-01
4.5000	2.134E-01	9.372E-01	9.487E-01	9.372E-01	-7.051E-07	2.610E-01	2.134E-01	5.650E-02	0.000E+00	2.139E-01
4.7500	2.126E-01	9.318E-01	9.453E-01	9.318E-01	-2.116E-06	2.678E-01	2.126E-01	6.364E-02	0.000E+00	2.200E-01
5.0000	2.114E-01	9.262E-01	9.419E-01	9.262E-01	-2.930E-07	2.746E-01	2.114E-01	7.087E-02	0.000E+00	2.258E-01
5.2500	2.100E-01	9.207E-01	9.386E-01	9.207E-01	-6.077E-07	2.814E-01	2.100E-01	7.792E-02	0.000E+00	2.314E-01
5.5000	2.092E-01	9.155E-01	9.355E-01	9.155E-01	-5.677E-07	2.878E-01	2.082E-01	8.452E-02	0.000E+00	2.366E-01
5.7500	2.065E-01	9.106E-01	9.320E-01	9.106E-01	-4.754E-07	2.935E-01	2.060E-01	9.068E-02	0.000E+00	2.416E-01
6.0000	2.036E-01	9.053E-01	9.305E-01	9.053E-01	-1.287E-06	2.985E-01	2.036E-01	9.689E-02	0.000E+00	2.461E-01
6.2500	2.009E-01	9.027E-01	9.287E-01	9.027E-01	-2.233E-07	3.026E-01	2.008E-01	1.006E-01	0.000E+00	2.503E-01
6.5000	1.976E-01	8.997E-01	9.273E-01	8.997E-01	-5.894E-07	3.057E-01	1.976E-01	1.047E-01	0.000E+00	2.541E-01
6.7500	1.942E-01	8.975E-01	9.253E-01	8.975E-01	-0.649E-07	3.077E-01	1.942E-01	1.078E-01	0.000E+00	2.575E-01
7.0000	1.903E-01	8.959E-01	9.250E-01	8.959E-01	-3.574E-07	3.087E-01	1.903E-01	1.102E-01	0.000E+00	2.605E-01
7.2500	1.861E-01	8.951E-01	9.257E-01	8.951E-01	-1.971E-06	3.086E-01	1.861E-01	1.119E-01	0.000E+00	2.630E-01
7.5000	1.816E-01	8.950E-01	9.260E-01	8.950E-01	-1.646E-06	3.073E-01	1.816E-01	1.129E-01	0.000E+00	2.651E-01
7.7500	1.767E-01	8.950E-01	9.267E-01	8.950E-01	-1.549E-06	3.050E-01	1.767E-01	1.132E-01	0.000E+00	2.668E-01
8.0000	1.715E-01	8.953E-01	9.278E-01	8.969E-01	-2.788E-07	3.014E-01	1.715E-01	1.120E-01	0.000E+00	2.679E-01
8.2500	1.659E-01	8.989E-01	9.292E-01	8.989E-01	-1.431E-06	2.967E-01	1.659E-01	1.110E-01	0.000E+00	2.686E-01
8.5000	1.599E-01	9.016E-01	9.311E-01	9.016E-01	-3.170E-07	2.907E-01	1.599E-01	1.100E-01	0.000E+00	2.680E-01
8.7500	1.536E-01	9.051E-01	9.334E-01	9.051E-01	-1.418E-06	2.834E-01	1.536E-01	1.075E-01	0.000E+00	2.665E-01
9.0000	1.469E-01	9.072E-01	9.351E-01	9.092E-01	-1.037E-06	2.748E-01	1.469E-01	1.042E-01	0.000E+00	2.678E-01

9.2500	1.399E-01	9.141E-01	9.392E-01	9.141E-01	-5.248E-06	2.549E-01	1.399E-01	1.600E-01	0.000E+00	2.666E-01
9.5000	1.325E-01	9.196E-01	9.428E-01	9.196E-01	-1.557E-06	2.536E-01	1.325E-01	9.507E-02	0.000E+00	2.649E-01
9.7500	1.247E-01	9.258E-01	9.468E-01	9.258E-01	-5.176E-06	2.489E-01	1.247E-01	8.928E-02	0.000E+00	2.628E-01
10.0000	1.1F5E-01	9.324E-01	9.512E-01	9.324E-01	1.179E-06	2.270E-01	1.165E-01	8.275E-02	0.000E+00	2.602E-01
10.2500	1.080E-01	9.393E-01	9.558E-01	9.393E-01	-8.275E-06	2.120E-01	1.080E-01	7.562E-02	0.000E+00	2.571E-01
10.5000	9.904E-02	9.464E-01	9.606E-01	9.464E-01	-1.279E-05	1.962E-01	9.903E-02	6.803E-02	0.000E+00	2.536E-01
10.7500	0.960E-02	9.534E-01	9.654E-01	9.534E-01	4.463E-06	1.790E-01	8.960E-02	6.045E-02	0.000E+00	2.497E-01
11.0000	7.990E-02	9.600E-01	9.700E-01	9.600E-01	-4.340E-05	1.633E-01	7.990E-02	5.255E-02	0.000E+00	2.454E-01
11.2500	6.950E-02	9.661E-01	9.743E-01	9.661E-01	2.883E-05	1.476E-01	6.969E-02	4.682E-02	0.000E+00	2.407E-01
11.5000	5.903E-02	9.714E-01	9.782E-01	9.714E-01	-9.175E-05	1.313E-01	5.902E-02	3.976E-02	0.000E+00	2.358E-01
11.7500	4.792E-02	9.759E-01	9.815E-01	9.759E-01	-3.621E-05	1.167E-01	4.792E-02	3.436E-02	0.000E+00	2.305E-01
12.0000	3.635E-02	9.796E-01	9.843E-01	9.796E-01	-7.165E-04	1.034E-01	3.631E-02	2.986E-02	0.000E+00	2.249E-01
12.2500	2.431E-02	9.826E-01	9.865E-01	9.826E-01	6.310E-10	9.197E-02	2.431E-02	2.626E-02	0.000E+00	2.191E-01
12.5000	1.179E-02	9.848E-01	9.881E-01	9.848E-01	-1.751E-09	8.279E-02	1.177E-02	2.348E-02	0.000E+00	2.131E-01
12.7500	-1.210E-03	9.864E-01	9.893E-01	9.864E-01	-6.641E-09	7.649E-02	0.000E+00	2.136E-02	0.000E+00	2.069E-01
13.0000	-1.459E-02	9.874E-01	9.899E-01	9.874E-01	-1.377E-08	7.359E-02	1.457E-02	1.979E-02	0.000E+00	2.005E-01
13.2500	-2.865E-02	9.879E-01	9.902E-01	9.879E-01	-7.713E-10	7.437E-02	2.865E-02	1.864E-02	0.000E+00	1.939E-01
13.5000	-4.310E-02	9.880E-01	9.901E-01	9.880E-01	1.082E-04	7.875E-02	4.311E-02	1.783E-02	0.000E+00	1.872E-01
13.7500	-5.802E-02	9.875E-01	9.897E-01	9.876E-01	-2.370E-04	8.627E-02	5.796E-02	1.725E-02	0.000E+00	1.804E-01
14.0000	-7.342E-02	9.869E-01	9.889E-01	9.869E-01	-1.241E-04	9.624E-02	7.338E-02	1.685E-02	0.000E+00	1.735E-01
14.2500	-8.928E-02	9.859E-01	9.877E-01	9.859E-01	5.135E-07	1.001E-01	8.928E-02	1.658E-02	0.000E+00	1.665E-01
14.5000	-1.056E-01	9.844E-01	9.862E-01	9.844E-01	-3.266E-05	1.215E-01	1.056E-01	1.639E-02	0.000E+00	1.595E-01
14.7500	-1.224E-01	9.826E-01	9.844E-01	9.826E-01	-1.949E-05	1.350E-01	1.224E-01	1.626E-02	0.000E+00	1.525E-01
15.0000	-1.396E-01	9.804E-01	9.822E-01	9.804E-01	-2.035E-06	1.515E-01	1.395E-01	1.617E-02	0.000E+00	1.454E-01
15.2500	-1.572E-01	9.778E-01	9.796E-01	9.778E-01	-6.578E-05	1.677E-01	1.571E-01	1.612E-02	0.000E+00	1.384E-01
15.5000	-1.752E-01	9.748E-01	9.765E-01	9.748E-01	-1.478E-07	1.047E-01	1.752E-01	1.606E-02	0.000E+00	1.314E-01
15.7500	-1.935E-01	9.714E-01	9.731E-01	9.714E-01	-1.020E-06	2.022E-01	1.935E-01	1.605E-02	0.000E+00	1.245E-01
16.0000	-2.123E-01	9.675E-01	9.693E-01	9.675E-01	-9.846E-07	2.282E-01	2.123E-01	1.603E-02	0.000E+00	1.177E-01
16.2500	-2.313E-01	9.632E-01	9.649E-01	9.632E-01	-3.407E-07	2.386E-01	2.313E-01	1.602E-02	0.000E+00	1.110E-01
16.5000	-2.506E-01	9.593E-01	9.601E-01	9.593E-01	-3.645E-07	2.574E-01	2.506E-01	1.602E-02	0.000E+00	1.045E-01
16.7500	-2.702E-01	9.550E-01	9.540E-01	9.550E-01	-8.706E-08	2.766E-01	2.703E-01	1.601E-02	0.000E+00	9.803E-02
17.0000	-2.901E-01	9.472E-01	9.498E-01	9.472E-01	-1.509E-07	2.961E-01	2.901E-01	1.601E-02	0.000E+00	9.179E-02
17.2500	-3.101E-01	9.409E-01	9.427E-01	9.409E-01	-6.181E-08	3.156E-01	3.101E-01	1.600E-02	0.000E+00	8.573E-02
17.5000	-3.304E-01	9.349E-01	9.359E-01	9.349E-01	-1.062E-07	3.357E-01	3.304E-01	1.600E-02	0.000E+00	7.988E-02
17.7500	-3.507E-01	9.266E-01	9.285E-01	9.266E-01	2.915E-08	3.557E-01	3.507E-01	1.600E-02	0.000E+00	7.424E-02
18.0000	-3.711E-01	9.186E-01	9.205E-01	9.186E-01	-1.752E-07	3.759E-01	3.711E-01	1.600E-02	0.000E+00	6.883E-02
18.2500	-3.916E-01	9.101E-01	9.120E-01	9.101E-01	-1.566E-07	3.962E-01	3.916E-01	1.600E-02	0.000E+00	6.366E-02
18.5000	-4.122E-01	9.010E-01	9.029E-01	9.010E-01	-1.509E-08	4.164E-01	4.122E-01	1.600E-02	0.000E+00	5.873E-02
18.7500	-4.327E-01	8.913E-01	8.933E-01	8.913E-01	-2.474E-08	4.368E-01	4.327E-01	1.600E-02	0.000E+00	5.405E-02
19.0000	-4.532E-01	8.811E-01	8.831E-01	8.811E-01	3.219E-00	4.570E-01	4.532E-01	1.600E-02	0.000E+00	4.963E-02
19.2500	-4.736E-01	8.703E-01	8.723E-01	8.703E-01	-7.090E-08	4.773E-01	4.736E-01	1.600E-02	0.000E+00	4.546E-02
19.5000	-4.939E-01	8.590E-01	8.610E-01	8.590E-01	3.296E-08	4.974E-01	4.939E-01	1.600E-02	0.000E+00	4.154E-02
19.7500	-5.141E-01	8.471E-01	8.491E-01	8.471E-01	-4.199E-08	5.174E-01	5.141E-01	1.600E-02	0.000E+00	3.787E-02
20.0000	-5.341E-01	8.347E-01	8.367E-01	8.347E-01	1.796E-08	5.372E-01	5.341E-01	1.600E-02	0.000E+00	3.445E-02
20.2500	-5.539E-01	8.217E-01	8.237E-01	8.217E-01	-3.355E-08	5.569E-01	5.539E-01	1.600E-02	0.000E+00	3.127E-02
20.5000	-5.736E-01	8.081E-01	8.101E-01	8.081E-01	-2.463E-08	5.764E-01	5.735E-01	1.600E-02	0.000E+00	2.832E-02
20.7500	-5.929E-01	7.941E-01	7.960E-01	7.941E-01	-1.173E-08	5.956E-01	5.929E-01	1.600E-02	0.000E+00	2.559E-02
21.0000	-6.121E-01	7.794E-01	7.814E-01	7.794E-01	-3.437E-09	6.146E-01	6.121E-01	1.600E-02	0.000E+00	2.309E-02
21.2500	-6.310E-01	7.643E-01	7.662E-01	7.643E-01	-1.519E-08	6.334E-01	6.310E-01	1.600E-02	0.000E+00	2.070E-02
21.5000	-6.496E-01	7.486E-01	7.505E-01	7.486E-01	-5.398E-09	6.518E-01	6.496E-01	1.600E-02	0.000E+00	1.867E-02
21.7500	-6.679E-01	7.323E-01	7.343E-01	7.323E-01	-2.411E-08	6.700E-01	6.679E-01	1.600E-02	0.000E+00	1.675E-02
22.0000	-6.859E-01	7.153E-01	7.175E-01	7.153E-01	2.165E-09	6.879E-01	6.853E-01	1.600E-02	0.000E+00	1.500E-02
22.2500	-7.036E-01	6.982E-01	7.001E-01	6.982E-01	-7.009E-09	7.055E-01	7.036E-01	1.600E-02	0.000E+00	1.341E-02
22.5000	-7.209E-01	6.803E-01	6.822E-01	6.803E-01	-1.061E-08	7.227E-01	7.209E-01	1.600E-02	0.000E+00	1.197E-02
22.7500	-7.379E-01	6.619E-01	6.638E-01	6.619E-01	-1.610E-08	7.396E-01	7.379E-01	1.600E-02	0.000E+00	1.067E-02
23.0000	-7.546E-01	6.424E-01	6.447E-01	6.424E-01	-8.024E-09	7.562E-01	7.546E-01	1.600E-02	0.000E+00	9.499E-03
23.2500	-7.709E-01	6.235E-01	6.251E-01	6.235E-01	0.000E+00	7.724E-01	7.709E-01	1.600E-02	0.000E+00	8.445E-03
23.5000	-7.868E-01	6.031E-01	6.050E-01	6.031E-01	0.000E+00	7.882E-01	7.868E-01	1.600E-02	0.000E+00	7.501E-03
23.7500	-8.027E-01	5.824E-01	5.842E-01	5.824E-01	-4.592E-09	8.036E-01	8.023E-01	1.600E-02	0.000E+00	6.655E-03

24.0000	-8.174E-01	5.611E-01	5.629E-01	5.611E-01	0.000E+00	8.186E-01	8.174E-01	1.600E-02	0.000E+00	5.899E-03
24.2500	-8.320E-01	5.391E-01	5.409E-01	5.391E-01	-5.947E-09	8.332E-01	8.320E-01	1.600E-02	0.000E+00	5.225E-03
24.5000	-8.452E-01	5.166E-01	5.184E-01	5.166E-01	0.000E+00	8.473E-01	8.452E-01	1.600E-02	0.000E+00	4.625E-03
24.7500	-8.599E-01	4.935E-01	4.953E-01	4.935E-01	-1.042E-08	8.610E-01	8.599E-01	1.600E-02	0.000E+00	4.092E-03
25.0000	-8.731E-01	4.699E-01	4.717E-01	4.699E-01	-9.798E-09	8.741E-01	8.731E-01	1.600E-02	0.000E+00	3.619E-03
25.2500	-8.857E-01	4.458E-01	4.476E-01	4.458E-01	0.000E+00	8.866E-01	8.857E-01	1.600E-02	0.000E+00	3.200E-03
25.5000	-8.976E-01	4.213E-01	4.231E-01	4.213E-01	0.000E+00	8.985E-01	8.976E-01	1.600E-02	0.000E+00	2.830E-03
25.7500	-9.089E-01	3.964E-01	3.983E-01	3.954E-01	2.779E-09	9.097E-01	9.089E-01	1.600E-02	0.000E+00	2.502E-03
26.0000	-9.194E-01	3.715E-01	3.734E-01	3.715E-01	-2.653E-09	9.201E-01	9.194E-01	1.600E-02	0.000E+00	2.214E-03
26.2500	-9.290E-01	3.467E-01	3.485E-01	3.465E-01	0.000E+00	9.298E-01	9.290E-01	1.600E-02	0.000E+00	1.959E-03
26.5000	-9.370E-01	3.223E-01	3.243E-01	3.223E-01	-2.450E-09	9.385E-01	9.370E-01	1.600E-02	0.000E+00	1.735E-03
26.7500	-9.455E-01	2.990E-01	3.010E-01	2.990E-01	-4.741E-09	9.451E-01	9.455E-01	1.600E-02	0.000E+00	1.539E-03
27.0000	-9.521E-01	2.773E-01	2.794E-01	2.773E-01	-4.610E-09	9.527E-01	9.521E-01	1.600E-02	0.000E+00	1.366E-03
27.2500	-9.575E-01	2.582E-01	2.603E-01	2.582E-01	2.254E-09	9.590E-01	9.575E-01	1.600E-02	0.000E+00	1.214E-03
27.5000	-9.615E-01	2.430E-01	2.450E-01	2.429E-01	0.000E+00	9.620E-01	9.615E-01	1.600E-02	0.000E+00	1.091E-03
27.7500	-9.640E-01	2.328E-01	2.348E-01	2.328E-01	-2.193E-09	9.645E-01	9.640E-01	1.600E-02	0.000E+00	9.648E-04
28.0000	-9.649E-01	2.289E-01	2.309E-01	2.289E-01	-6.552E-09	9.654E-01	9.649E-01	1.600E-02	0.000E+00	8.630E-04
28.2500	-9.642E-01	2.322E-01	2.341E-01	2.322E-01	0.000E+00	9.646E-01	9.642E-01	1.600E-02	0.000E+00	7.740E-04
28.5000	-9.616E-01	2.429E-01	2.445E-01	2.420E-01	-2.215E-09	9.620E-01	9.616E-01	1.600E-02	0.000E+00	6.961E-04
28.7500	-9.570E-01	2.602E-01	2.617E-01	2.602E-01	-2.257E-09	9.574E-01	9.570E-01	1.600E-02	0.000E+00	6.281E-04
29.0000	-9.505E-01	2.833E-01	2.845E-01	2.833E-01	-6.960E-09	9.509E-01	9.504E-01	1.600E-02	0.000E+00	5.688E-04
29.2500	-9.410E-01	3.108E-01	3.119E-01	3.108E-01	-2.406E-09	9.422E-01	9.418E-01	1.600E-02	0.000E+00	5.170E-04
29.5000	-9.311E-01	3.417E-01	3.426E-01	3.417E-01	0.000E+00	9.314E-01	9.311E-01	1.600E-02	0.000E+00	4.718E-04
NDERV	282									
NDAMP	0									
ISTOP	1									
IFLAG	2									
-1.9000	1.612E+01	2.041E+01	5.689E+00	1.543E+01	1.900E+01	4.710E+00	0.000E+00	1.000E-01	3.620E-02	0.000E+00

Output file FOR21.DAT (Example II)

FFFFFFFFFFFF	00000000	RRRRRRRRRR	22222222	111
FFFFFFFFFFFF	00000000	RRRRRRRRRR	22222222	111
FFFFFFFFFFFF	00000000	RRRRRRRRRR	22222222	111
FFF	000 000	RRR RRR	222 222	111111
FFF	000 000	RRR RRR	222 222	111111
FFF	000 000	RRR RRR	222 222	111111
FFF	000 000	RRR RRR	222 222	111
FFF	000 000	RRR RRR	222 222	111
FFF	000 000	RRR RRR	222 222	111
FFFFFFFFFFFF	000 000	RRRRRRRRRR	222	111
FFFFFFFFFFFF	000 000	RRRRRRRRRR	222	111
FFFFFFFFFFFF	000 000	RRRRRRRRRR	222	111
FFI	000 000	RRR RRR	222	111
FFF	000 000	RRR RRR	222	111
FFF	000 000	RRR RRR	222	111
FFF	000 000	RRR RRR	222	111
FFF	000 000	RRR RRR	222	111
FFF	000 000	RRR RRR	222	111
FFF	000 000	RRR RRR	222	111
FFF	00000000	RRR RRR	22222222222222	11111111
FFF	00000000	RRR RRR	22222222222222	11111111
FFF	00000000	RRR RRR	22222222222222	11111111

DDDDDDDDDD	AAAAAA	TTTTTTTTTTTT
DDDDDDDDDD	AAAAAA	TTTTTTTTTTTT
DDDDDDDDDD	AAAAAA	TTTTTTTTTTTT
DDD DDD	AAA AAA	TTT
DDD DDD	AAA AAA	TTT
DDD DDD	AAA AAA	TTT
DDD DDD	AAA AAA	TTT
DDD DDD	AAA AAA	TTT
DDD DDD	AAA AAA	TTT
DDD DDD	AAA AAA	TTT
DDD DDD	AAA AAA	TTT
DDD DDD	AAAAAA	TTT
DDD DDD	AAAAAA	TTT
DDD DDD	AAAAAA	TTT
DDD DDD	AAA AAA	TTT
DDD DDD	AAA AAA	TTT
DDD DDD	AAA AAA	TTT
DDD DDD	AAA AAA	TTT
DDDDDDDDDD	AAA AAA	TTT
DDDDDDDDDD	AAA AAA	TTT
DDDDDDDDDD	AAA AAA	TTT

LPTSPL Version 6(34413) Running on EPL010
 START Use: A30 GOLDFING (240,23025) Job FOR20 Seq. 2420 Date 21-Aug-81 14:56:01 Monitor ORNL/FED SMP *START*
 Request created: 21-Aug-81 14:57:06
 File: DSK00:FOR21.DAT(240,23025) Created: 21-Aug-81 14:52:00 (155) Printed: 21-Aug-81 14:56:42
 QUEUE Switches: /PRINT:ARROW /FILE:FORT /COPIES:1 /SPACING:1 /LIMIT:271 /FORMS:NORMAL
 File will be RENAMED to <055> protection

21-Aug-81 14:52

\$DATA
 IEQ= 1, IO1= 20, IO2= 21, IBUG= 0, IDAMP= 0, DS= 0.2500000
 SMAX= 100000.0, PHI0= 30.00000, NPHI= 1, DPHI= 0.1070000E-02, THETA0= 30.00000, 1, IYMX= 1, IZMX= 1,
 NTHETA= 3, DTHETA= 25.00000, 1, IYMX= 1, IZMX= 1,
 DX= -5.000000, DY= 0.1500000, DZ= 5.000000, X0= -10.00000, Y0= 0.000000E+00, Z0= 0.000000E+00,
 SGH= -1.000000, PFE0= 0.4000000, BETANN= 0.1600000, CFE0= 0.6000000, FMU= 120.0000, TE= 100.0000
 TEHOT= 1000000, TI= 500.0000, XMAX= 10.00000, YMAX= 25.00000, ZMAX= 12.50000, RZ0= 1.100000
 NRZ= 1, NRZ= 0.000000E+00, ISLAB= 2, RSLAB= 10.00000, NCOIL= 4,
 SEP= 25.00000, RCOIL= 10.00000, RNOT= 6.000000, DELTA= 2.500000, DINF= 0.1000000E+00, IPARAM=
 1,
 ICONV= 0, RELERR= 0.6000000E-06, ABSERR= 0.6000000E-06, CPUTR= 10.00000, \$
 COLD
 EQMC
 PDP10
 DMPEC
 NRCL

5000.0000	-1.000E+01	0.000E+00	5.000E-01	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	-9.962E+00	0.000E+00	9.986E-01	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	-9.080E+00	0.000E+00	1.493E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	-9.779E+00	0.000E+00	1.981E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	-9.630E+00	0.000E+00	2.461E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	-9.459E+00	0.000E+00	2.931E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	-9.277E+00	0.000E+00	3.393E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	-9.064E+00	0.000E+00	3.846E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	-8.836E+00	0.000E+00	4.298E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	-8.595E+00	0.000E+00	4.729E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	-8.347E+00	0.000E+00	5.162E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	-8.093E+00	0.000E+00	5.593E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	-7.836E+00	0.000E+00	6.022E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	-7.581E+00	0.000E+00	6.452E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	-7.329E+00	0.000E+00	6.884E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	-7.083E+00	0.000E+00	7.319E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	-6.846E+00	0.000E+00	7.760E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	-6.621E+00	0.000E+00	8.206E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	-6.410E+00	0.000E+00	8.659E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	-6.215E+00	0.000E+00	9.120E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	-6.039E+00	0.000E+00	9.588E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	-5.884E+00	0.000E+00	1.006E+01	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	-5.752E+00	0.000E+00	1.055E+01	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	-5.645E+00	0.000E+00	1.105E+01	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	-5.563E+00	0.000E+00	1.155E+01	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	-5.509E+00	0.000E+00	1.202E+01	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	-5.480E+00	0.000E+00	1.252E+01	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	-5.483E+00	0.000E+00	1.252E+01	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	-7.500E+00	0.000E+00	5.000E-01	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	-7.474E+00	0.000E+00	9.993E-01	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	-7.422E+00	0.000E+00	1.457E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00

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5000.0000	5.329E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	5.501E+00	0.000E+00	4.216E-01	0.090E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	5.673E+00	0.000E+00	1.023E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	5.845E+00	0.000E+00	1.391E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	6.017E+00	0.000E+00	1.686E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	6.189E+00	0.000E+00	1.943E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	6.361E+00	0.000E+00	2.175E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	6.533E+00	0.000E+00	2.389E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	6.705E+00	0.000E+00	2.589E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	6.877E+00	0.000E+00	2.779E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	7.049E+00	0.000E+00	2.962E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	7.221E+00	0.000E+00	3.139E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	7.393E+00	0.000E+00	3.308E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	7.564E+00	0.000E+00	3.474E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	7.736E+00	0.000E+00	3.637E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	7.908E+00	0.000E+00	3.796E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	8.080E+00	0.000E+00	3.954E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	8.252E+00	0.000E+00	4.109E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	8.424E+00	0.000E+00	4.264E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
5000.0000	8.596E+00	0.000E+00	4.417E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
-1.0000	8.596E+00	0.000E+00	4.417E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00	0.000E+00
0.0000	-1.000E+01	0.000E+00	0.000E+00	1.075E+01	6.213E+00	2.152E+01	0.000E+00	1.012E-01	5.071E-01	0.000E+00	0.000E+00
0.2500	-9.892E+00	6.231E-02	2.167E-01	1.075E+01	6.213E+00	2.152E+01	0.000E+00	9.182E-09	1.445E-08	0.000E+00	0.000E+00
0.5000	-9.784E+00	1.246E-01	4.335E-01	1.075E+01	6.213E+00	2.152E+01	0.000E+00	0.000E+00	-1.410E-08	0.000E+00	0.000E+00
0.7500	-9.676E+00	1.869E-01	6.502E-01	1.074E+01	6.213E+00	2.152E+01	0.000E+00	0.000E+00	1.391E-08	0.000E+00	0.000E+00
1.0000	-9.569E+00	2.493E-01	8.670E-01	1.073E+01	6.213E+00	2.151E+01	0.000E+00	-1.822E-08	-1.362E-08	0.000E+00	0.000E+00
1.2500	-9.461E+00	3.116E-01	1.004E+00	1.073E+01	6.213E+00	2.151E+01	0.000E+00	-1.817E-08	-2.664E-08	0.000E+00	0.000E+00
1.5000	-9.353E+00	3.739E-01	1.301E+00	1.072E+01	6.214E+00	2.151E+01	0.000E+00	2.717E-08	-3.904E-08	0.000E+00	0.000E+00
1.7500	-9.245E+00	4.362E-01	1.517E+00	1.071E+01	6.214E+00	2.151E+01	0.000E+00	0.000E+00	-3.809E-08	0.000E+00	0.000E+00
2.0000	-9.130E+00	4.985E-01	1.734E+00	1.070E+01	6.215E+00	2.151E+01	0.000E+00	-3.600E-08	1.237E-08	0.000E+00	0.000E+00
2.2500	-9.030E+00	5.609E-01	1.951E+00	1.069E+01	6.216E+00	2.150E+01	0.000E+00	8.973E-09	-3.614E-08	0.000E+00	0.000E+00
2.5000	-8.923E+00	6.232E-01	2.160E+00	1.068E+01	6.217E+00	2.150E+01	0.000E+00	2.684E-08	-4.686E-08	0.000E+00	0.000E+00
2.7500	-8.815E+00	6.856E-01	2.305E+00	1.066E+01	6.218E+00	2.150E+01	0.000E+00	-5.354E-09	1.130E-08	0.000E+00	0.000E+00
3.0000	-8.709E+00	7.479E-01	2.602E+00	1.065E+01	6.220E+00	2.150E+01	0.000E+00	0.000E+00	-2.209E-08	0.000E+00	0.000E+00
3.2500	-8.601E+00	8.103E-01	2.819E+00	1.064E+01	6.221E+00	2.149E+01	0.000E+00	4.440E-08	2.141E-08	0.000E+00	0.000E+00
3.5000	-8.493E+00	8.727E-01	3.036E+00	1.062E+01	6.223E+00	2.149E+01	0.000E+00	3.546E-08	1.037E-08	0.000E+00	0.000E+00
3.7500	-8.386E+00	9.351E-01	3.253E+00	1.060E+01	6.225E+00	2.149E+01	0.000E+00	9.735E-08	7.026E-08	0.000E+00	0.000E+00
4.0000	-8.279E+00	9.975E-01	3.471E+00	1.059E+01	6.220E+00	2.148E+01	0.000E+00	1.501E-07	5.023E-08	0.000E+00	0.000E+00
4.2500	-8.173E+00	1.060E+00	3.688E+00	1.057E+01	6.231E+00	2.148E+01	0.000E+00	2.738E-07	1.313E-07	0.000E+00	0.000E+00
4.5000	-8.066E+00	1.122E+00	3.905E+00	1.055E+01	6.235E+00	2.147E+01	0.000E+00	3.532E-07	1.177E-07	0.000E+00	0.000E+00
4.7500	-7.959E+00	1.185E+00	4.122E+00	1.053E+01	6.238E+00	2.146E+01	0.000E+00	3.797E-07	1.572E-07	0.000E+00	0.000E+00
5.0000	-7.853E+00	1.247E+00	4.340E+00	1.050E+01	6.243E+00	2.145E+01	0.000E+00	3.357E-07	1.179E-07	0.000E+00	0.000E+00
5.2500	-7.747E+00	1.310E+00	4.557E+00	1.048E+01	6.240E+00	2.144E+01	0.000E+00	3.990E-07	1.136E-07	0.000E+00	0.000E+00
5.5000	-7.640E+00	1.372E+00	4.775E+00	1.045E+01	6.254E+00	2.143E+01	0.000E+00	3.886E-07	1.406E-07	0.000E+00	0.000E+00
5.7500	-7.534E+00	1.435E+00	4.992E+00	1.042E+01	6.261E+00	2.141E+01	0.000E+00	3.191E-07	1.052E-07	0.000E+00	0.000E+00
6.0000	-7.428E+00	1.497E+00	5.210E+00	1.039E+01	6.260E+00	2.139E+01	0.000E+00	3.019E-07	1.302E-07	0.000E+00	0.000E+00
6.2500	-7.323E+00	1.560E+00	5.428E+00	1.036E+01	6.277E+00	2.136E+01	0.000E+00	2.980E-07	1.112E-07	0.000E+00	0.000E+00
6.5000	-7.217E+00	1.623E+00	5.646E+00	1.032E+01	6.287E+00	2.133E+01	0.000E+00	2.675E-07	1.069E-07	0.000E+00	0.000E+00
6.7500	-7.112E+00	1.686E+00	5.863E+00	1.028E+01	6.299E+00	2.129E+01	0.000E+00	3.575E-07	1.284E-07	0.000E+00	0.000E+00
7.0000	-7.007E+00	1.748E+00	6.081E+00	1.023E+01	6.313E+00	2.123E+01	0.000E+00	2.687E-07	1.356E-07	0.000E+00	0.000E+00
7.2500	-6.902E+00	1.811E+00	6.299E+00	1.018E+01	6.330E+00	2.115E+01	0.000E+00	3.253E-07	9.474E-08	0.000E+00	0.000E+00
7.5000	-6.797E+00	1.874E+00	6.517E+00	1.011E+01	6.352E+00	2.104E+01	0.000E+00	3.150E-07	9.096E-08	0.000E+00	0.000E+00
7.7500	-6.693E+00	1.937E+00	6.735E+00	1.004E+01	6.379E+00	2.098E+01	0.000E+00	3.153E-07	9.025E-08	0.000E+00	0.000E+00
8.0000	-6.589E+00	2.000E+00	6.953E+00	9.932E+00	6.415E+00	2.092E+01	0.000E+00	3.527E-07	9.453E-08	0.000E+00	0.000E+00
8.2500	-6.482E+00	2.063E+00	7.171E+00	9.780E+00	6.450E+00	2.017E+01	0.000E+00	3.444E-07	8.052E-08	0.000E+00	0.000E+00
8.5000	-6.376E+00	2.127E+00	7.389E+00	9.530E+00	6.562E+00	1.921E+01	0.000E+00	2.905E-07	9.650E-08	0.000E+00	0.000E+00
8.7500	-6.266E+00	2.191E+00	7.604E+00	9.001E+00	6.002E+00	1.586E+01	0.000E+00	3.455E-07	5.292E-08	0.000E+00	0.000E+00
9.0000	-6.170E+00	2.291E+00	7.620E+00	4.310E+00	8.400E+00	-1.663E+01	0.000E+00	3.534E-07	1.016E-07	0.000E+00	0.000E+00
9.2500	-6.144E+00	2.307E+00	7.409E+00	3.517E+00	8.746E+00	-2.026E+01	0.000E+00	3.143E-07	9.640E-08	0.000E+00	0.000E+00

9.5000	-6.118E+00	2.480E+00	7.169E+00	3.223E+00	8.849E+00	-2.131E+01	0.000E+00	3.106E-07	1.299E-07	0.000E+00
9.7500	-6.091E+00	2.572E+00	6.938E+00	3.042E+00	8.915E+00	-2.170E+01	0.000E+00	4.024E-07	1.038E-07	0.000E+00
10.0000	-6.065E+00	2.665E+00	6.707E+00	2.903E+00	8.960E+00	-2.204E+01	0.000E+00	3.009E-07	1.402E-07	0.000E+00
10.2500	-6.040E+00	2.757E+00	6.476E+00	2.785E+00	9.015E+00	-2.220E+01	0.000E+00	2.864E-07	8.954E-08	0.000E+00
10.5000	-6.011E+00	2.849E+00	6.245E+00	2.677E+00	9.060E+00	-2.230E+01	0.000E+00	3.455E-07	1.045E-07	0.000E+00
10.7500	-5.991E+00	2.942E+00	6.014E+00	2.575E+00	9.105E+00	-2.237E+01	0.000E+00	1.523E-07	1.083E-07	0.000E+00
11.0000	-5.968E+00	3.033E+00	5.783E+00	2.474E+00	9.152E+00	-2.242E+01	0.000E+00	2.336E-07	9.974E-08	0.000E+00
11.2500	-5.945E+00	3.128E+00	5.553E+00	2.375E+00	9.200E+00	-2.245E+01	0.000E+00	2.719E-07	7.744E-08	0.000E+00
11.5000	-5.924E+00	3.222E+00	5.322E+00	2.274E+00	9.251E+00	-2.245E+01	0.000E+00	2.925E-07	1.068E-07	0.000E+00
11.7500	-5.903E+00	3.316E+00	5.091E+00	2.173E+00	9.304E+00	-2.247E+01	0.000E+00	1.840E-07	9.660E-08	0.000E+00
12.0000	-5.883E+00	3.411E+00	4.861E+00	2.070E+00	9.360E+00	-2.247E+01	0.000E+00	2.464E-07	8.552E-08	0.000E+00
12.2500	-5.864E+00	3.506E+00	4.632E+00	1.965E+00	9.419E+00	-2.247E+01	0.000E+00	2.783E-07	8.827E-08	0.000E+00
12.5000	-5.846E+00	3.602E+00	4.403E+00	1.860E+00	9.481E+00	-2.246E+01	0.000E+00	2.955E-07	9.102E-08	0.000E+00
12.7500	-5.829E+00	3.699E+00	4.170E+00	1.753E+00	9.545E+00	-2.245E+01	0.000E+00	3.743E-08	9.378E-08	0.000E+00
13.0000	-5.813E+00	3.796E+00	3.941E+00	1.646E+00	9.612E+00	-2.243E+01	0.000E+00	4.738E-07	9.654E-08	0.000E+00
13.2500	-5.798E+00	3.894E+00	3.711E+00	1.540E+00	9.681E+00	-2.241E+01	0.000E+00	2.136E-07	9.930E-08	0.000E+00
13.5000	-5.784E+00	3.993E+00	3.482E+00	1.434E+00	9.752E+00	-2.240E+01	0.000E+00	1.744E-07	1.105E-07	0.000E+00
13.7500	-5.771E+00	4.092E+00	3.253E+00	1.330E+00	9.823E+00	-2.230E+01	0.000E+00	4.232E-07	1.047E-07	0.000E+00
14.0000	-5.750E+00	4.192E+00	3.024E+00	1.227E+00	9.895E+00	-2.236E+01	0.000E+00	1.501E-07	1.432E-07	0.000E+00
14.2500	-5.747E+00	4.293E+00	2.795E+00	1.127E+00	9.968E+00	-2.234E+01	0.000E+00	4.593E-07	1.101E-07	0.000E+00
14.5000	-5.737E+00	4.394E+00	2.567E+00	1.030E+00	1.004E+01	-2.234E+01	0.000E+00	3.570E-07	1.220E-07	0.000E+00
14.7500	-5.720E+00	4.496E+00	2.339E+00	9.374E-01	1.011E+01	-2.231E+01	0.000E+00	1.451E-07	1.152E-07	0.000E+00
15.0000	-5.719E+00	4.599E+00	2.111E+00	8.404E-01	1.010E+01	-2.230E+01	0.000E+00	3.587E-07	1.274E-07	0.000E+00
15.2500	-5.711E+00	4.702E+00	1.884E+00	7.638E-01	1.025E+01	-2.225E+01	0.000E+00	2.935E-07	1.199E-07	0.000E+00
15.5000	-5.705E+00	4.806E+00	1.656E+00	6.840E-01	1.031E+01	-2.228E+01	0.000E+00	5.724E-07	1.426E-07	0.000E+00
15.7500	-5.698E+00	4.911E+00	1.429E+00	6.092E-01	1.039E+01	-2.227E+01	0.000E+00	8.145E-07	1.347E-07	0.000E+00
16.0000	-5.693E+00	5.016E+00	1.203E+00	5.397E-01	1.044E+01	-2.226E+01	0.000E+00	4.629E-07	1.158E-07	0.000E+00
16.2500	-5.688E+00	5.121E+00	9.762E-01	4.755E-01	1.049E+01	-2.226E+01	0.000E+00	3.643E-07	1.389E-07	0.000E+00
16.5000	-5.683E+00	5.227E+00	7.498E-01	4.166E-01	1.055E+01	-2.225E+01	0.000E+00	4.485E-07	1.192E-07	0.000E+00
16.7500	-5.680E+00	5.334E+00	5.237E-01	3.631E-01	1.060E+01	-2.225E+01	0.000E+00	3.715E-07	1.426E-07	0.000E+00
17.0000	-5.676E+00	5.441E+00	2.976E-01	3.140E-01	1.064E+01	-2.225E+01	0.000E+00	5.939E-07	1.330E-07	0.000E+00
17.2500	-5.673E+00	5.549E+00	7.201E-02	2.716E-01	1.066E+01	-2.225E+01	0.000E+00	3.947E-07	1.231E-07	0.000E+00
17.5000	-5.671E+00	5.656E+00	-1.536E-01	2.332E-01	1.072E+01	-2.226E+01	0.000E+00	5.336E-07	1.354E-07	0.000E+00
-1.0000	-5.671E+00	5.656E+00	-1.535E-01	2.332E-01	1.072E+01	-2.226E+01	0.000E+00	1.326E-01	6.603E-01	0.000E+00
0.0000	-1.000E+01	0.000E+00	0.000E+00	1.765E+01	1.019E+01	1.427E+01	0.000E+00	1.012E-01	5.071E-01	0.000E+00
0.2500	-9.023E+00	1.022E-01	1.439E-01	1.764E+01	1.019E+01	1.427E+01	0.000E+00	-1.833E-05	0.000E+00	0.000E+00
0.5000	-9.040E+00	2.044E-01	2.879E-01	1.764E+01	1.019E+01	1.426E+01	0.000E+00	-9.119E-09	-1.393E-08	0.000E+00
0.7500	-9.069E+00	3.067E-01	4.319E-01	1.763E+01	1.019E+01	1.426E+01	0.000E+00	1.912E-08	-2.712E-08	0.000E+00
1.0000	-9.292E+00	4.080E-01	5.755E-01	1.762E+01	1.019E+01	1.426E+01	0.000E+00	0.000E+00	-3.962E-08	0.000E+00
1.2500	-9.115E+00	5.111E-01	7.199E-01	1.761E+01	1.019E+01	1.426E+01	0.000E+00	-1.777E-09	2.572E-08	0.000E+00
1.5000	-8.930E+00	6.134E-01	8.640E-01	1.760E+01	1.019E+01	1.425E+01	0.000E+00	-5.261E-08	1.252E-08	0.000E+00
1.7500	-8.761E+00	7.157E-01	1.000E+00	1.759E+01	1.019E+01	1.425E+01	0.000E+00	3.449E-09	0.000E+00	0.000E+00
2.0000	-8.585E+00	8.180E-01	1.152E+00	1.758E+01	1.019E+01	1.425E+01	0.000E+00	8.444E-09	3.565E-08	0.000E+00
2.2500	-8.408E+00	9.204E-01	1.297E+00	1.756E+01	1.019E+01	1.425E+01	0.000E+00	4.116E-08	0.000E+00	0.000E+00
2.5000	-8.232E+00	1.023E+00	1.441E+00	1.755E+01	1.020E+01	1.425E+01	0.000E+00	5.590E-03	1.128E-08	0.000E+00
2.7500	-8.055E+00	1.125E+00	1.580E+00	1.751E+01	1.020E+01	1.425E+01	0.000E+00	7.701E-08	-3.298E-08	0.000E+00
3.0000	-7.879E+00	1.228E+00	1.730E+00	1.747E+01	1.021E+01	1.425E+01	0.000E+00	2.362E-07	0.000E+00	0.000E+00
3.2500	-7.703E+00	1.331E+00	1.875E+00	1.743E+01	1.022E+01	1.425E+01	0.000E+00	2.671E-07	-1.045E-08	0.000E+00
3.5000	-7.528E+00	1.433E+00	2.021E+00	1.737E+01	1.023E+01	1.425E+01	0.000E+00	1.730E-07	1.019E-08	0.000E+00
3.7500	-7.353E+00	1.536E+00	2.166E+00	1.731E+01	1.024E+01	1.426E+01	0.000E+00	1.627E-07	9.934E-09	0.000E+00
4.0000	-7.179E+00	1.640E+00	2.312E+00	1.723E+01	1.026E+01	1.427E+01	0.000E+00	-2.341E-07	3.876E-08	0.000E+00
4.2500	-7.003E+00	1.743E+00	2.459E+00	1.713E+01	1.026E+01	1.428E+01	0.000E+00	3.051E-07	0.000E+00	0.000E+00
4.5000	-6.831E+00	1.847E+00	2.606E+00	1.702E+01	1.031E+01	1.429E+01	0.000E+00	1.921E-07	9.228E-09	0.000E+00
4.7500	-6.658E+00	1.951E+00	2.754E+00	1.690E+01	1.035E+01	1.431E+01	0.000E+00	4.602E-07	-9.000E-09	0.000E+00
5.0000	-6.487E+00	2.056E+00	2.903E+00	1.673E+01	1.040E+01	1.434E+01	0.000E+00	3.467E-08	0.000E+00	0.000E+00
5.2500	-6.317E+00	2.162E+00	3.053E+00	1.659E+01	1.046E+01	1.436E+01	0.000E+00	-3.212E-08	3.436E-08	0.000E+00
5.5000	-6.140E+00	2.269E+00	3.204E+00	1.644E+01	1.054E+01	1.439E+01	0.000E+00	-2.089E-07	4.196E-08	0.000E+00
5.7500	-5.963E+00	2.375E+00	3.356E+00	1.611E+01	1.063E+01	1.443E+01	0.000E+00	4.177E-07	-8.159E-09	0.000E+00
6.0000	-5.787E+00	2.483E+00	3.509E+00	1.583E+01	1.074E+01	1.447E+01	0.000E+00	-7.855E-08	3.200E-08	0.000E+00

6.2500	-5.654E+00	2.595E+00	3.664E+00	1.557E+01	1.007E+01	1.451E+01	0.000E+00	-2.836E-07	3.134E-08	0.000E+00
6.5000	-5.494E+00	2.706E+00	3.020E+00	1.526E+01	1.103E+01	1.456E+01	0.000E+00	1.173E-07	3.064E-08	0.000E+00
6.7500	-5.337E+00	2.820E+00	3.978E+00	1.493E+01	1.120E+01	1.461E+01	0.000E+00	3.376E-07	2.997E-08	0.000E+00
7.0000	-5.183E+00	2.935E+00	4.158E+00	1.458E+01	1.140E+01	1.466E+01	0.000E+00	-6.535E-09	4.397E-08	0.000E+00
7.2500	-5.032E+00	3.052E+00	4.298E+00	1.421E+01	1.163E+01	1.471E+01	0.000E+00	-3.726E-07	0.000E+00	0.000E+00
7.5000	-4.004E+00	3.172E+00	4.461E+00	1.383E+01	1.188E+01	1.476E+01	0.000E+00	-5.257E-09	2.806E-08	0.000E+00
7.7500	-4.740E+00	3.295E+00	4.624E+00	1.342E+01	1.216E+01	1.481E+01	0.000E+00	-2.310E-07	5.492E-09	0.000E+00
8.0000	-4.601E+00	3.421E+00	4.789E+00	1.301E+01	1.247E+01	1.486E+01	0.000E+00	-4.348E-07	4.032E-08	0.000E+00
8.2500	-4.465E+00	3.550E+00	4.954E+00	1.260E+01	1.280E+01	1.490E+01	0.000E+00	-2.061E-07	3.947E-08	0.000E+00
8.5000	-4.333E+00	3.683E+00	5.121E+00	1.218E+01	1.316E+01	1.494E+01	0.000E+00	4.500E-08	1.280E-08	0.000E+00
8.7500	-4.205E+00	3.819E+00	5.287E+00	1.177E+01	1.353E+01	1.498E+01	0.000E+00	1.426E-07	1.261E-08	0.000E+00
9.0000	-4.083E+00	3.959E+00	5.454E+00	1.137E+01	1.392E+01	1.501E+01	0.000E+00	2.399E-07	1.235E-08	0.000E+00
9.2500	-3.965E+00	4.103E+00	5.621E+00	1.100E+01	1.432E+01	1.503E+01	0.000E+00	-1.915E-07	1.210E-08	0.000E+00
9.5000	-3.850E+00	4.251E+00	5.787E+00	1.064E+01	1.471E+01	1.503E+01	0.000E+00	-1.503E-07	3.556E-08	0.000E+00
9.7500	-3.740E+00	4.402E+00	5.952E+00	1.032E+01	1.509E+01	1.503E+01	0.000E+00	-1.838E-07	3.484E-08	0.000E+00
10.0000	-3.633E+00	4.550E+00	6.116E+00	1.004E+01	1.545E+01	1.500E+01	0.000E+00	-8.437E-08	1.138E-08	0.000E+00
10.2500	-3.529E+00	4.716E+00	6.279E+00	9.799E+00	1.578E+01	1.495E+01	0.000E+00	3.375E-07	4.459E-08	0.000E+00
10.5000	-3.427E+00	4.878E+00	6.440E+00	9.590E+00	1.607E+01	1.487E+01	0.000E+00	4.152E-07	5.461E-08	0.000E+00
10.7500	-3.327E+00	5.042E+00	6.600E+00	9.428E+00	1.633E+01	1.476E+01	0.000E+00	-3.049E-07	5.350E-08	0.000E+00
11.0000	-3.230E+00	5.209E+00	6.758E+00	9.291E+00	1.656E+01	1.459E+01	0.000E+00	0.000E+00	4.193E-08	0.000E+00
11.2500	-3.133E+00	5.379E+00	6.915E+00	9.178E+00	1.676E+01	1.436E+01	0.000E+00	-2.665E-07	7.188E-08	0.000E+00
11.5000	-3.037E+00	5.550E+00	7.069E+00	9.079E+00	1.695E+01	1.404E+01	0.000E+00	9.977E-08	4.023E-08	0.000E+00
11.7500	-2.941E+00	5.725E+00	7.220E+00	8.986E+00	1.715E+01	1.354E+01	0.000E+00	-4.683E-07	7.880E-08	0.000E+00
12.0000	-2.846E+00	5.903E+00	7.367E+00	8.883E+00	1.737E+01	1.273E+01	0.000E+00	-4.730E-07	5.790E-08	0.000E+00
12.2500	-2.749E+00	6.088E+00	7.505E+00	8.742E+00	1.776E+01	1.124E+01	0.000E+00	-4.726E-07	6.625E-08	0.000E+00
12.5000	-2.651E+00	6.280E+00	7.621E+00	8.490E+00	1.830E+01	7.956E+00	0.000E+00	-5.606E-07	4.657E-08	0.000E+00
12.7500	-2.556E+00	6.509E+00	7.673E+00	8.044E+00	1.937E+01	1.654E+00	0.000E+00	-5.455E-07	2.784E-08	0.000E+00
13.0000	-2.472E+00	6.742E+00	7.640E+00	7.674E+00	2.029E+01	-3.415E+00	0.000E+00	-5.565E-07	3.760E-08	0.000E+00
13.2500	-2.395E+00	6.970E+00	7.572E+00	7.475E+00	2.077E+01	-5.824E+00	0.000E+00	-5.401E-07	5.760E-08	0.000E+00
13.5000	-2.321E+00	7.194E+00	7.491E+00	7.371E+00	2.105E+01	-7.033E+00	0.000E+00	-5.765E-07	6.092E-08	0.000E+00
13.7500	-2.240E+00	7.417E+00	7.404E+00	7.303E+00	2.123E+01	-7.721E+00	0.000E+00	-5.502E-07	5.062E-08	0.000E+00
14.0000	-2.176E+00	7.639E+00	7.315E+00	7.256E+00	2.135E+01	-0.151E+00	0.000E+00	-5.305E-07	3.131E-08	0.000E+00
14.2500	-2.104E+00	7.861E+00	7.224E+00	7.223E+00	2.144E+01	-0.439E+00	0.000E+00	-5.585E-07	4.313E-08	0.000E+00
14.5000	-2.032E+00	8.082E+00	7.132E+00	7.198E+00	2.151E+01	-8.641E+00	0.000E+00	-5.493E-07	4.466E-08	0.000E+00
14.7500	-1.960E+00	8.302E+00	7.039E+00	7.178E+00	2.157E+01	-8.709E+00	0.000E+00	-5.367E-07	6.949E-08	0.000E+00
15.0000	-1.889E+00	8.523E+00	6.946E+00	7.163E+00	2.161E+01	-0.900E+00	0.000E+00	-5.587E-07	1.204E-08	0.000E+00
15.2500	-1.817E+00	8.744E+00	6.852E+00	7.151E+00	2.165E+01	-8.986E+00	0.000E+00	-5.398E-07	5.015E-08	0.000E+00
15.5000	-1.746E+00	8.964E+00	6.758E+00	7.140E+00	2.169E+01	-9.053E+00	0.000E+00	-5.494E-07	5.232E-08	0.000E+00
15.7500	-1.675E+00	9.185E+00	6.654E+00	7.132E+00	2.172E+01	-9.107E+00	0.000E+00	-5.401E-07	2.734E-08	0.000E+00
16.0000	-1.604E+00	9.405E+00	6.570E+00	7.125E+00	2.174E+01	-9.150E+00	0.000E+00	-5.494E-07	5.723E-08	0.000E+00
16.2500	-1.533E+00	9.626E+00	6.476E+00	7.119E+00	2.176E+01	-9.186E+00	0.000E+00	-5.401E-07	0.000E+00	0.000E+00
16.5000	-1.461E+00	9.846E+00	6.382E+00	7.114E+00	2.178E+01	-9.215E+00	0.000E+00	-5.401E-07	1.575E-08	0.000E+00
16.7500	-1.390E+00	1.007E+01	6.290E+00	7.110E+00	2.179E+01	-9.239E+00	0.000E+00	-5.589E-07	4.138E-08	0.000E+00
17.0000	-1.319E+00	1.029E+01	6.194E+00	7.106E+00	2.180E+01	-9.260E+00	0.000E+00	-5.681E-07	1.742E-08	0.000E+00
17.2500	-1.249E+00	1.051E+01	6.100E+00	7.103E+00	2.183E+01	-9.277E+00	0.000E+00	-5.455E-07	5.508E-08	0.000E+00
17.5000	-1.177E+00	1.073E+01	6.005E+00	7.100E+00	2.184E+01	-9.291E+00	0.000E+00	-5.681E-07	-2.905E-08	0.000E+00
17.7500	-1.106E+00	1.095E+01	5.911E+00	7.098E+00	2.185E+01	-9.304E+00	0.000E+00	-5.308E-07	1.023E-08	0.000E+00
18.0000	-1.035E+00	1.117E+01	5.817E+00	7.095E+00	2.187E+01	-9.314E+00	0.000E+00	-5.538E-07	-4.323E-08	0.000E+00
18.2500	-9.636E-01	1.139E+01	5.723E+00	7.095E+00	2.187E+01	-9.325E+00	0.000E+00	-5.495E-07	-1.143E-08	0.000E+00
18.5000	-8.927E-01	1.161E+01	5.628E+00	7.093E+00	2.188E+01	-9.331E+00	0.000E+00	-5.495E-07	-2.420E-08	0.000E+00
18.7500	-8.216E-01	1.183E+01	5.534E+00	7.092E+00	2.189E+01	-9.338E+00	0.000E+00	-5.500E-07	-6.410E-08	0.000E+00
19.0000	-7.505E-01	1.205E+01	5.440E+00	7.091E+00	2.190E+01	-9.344E+00	0.000E+00	-5.681E-07	-4.076E-08	0.000E+00
19.2500	-6.795E-01	1.227E+01	5.345E+00	7.090E+00	2.190E+01	-9.345E+00	0.000E+00	-5.495E-07	-4.323E-08	0.000E+00
19.5000	-6.084E-01	1.249E+01	5.251E+00	7.089E+00	2.191E+01	-9.354E+00	0.000E+00	-5.402E-07	-2.294E-08	0.000E+00
19.7500	-5.374E-01	1.271E+01	5.157E+00	7.089E+00	2.191E+01	-9.358E+00	0.000E+00	-5.495E-07	0.000E+00	0.000E+00
20.0000	-4.663E-01	1.293E+01	5.063E+00	7.088E+00	2.192E+01	-9.361E+00	0.000E+00	-5.586E-07	8.623E-09	0.000E+00
20.2500	-3.953E-01	1.315E+01	4.960E+00	7.088E+00	2.192E+01	-9.364E+00	0.000E+00	-5.586E-07	1.833E-08	0.000E+00
20.5000	-3.242E-01	1.337E+01	4.874E+00	7.087E+00	2.193E+01	-9.367E+00	0.000E+00	-5.495E-07	-1.948E-08	0.000E+00
20.7500	-2.531E-01	1.359E+01	4.780E+00	7.087E+00	2.193E+01	-9.370E+00	0.000E+00	-5.402E-07	-5.180E-08	0.000E+00

21.0000	-1.021E-01	1.301E+01	4.686E+00	7.007E+00	2.193E+01	-9.372E+00	0.000E+00	-5.691E-07	-7.716E-08	0.000E+00
21.2500	-1.110E-01	1.403E+01	4.591E+00	7.006E+00	2.194E+01	-9.374E+00	0.000E+00	-5.495E-07	-1.173E-07	0.000E+00
21.5000	-3.996E-02	1.425E+01	4.497E+00	7.006E+00	2.194E+01	-9.376E+00	0.000E+00	-5.588E-07	-8.746E-08	0.000E+00
21.7500	3.110E-02	1.447E+01	4.403E+00	7.006E+00	2.194E+01	-9.377E+00	0.000E+00	-5.588E-07	-9.317E-08	0.000E+00
22.0000	1.022E-01	1.469E+01	4.309E+00	7.006E+00	2.195E+01	-9.379E+00	0.000E+00	-5.305E-07	-9.929E-08	0.000E+00
22.2500	1.732E-01	1.491E+01	4.214E+00	7.006E+00	2.195E+01	-9.380E+00	0.000E+00	-5.681E-07	-9.029E-08	0.000E+00
22.5000	2.443E-01	1.513E+01	4.120E+00	7.006E+00	2.195E+01	-9.381E+00	0.000E+00	-5.402E-07	-1.371E-07	0.000E+00
22.7500	3.153E-01	1.536E+01	4.026E+00	7.006E+00	2.195E+01	-9.383E+00	0.000E+00	-5.402E-07	-8.605E-08	0.000E+00
23.0000	3.864E-01	1.550E+01	3.931E+00	7.005E+00	2.195E+01	-9.384E+00	0.000E+00	-5.309E-07	-1.562E-07	0.000E+00
23.2500	4.574E-01	1.580E+01	3.837E+00	7.005E+00	2.195E+01	-9.385E+00	0.000E+00	-5.495E-07	-1.766E-07	0.000E+00
23.5000	5.205E-01	1.602E+01	3.743E+00	7.005E+00	2.195E+01	-9.386E+00	0.000E+00	-5.681E-07	-8.390E-08	0.000E+00
23.7500	5.996E-01	1.624E+01	3.649E+00	7.005E+00	2.195E+01	-9.386E+00	0.000E+00	-5.588E-07	-2.355E-07	0.000E+00
24.0000	6.706E-01	1.646E+01	3.554E+00	7.005E+00	2.195E+01	-9.387E+00	0.000E+00	-5.681E-07	-1.440E-07	0.000E+00
24.2500	7.417E-01	1.668E+01	3.460E+00	7.005E+00	2.196E+01	-9.388E+00	0.000E+00	-5.309E-07	-2.056E-07	0.000E+00
24.5000	8.127E-01	1.690E+01	3.366E+00	7.005E+00	2.196E+01	-9.389E+00	0.000E+00	-5.451E-07	-1.789E-07	0.000E+00
24.7500	8.839E-01	1.712E+01	3.272E+00	7.005E+00	2.196E+01	-9.389E+00	0.000E+00	-5.402E-07	-5.903E-08	0.000E+00
25.0000	9.540E-01	1.734E+01	3.177E+00	7.005E+00	2.196E+01	-9.390E+00	0.000E+00	-5.402E-07	-2.138E-07	0.000E+00
25.2500	1.026E+00	1.756E+01	3.083E+00	7.005E+00	2.197E+01	-9.391E+00	0.000E+00	-5.681E-07	-1.616E-07	0.000E+00
25.5000	1.097E+00	1.778E+01	2.989E+00	7.005E+00	2.197E+01	-9.391E+00	0.000E+00	-5.402E-07	-2.011E-07	0.000E+00
25.7500	1.166E+00	1.800E+01	2.895E+00	7.005E+00	2.197E+01	-9.392E+00	0.000E+00	-5.402E-07	-3.443E-07	0.000E+00
26.0000	1.239E+00	1.822E+01	2.801E+00	7.005E+00	2.197E+01	-9.392E+00	0.000E+00	-5.495E-07	-4.027E-07	0.000E+00
26.2500	1.310E+00	1.844E+01	2.706E+00	7.005E+00	2.197E+01	-9.393E+00	0.000E+00	-5.309E-07	-3.657E-07	0.000E+00
26.5000	1.381E+00	1.866E+01	2.612E+00	7.006E+00	2.197E+01	-9.393E+00	0.000E+00	-5.495E-07	-3.949E-07	0.000E+00
26.7500	1.452E+00	1.888E+01	2.518E+00	7.006E+00	2.197E+01	-9.394E+00	0.000E+00	-5.495E-07	-2.136E-07	0.000E+00
27.0000	1.523E+00	1.910E+01	2.423E+00	7.006E+00	2.197E+01	-9.394E+00	0.000E+00	-5.495E-07	-3.101E-07	0.000E+00
27.2500	1.594E+00	1.932E+01	2.329E+00	7.006E+00	2.197E+01	-9.394E+00	0.000E+00	-5.681E-07	-5.082E-07	0.000E+00
27.5000	1.665E+00	1.954E+01	2.235E+00	7.006E+00	2.197E+01	-9.395E+00	0.000E+00	-5.588E-07	-6.099E-07	0.000E+00
27.7500	1.736E+00	1.976E+01	2.140E+00	7.006E+00	2.197E+01	-9.395E+00	0.000E+00	-5.681E-07	-9.845E-07	0.000E+00
28.0000	1.808E+00	1.998E+01	2.046E+00	7.006E+00	2.197E+01	-9.396E+00	0.000E+00	-5.402E-07	-1.014E-06	0.000E+00
28.2500	1.879E+00	2.020E+01	1.952E+00	7.006E+00	2.197E+01	-9.396E+00	0.000E+00	-5.495E-07	-1.088E-06	0.000E+00
28.5000	1.950E+00	2.042E+01	1.858E+00	7.006E+00	2.197E+01	-9.396E+00	0.000E+00	-5.495E-07	-1.085E-06	0.000E+00
28.7500	2.021E+00	2.064E+01	1.763E+00	7.006E+00	2.197E+01	-9.397E+00	0.000E+00	-5.588E-07	-1.329E-06	0.000E+00
29.0000	2.092E+00	2.086E+01	1.669E+00	7.006E+00	2.197E+01	-9.397E+00	0.000E+00	-5.402E-07	-1.558E-06	0.000E+00
29.2500	2.163E+00	2.109E+01	1.575E+00	7.006E+00	2.197E+01	-9.397E+00	0.000E+00	-5.588E-07	-1.747E-06	0.000E+00
29.5000	2.234E+00	2.131E+01	1.481E+00	7.006E+00	2.197E+01	-9.397E+00	0.000E+00	-5.402E-07	-1.545E-06	0.000E+00
29.7500	2.305E+00	2.153E+01	1.386E+00	7.006E+00	2.198E+01	-9.398E+00	0.000E+00	-5.588E-07	-2.311E-06	0.000E+00
30.0000	2.376E+00	2.175E+01	1.292E+00	7.006E+00	2.198E+01	-9.398E+00	0.000E+00	-5.495E-07	-2.075E-06	0.000E+00
30.2500	2.447E+00	2.197E+01	1.198E+00	7.006E+00	2.198E+01	-9.398E+00	0.000E+00	-5.681E-07	-3.505E-06	0.000E+00
30.5000	2.518E+00	2.219E+01	1.104E+00	7.006E+00	2.198E+01	-9.399E+00	0.000E+00	-5.588E-07	-3.771E-06	0.000E+00
30.7500	2.589E+00	2.241E+01	1.009E+00	7.006E+00	2.198E+01	-9.399E+00	0.000E+00	-5.495E-07	-4.123E-06	0.000E+00
30.7500	2.589E+00	2.241E+01	1.009E+00	7.006E+00	2.198E+01	-9.399E+00	0.000E+00	-5.495E-07	-4.123E-06	0.000E+00
-1.0000	2.509E+00	2.241E+01	1.009E+00	7.006E+00	2.198E+01	-9.399E+00	0.000E+00	1.000E-01	1.310E-02	0.000E+00
0.0000	-1.000E+01	0.000E+00	0.000E+00	2.124E+01	1.226E+01	4.324E+00	0.000E+00	1.012E-01	5.071E-01	0.000E+00
0.2500	-9.787E+00	1.231E-01	4.394E-02	2.123E+01	1.226E+01	4.322E+00	0.000E+00	4.576E-08	-5.694E-08	0.000E+00
0.5000	-9.574E+00	2.461E-01	8.783E-02	2.123E+01	1.226E+01	4.321E+00	0.000E+00	-1.000E-07	-1.390E-08	0.000E+00
0.7500	-9.361E+00	3.692E-01	1.319E-01	2.123E+01	1.226E+01	4.319E+00	0.000E+00	-2.612E-07	-1.340E-08	0.000E+00
1.0000	-9.148E+00	4.923E-01	1.758E-01	2.122E+01	1.226E+01	4.317E+00	0.000E+00	-3.466E-07	1.302E-08	0.000E+00
1.2500	-8.934E+00	6.155E-01	2.198E-01	2.121E+01	1.226E+01	4.315E+00	0.000E+00	-3.402E-07	-1.267E-08	0.000E+00
1.5000	-8.721E+00	7.387E-01	2.639E-01	2.120E+01	1.226E+01	4.314E+00	0.000E+00	-3.573E-07	2.466E-08	0.000E+00
1.7500	-8.508E+00	8.619E-01	3.080E-01	2.119E+01	1.226E+01	4.312E+00	0.000E+00	-3.949E-07	3.606E-08	0.000E+00
2.0000	-8.295E+00	9.852E-01	3.521E-01	2.117E+01	1.227E+01	4.310E+00	0.000E+00	-3.227E-07	0.000E+00	0.000E+00
2.2500	-8.083E+00	1.109E+00	3.963E-01	2.114E+01	1.227E+01	4.308E+00	0.000E+00	-4.908E-07	4.581E-08	0.000E+00
2.5000	-7.870E+00	1.232E+00	4.407E-01	2.111E+01	1.228E+01	4.308E+00	0.000E+00	-1.108E-07	-1.120E-08	0.000E+00
2.7500	-7.657E+00	1.356E+00	4.851E-01	2.108E+01	1.228E+01	4.307E+00	0.000E+00	-3.683E-07	2.191E-08	0.000E+00
3.0000	-7.445E+00	1.480E+00	5.290E-01	2.106E+01	1.229E+01	4.306E+00	0.000E+00	1.147E-08	0.000E+00	0.000E+00
3.2500	-7.233E+00	1.604E+00	5.747E-01	2.093E+01	1.231E+01	4.306E+00	0.000E+00	3.063E-06	1.052E-08	0.000E+00
3.5000	-7.021E+00	1.729E+00	6.200E-01	2.080E+01	1.233E+01	4.310E+00	0.000E+00	-2.969E-07	0.000E+00	0.000E+00
3.7500	-6.809E+00	1.855E+00	6.657E-01	2.067E+01	1.236E+01	4.313E+00	0.000E+00	2.910E-07	0.000E+00	0.000E+00
4.0000	-6.597E+00	1.981E+00	7.119E-01	2.054E+01	1.241E+01	4.317E+00	0.000E+00	-1.372E-07	0.000E+00	0.000E+00

4.2500	-6.389E+00	2.108E+00	7.587E-01	2.039E+01	1.246E+01	4.323E+00	0.000E+00	-5.870E-07	1.963E-08	0.000E+00
4.5000	-6.180E+00	2.237E+00	8.062E-01	2.020E+01	1.252E+01	4.329E+00	0.000E+00	-2.427E-07	1.933E-08	0.000E+00
4.7500	-5.973E+00	2.367E+00	8.545E-01	1.998E+01	1.262E+01	4.337E+00	0.000E+00	-3.184E-07	2.859E-08	0.000E+00
5.0000	-5.765E+00	2.499E+00	9.036E-01	1.974E+01	1.271E+01	4.346E+00	0.000E+00	-1.682E-07	4.704E-08	0.000E+00
5.2500	-5.556E+00	2.632E+00	9.535E-01	1.949E+01	1.283E+01	4.355E+00	0.000E+00	-8.414E-08	2.788E-08	0.000E+00
5.5000	-5.356E+00	2.767E+00	1.004E+00	1.923E+01	1.296E+01	4.364E+00	0.000E+00	-2.819E-08	0.000E+00	0.000E+00
5.7500	-5.153E+00	2.905E+00	1.056E+00	1.897E+01	1.310E+01	4.373E+00	0.000E+00	-1.577E-07	4.540E-08	0.000E+00
6.0000	-4.953E+00	3.045E+00	1.108E+00	1.871E+01	1.325E+01	4.381E+00	0.000E+00	-1.116E-07	2.783E-08	0.000E+00
6.2500	-4.754E+00	3.187E+00	1.161E+00	1.846E+01	1.342E+01	4.389E+00	0.000E+00	-1.538E-07	2.660E-08	0.000E+00
6.5000	-4.557E+00	3.331E+00	1.215E+00	1.822E+01	1.359E+01	4.396E+00	0.000E+00	0.000E+00	2.660E-08	0.000E+00
6.7500	-4.362E+00	3.476E+00	1.269E+00	1.799E+01	1.377E+01	4.403E+00	0.000E+00	-5.529E-08	3.524E-08	0.000E+00
7.0000	-4.169E+00	3.627E+00	1.323E+00	1.777E+01	1.396E+01	4.407E+00	0.000E+00	-2.408E-07	3.503E-08	0.000E+00
7.2500	-3.977E+00	3.778E+00	1.378E+00	1.756E+01	1.415E+01	4.412E+00	0.000E+00	4.262E-08	1.743E-08	0.000E+00
7.5000	-3.780E+00	3.932E+00	1.433E+00	1.735E+01	1.436E+01	4.418E+00	0.000E+00	2.112E-07	3.473E-08	0.000E+00
7.7500	-3.681E+00	4.083E+00	1.487E+00	1.716E+01	1.457E+01	4.423E+00	0.000E+00	1.264E-07	3.462E-08	0.000E+00
8.0000	-3.415E+00	4.247E+00	1.542E+00	1.698E+01	1.479E+01	4.429E+00	0.000E+00	-9.509E-08	3.455E-08	0.000E+00
8.2500	-3.232E+00	4.407E+00	1.597E+00	1.680E+01	1.503E+01	4.436E+00	0.000E+00	8.532E-08	8.625E-09	0.000E+00
8.5000	-3.038E+00	4.571E+00	1.651E+00	1.664E+01	1.527E+01	4.445E+00	0.000E+00	-4.110E-07	3.449E-08	0.000E+00
8.7500	-2.871E+00	4.736E+00	1.795E+00	1.640E+01	1.552E+01	4.456E+00	0.000E+00	-2.652E-07	2.588E-08	0.000E+00
9.0000	-2.654E+00	4.905E+00	1.759E+00	1.633E+01	1.579E+01	4.470E+00	0.000E+00	-2.632E-07	3.455E-08	0.000E+00
9.2500	-2.519E+00	5.075E+00	1.812E+00	1.619E+01	1.606E+01	4.486E+00	0.000E+00	-7.150E-08	3.403E-08	0.000E+00
9.5000	-2.346E+00	5.249E+00	1.865E+00	1.606E+01	1.634E+01	4.506E+00	0.000E+00	-2.509E-08	3.474E-08	0.000E+00
9.7500	-2.176E+00	5.423E+00	1.917E+00	1.594E+01	1.663E+01	4.529E+00	0.000E+00	-2.537E-07	3.488E-08	0.000E+00
10.0000	-2.007E+00	5.600E+00	1.969E+00	1.583E+01	1.692E+01	4.556E+00	0.000E+00	1.152E-07	1.753E-08	0.000E+00
10.2500	-1.841E+00	5.780E+00	2.020E+00	1.573E+01	1.721E+01	4.585E+00	0.000E+00	4.493E-07	0.000E+00	0.000E+00
10.5000	-1.676E+00	5.961E+00	2.071E+00	1.565E+01	1.746E+01	4.615E+00	0.000E+00	-2.626E-07	1.775E-08	0.000E+00
10.7500	-1.514E+00	6.144E+00	2.121E+00	1.559E+01	1.774E+01	4.647E+00	0.000E+00	-1.075E-06	4.473E-08	0.000E+00
11.0000	-1.353E+00	6.329E+00	2.171E+00	1.553E+01	1.797E+01	4.677E+00	0.000E+00	-1.035E-06	9.024E-09	0.000E+00
11.2500	-1.193E+00	6.514E+00	2.220E+00	1.549E+01	1.818E+01	4.706E+00	0.000E+00	-1.360E-06	1.822E-08	0.000E+00
11.5000	-1.034E+00	6.701E+00	2.269E+00	1.547E+01	1.838E+01	4.731E+00	0.000E+00	-1.327E-06	1.841E-08	0.000E+00
11.7500	-0.876E-01	6.889E+00	2.318E+00	1.545E+01	1.849E+01	4.753E+00	0.000E+00	-1.873E-06	2.793E-08	0.000E+00
12.0000	-0.719E-01	7.077E+00	2.367E+00	1.543E+01	1.869E+01	4.772E+00	0.000E+00	-1.925E-06	1.885E-08	0.000E+00
12.2500	-0.563E-01	7.266E+00	2.416E+00	1.543E+01	1.865E+01	4.786E+00	0.000E+00	-2.455E-06	-9.549E-09	0.000E+00
12.5000	-0.407E-01	7.456E+00	2.465E+00	1.542E+01	1.877E+01	4.797E+00	0.000E+00	-3.236E-06	1.937E-08	0.000E+00
12.7500	-0.251E-01	7.645E+00	2.513E+00	1.542E+01	1.881E+01	4.805E+00	0.000E+00	-3.349E-06	9.828E-09	0.000E+00
13.0000	-0.094E-02	7.835E+00	2.561E+00	1.542E+01	1.884E+01	4.810E+00	0.000E+00	-3.554E-06	2.995E-08	0.000E+00
13.2500	0.083E-02	8.025E+00	2.610E+00	1.542E+01	1.887E+01	4.813E+00	0.000E+00	-4.180E-06	2.030E-08	0.000E+00
13.5000	2.140E-01	8.215E+00	2.658E+00	1.542E+01	1.889E+01	4.814E+00	0.000E+00	-4.447E-06	1.033E-08	0.000E+00
13.7500	3.696E-01	8.405E+00	2.706E+00	1.542E+01	1.890E+01	4.815E+00	0.000E+00	-4.440E-06	-3.157E-08	0.000E+00
14.0000	5.248E-01	8.595E+00	2.754E+00	1.542E+01	1.891E+01	4.814E+00	0.000E+00	-4.324E-06	2.146E-08	0.000E+00
14.2500	6.789E-01	8.785E+00	2.802E+00	1.542E+01	1.892E+01	4.812E+00	0.000E+00	-4.045E-06	1.095E-08	0.000E+00
14.5000	8.339E-01	8.976E+00	2.850E+00	1.542E+01	1.893E+01	4.810E+00	0.000E+00	-3.819E-06	1.119E-08	0.000E+00
14.7500	9.888E-01	9.166E+00	2.898E+00	1.542E+01	1.893E+01	4.808E+00	0.000E+00	-3.638E-06	-4.579E-08	0.000E+00
15.0000	1.144E+00	9.356E+00	2.946E+00	1.542E+01	1.894E+01	4.805E+00	0.000E+00	-3.529E-06	1.172E-08	0.000E+00
15.2500	1.290E+00	9.547E+00	2.993E+00	1.542E+01	1.894E+01	4.802E+00	0.000E+00	-3.496E-06	-2.403E-08	0.000E+00
15.5000	1.433E+00	9.737E+00	3.041E+00	1.542E+01	1.894E+01	4.799E+00	0.000E+00	-3.485E-06	0.000E+00	0.000E+00
15.7500	1.600E+00	9.927E+00	3.089E+00	1.542E+01	1.894E+01	4.795E+00	0.000E+00	-3.509E-06	0.000E+00	0.000E+00
16.0000	1.763E+00	1.012E+01	3.136E+00	1.542E+01	1.895E+01	4.792E+00	0.000E+00	-3.531E-06	-1.303E-08	0.000E+00
16.2500	1.918E+00	1.031E+01	3.184E+00	1.542E+01	1.895E+01	4.788E+00	0.000E+00	-3.534E-06	4.025E-08	0.000E+00
16.5000	2.073E+00	1.050E+01	3.231E+00	1.542E+01	1.895E+01	4.785E+00	0.000E+00	-3.554E-06	-1.383E-08	0.000E+00
16.7500	2.227E+00	1.069E+01	3.279E+00	1.542E+01	1.895E+01	4.781E+00	0.000E+00	-3.509E-06	-2.855E-08	0.000E+00
17.0000	2.382E+00	1.088E+01	3.326E+00	1.542E+01	1.895E+01	4.778E+00	0.000E+00	-3.482E-06	0.000E+00	0.000E+00
17.2500	2.537E+00	1.107E+01	3.373E+00	1.542E+01	1.896E+01	4.774E+00	0.000E+00	-3.463E-06	0.000E+00	0.000E+00
17.5000	2.692E+00	1.126E+01	3.421E+00	1.542E+01	1.896E+01	4.771E+00	0.000E+00	-3.473E-06	7.908E-09	0.000E+00
17.7500	2.847E+00	1.145E+01	3.468E+00	1.542E+01	1.896E+01	4.768E+00	0.000E+00	-3.445E-06	-8.203E-09	0.000E+00
18.0000	3.001E+00	1.164E+01	3.515E+00	1.542E+01	1.896E+01	4.764E+00	0.000E+00	-3.455E-06	-2.556E-08	0.000E+00
18.2500	3.156E+00	1.183E+01	3.563E+00	1.542E+01	1.896E+01	4.761E+00	0.000E+00	-3.464E-06	-1.772E-08	0.000E+00
18.5000	3.311E+00	1.202E+01	3.610E+00	1.542E+01	1.896E+01	4.758E+00	0.000E+00	-3.455E-06	-9.223E-09	0.000E+00
18.7500	3.466E+00	1.221E+01	3.657E+00	1.542E+01	1.897E+01	4.755E+00	0.000E+00	-3.455E-06	-4.607E-09	0.000E+00

19.0000	3.620E+00	1.240E+01	3.705E+00	1.542E+01	1.897E+01	4.752E+00	0.000E+00	-3.454E-06	-4.013E-08	0.000E+00
19.2500	3.775E+00	1.259E+01	3.752E+00	1.542E+01	1.897E+01	4.756E+00	0.000E+00	-3.464E-06	-6.290E-08	0.000E+00
19.5000	3.930E+00	1.279E+01	3.799E+00	1.542E+01	1.897E+01	4.747E+00	0.000E+00	-3.474E-06	-8.774E-08	0.000E+00
19.7500	4.085E+00	1.298E+01	3.846E+00	1.542E+01	1.897E+01	4.744E+00	0.000E+00	-3.484E-06	-8.040E-08	0.000E+00
20.0000	4.239E+00	1.317E+01	3.894E+00	1.542E+01	1.897E+01	4.742E+00	0.000E+00	-3.494E-06	-4.817E-08	0.000E+00
20.2500	4.394E+00	1.336E+01	3.941E+00	1.542E+01	1.897E+01	4.740E+00	0.000E+00	-3.454E-06	-6.320E-08	0.000E+00
20.5000	4.549E+00	1.355E+01	3.988E+00	1.542E+01	1.897E+01	4.737E+00	0.000E+00	-3.483E-06	-1.461E-07	0.000E+00
20.7500	4.704E+00	1.374E+01	4.036E+00	1.542E+01	1.890E+01	4.735E+00	0.000E+00	-3.465E-06	-1.677E-07	0.000E+00
21.0000	4.850E+00	1.393E+01	4.083E+00	1.542E+01	1.890E+01	4.733E+00	0.000E+00	-3.455E-06	-1.912E-07	0.000E+00
21.2500	5.013E+00	1.412E+01	4.130E+00	1.542E+01	1.890E+01	4.732E+00	0.000E+00	-3.474E-06	-2.558E-07	0.000E+00
21.5000	5.160E+00	1.431E+01	4.177E+00	1.542E+01	1.890E+01	4.730E+00	0.000E+00	-3.474E-06	-3.189E-07	0.000E+00
21.7500	5.323E+00	1.450E+01	4.225E+00	1.542E+01	1.890E+01	4.728E+00	0.000E+00	-3.455E-06	-3.454E-07	0.000E+00
22.0000	5.477E+00	1.469E+01	4.272E+00	1.542E+01	1.890E+01	4.727E+00	0.000E+00	-3.465E-06	-3.650E-07	0.000E+00
22.2500	5.631E+00	1.488E+01	4.319E+00	1.542E+01	1.890E+01	4.725E+00	0.000E+00	-3.455E-06	-4.922E-07	0.000E+00
22.5000	5.787E+00	1.507E+01	4.366E+00	1.542E+01	1.896E+01	4.724E+00	0.000E+00	-3.455E-06	-5.414E-07	0.000E+00
22.7500	5.942E+00	1.526E+01	4.414E+00	1.542E+01	1.899E+01	4.723E+00	0.000E+00	-3.455E-06	-3.095E-07	0.000E+00
23.0000	6.097E+00	1.545E+01	4.461E+00	1.543E+01	1.899E+01	4.721E+00	0.000E+00	-3.465E-06	-4.931E-07	0.000E+00
23.2500	6.251E+00	1.564E+01	4.508E+00	1.543E+01	1.899E+01	4.720E+00	0.000E+00	-3.474E-06	-5.716E-07	0.000E+00
23.5000	6.406E+00	1.583E+01	4.555E+00	1.543E+01	1.899E+01	4.719E+00	0.000E+00	-3.455E-06	-5.549E-07	0.000E+00
23.7500	6.561E+00	1.603E+01	4.603E+00	1.543E+01	1.899E+01	4.719E+00	0.000E+00	-3.455E-06	-6.850E-07	0.000E+00
24.0000	6.716E+00	1.622E+01	4.650E+00	1.543E+01	1.899E+01	4.718E+00	0.000E+00	-3.465E-06	-7.275E-07	0.000E+00
24.2500	6.870E+00	1.641E+01	4.697E+00	1.543E+01	1.899E+01	4.717E+00	0.000E+00	-3.474E-06	-7.885E-07	0.000E+00
24.5000	7.025E+00	1.660E+01	4.744E+00	1.543E+01	1.899E+01	4.716E+00	0.000E+00	-3.474E-06	-7.559E-07	0.000E+00
24.7500	7.180E+00	1.679E+01	4.792E+00	1.543E+01	1.899E+01	4.715E+00	0.000E+00	-3.474E-06	-7.338E-07	0.000E+00
25.0000	7.335E+00	1.698E+01	4.839E+00	1.543E+01	1.899E+01	4.715E+00	0.000E+00	-3.483E-06	-7.895E-07	0.000E+00
25.2500	7.490E+00	1.717E+01	4.886E+00	1.543E+01	1.899E+01	4.714E+00	0.000E+00	-3.445E-06	-8.890E-07	0.000E+00
25.5000	7.644E+00	1.736E+01	4.933E+00	1.543E+01	1.899E+01	4.714E+00	0.000E+00	-3.474E-06	-1.008E-06	0.000E+00
25.7500	7.799E+00	1.755E+01	4.981E+00	1.543E+01	1.900E+01	4.713E+00	0.000E+00	-3.455E-06	-1.061E-06	0.000E+00
26.0000	7.954E+00	1.774E+01	5.028E+00	1.543E+01	1.900E+01	4.713E+00	0.000E+00	-3.465E-06	-8.670E-07	0.000E+00
26.2500	8.108E+00	1.793E+01	5.075E+00	1.543E+01	1.900E+01	4.713E+00	0.000E+00	-3.455E-06	-1.212E-06	0.000E+00
26.5000	8.263E+00	1.812E+01	5.122E+00	1.543E+01	1.900E+01	4.712E+00	0.000E+00	-3.483E-06	-1.100E-06	0.000E+00
26.7500	8.418E+00	1.831E+01	5.170E+00	1.543E+01	1.900E+01	4.712E+00	0.000E+00	-3.474E-06	-1.567E-06	0.000E+00
27.0000	8.573E+00	1.850E+01	5.217E+00	1.543E+01	1.900E+01	4.712E+00	0.000E+00	-3.474E-06	-1.527E-06	0.000E+00
27.2500	8.727E+00	1.869E+01	5.264E+00	1.543E+01	1.900E+01	4.711E+00	0.000E+00	-3.465E-06	-1.700E-06	0.000E+00
27.5000	8.882E+00	1.888E+01	5.311E+00	1.543E+01	1.900E+01	4.711E+00	0.000E+00	-3.465E-06	-1.487E-06	0.000E+00
27.7500	9.037E+00	1.907E+01	5.359E+00	1.543E+01	1.900E+01	4.711E+00	0.000E+00	-3.465E-06	-1.898E-06	0.000E+00
28.0000	9.192E+00	1.926E+01	5.406E+00	1.543E+01	1.900E+01	4.711E+00	0.000E+00	-3.465E-06	-1.902E-06	0.000E+00
28.2500	9.346E+00	1.946E+01	5.453E+00	1.543E+01	1.900E+01	4.710E+00	0.000E+00	-3.465E-06	-1.747E-06	0.000E+00
28.5000	9.501E+00	1.965E+01	5.500E+00	1.543E+01	1.900E+01	4.710E+00	0.000E+00	-3.474E-06	-1.821E-06	0.000E+00
28.7500	9.656E+00	1.984E+01	5.548E+00	1.543E+01	1.900E+01	4.710E+00	0.000E+00	-3.474E-06	-2.085E-06	0.000E+00
29.0000	9.811E+00	2.003E+01	5.595E+00	1.543E+01	1.900E+01	4.710E+00	0.000E+00	-3.474E-06	-1.886E-06	0.000E+00
29.2500	9.965E+00	2.022E+01	5.642E+00	1.543E+01	1.900E+01	4.710E+00	0.000E+00	-3.474E-06	-2.138E-06	0.000E+00
29.5000	1.012E+01	2.041E+01	5.689E+00	1.543E+01	1.900E+01	4.710E+00	0.000E+00	-3.483E-06	-2.779E-06	0.000E+00
-1.0000	1.012E+01	2.041E+01	5.689E+00	1.543E+01	1.900E+01	4.710E+00	0.000E+00	1.000E-01	3.620E-02	0.000E+00
-10.0000	1.012E+01	2.041E+01	5.689E+00	1.543E+01	1.900E+01	4.710E+00	0.000E+00	1.000E-01	3.620E-02	0.000E+00

PRECISE VALUES FOR V VECTOR AT END

0.101200460E+02	0.204082730E+02	0.568933708E+01	0.154305440E+02	0.190013690E+02
0.470982990E+01	0.000000000E+00	0.100000300E+00	0.362000340E-01	0.000000000E+00

NDERV 292
 NDATA 0
 ISTOP 1
 IFLAG 2

RAYPLT plot (Example II)

MINUS BRANCH PROPAGATION

Appendix IV: FORTRAN LISTINGS OF SUBROUTINES IN RAYS

[illegible]

126

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C RAYS.RAY
C THIS COMPUTER CODE TRACES RAYS IN A THREE DI-
C MENSIONAL, ARBITRARY, INHOMOGENEOUS, MAGNETIZED COLD
C PLASMA. IT WAS WRITTEN BY D.B. BATCHELOR AND R.C. GOLDFINGER
C AT OAK RIDGE NATIONAL LABORATORY AND IS FULLY DOCUMENTED IN
C ORNL TM/6044 (1981).
C THERE IS ONE INPUT FILE, RAYD.DAT,
C AND TWO OUTPUT FILES, FORI01.DAT AND FORI02.DAT. I01 AND I02
C ARE INTEGER UNIT NUMBERS DEFINED BY THE USER IN THE INPUT DATA NAMELIST.
C FORI02.DAT CONTAINS A LIST OF THE INPUT DATA AND THEN EACH SUBSEQUENT
C LINE CONTAINS S AND THE TEN ELEMENT ARRAY, V. S IS ARCLENGTH ALONG THE RAY.
C V(1)-V(3) IS POSITION, V(4)-V(6) IS THE WAVEVECTOR.
C V(7) - V(10) ARE USED FOR MULTIPLE PURPOSES. IN THIS VERSION OF RAYS,
C V(7) IS THE TOTAL ABSORBED POWER AS DEFINED BY THE DAMP SUBROUTINE.
C V(8) COMPARES THE RELATIVE ERROR BETWEEN THE INTEGRATED
C VALUE OF GRAD-D WITH THE LOCAL VALUE OF DENSITY. V(9) IS ANALOGOUS
C QUANTITY FOR BHAG. FORI01.DAT CONTAINS VARIOUS CHECKS AND QUANTITIES
C FOR POINTS ON THE RAY TRAJECTORY. THESE QUANTITIES ARE DEFINED
C BELOW. IF ISTOP .GT. 0, ODE (DIFFERENTIAL EQUATION SOLVER) RETURNS.
C X0,Y0,Z0 = INITIAL POSITION
C KX0,KY0,KZ0 = INITIAL WAVE VECTOR DIRECTION COSINES
C THETA,PHI ARE INITIAL PROJECTION ANGLES. RZ IS INITIAL N-PARALLEL
C FMU = WAVE FREQUENCY IN GHZ
C PFE0 = PLASMA FREQ/1-FREQ AT ORIGIN (DEFINES ABSOLUTE DENSITY)
C CF00 = CYCLOTRON FREQ/1-FREQ AT ORIGIN (DEFINES ABSOLUTE B)

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REAL KX9,KY9,KZ9,KM9,LDS
DIMENSION V(10),DV(10),WORK(500),IWORK(5),INFER(5),ZFER(5)
DIMENSION DAY(2),BV(3),GRB(3),GRD(3),GRBIJ(3,3),HEAD(10),DIAG(10)
COMPLEX ZRH
COMMON/PASS/IDAMP,ICONV,ZFLAG,HOLD(20)
BLOCK/DIAG2C/CONTAINS DIAGNOSTICS FROM SUBROUTINE TWOIMP
COMMON/DIAG2C/A,B,C,DISCR,XRAY,YRAY,ZRAY,XXK,XXY,XXZ
COMMON/ANUL/DANUL,GRPA(3)
COMMON/SLAS/ISLAS,RLSLD
COMMON/EUCB/ICOIL,SEP,RCOIL,RHOT,DELTA,DINF
COMMON/PIUG,I0,I01,CFOB,PFOB,SETANH,SGN,LDS,FMU,
1 VTE,VTEHOT,VTI,IPARAM
ISTOP,GT,0 ONE RETURNS
COMMON/STOP/ISTOP
S BLOCK USED TO PLAT RESONANT ZONES
COMMON/ZONES/XTRP,IFREQ
THIS BLOCK TELLS OUTPUT WHICH SUBROUTINES LINKED IN. SEE BELOW
COMMON/TIMES/XNAME(10),NDERV,NDATT
INPUT NAMELIST 'DATA' IS CONTAINED ON RAYD.DAT FILE
NAMELIST/1/DATA/I0,I01,I02,I0UG,I0AMP,DS,SMAX,PHI0,NPHI,DPHI,
1 THELO,NTHETA,DELTA,IEXP,IVMX,IZMX,DX,DY,DZ,X0,Y0,Z0,SGN
2 , PFOB,REVDIAG,CFOB,FMU,TE,TEHOT,TI,XMAX,YMAX,ZMAX,RZ0,
3 NRZ,BI,ISIAD,RLSLD,ICOIL,SEP,RCOIL,RHOT,DELTA,DINF,
4 IPARAM,ICONV,SELEK,ABSERR,CMPTUR
EXTERNAL DERV,ZONE
DATA CONV/57.29577951/,ZERO/0.0/,XNAME(5)/'PDP10'/
DATA PI/3.141592653 59979/

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V(3)=V(3)+DSFLD*BV(3)/BMAG
S=5+DSFLD
C
WRITE (102,250) SFIELD,(V(I),I=1,10)
C
IF (V(3).LT.ZMAX .AND. ABS(V(1)) .LT. 1.1*MAX) GO TO 53
CYCLE OVER X FOR DIFFERENT FIELD LINE FOLLOWINGS.
C
NLines IS NUMBER OF FIELD LINES DRAWN EACH SIDE OF X=0.
NLines=4
XTMP=XCRP+XMAX/NLines
AVOID FIELD LINE FOR X=0
IF (ABS(XTMP).LT.1.E-6) XTMP=XMAX/NLines
S=-1.
WRITE (102,250) S,(V(I),I=1,10)
S=0.
IF (XTMP.LE.XMAX) GO TO 50.
C
PLOT LOCATION OF CYCLOTRON RESONANT ZONE (IFREQ=1)
C
RIGHT HAND CUTOFF (IFREQ=2), SECOND HARMONIC RESONANCE (IFREQ=3)
C
IF (IEQ.LT.1) GO TO 665
C
ZRH=CMPLX(-1.0,0.0)
DO 660 IFREQ=1,2
DO 650 I=1,101
XTMP=XCRS*(1.-.02*(I-1))
IF (IFREQ .EQ. 2) ZRH=ZONE(0.0)
IF (REAL(ZRH) .LT. 0.) GO TO 651
V(1)=XTMP
V(3)=0.0
WRITE(102,250) SFIELD,(V(J),J=1,10)
GO TO 650
651 CONTINUE
ZFER(1)=ZCRS
EPS=1.E-5
NSIG=4
KN=0
N=1
NGUESS=1
ITMAX=50
CALL ZRLYT (ZONE,EPS,NSIG,KN,NGUESS,N,ZFER,ITMAX,INFER,IER)
V(1)=XTMP
V(3)=ZFER(1)
WRITE (102,250) SFIELD,(V(J),J=1,10)
650 CONTINUE
S=-1.
WRITE (102,250) S,(V(I),I=1,10)
660 S=0
C
PLOT SECOND HARMONIC RESONANCE
IFREQ=3
DO 670 I=1,101
XTMP=XCRS2*(1.-.02*(I-1))
ZRH=ZONE(0.)
IF (REAL(ZRH) .LT. 0.) GO TO 671
V(1)=XTMP
V(3)=0.0
WRITE(102,250) SFIELD,(V(J),J=1,10)
GO TO 670
671 CONTINUE

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BETA=(BV(1)**2+BV(2)**2+BV(3)**2)*CFE0**2
DOT=(BV(1)*V(4)+BV(2)*V(5)+BV(3)*V(6))
BIMG2=BV(1)**2+BV(2)**2+BV(3)**2
BIMG=SQRT(BIMG2)
C N-PARALLEL AND N-PERPENDICULAR FROM RAYS CODE
RPAR=SQRT(LDS)*DOT/BIMG
RPAR2=RPAR**2
RPERP2=LDS*(V(4)**2+V(5)**2+V(6)**2)-RPAR2
RPERP=SQRT(RPERP2)
MODE=3
XRAY=V(1)
YRAY=V(2)
ZRAY=V(3)
XX=V(4)
XY=V(5)
XZ=V(6)
C SOLVE FOR N-PERP**2 FROM TWOCMP USING N-PAR**2 FROM RAYS CODE.
C RPPLUS IS TWOCMP'S N-PERP**2 WITH SIGN=+1
C RPMIN IS TWOCMP'S N-PERP**2 WITH SIGN=-1
SPLUS=1.
SMIN=-1.
CALL TWOCMP(ALFA,BETA,SPLUS,THETA,RS,RPPLUS,RPAR2,MODE,DIS)
CALL TWOCMP(ALFA,BETA,SMIN,THETA,RS,RPMIN,RPAR2,MODE,DIS)
C SAVE A,B,C COEFFICIENTS FROM TWOCMP CALL WHEN MODE =3
AHOLD3=A
BHOLD3=B
CHOLD3=C
C ALSO INTERESTING TO LOOK AT WHAT TWOCMP PREDICTS FOR
C THE TWO MODES OF NZ AS A FUNCTION OF THE RAYS CODE'S NX.
C THIS IS THE MORE RELEVANT QUANTITY IN PARALLEL STRATIF.
MODE =2
CALL TWOCMP(ALFA,BETA,SPLUS,THETA,RS,RPERP2,RZPLUS,MODE,DIS)
CALL TWOCMP(ALFA,BETA,SMIN,THETA,RS,RPERP2,RZMIN,MODE,DIS)
AHOLD2=A
BHOLD2=B
CHOLD2=C
C DEFINE DIAG ARRAY FOR PRINTING OUT ON IO1 FILE OUTPUT.
DIAG(1)=RPAR
DIAG(2)=RPERP
C IF EITHER OF TWOCMP'S ROOTS FOR N-PERP**2 .LT. 0. (I.E. RAY CUTOFF)
C THEN SET SORT TO MINUS INFINITY.
DIAG(3)=-1.E38
DIAG(4)=-1.E38
IF(RPPLUS .GE. 0.) DIAG(3)=SQRT(RPPLUS)
IF(RPMIN .GE. 0.) DIAG(4)=SQRT(RPMIN)
C SAME FOR RZS FROM TWOCMP
DIAG(5)=-1.E38
DIAG(6)=-1.E38
IF(RZPLUS .GE. 0.) DIAG(5)=SQRT(RZPLUS)
IF(RZMIN .GE. 0.) DIAG(6)=SQRT(RZMIN)
C DETERMINE RESIDUAL OF DISPERSION RELATION, I.E. D=0?
MODE =4
CALL TWOCMP(ALFA,BETA,SGN,THETA,RS,RPERP2,RPAR2,MODE,DIS)
DIAG(5)=DIS
C
C
C
C PUT YOUR CHOICE OF DIAGNOSTICS INTO DIAG(3),(9),AND (10)
DIAG(9)=AHOLD2

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      IF (ABS(V(1)) .GT. XMAX) ISTOP=1
      IF (ABS(C(2)) .GT. YMAX) ISTOP=1
      IF (V(7) .GT. 0.99) ISTOP=7
      IF (S .GE. SMAX-.25*DS) ISTOP = 1
      IF (ISTOP .GT. 0 .OR. IFLAG .NE. 2) GO TO 300
      GO TO 200

```

C
C
C
C

C END OF RAY

```

300      WRITE(101,261) NDERV, NDAMP, ISTOP, IFLAG
      WRITE(59,330) ISTOP, IFLAG, V(1), V(2), V(3)
320      FORMAT (7H ISTOP=,I4,' IFLAG=',I4)
330      FORMAT(' ISTOP,IFLAG',2I4,' AT ',3E15.4)
C      S=-1 SIGNIFIES END OF RAY
      S=-1.
      WRITE (101,250) S,(V(I),I=1,10)
      WRITE (102,250) S,(V(I),I=1,10)
      IF (IFLAG .EQ. 5) WRITE (101,256) (HOLD(I),I=10,20)
500      CONTINUE
C      S=-10 SIGNIFIES END OF RUN.
      S=-10.
      WRITE (102,250) S,(V(I),I=1,10)
      WRITE (59,255) (V(I),I=1,10)
      WRITE (102,255) (V(I),I=1,10)
255      FORMAT('      PRECISE VALUES FOR V VECTOR AT END'//
1        ,2(5E20.9//))
C      SEE WHAT HAPPENED WHEN IFLAG .EQ. 5 (STIFF EQUATIONS)
      IF (IFLAG .EQ. 5) WRITE (102,256) (HOLD(I),I=10,20)
256      FORMAT(' IFLAG EQ. 5 TERMINATION. DERIVATIVES:'//
1        ,10(1PE12.3) )
      WRITE(102,261) NDERV, NDAMP, ISTOP, IFLAG
261      FORMAT(5X,' NDERV',16/,5X,' NDAMP',16/,5X,' ISTOP',16/,
1        5X,' IFLAG',16)
      CALL EXIT
      END

```

C
C

```

      COMPLEX FUNCTION ZONE(Z)
      DIMENSION V(10), BV(3), GRB(3), GRD(3)
      REAL LDS
      COMMON /BUG, 10, 101, CFE0, PFE0, BETANN, SGN, LDS, FMU,
1        VIE, VIEHOT, VT1, IPARAM
      COMMON /ZONES/ IZTP, IFREQ

```

C
C
C
C
C

```

      THIS FUNCTION DEFINES ZONE TO BE ZERO FOR POINTS WHICH LIE
      ON DESIRED SURFACE. IFREQ=1 REFERS TO ELECTRON CYCLOTRON RESONANCE,
      IFREQ=2 REFERS TO RIGHT HAND CUTOFF, IFREQ=3 REFERS TO SECOND
      HARMONIC, AND IFREQ=4 FOR UPPER HYBRID RESONANCE.
      V(1) = X

```

```

V(2)=0.
V(3)=Z
CALL EQUIB (V,BV,GRB,GRBIJ,D,GRD)
BMAG=SQRT(BV(1)**2+BV(2)**2+BV(3)**2)
CF=BMAG*CFE0
GO TO (1,2,3,4),IFREQ
1  ZONE=CMPLX(CF-1.,0.)
   RETURN
2  CONTINUE
   PFS=PFE0**2*D
   FRH=CF*(1.+SQRT(1.+4.*PFS/CF**2))/2.
   ZONE=FRH-1.
   RETURN
3  CONTINUE
   TEMP=2.*CF
   ZONE=CMPLX(TEMP-1.,0.)
   RETURN
4  CONTINUE
   PFS=PFE0**2*D
   ZONE=SQRT(CF**2+PFS)
   ZONE=ZONE-1.
   RETURN
END

```

>DERV2C.RAY

```

      SUBROUTINE DERV (S,V,DV)
      REAL KIM(3),K(3),KB,KP2,KDOTB,KMAG,LD,LDS
      DIMENSION V(10),DV(10),B(3),GRB(3),GRD(3),DRBK(3),DRPK(3)
      DIMENSION DRBK(3),DRPK(3),DVCOP(10),GRBV(3,3),GRBIJ(3,3)
      COMMON/ANNUL/DANNUL,GRPA(3)
      COMMON/PASS/IDAMP,ICONV,ZFLAG,HOLD(20)
      COMMON IBUG,IO,IOI,CFE0,PFE0,BETANH,SGN,LDS,FNU,
1      VTE,VTEHOT,VTI,IPARAM
      COMMON /STP/ ISTOP
      COMMON/NAMES/X(10),NDERV,NDAMP
      COMMON/DIAG2C/ADUM,BDUM,CDUM,DISCR,XRAY,YRAY,ZRAY,XX,XKY,XXZ
      COMPLEX XC(5)
      EXTERNAL DFUN
C      APPEARS IN OUTPUT TO TELL WHICH SUBROUTINE WAS LINKED IN.
      DATA X(1)/'COLD',NRAY/0/
      DATA HMIN/-2/,NMAX/2/,NDERV/0/,ZFLAG/0/,NDAMP/0/
      DATA FINITY/1.E39/,RMASS/5.4466231E-4/,RMI/1.00054466231/
      DATA RM2/2.9565703E-7/
C      COUNT NUMBER OF TIMES DERV IS ACCESSED PER RAY
      NDERV=NDERV+1
      XRAY=V(1)
      YRAY=V(2)
      ZRAY=V(3)
      XX=V(4)
      XKY=V(5)
      XKZ=V(6)
      LD=SQRT(LDS)
      CALL EDUIB(V,B,GRD,GRBIJ,D,GRD)
      BMAG=SQRT(B(1)**2+B(2)**2+B(3)**2)
      BETA=(CFE0*BMAG)**2
      VTCORE=VTE*SQRT(D)
      VTICOR=VTI*SQRT(D)
      ALFA=PFE0**2*D
      ALFMAX=BETANH*(CFE0/VTEHOT)**2
      ALFHOT=ALFMAX*DANNUL
      ALFCLD=ALFA
      KMAG=0.
      KDOTB=0.
      DO 20 I=1,3
      K(I)=V(I+3)
      KMAG=KMAG+V(I+3)**2
20      KDOTB=KDOTB+K(I)*B(I)
      KMAG=SQRT(KMAG)
      THETA=ACOS(KDOTB/BMAG/KMAG)
C      KB=K-PARALLEL, RMB=N-PARALLEL
C      KP=K-PERP, RMP=N-PERP
      KB=KDOTB/DMAG
      RX0=K*LD
      RXB2=K**2**2
      RXD4=K**2**2
      KP2=KMAG**2-K**2
      RXP2=KP2*LD
      RX=SQRT(RXP2)
      RXP4=K**2**2
      RSKAY=RXP2+RXD2
C
C
C***** DRUGERY

```

```

      IF (IBUS.LT. 2) GO TO 901
      IF (IQ.LT.1) WRITE (101,903)
903  FORMAT (/)
      IF (IQ.LT.1) WRITE (101,900) V(1),ALFA,BETA,THETA,KB,KP2,KMAG
900  FORMAT (10(1PE12.3))
901  CONTINUE
C*****
C IF THIS IS FIRST TIME THROUGH , INITIALIZE KMAG TO
C BE A SOLUTION OF DISPERSION RELATION
      IF (S.GE.0.) GO TO 40
      NDERV=1
      NDATA=0
      NRAY=NRAY+1
      IF (S.EQ.-1) GO TO 36
C      S IS -2 SO INITIALIZATION WITH SPECIFIED N-PARALLEL
C      IS DESIRED. FIND THE N-PERP FOR GIVEN N-PARALLEL TO SATISFY
C      THE COLD PLASMA DISPERSION RELATION.
C      NX > 0. ASSUMED. EASY ENOUGH TO CHANGE LATER.
      MODE = 3
      RZS=V(6)**2
C      CALL TWOCHP TO SOLVE COLD PLASMA DISPERSION RELATION FOR
C      N-PERP**2 AS A FUNCTION OF N-PARALLEL. IF WAVE IS EVANESCENT,
C      OR RESONANT SET ISTOP FLAG TO 2 OR 3, RESPECTIVELY.
C      THIS WILL PASS BACK TO MAIN PROGRAM AND TERMINATE THE RAY.
      CALL TWOCHP(ALFA,BETA,SGN,THETA,RS,RXS,RZS,MODE,DIS)
      IF (RXS.LT.0. .OR. RZS.LT. 0.) ISTOP=2
      IF (ABS(RS).GT. 1.E6) ISTOP=3
C      MUST APPLY A ROTATION MATRIX TO GO FROM LOCAL MAGNETIC COORDIN-
C      ATE SYSTEM TO FIXED CARTESIAN COMPONENTS.
C      ANGLE IS ANGLE B MAKES WITH Z AXIS AT THIS POINT.
C      NOTE THAT THE "NEGATIVE" ROOT FOR RZS HAS BEEN CHOSEN.
C      THIS CORRESPONDS TO CHOOSING THE DIRECTION OF K-PERP
C      TO BE 90 DEGREES CLOCKWISE FROM K-PARALLEL. TO HAVE
C      K-PERP BE 90 DEGREES COUNTER CLOCKWISE FROM THE DIRECTION.
C      OF B, TAKE V(5)=SQRT(RZS)*COS-SQRT(RXS)*SIN
C      V(4)=SQRT(RZS)*SIN+SQRT(RXS)*COS
      ANGLE=ATAN(B(1)/D(3))
      V(5)=(SQRT(RZS)*COS(ANGLE)+SQRT(RXS)*SIN(ANGLE))/LD
      V(4)=(SQRT(RZS)*SIN(ANGLE)-SQRT(RXS)*COS(ANGLE))/LD
      THETA=ACOS(SQRT(RZS/RS))
      THPRI=THETA*57.2958
      WRITE(59,110) NRAY
110  FORMAT(5(' ',/),' RAY #',I2,9X,
1  ' INITIALIZATION WITH SPECIFIED (N-PARALLEL)**2')
      WRITE(59,76)V(4),V(5),V(6),RZS,RXS,RS,ALFA,BETA,THPRI
76  FORMAT(' KX0 = ',1PE10.3,' KY0 = ',1PE10.3,
1  ' KZ0 = ',1PE10.3,/, ' N-PARA**2 = ',1PE10.3,
2  ' N-PERP**2 = ',1PE10.3, ' N**2 = ',1PE10.3,/, ' ALFA = ',
3  1PE10.3, ' BETA = ',1PE10.3, ' THETA = ',1PE10.3//)
      MODE =4
      CALL TWOCHP(ALFA,BETA,SGN,THETA,RS,RXS,RZS,MODE,DIS)
      WRITE(59,77)DIS
77  FORMAT(' RESIDUAL OF DISPERSION RELATION ',E15.4//)
      RETURN
C
C      INITIALIZE WITH SPECIFIED ANGLES FOR K VECTORS.
C
36  CONTINUE
      NDATA=1

```

```

      CALL TUDCMP(ALFA,BETA,SGN,THETA,RS,RXS,RZS,MODE,DIS)
      KMG=SQRT(RS/LDS)
      THETA=ACOS(SQRT(RZS/RS))*57.2958
      WRITE(101,35) THETA,KMG
35  FORMAT(///, ' INITIAL ANGLE OF K WRT LOCAL B',
11PE10.3,5X,10HINITIAL K=,1PE10.3,/)
      DO 37 I=1,3
37  V(I+3)=V(I+3)*KMG
      WRITE(59,119) IRAY
119  FORMAT( 5( ' *',/), ' RAY #',I2.9X,
1  '  INITIALIZATION WITH SPECIFIED ANGLE FOR K')
      WRITE(59,76)V(4),V(5),V(6),RZS,RXS,RS,ALFA,BETA,THETA
      RETURN
40  CONTINUE
C
C  TEST FOR CUTOFF OR RESONANCE CONDITIONS WHICH TERMINATE THE RAY.
C
      MODE=3
      CALL TUDCMP (ALFA,BETA,SGN,THETA,RS2COM,RXS,RXB2;MODE,DIS)
C
C  TEST FOR IMAGINARY INDEX OF REFRACTION
C
      IF (RXS.GT.0.) GO TO 666
      ISTOP = 2
      WRITE(59,621) ISTOP,ALFA,BETA,SGN,RS2COM,RXS,RXB2.
1  RXP2,V(1),V(3)
666  CONTINUE
C  TEST FOR RESONANCE
C
      IF (ABS(RS2COM).LT.1.E6) GO TO 723
      ISTOP=3
      WRITE(59,621) ISTOP,ALFA,BETA,SGN,RS2COM,RXS,RXB2.
1  RXP2,V(1),V(3)
621  FORMAT(' ISTOP FLAG HAS BEEN SET IN DERV2C ISTOP=',I4,/,
1  ' ALFA BETA SGN RS RXS RZS (ALL FROM TUDCMP)',
1  ' 3E17.7/3E17.7,/, ' RXS X AND Z FROM RAYS CODE',4E17.7//)
723  CONTINUE
C
C
C  IF ICONV FLAG SET TO 1, THEN SEE IF WARM PLASMA MODE CONVERSION
C  CRITERION IS SATISFIED.
C
      IF (ICONV.EQ.1)
1  CALL CONVRT(ALFA,BETA,VTCAPE,VTICOR,V,KP2,RXB,RXP)
C
C
C  CALCULATE DERIVATIVES OF DISPERSION RELATION REQUIRED FOR
C  RAY TRACING
C
      P=1.-RM1*ALFA
      T=(1.-GEFA)*(1.-RM2*BETA)
      STERM=T-RM1*ALFA+RM3S*RM1*ALFA*BETA
      Q=T-RM1*ALFA*(1.-RM3S*BETA)+RM1**2*ALFA**2

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```

C      XA=T*P
C      XB=-2.*P*STERM+(T*P+STERM)*RXP2
C
C      DDPALF=-RM1
C      DSDALF=-RM1+RMASG*RM1*BETA
C      DQDALF=2.*DSDALF/2.*PM1*B*ALFA
C
C      DTDDET=-(1.+RM2)+2.*RM2*BETA
C      DSDDET=DTDDET+RMASG*RM1*ALFA
C      DQDDET=DTDDET+2.*RMASG*RM1*ALFA
C
C      DADALF=T*DPDALF
C      DBDALF=-2.*(DPDALF*STERM+P*DSDALF)+(T*DPDALF+DSDALF)*RXP2
C      DCDALF=DPDALF*Q+P*DQDALF-(DQDALF+DPDALF*STERM+P*DSDALF)*RXP2
C      &+DSDALF*RXP4
C
C      DADDET=P*DTDDET
C      DBDDET=-2.*P*DSDDET+(P*DTDDET+DSDDET)*RXP2
C      DCDDET=P*DQDDET-(DQDDET+P*DSDDET)*RXP2+DSDDET*RXP4
C      DRXP=D(D)/D(N)*2, DALFA=D(D)/D(ALFA), DBETA=D(D)/D(BETA)
C      D1=D(D)/D(NZ)
C      DRXP=(T*P+STERM)*RXP2+(2.*STERM*RXP2-Q-P*STERM)
C      DALFA=DADALF*RXD4+DBDALF*RXP2+DCDALF
C      DBETA=ADDET*RXD4+DBDDET*RXP2+DCDDET
C      D1=4.*RXP2*RXB+2.*XB*RXB
C      DDXMAG=B.
C      DDKMAG=B.
C      DRXP=D(D)/D(N-PERP**2)
C      DRPX=D(N-PERP**2)/D(R)
C      DBY=D(N-PAR)/D(R)
C      D1=D(D)/D(N-PAR)
C      DO 50 I=1,3
C      DRBK(I)=LD*B(I)/BMAG
C      DRPK(I)=2.*LDS*(K(I)-KB*B(I)/BMAG)
C      DRX=B.
C      DO 45 J=1,3
C      DRBX=DRBK+LD*(J)*(BMAG*GRB1(J,I)-B(J)*GRB(I))/BMAG**2
C      CONTINUE
C      DRPX=-2.*RXP*DRBX
C      DDK(I)=D1*DKK(I)+DRXP*DRPK(I)
C      DDX(I)=DALFA*PFE0**2*GRD(I)+2.*DBETA*CFE0**2*BMAG*GRB(I)
C      +D1*DRBX+DRXP*DRPX
C      NOTE THAT DDDJ ACTUALLY EQUALS D(D)/D(OMEGA)*1/OMEGA
C      THIS MEANS THAT V-GROUP=OMEGA*DMAG, AND ALSO THAT WHEN
C      QUANTITIES ARE PRINTED OUT UNDER THE 'TIME' PARAMETRIZATION
C      TIME INTERVALS ARE IN UNITS OF 1./OMEGA.
C      DDDJ=-(2.*DALFA*ALFA)+2.*DBETA*BETA+2.*DRXP*RXP2+D1*(R/B)
C      DDKMAG=DKK*BMAG+DDK(I)**2
C      DDXMAG=DRX*BMAG+DDX(I)**2
C      50 CONTINUE
C
C      DDKMAG=SQRT(DDKMAG)
C      DDXMAG=SQRT(DDXMAG)
C      SEND=1.
C      IF (DDDU.LT.0.) SEND=-1.
C      DO 60 I=1,3
C      EITHER OF TWO CHOICES FOR DEFINITION OF DV (I.E. DIFFERENTIATION
C      BY LENGTHEN OR BY TIME) IS MADE BELOW.

```



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      IF (ABS(ZETA1) .GE. 5.) GO TO 75
CEC
CEC
C      NDAMP COUNTS NUMBER OF TIMES DAMPING MODULE CALLED.
      NDAMP=NDAMP+1
C      ZFLAG IS SET TO -1 IF DERY IS CALCULATING DAMPING
C      THIS PASSES THROUGH COMMON TO MAIN PROGRAM TO ALERT ODE
C      TO RE-EVALUATE STUFF AT BEGINNING OF EACH STEP.
      ZFLAG=-1
      CALL DAMP(ALFA,BETA,VTCORE,RXB,RXP,RX1)
      RXR=SQRT(RXB**2+RXP**2)
      TEMP=RXR/1.D
      XKIM=RX1/LD
      IF (NDAMP .EQ. 1)
1  WRITE (59,9797) TEMP,XKIM,V(1),V(2),V(3)
9797  FORMAT(' FIRST CALL TO DAMPING SUBROUTINE.',
1  // ' K-REAL =',1PE13.5,' K-IMAG =',1PE13.5,/,
1  // ' AT X,Y,Z =',3(1PE14.5)//)
C      HOLD(1) AND HOLD(2) PASS THROUGH COMMON BLOCK /PASS/ TO MAIN
C      PROGRAM FOR PRINTOUT ALONG RAY PATH.
      HOLD(1)=TEMP
      HOLD(2)=XKIM
C      DEFINE DIFFERENTIAL EQUATION WHOSE SOLUTION IS FRACTIONAL POWER
C      ABSORPTION, VIZ
      V(7)= 1 - EXP(-2*INTEGRAL(K-IMAG 'DOT' DS))
      DV(7)=2.*XKIM*CUSPHI*(1.-V(7))
      IF (IPRARM .EQ. 0) DV(7)=DV(7)*SQRT(DVMAG)
75  CONTINUE
C
C
C      CALCULATE PHASE PATH LENGTH
C
C      DV(7)=0.
C      DO 78 I=1,3
C78  DV(7)=DV(7)+V(I+3)*DV(I)*SQRT(LDS)
C
C
C ***** DOUGLERY *****
      IF (IDUG.LT.2) GO TO 920
      IF (IDUG.GT.0) GO TO 915
      WRITE (101,905) (V(I),I=1,10)
905  FORMAT(3H V ,10(1PE12.3))
      WRITE(101,910) (DV(I),I=1,7)
910  FORMAT(3H DV,7(1PE12.3))
      WRITE (101,900) D,DRXP,DALFA,DBETA,D1,DDKMAG,DDXMAG
915  ID=ID+1
      IF (ID.GT.2) ID=0.
920  CONTINUE
C ***** DOUGLERY *****
91  CONTINUE
C      INTERNAL CHECKS ON EQUILIBRIUM SELF-CONSISTENCY (EQUID SUBROUTINE)
C      THE FACT THAT V(8) REMAINS SMALL ALONG RAY (FOUND IN FOR102.DAT)
C      MEANS THAT THE DENSITY AND DENSITY GRADIENT ARE CONSISTENT WITH
C      EACH OTHER. V(9) IS THE ANALOGOUS QUANTITY FOR B-MAG.
      DV(9)=GRD(1)*DV(1)+GRD(2)*DV(2)+GRD(3)*DV(3)
      DV(9)=GRD(1)*DV(1)+GRD(2)*DV(2)+GRD(3)*DV(3)
      DO 904 I=1 10

```


>DERV.RAY

SUBROUTINE DERV (S,V,DV)

C DERV CALCULATES PARTIAL DERIVATIVES OF V-VECTOR WITH RESPECT
C TO ARCLENGTH S (IPARAM=1) OR LRT TIME (IPARAM=0).
C THIS VERSION OF DERV USES THE APPLETON-HARTREE
C DISPERSION RELATION.

C
C REAL K(3),KIM(3),KDOTB,KPAR,KPERP,KMAG,LDS
C DIMENSION V(10),DV(10),B(3),GRB(3),GRD(3),T(3),DR(3),DK(3)
C DIMENSION GRBIJ(3,3)
C COMPLEX XK(2),XKM,DIS,DDK,DDT,DDW,DDR(3),EPSS(3,3),XC(5)
C COMMON/PASS/IDAMP,ICONV,ZFLAG,HOLD(20)
C COMMON/NAMES/XNAME(10),NDERV,NDAMP
C COMMON IBUG,IO,IOI,CFE0,PFEB,BETAN,SGN,LDS,FMU,
C VTE,VTEHOT,VTI,IPARAM

C COMMON /STP/ ISTOP
C DATA KIM/-1.,0.,0./
C DATA NMH/-2./,NHAX/2./,IPARAM/1/,NDERV/0/
C DATA CONV/37.29577951/
C PASS INFORMATION THROUGH 'NAMES' BLOCK TELLING
C WHICH DISPERSION MODULE USED FOR CALCULATION.
C DATA XNAME(1)='APPLE'

C COUNT NUMBER OF TIMES DERV IS ACCESSED, APPEARS IN OUTPUT FILES
C CALL EQU1B(V,D,GRB,GRBIJ,D,GRD)

NDERV=NDERV+1

C VT=VTE
C FREQ=FMU
C BMAG=SQRT(B(1)**2+B(2)**2+B(3)**2)
C BETA=(CFE0*BMAG)**2
C ALFA=PFEB**2*D
C KMAG=0.
C KDOTB=0.
C DO 25 I=1,3
C K(I)=V(I)/43
C KMAG=KMAG+V(I+3)**2
C 20 KDOTB=KDOTB+K(I)*B(I)
C KMAG=SQRT(KMAG)
C KPAR=KDOTB/BMAG
C KPERP=SQRT(KMAG**2-KPAR**2)
C LDS=KPAR*SQRT(LDS)
C KXP=KPAR*SQRT(LDS)
C QUAN=KDOTB/BMAG/KMAG
C IF (QUAN.GT. 1.0) WRITE(59, 332)QUAN
C 332 FORMATT ' QUAN', E15.6
C THETA=ACOS(KDOTB/BMAG/KMAG)

C THAG=0.
C DO 25 I=1,3
C T(I)=K(I)*KDOTB-D(I)*KMAG**2
C 25 THAG=THAG+T(I)**2
C THAG=SQRT(THAG)

C C NORMALIZE K(I) AND T(I)

```

C
DO 30 I=1,3
T(I)=T(I)/TMAG
K(I)=K(I)/KMAG
30 CONTINUE
C
C
CS=KDOTB/OMAG/KMAG
SH=SQRT(1.-CS**2)
GAMMA=SQRT(BETA**2*SH**4+4.*BETA*(1.-ALFA)**2*CS**2)
D1=2.*ALFA*(1.-ALFA)
D2=2.*(1.-ALFA)-GAMMA*SH**2+SGN*GAMMA
C
C TEST FOR IMAGINARY INDEX OF REF (SPITZE)
C
IF (D1/D2.GT.1.) ISTOP=2
IF (ISTOP.EQ. 2) WRITE(59, 74)V(1),V(2),V(3),V(4),V(5),V(6)
74 FORMAT(' RAY CUTOFF: V 1-3 AND 4-6',3E16.8/3E16.8///)
C
C
C TEST FOR RESONANCE
C
IF (ABS(D1/D2).GT.500.) ISTOP=3
C
C***** DRUGGERY
IF (IBUG.LT.2) GO TO 901
IF (IQ.LT.1) WRITE (101,903)
903 FORMAT (/)
IF (IQ.LT.1) WRITE (101,900) V(1),ALFA,THETA,GAMMA,D1,D2,T
900 FORMAT (10(1PE12.3))
901 CONTINUE
C*****
C
C
C
C
C IF THIS IS FIRST TIME THROUGH , INITIALIZE KMAG TO
C BE A SOLUTION OF DISPERSION RELATION
C
IF (S.GE.0.) GO TO 40
ICNT USED INITIALIZE ZANLYT AT BEGINNING OF EACH REGION
C WHERE ZTEST LT 5 FOR DIFFERENT RAYS
ICNT=0
NDER?=1
NDAP?=0
KMAG=SQRT((1.-D1/D2)/LDS)
THETA=THETA*57.2958
WRITE(59,35) THETA,KMAG
WRITE (101,35) THETA,KMAG
35 FORMAT(//,' INITIAL ANGLE OF K WRT LOCAL B',
1 1PE10.3,5X,10HINITIAL K=,1PE10.3,/)
DO 37 I=1,3
37 V(I:3)=V(I+3)*KMAG
RETURN
C
C CALCULATE DERIVATIVES OF DISPERSION FUNCTION
C
40 DDK=-2.*K*ICM/LDS

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```

DDTHET=-2.*D1*SI*CS*(BETA-SGN*(BETA**2*SN**2-2.*BETA*
1(1.-ALFA)**2)/GAMMA)/D2**2
C
DRMAG=0.
DO 50 I=1,3
DR(I)=DDK*(I)+DTHET/KMAG*T(I)
50 DRMAG=DRMAG+DR(I)**2
C
C
DRMAG=SQRT(DRMAG)
C
DGDALF=(2.*(1.-2.*ALFA)*D2+2.*D1+SGN*D1*4.*BETA*(1.-ALFA)
1*CS**2/GAMMA)/D2**2
DGBET=D1*(SN**2-SGN*(BETA*SN**4+2.*(1.-ALFA)**2*CS**2)
1/GAMMA)/D2**2
C
DDW=KMAG**2*LDS-ALF/(DGDALF+BETA*DGBET)
SGND=1.
IF (REAL(DDW).LT.0.) SGND=-1.
C
IF IPARAM =1. THE RAYS ARE PARAMETRIZED
C
USING ARCLENGTH S AS THE RUNNING VARIABLE.
C
AT A CUTOFF, YOU WANT TIME TO BE THE RUNNING VARIABLE.(IPARAM=0)
DO 60 I=1,3
C
NOTE THAT THETA=ACOS(K.B) IS A FUNCTION OF POSITION, IN GENERAL.
DTHDR=0.0
DO 45 J=1,3
C
NOTE THAT K HERE IS A UNIT VECTOR.
DTHR=DTHDR+K(J)*(BMAG*GRB(J,I)-B(J)*GRB(I))/BMAG**2
45 CONTINUE
DTHR=-DTHR/SN
DK(I)=-(DGDALF*PFEB**2*GRD(I)+2.*DGBET*CFEB**2*DMAG*GRB(I))
1 +DTHR*DTHET
C
NEXT TWO LINES GIVE DERIVATIVES WRT ARCLENGTH
DV(I)=-SGND*DR(I)/DRMAG
DV(I+3)=SGND*DK(I)/DRMAG
IF (IPARAM .EQ. 1) GO TO 60
C
NEXT TWO LINES GIVE DERIVATIVES WRT TIME
DV(I)=-DR(I)/DDW
DV(I+3)=DK(I)/DDW
60 CONTINUE
C
CHOOSE DIRECTION OF K-IM TO BE ALONG THE GROUP VELOCITY.
C
AND CALCULATE COSPHI WHICH IS THE COSINE OF THE ANGLE BETWEEN KIM
C
AND V-GROUP(-DV).
KIM(1)=DV(1)
KIM(2)=DV(2)
KIM(3)=DV(3)
TEMP=0.0
COSPHI=0.0
BVMAG=0.0
DO 80 I=1,3
COSPHI=DV(I)*KIM(I)+COSPHI
BVMAG=BVMAG+DV(I)**2
TEMP=TEMP+KIM(I)**2
80 CONTINUE
C
DIVIDE BY MAGNITUDES TO FORM DOT PRODUCT
COSPHI=COSPHI/SQRT(BVMAG)/SQRT(TEMP)
C
IF (COSPHI .GT. 1.0) WRITE(59, 557)DV(1),DV(2),DV(3),
C
1KIM(1),KIM(2),KIM(3),COSPHI
557 FORMAT(' DV KIM COSPHI',/,3E20.18,/,
1 '-----',/,3E20.18,/,/,)

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      COSPHI=AMIN1(1.0,COSPHI)
      DV(7)=0.0
      XREAL=KIMAG*SQRT(LDS)
      XKIM=0.0
      ZTEST=(1.-SQRT(BETA))/VTE/XREAL/ABS(COS(THETA))
      ZTEST2=(1.-SQRT(BETA)*2.)/VTE/XREAL/ABS(COS(THETA))
C     ZTEST (ZTEST2) MEASURES PROXIMITY TO CYCLOTRON RESONANCE (SECOND
C     HARMONIC.). IF FAR OFF EITHER, CPU TIME SAVED BY NOT FINDING K-IMAG.
C     ZFLAG IS SET --1 IN DERV IF DAMPING IS BEING CALCULATED.
C     THIS PASSES THROUGH COMMON TO MAIN PROGRAM TO ALERT ODE
C     TO RE-EVALUATE STUFF AT BEGINING OF EACH STEP.
      ZFLAG=1.
C     IDAMP IS INPUT PARAMETER.
C     IDAMP=0 NO DAMPING CALCULATION
C     IDAMP=1 ONLY NEAR FIRST HARMONIC
C     IDAMP=2 ONLY NEAR SECOND
C     IDAMP=3 NEAR BOTH HARMONICS.
      IF (IDAMP.EQ. 0) GO TO 73
C     NEXT LINE RULES OUT SECOND HARMONIC CONTRIBUTION.
      IF (IDAMP.EQ. 1) ZTEST2=100.
C     NEXT LINE RULES OUT FIRST HARMONIC CONTRIBUTION
      IF (IDAMP.EQ. 2) ZTEST=100.
      IF (ABS(ZTEST).GT. 4.5 .AND. ABS(ZTEST2).GT. 4.5) GO TO 73
      CALL DAMP(ALFA,BETA,VTE,RXB,RXP,RXI)
      XKIM=RXI/SQRT(LDS)
      DV(7)=(2.)*XKIM*COSPHI*(1.-V(7))
      IF (IDAMP.EQ. 0) DV(7)=DV(7)*SQRT(DVMAG)
73    CONTINUE
C     THIS STOPS RAY WHEN IT IS COMPLETELY ABSORBED. HOPEFULLY
C     THIS WILL STOP X MODE RAYS FROM WINGING INTO EVANESC. REGION.
      IF (V(7).GE. .90) ISTOP=5
C     CALCULATE PHASE PATH LENGTH
C
C     DV(7)=0.
C     DO 70 I=1,3
C70   DV(7)=DV(7)+V(I+3)*DV(I)*SQRT(LDS)
C
C
C     ***** DAUGGERY
      IF (IBUG.LT.2) GO TO 920
      IF (IO.GT.0) GO TO 915
      WRITE (101,905) (V(I),I=1,10)
905   FORMAT(3H V ,10(IPE12.3))
      WRITE (101,910) (DV(I),I=1,7)
910   FORMAT(3H DV,7(IPE12.3))
C     CALL BACK(V)
      WRITE (101,906) DAK,DDTHET,DGDALF,DGDBET,DDW,KMAG,DRMAG
915   IO=IO+1
      IF (IO.GT.2) IO=0.
920   CONTINUE
C     *****
      DV(9)=GRB(1)*DV(1)+GRB(2)*DV(2)+GRB(3)*DV(3)
      DV(5)=GRD(1)*DV(1)+GRD(2)*DV(2)+GRD(3)*DV(3)
      HOLD(1)=XREAL
      HOLD(2)=XKIM
      RETURN
      END

```

```

>EPOLAR.RAY
C POLARIZATION VECTORS FOR APPLETON-HARTREE DISP. REL.
SUBROUTINE EPOLAR (S,V)
REAL K(3),KDOTB,KMAG,LDS
COMPLEX EPS(3,3),PL(3),PZ(3,3)
DIMENSION WK(25),EXH(3),EYH(3),EZH(3)
DIMENSION VK(18),W(18),B(3),GRB(3),GRD(3),T(3),DR(3),DK(3)
COMMON /BUG, IQ, IOI, CFEB, PFEB, BETANN, SGH, LDS, FMJ,
1 VTE, VTEROT, VI1, IPARAM
COMMON /STP/ ISTOP
C
C
CALL EQUID(V,B,GRB,D,GRD)
BMAG=SQRT(B(1)**2+B(2)**2+B(3)**2)
BETA=(CFEB*BMAG)**2
C
ALFA=PFEB**2*D
C
KMAG=0.
KDOTB=0.
DO 20 I=1,3
EZH(I)=B(I)/BMAG
K(I)=V(I+3)
KMAG=KMAG+V(I+3)**2
20 KDOTB=KDOTB+K(I)*B(I)
KMAG=SQRT(KMAG)
THETA=ACOS(KDOTB/BMAG/KMAG)
C
TMAG=0.
DO 25 I=1,3
T(I)=K(I)*KDOTB-B(I)*KMAG**2
25 TMAG=TMAG+T(I)**2
TMAG=SQRT(TMAG)
C
C NORMALIZE K(I) AND T(I)
C
DO 30 I=1,3
T(I)=T(I)/TMAG
K(I)=K(I)/KMAG
30 CONTINUE
C
C CONSTRUCT ORTHOG UNIT VECTORS EH- 1) PARALLEL TO D
C 2) PERP TO D IN D-K PLANE 39 PERP TO B AND K
C EZH=UNIT VECT PARALLEL TO D
C EYH = B CROSS K
C
EYH(1)=B(2)*K(3)-B(3)*K(2)
EYH(2)=B(3)*K(1)-B(1)*K(3)
EYH(3)=B(1)*K(2)-B(2)*K(1)
EYMAG=SQRT(EYH(1)**2+EYH(2)**2+EYH(3)**2)
C
C IF B PARALLEL TO K, THEN EXH AND EYH ARE ARBITRARY
C SO DEFINE EYH = B CROSS X-AXIS, EYH = Y-AXIS CROSS D
C
IF (CETMS.GT.1.E-7) GO TO 32
EYH(1)=0.
EYH(2)=EYH(3)
EYH(3)=-EYH(2)
EZH(1)=EZH(3)

```

```

      EXH(2)=0.
      EXH(3)=-EZH(1)
      GO TO 33
C
C B NOT PARO TO K, THEN EXH IN B-K PLANE
C
32   EXMAG=0.
      DO 325 I=1,3
      EXH(I)=KMAG*K(I)*BMAG**2-B(I)*KDOTB
      EYH(I)=C*YIG+EXH(I)**2
325   EYH(I)=EYH(I)/EYMAG
      EXMAG=SQRT(EXMAGS)
      DO 320 I=1,3
320   EXH(I)=EXH(I)/EXMAG
33   CONTINUE
C
C
C
      CS=KDOTB/BMAG/KMAG
      SH=SQRT(1.-CS**2)
C
      RINDS=KIAG**2*LDS
      BT=1.-DATA
      SIGN=1.
      IF (BT.LT.0.) SIGN=-1.
      IF (ABS(BT).LT.1.E-10) BT=1.E-10*SIGN
      A=ALFA/DT
C
C LOAD UP DISPERSION MATRIX
C
      EPS(1,1)=1.-A-RINDS*CS**2
      EPS(1,2)=CMPLX(0.,-SQRT(BETA)*A)
      EPS(1,3)=RINDS*COS(THETA)*SIN(THETA)
      EPS(2,1)=-EPS(1,2)
      EPS(2,2)=1.-A-RINDS
      EPS(2,3)=0.
      EPS(3,1)=EPS(1,3)
      EPS(3,2)=0.
      EPS(3,3)=1.-ALFA-RINDS*SN**2
C
C***** DOUGGERY
      IF (IDUG.LT.2) GO TO 40
      WRITE (101,35) S,(V(I),I=1,10)
35   FORMAT (//,F12.4,10E12.3)
      VAR=SHEPS
      WRITE (101,110) VAR
      WRITE (101,120) EPS
40   CONTINUE
C*****
C
C FIND EIG.VALUES AND EIG.VECTORS
C
C      DELETE FOR CRAY USE WHERE IMSL DOESNT EXIST*****
C      CALL EIGUC(EPS,S,3,2,PL,PI,3,UK,IER)
C
C FIND ZERO (OR SMALLEST) EIGENVALUE
C
      ELFIN=-1.E35

```

```

      DO 50 I=1,3
      IF (CABS(PL(I)).GT.PLMAX) GO TO 50
      PLMAX=CABS(PL(I))
      IP=1
53    CONTINUE
      C
      C MAG OF EIG VECTOR
      C
      PMAG=0.
      DO 60 I=1,3
      PMAG=PMAG+CABS(PZ(I,IP))**2
      PMAG=SQRT(PMAG)
      C
      C NORMALIZE E-FIELD VECTOR
      C
      DO 70 I=1,3
      V(I+7)=(CABS(PZ(I,IP))*EXH(I)+CABS(PZ(I,IP))*EYH(I)
      1+CABS(PZ(I,IP))*EZH(I))/PMAG
      C
      C*****DEBUGGERY
      IF (IDUG.LT.2) GO TO 100
      VAR=SHPERFM
      WRITE (101,110) VAR
      WRITE (101,120) WK(1)
      VAR=SH PL=
      WRITE (101,110) VAR
      WRITE (101,120) PL
      VAR=SH PZ=
      WRITE (101,110) VAR
      WRITE (101,120) PZ
110    FORMAT(1H ,A5)
120    FORMAT(1X,3(1PE12.3,1PE12.3,5X))
100    CONTINUE
      C*****
      C
      RETURN
      END

```



```

>TWOOMP.RAY
C DISPERSION RELATION FOR TWO COMPONENT, COLD PLASMA
C MODE=1 GIVES N**2 VS. THETA
C MODE=2 GIVES NZ**2 VS. N**2
C MODE=3 GIVES NX**2 VS. NZ**2
C MODE=4 GIVES D(NX**2, NZ**2)
C ALFA, BETA ARE QUANTITIES FOR ELECTRONS.
SUBROUTINE TWOOMP(ALFA, BETA, SGN, THETA, RS, RXS, RZS, MODE, DIS)
C IF N**2 .LT. 0 VALUE RETURNED FOR N IS -INFINITY.
COMPLEX REF2, DCOM
COMMON/DIAG2C/A, B, C, D, XRAY, YRAY, ZRAY, XX, XY, XZ
DATA FINITY/1.E30/, RM/5.4466231E-4/, RM1/1.00054466231/
DATA RM2/2.9665703E-7/
P=1.-RM1*ALFA
T=(1.-BETA)*(1.-RM2*BETA)
S=T-RM1*ALFA+RM1*RM1*ALFA*BETA
Q=T-2.*RM1*ALFA*(1.-RM1*BETA)+RM1**2*ALFA**2
C
GO TO (SGN, 100, 300) MODE-1
C
MODE = 1
CS=COS(THETA)**2
SN=1.-CS
N=T*P*CS+S*SN
B=-((1.+CS)*P*S+N*SN)
C=P*Q
D=B**2-4.*A*C
C
IF (D.LE.0.) GO TO 20
RS=-FINITY
RETURN
20 CONTINUE
RS=ROOT(A, B, C, SGN)
RXS=RS*SN
RZS=RS*CS
RETURN
C
C
C
MODE = 2
50 CONTINUE
A=T*P
B=-2.*P*Q+(T*P+S)*RXS
C=P*Q-(C*P*Q)*RXS+S*RXS**2
D=B**2-4.*A*C
C
IF (D.LE.0.) GO TO 70
RZS=-FINITY
GO TO 200
70 RZS=ROOT(A, B, C, SGN)
CU TO 200
C
C
C
MODE = 3
100 A=S
B=-(P*S+Q)+(S+T*P)*RZS
C=P*Q-2.*P*S*RZS+T*P*RZS**2
D=B**2-4.*A*C
C
IF (D.LE.0.) GO TO 120
665 PRINT*, B**2-4*A*C IS NEGATIVE HERE. ALFA BETA RXS RZS:

```

```

1  /,4E16.6//)
   RXS=-FINITY
   TYPE 666,XRAY,YRAY,ZRAY,XX,XY,XZ
666 FORMAT( ' X,Y,Z, KX,KY,KZ:',3E15.6/10X,3E15.6//)
   TYPE 665, ALFA,BETA,RXS,RZS
   GO TO 200
120  RXS=ROOT(A,B,C,SGN)
   C
   C
200  RS=RXS+PZS
   C  THETA=ACOS(SQRT(RZS/RS))
   RETURN
   C  MODE = 4
300  A=T*P
   D=-2.*P*S+(T*P+S)*RXS
   C=P*D-(Q+P*S)*RXS+S*RXS**2
   RS=RXS+RZS
   DENOM=(ABS(A*RZS**2)+ABS(B*RZS)+ABS(C))
   C  AVOID 0/0 FURN FOR PARALLEL PROPAGATION
   IF (ABS(RZS/RXS) .LT. 1.E-3) DENOM=1.
   DIS=(A*RZS**2+B*RZS+C)/DENOM
   RETURN
   END

```

```

FUNCTION ROOT(A,B,C,SGN)
C  THIS FUNCTIONS GIVES BETTER ROOTS OF QUADRATICS BY AVOIDING
C  CANCELLATION OF SMALLER ROOT.
   DISC=SQRT(B*B-4.*A*C)
   IF (B*SGN .GE. 0.0) GO TO 10
C  B AND SGN ARE OPPOSITE SIGN
   ROOT=(-B+SGN*DISC)/2./A
   RETURN
10  CONTINUE
C  B AND SGN ARE SAME SIGN
   ROOT=-2.*C/(B+SGN*DISC)
   RETURN
   END

```

```

>SLAB.RAY
SUBROUTINE EQUIA(V,B,GRD,GRBIJ,D,GRD)
  DIMENSION V(10),B(3),GRB(3),GRBIJ(3,3),GRD(3)
  REAL LDS
  COMMON IBUG,IO,IOI,CFE0,PFE0,BETANN,SGN,LDS,FNU,
1      VTE,VTEHOT,VTI,IPARAM
  COMMON/SLAB/ISLAB,RSLAB
  COMMON/HAMES/X(10)
  DATA IENTER/0/,X(2)"/SLAB"/

C
C
C
C
C      THIS SUBROUTINE DEFINES THE MAGNETIC FIELD AND PLASMA DENSITY
C      IN A PLANE STRATIFIED GEOMETRY.
C      THE USER CHOOSES ONE OF FOUR EQUILIBRIA BY SETTING ISLAB
C      IN THE INPUT DATA NAMELIST. THE POSSIBILITIES ARE:
C      ISLAB=1:  $D=(1+Z/RSLAB)$ ,  $D=1$ 
C               2:  $B=(1+X/RSLAB)$ ,  $D=1$ 
C               3:  $D=1$ ,  $D=(1+Z/RSLAB)$ 
C               4:  $B=1$ ,  $D=(1+X/RSLAB)$ 
C      WITH B IN THE Z DIRECTION FOR ALL FOUR CASES.
C      NOTE THAT YOU CAN CHOOSE RSLAB, THE SCALE LENGTH, TO HAVE
C      NEGATIVE VALUES AS WELL AS POSITIVE.
C
C
C
C
C      DO 2 I=1,3
C      B(I)=0.0
C      GRB(I)=0.0
C      GRD(I)=0.0
C      DO 2 J=1,3
C      GRBIJ(I,J)=0.0
C      CONTINUE
C      D(3)=1.0
C      D=1.0
C      GO TO (11,12,13,14) ISLAB
C
C
C      ISLAB=1
C      CONTINUE
C      B(3)=(1.+V(3)/RSLAB)
C      GRB(3)=1./RSLAB
C      GRBIJ(3,3)=1./RSLAB
C      RETURN
C
C
C      ISLAB=2
C      CONTINUE
C      B(3)=(1.+V(1)/RSLAB)
C      GRB(3)=1./RSLAB
C      GRBIJ(3,1)=1./RSLAB
C      RETURN
C
C
C      ISLAB=3
C      CONTINUE
C      D=(1.+V(3)/RSLAB)
C      GRD(3)=1./RSLAB
C      RETURN

```

```
C
C
C      ISLAB=4
      CONTINUE
      D=(1.+V(1)/RSLAB)
      GRD(1)=1./RSLAB
      RETURN
      END
```

```

>EQBC.RAY
SUBROUTINE EQU1B(V,BV,GRB,GRBIJ,D,GRD)
C   EQU1B CALLS NORM, BCOIL, AND TRANS AND SERVES
C   A. THE CONTROLLING SUBROUTINE TO COMMUNICATE BETWEEN
C   THOSE SUBROUTINES AND THE MAIN PROGRAM. EQU1B ALSO DEFINES
C   THE DENSITY FUNCTION. NORM DEFINES THE
C   SPECIFIC EQUILIBRIUM THE USER DESIRES AS WELL AS INITIALIZING
C   THE MAGNETIC FIELD AND DENSITY TO BOTH BE NORMALIZED TO
C   UNITY AT THE ORIGIN. DCOIL DOES THE ACTUAL CALCULATION OF
C   THE MAGNETIC FIELD IN CYLINDRICAL COORDINATES.
C   TRANS TRANSFORMS THESE RESULTS FROM CYLINDRICAL COORDINATES
C   INTO RECTANGULAR COORDINATES.
C
C   DIMENSION V(10),BV(3),GRB(3),GRD(3),GRBIJ(3,3)
C   REAL LDS
COMMON IOUG,IO,IO1,CFE0,PFEO,BETANN,SGN,LDS,FMJ,
1   VTE,VTEHOT,VTI,IPARAM
COMMON/HAMES/X(10),NDERV,NDAMP
COMMON/EOBC/NCIL,SEP,PCOIL,RNOT,DELTA,DINF
COMMON/ANNUL/DANNUL,GRPA(3)
DATA X(2)/'EQBC'/
DATA IENTER/0/

C   CALL NORM UPON FIRST ENTRY INTO EQU1B
C   IF (IENTER.EQ.0) GO TO 1
C   DINF, FROM COMMON/EOBC/, IS THE ASYMPTOTIC DENSITY
C   CALL NORM(D0,SINOT,CURREN)
DCONST=1.+DINF*(1.+D0)/(1.-DINF)
IENTER=1
1   CONTINUE

C   RHO=SQRT(V(1)**2+V(2)**2)
C   ZETA=V(3)

C   CALL BCOIL TO GET RESULTS IN CYLINDRICAL COORDINATES
C   CALL DCOIL(RHO,V(3),BRHO,BZETA,DBRDR,DBZDR,DBZDZ,S1,
1   NCIL,SEP,PCOIL,CURREN)

C   CALL TRANS TO TRANSFORM RESULTS INTO RECTANGULAR COORDINATES.
C   CALL TRANS(V,BRHO,BZETA,DBRDR,DBZDR,DBZDZ,BV,GRB,GRBIJ)

C   DENSITY IS A FUNCTION OF S1, THE MAGNETIC FLUX.
ARG=(S1-SINOT)/DELTA**2
P=(DCONST-TANH(ARG))/(DCONST+D0)
DNDST=-1./(COSH(ARG)*DELTA)**2/(DCONST+D0)
DNDZDZ=DNDST*BZETA
GRB(1)=DNDZDZ*V(1)
GRB(2)=DNDZDZ*V(2)
GRD(3)=-DNDST*GRHO*GRHO
SIPASS=S1

C   CALL ANN TO GET ANNULUS DENSITY FOR EBT ANNULUS MODELLING
C   BRNG=SQRT(BV(1)**2+BV(2)**2+BV(3)**2)
C   CALL ANN(S1,BRNG,DA,GRPA,NCIL,SEP,PCOIL,CURREN)
DANNUL=0

```

```

RETURN
END
SUBROUTINE ELLIP
COMMON/LLIP/ARG,SECOND,FIRST,TOL
DATA PI02/1.570796326794897/

```

```

THIS SUBROUTINE COMPUTES THE COMPLETE ELLIPTIC INTEGRALS (CEI)
OF THE FIRST AND SECOND KIND USING THE ITERATIVE METHOD OF THE
ARITHMETIC-GEOMETRIC MEAN. THE I/O PASSES THROUGH COMMON BLOCK
LLIP WITH 'ARG' BEING THE ARGUMENT AND THE RESULT BEING 'SECOND'
AND 'FIRST' WHICH ARE THE CEI OF THE SECOND AND FIRST KINDS.
THE ITERATION CONTINUES UNTIL THE ERROR IS LESS THAN 'TOL'.

```

```

A=1.0
AN=1.0
B=1.0-ARG
TWOP=0.50
SIG=0.50*ARG
B=SQRT(A*B)
A=AN
AN=(A+B)*0.50
CSQ=(A-AN)**2
TWOP=TWOP*2.0
SIG=SIG+TWOP*CSQ
IF(CSQ.GT.TOL) GO TO 10
FIRST=PI02/AN
SECOND=FIRST*(1.0-SIG)
RETURN
END

```

```

SUBROUTINE NORM(D0,SINOT,CURREN)
THIS NORMALIZES B AND PSI AT THE VERY BEGINNING
AND IS CALLED ONLY ONCE.
THIS IS DONE AUTOMATICALLY BY SUBROUTINE EQUIB.
NORM ALSO IS USED TO SET NCOIL,SEP,RCOIL,AND
CURREN FOR USE BY SUBROUTINE BCOIL.

```

```

REAL LDS
COMMON IEUG,IO,I01,CFE0,PF00,BETANN,SGN,LDS,FMU,
VTE,VTFHT,VFI,IPARAM

```

```

1 COMMON/EQBC/NCOIL,SEP,RCOIL,RNOT,DELTA,DINF
COMMON/NAMES/XC(10),NDSRV,HDAMP
DATA IENTER/0/

```

```

C IENTER FLAG PREVENTS NORM FROM BEING DONE MORE THAN ONCE.

```

```

IF (IENTER.GT.0) RETURN

```

```

C PARAMETERS FOR ORIL/TN

```

```

CURREN=1.0

```

```

C NCOIL=4

```

```

C RCOIL=10

```

```

C RNOT=8.

```

```

C DELTA 1.

```

```

C LN EDT-S PARAMETERS

```

```

C NCOIL=50

```

```

C SEP=2.*CM

```

```

C RCOIL=RN

```

```

C RNOT=RCOIL*RCOIL

```

```

C DELTA=RNOT/2.

```

```

C LN EDT-P PARAMETERS

```

```

C NCOIL=30

```

```

C      SEP=2.*ZM1-
C      RCOIL=RM
C      RNOT=18.
C      DELTA=RNOT/2.
C      DELTA=RNOT/4.

      RHO=0.0
      ZETA=0.0
      CALL BC0IL(RHO,ZETA,BR,BZ,DBRDR,DBZDR,DBZDZ,SI,
1 NCOIL,SEP,RCOIL,CURREN)

C
C      NORMALIZE THE B FIELD TO 1.
C      CURREN=1./BZ
C
C      RHO=RNOT
C      CALL AC0IL(RHO,ZETA,BR,BZ,DBRDR,DBZDR,DBZDZ,SI,
1 NCOIL,SEP,RCOIL,CURREN)
C      SINOT=SI
C      DEFINE D0 WHICH NORMALIZES THE DENSITY TO BE EXACTLY
C      UNITY AT R=0.
C      THIS MAKES THE DENSITY APPROXIMATELY .5 AT R=RNOT.
C      ARG0=SINOT/DELTA**2
C      D0=TANH(ARG0)
C      IENTER=1
C      PETURN
C      END

      SUBROUTINE BC0IL(RHO,ZETA,BRHO,BZETA,DBRDR,DBZDR,DBZDZ,SI,
1 NCOIL,SEP,RCOIL,CURREN)
      DIMENSION Z(100),XKSO(100),AA(100),B(100),C(100),D(100)
      COMMON/LLIP/ARGM,AE,AK,TOL

      DATA IENTER/0/,PERM0/1.2566 37051 43591 72953E-6/,BOUND/0.3/
1 ,TWOPI/6.2831 85307 17958 64769/

      THIS SUBROUTINE,ALONG WITH ELLIP, CALCULATES B,SI,GRAD B DUE TO A
      SET OF FILAMENTARY CURRENT LOOPS. A CYLINDRICAL COORDINATE
      SYSTEM IS USED AND ALL I/O IS IN THE MKS SYSTEM OF UNITS.RHO,ZETA
      DESIGNATE THE FIELD POINT IN THE CONVENTIONAL CYLINDRICAL
      COORDINATE SYSTEM WITH RHO MEASURED PERPENDICULAR TO THE LOOP
      AXIS AND ZETA MEASURED ALONG THE AXIS.
      THE LOOPS ARE EQUALLY SPACED AND COAXIAL WITH THE SAME RADIUS
      AND CURRENT. NCOIL SETS THE NUMBER OF LOOPS; PERMISSIBLE VALUES
      ARE UNITY OR ANY EVEN NUMBER (I.E. 100). FOR NCOIL = 1
      THE ORIGIN LIES IN THE CENTER OF THE LOOP. FOR NCOIL .GE. 2
      THE ORIGIN LIES AT THE CENTER OF THE INNER PAIR. THE USER
      SPECIFIES PARAMETERS OF THE CALCULATION THROUGH THE QUANTITIES
      NCOIL, SEP, AND RCOIL, AND CURREN.
      THESE REPRESENT THE NUMBER OF COILS, THE SEPARATION BETWEEN
      ADJACENT COILS, THE COIL RADIUS, AND THE CURRENT FLOWING IN EACH

```

```

C      COIL RESPECTIVELY.
C      FOR A GIVEN (RHO, ZETA) B, THE THREE DER. OF B AND SI ARE OUTPUT
C      QUANTITIES PASSED THROUGH THE CALLING STATEMENT.
C       $SI = (1/2 * PI) * \text{MAGNETIC FLUX ENCLOSED BY A FLUX TUBE}$ 
C      OF RADIUS RHO. THUS SI HAS THE USEFUL PROPERTY OF BEING CONSTANT
C      ON A FIELD LINE. SINCE THERE IS
C      ROTATIONAL SYMMETRY AND SINCE  $CURL(B) = 0$ , THERE ARE NO POLOIDAL
C      COMPONENTS AND  $DBRDZ = DBZDR$ .
C      BCOIL IS DESIGNED TO OPTIMIZE THE TRADEOFF FOR THE USER'S
C      COMPUTER BETWEEN MAXIMUM POSSIBLE ACCURACY AND REASONABLE
C      EXECUTION TIME. THIS RESULTS IN EXPRESSIONS
C      WHICH ARE ACCURATE TO WITHIN (NSIG-2) SIGNIFICANT FIGURES,
C      WHERE NSIG IS THE APPROXIMATE NUMBER OF SIGNIFICANT FIGURES
C      AVAILABLE (COMPUTED AUTOMATICALLY BELOW.)
C
C
C
C
C      IF (ENTER .GT. 0) GO TO 30
C      COMPUTE COEFFICIENTS FOR POWER SERIES EXPANSION.
C      ENTER=1
C      AA(1)=0.25
C      COMPUTE MACHINE EPSILON.
C      EPS=1.0
C      EPS=0.5*EPS
C      EPSP1=EPS+1.0
C      IF (EPSP1 .GT. 1.0) GO TO 5
C      EPS = 2.0*EPS
C      GET APPROXIMATE NUMBER OF SIGNIFICANT FIGURES AVAILABLE BY
C      ROUNDING DOWN -LOG(EPS) TO THE NEAREST INTEGER.
C      NSIG=-ALOG10(EPS)
C      NTERMS=1.9125*NSIG+3
C      IF (NSIG .GT. 100) STOP
C      TOL=10.*EPS
C      DO 20 N=2, NTERMS
C      AA(N)=AA(N-1)*((2.*N-1.)/(2.*N))*X2
C      TERM=0.0
C      DO 10 M=1, N-1
C      TERM=TERM+AA(M)/(2.*M-1.)
C      B(N)=1.-4.*N/(2.*N-1.)*AA(N)-TERM
C      C(N)=2.*N/(2.*N-1.)*AA(N)-AA(N-1)-2.
C      D(N)=(N-1)*B(N)
C      20 CONTINUE
C      30 CONTINUE
C      CONST=PCRM0*CHUREN/TWOPI
C      FNC=PERM0*CHUREN
C      N2=BCOIL/2
C      SEP2=SEP/2.
C      IF (NCOIL .EQ. 1) GO TO 60
C      DO 40 I=1, N2
C      Z(I)=SEP/2.*ZETA+(I-1)*SEP
C      DO 50 I=N2+1, NCOIL
C      Z(I)=(SEP/2.-ZETA+(I-N2-1)*SEP)
C      40 GO TO 70
C      50 CONTINUE
C      ONLY ONE COIL (NCOIL=1)
C      Z(1)=ZETA
C      60 CONTINUE
C      70

```



```

DUMA=RCOIL**2+R**2
DUIB=(RCOIL+R)**2
DUMC=RCOIL**2-R**2
DUIO=(RCOIL-R)**2
DUIE=RCOIL+R
DUIF=RCOIL-R
R32=R*SQRT(R)*0.0
R2=R*0.0
S1=0.0
DROR=0.0
BZETA=0.0
DBZDR=0.0
DBZDZ=0.0
DO 120 I=1, NCOIL
ZIS=Z(I)**2
T=(RCOIL+R)**2+ZIS
T12=SQRT(T)
T32=T*T12
TSO=T**2
TS2=TS2*T
ARGM=4.*RCOIL*R/T
ARGM2=ARGM*SQRT(ARGM)
C   CREATE ELLIPTIC INTEGRALS OF FIRST AND SECOND KIND AS FUNCTIONS OF ARGM.
CALL ELLIP
B/FAC=(DUMC-ZIS)/(DUMD+ZIS)
BZT=(BZFAC*AE+AK)*CONST/T12
C   REGULAR FORMULAS FOLLOW, THEY ARE OK FOR NOT TOO SMALL ARGM.
IF (ARGM.LT. BOUND) GO TO 50
BRFAC=(DUMA+ZIS)/(DUMD+ZIS)
BDRRT=CONST**2(I)*(BRFAC*AE-AK)/T12/R**2
DUMG=1.-ARGM
DUMG2=DUMG**2
DUMH=ARGM*DUMF
DUMI=1./DUMG+ARGM*DUMF/(DUMG2*R)+(DUMH-R2)/(DUMG*R)
DUMJ=(ARGM*DUIE-R2)/(DUMG*R2)
TEMP=(ARGM/(4.*RCOIL**2))**1.5
DBZDZT=-CONST**2(I)*TEMP*(DUMI*AE-DUMJ*AK)
DUMI=-((DUMH-R2)/(R2*DUMG*RCOIL)*DUIE)+(ARGM*DUMA-R2*RCOIL)/
1 (R*RCOIL*DUMG2)+(DUMH-R2)/(R2*DUMG)*(2.*RCOIL-DUMH)/(ARGM*RCOIL)
1 +(2.*RCOIL-DUMH)/(ARGM*DUMG*RCOIL)
DUMJ=- (DUIE/RCOIL+(2.*RCOIL-DUMH)/(ARGM*RCOIL)*(DUMH-R2)/
1 (R2*DUMG)+(2.*RCOIL-DUMH)/(ARGM*RCOIL))
DBZDRT=CONST*TEMP*RCOIL*(DUMI*AE+DUMJ*AK)
SIT=2.*CONST*RCOIL*R/ARGM/T12*((2.-ARGM)*AK-2.*AE)
GO TO 110
90  CONTINUE
C   SPECIAL FORMULAS FOR ARGM SMALL (ALSO TAKES CARE OF SINGULARITY
C   NEAR CYLINDRICAL AXIS, RHO=0.)
ARGM2=1.
DUMM2=0.0
SIT=0.0
DORDM=0.0
C0=2.*FAC*RCOIL**2*Z(I)/TS2
C1=RCOIL*FAC/T12
C2=-3.*RCOIL*F1/T
C3=.5*Z(I)*RCOIL*FAC/T32
C4=4.*RCOIL*(RCOIL**2-R**2+Z(I)**2)/TSO
C5=1.5*RCOIL*FAC/T32*(1.-3.*Z(I)**2/T)
C6=2.*Z(I)/T*ARGM

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```

DO 100 N=2, NTERM5
  BMM12=BMM12+A(N)*ARGNM2
  SIT=C*(1+C(N)*ARGNM2)*ARGM
  DORDM=DORDM+D(N)*ARGNM2
  ARGNM2=ARGNM2*ARGM
100 CONTINUE
  BRORT=BMM12*C0
  DBRDZ1=C5+DMM12*ARGM
  SIT=SIT*C1
  DORDM=DORDM*C3
  DBZDR1=C2*BRORT*AR
  DMDR=C4
  DMDZ=C6
  DBZDR=1+DORDR1+DBZDR1*DMDR
  DORDZ=1+DBRDZ1+DORDM*DMDZ
  DBZDZT=-DBZDR-BRORT
  DBZDRT=DBRDZ
110 CONTINUE
  DBZDR=1+DBZDRT+DBZDR
  DBZDZ=1+DBZDZT+DBZDZ
  BROR=BRORT+BROR
  BZETA=BZETA+BZT
  SI=SI+SIT
120 CONTINUE
C  BROR IS B-RADIAL/RADIUS.
  DBZDR=- (BROR+DBZDZ)
  DRHO=BROR*RHO
  RETURN
END
SUBROUTINE TRANS(V, BR, BZ, DBZDR, DBZIR, DBZDZ, B, GRB, GRBIJ)
  DIMENSION B(3), GRB(3), GRBIJ(3,3), V(10)
  X=V(1)
  Y=V(2)
  R=SQRT(X**2+Y**2)
  BMAG=SQRT(BR**2+BZ**2)
  IF (R .LT. 1.E-17) GO TO 10
  OK TO USE EXACT FORMULAE SINCE RHO IS NOT TOO TINY.
  COS=X/R
  SIN=Y/R
  DCDX=SIN**2/R
  DCDY=-SIN*COS/R
  DSDX=DCDY
  DSDY=-COS**2/R
  GRBR=(BR*DBZDR+DZ*DCZDR)/BMAG
  GRB(3)=(BR*DBZDR+DZ*DBZDZ)/BMAG
  GRB(1)=GRBR*COS
  GRB(2)=GRBR*SIN
  B(1)=GRB*COS
  B(2)=GRB*SIN
  B(3)=1Z
  GRBIJ(1,1)=COS**2*DBZDR+BR*DCDX
  GRBIJ(1,2)=COS*SIN*DBZDR+BR*DCDY
  GRBIJ(1,3)=COS*DBZDR
  GRBIJ(2,1)=GRBIJ(1,2)
  GRBIJ(2,2)=SIN**2*DBZDR+BR*DSDY
  GRBIJ(2,3)=SIN*DBZDR
  GRBIJ(3,1)=GRBIJ(1,3)
  GRBIJ(3,2)=GRBIJ(2,3)
  GRBIJ(3,3)=DBZDZ

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```

10      RETURN
C      CONTINUE
C      CARE IS NEEDED IN CALCULATING TERMS WHEN RHO IS TINY
C      QUANTITIES CORRECT IN RHO=0 LIMIT.
      B(1)=0
      B(2)=0
      B(3)=0Z
      DO 15 I=1,3
      DO 15 J=1,3
15      GRBIJ(I,J)=0
      GRBIJ(1,1)=DBRDR
      GRBIJ(2,2)=GRBIJ(1,1)
      GRBIJ(3,3)=DBZDZ
      GRB(1)=0
      GRB(2)=0
      GRB(3)=DBZDZ
      RETURN
      END

```

```

>ANN.RAY
      SUBROUTINE ANN(SI,B,DA,GRDA,NCOIL,SEP,RCOIL,CURREN)
      DIMENSION GRDA(3)
      DATA IENTER/0/
      IF (IENTER .GT. 0) GO TO 1
C      FIRST TIME IN SET UP PARAMETERS OF ANNULUS DENSITY PROFILE
C      RC=MIDPLANE RADIAL POSITION OF ANNULUS CENTER
C      RDEL=MIDPLANE RADIAL WIDTH OF ANNULUS
C      FALL=STEEPNESS OF FALL OFF
      RC=10.
      RDEL=2.
C      EBT-P
      RC=15.
      RDEL=4.
      Z=0.0
      CALL BCOIL(RC,Z,BR,B0,DBRDR,DBZDR,DBZDZ,S10,NCOIL,SEP,
1 RCOIL,CURREN)
      R=RC+RDEL
      CALL BCOIL(R,Z,BR,B0PD,DBRDR,DBZDR,DBZDZ,S10PD,NCOIL,SEP,
1 RCOIL,CURREN)
      SIDMC=S10PD-S10
      FALL=SIDMC/1.0
C      SET BC=BCUTOFF TO BE FRACTION OF E AT CENTER
      BC=1.1*B0
      CON1=1/SIDMC**2+1./FALL**2
      IENTER=1
1      CONTINUE
      SIFAC1=1.-((S1-S10)/SIDMC)**2
      IF (SIFAC1 .LT. 0.) SIFAC1=0.
      ARG=-((S1-S10)/FALL)**2
      SIFAC2=EXP(ARG)
      BFAC=((B-BC)/(BC-B0))**2
      IF (B .GT. BC) BFAC=0.
C      IF (B .LT. B0) BFAC=1.0
      DA=SIFAC1*SIFAC2*BFAC
      DA=DA/1.3
      RETURN
      END

```

```

>RAYPLT.RAY
  DIMENSION V(10),X1(3500),Y1(3500),Z1(3500),X(3500),Y(3500),F(10)
  DIMENSION LABLE(15),XNAME(10),ZERO(3500),TDATE(6)
C
  NAMELIST/DATE,IEQ,IO1,IO2,IBUG,IDAMP,DS,SMAX,PHI0,NPHI,DPHI,
1  THETA0,NTHETA,DTHETA,IX0X,IY0X,IZ0X,DX,DY,DZ,X0,Y0,Z0,SGN,PFE0,
2  CF00,FFU,TE,TEHOT,T1,XMAX,YMAX,ZMAX,RZ0,HRZ,DRZ,ISLAB,RSLAB,
3  NCOIL,RCOIL,RNOT,DELTA,DINF,IPARAM,SEP,RELERR,ABSERR,SCALE,
4  ICONV,CMPUTR,BETAHN,NMTHRL,NMAXRL
  DATA IRAY/1/,XHARR/6.0/,YHARR/7.1/,DELR/0.3/,XHAR2/7.1/
  OPEN (UNIT=10,FILE='FOR21.DAT',DEVICE='DSK:')
  READ(10,13)TDATE
13  FORMAT(5A5)
  TDATE(6)=' '$
  READ (10,DATA)
  WRITE (13,DATA)
  READ (10,26) (XNAME(I),I=1,10)
  LK=0
  LE=0
  ISEN=0
  TYPE 5
5  FORMAT(' K-VECTS?(0 OR 1) E-VECTS?(0 OR 1)')
  ACCEPT*,LK,LE
10  FORMAT(13)
  DO 12 I=1,15
12  LABLE(I)=' '$
  TYPE 15
15  FORMAT(' TYPE LABLE')
  ACCEPT 17,LABLE
17  FORMAT(15A5)
  LABLE(15)=' '$
C
C
  DS=1.
  DP=.1
C  LET F,AS CALCULATE BY RAYS CODE, BE THE FRACTION OF
C  MICROWAVE POWER ABSORBED. DEFINE THE FUNCTION F(I), TO
C  BE THE FRACTIONS OF POWER ABSORBED
C  WHICH ARE INDICATED ON THE RAY WITH AN ASTERISK.
  DO 777 I=1,10
777  F(I)=FLOAT(I)/10.
  CALL VNSTEC
C
  CALL BGNPL(1)
  CALL CROSS
C  SCALE ORDINATE TO JUST FIT ON PAGE IN VERTICAL DIRECTION.
C  THEN SCALE HORIZONTAL AXIS, WITH SAME SCALE FACTOR IF IT WILL
C  FIT ON PAGE. IF NOT, SCALE DOWN HORIZONTAL AXIS SO IT
C  JUST FITS ON PAGE.
  CALL MAXALF ('L/CST0')
  YAXIS=7.25
  XAXIS=ZMAX*7.2/1./XMAX
  IF (ZMAX .GT. 2.5*XMAX) XAXIS=8.75
  CALL PHYSOR(2.2,.53)
  CALL TITLE(1H,-1.6HZ (CM),6
1.6 X (CM),6,XAXIS,YAXIS)
  TSGN=SGN
C  -XMAX,XMAX ARE THE BOUNDS ON X FOR THE PLOTS.
C  -YMAX,YMAX ARE THE BOUNDS ON Y FOR THE PLOTS

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C      Q,ZMAX ARE THE BOUNDS ON Z FOR THE PLOTS.
      DELZ=ZMAX/4.
      XMIN=-XMAX
      DELX=XMAX/3.
      AMAX=AMAX1(XMAX,ZMAX)
      DEL=XMAX/4.
      AXMAX1=-AMAX.
      CALL GRAF(0.,DELZ,ZMAX,XMIN,DELX,XMAX)
      XLAB=XPOSN('LEFT','LOWER')+1.07
      YLAB=YPOSN('LEFT','LOWER')+1.07
      CALL MESSAG(LADLE,100,0.,YLAB)
      CALL MESSAG(TDATE,100,XMARR,YLAB)
C
C RAY LOOP
C
      IVEC=0
      SVEC=0.
      IPLOT=1
      NRAY=0
      NPIS=0
      SMAX=0.
C      ICHT TELLS WHICH PERCENTAGE TO PLOT FOR DECREMENT IN DAMPING
C      IKNT TELLS WHETHER FIRST POINT ON RAY FOR NORMALIZATION
C      OF K VECTOR LENGTH TO VALUE OF K AT FIRST POINT
      ICHT=1
      IKNT=1
      PMARK=F(1)
150    READ (10,20) S,(V(I),I=1,10)
C      TYPE 20,S,(V(I),I=1,9)
20    FORMAT(F12.4,10E12.3)
C
      IF (S.LT.-2.) GO TO 500
      IF (S.LT.0.) GO TO 200
      IF (S.GT.SMAX) SMAX=S
C
C VECTORS ARE PLOTTED AT INTERVALS OF DS
C IF S.GT.SVEC PLOT VECTOR AND INCREMENT SVEC BY DS
C
      IF (S.LT.SVEC) GO TO 160
      IVEC=1
      SVEC=SVEC+DS
C
C SECOND TIME PLOT Y VS X
C
160    NPIS=NPIS+1
      XI(NPIS)=V(1)
      YI(NPIS)=V(2)
      XVEC=V(3)
      YVEC=V(4)
      XE=XVEC+V(8)
      YE=YVEC+V(9)
      ENORM=ABS(V(8))+ABS(V(9))
C      NORMALIZE VECTOR MAGNITUDE TO FIRST POINT ON EACH RAY
      IF (IKNT.EQ.1)
1    VFINO=SQRT(V(4)**2+V(5)**2+V(6)**2)/(1.007*AMAX1(ZMAX,XMAX))
C      CONVERTING OUT NEXT LINE LEAVES IKNT AT 1 SO ALL K
C      VECTORS SAME LENGTH (NO RESONANCE EFFECT)
      IKNT=IKNT+1
      XE=XVEC+V(4)/VFINO

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      YK=YVEC+V(5)/VKMAG
      VKNORM=ABS(V(4))+ABS(V(5))
      IF (IPLUT.GT.1) GO TO 170
C
C FIRST TIME (IE IPLUT=1) PLOT X VS Z
C
      XI(NPTS)=V(3)
      YI(NPTS)=V(1)
C      MODIFY TO CONVERT Z AXIS TO X AXIS AND X AXIS TO Y AXIS
C      (GIVES X-Y PLOT). 1-29-81
C      XI(NPTS)=V(2)
C      YI(NPTS)=V(1)
      XVEC=V(3)
      YVEC=V(1)
      XE=XVEC+V(10)
      YE=YVEC+V(8)
      ENORM=ABS(V(10))+ABS(V(8))
      XK=XVEC+V(6)/VKMAG
      YK=YVEC+V(4)/VKMAG
C
C MARK DECREMENT IN WAVE POWER
C
170  CONTINUE
      IF ((V(7).LT.PMARK).OR.(SMAX.GT.1000.)) GO TO 180
      ICHT=ICHT+1
      ICHT=MIN0(ICHT,10)
      PMARK=F(ICHT)
      IF(ICHT.GT.10) PMARK=1.E5
      CALL RLNESS (**,1,XI(NPTS),YI(NPTS))
180  CONTINUE
      VKNORM=ABS(V(4))+ABS(V(6))
C
C IF VECTORS ARE TO BE PLOTTED THEY ARE DONE HERE
C INSIDE THE 100-200 LOOP. THEY ARE NOT PLOTTED IF THEY
C ARE TOO SHORT (I.E. NORM.LT.1)
C
      IF (IVEC.EQ.0) GO TO 150
      CALL DOT
      IF((CLK.GT.0).AND.(VKNORM.GT..1)) CALL RLVEC(XVEC,YVEC,XK,YK,0101)
      CALL RESET("DOT")
      IF((ENORM.GT.0.1).AND.(LE.GT.0)) CALL RLVEC(XVEC,YVEC,XE,YE,0101)
      IVEC=0
      GO TO 150
200  CONTINUE
C
C PLOT CURVES
C IF SMAX.GT.1000 THIS IS A FIELD LINE CURVE, SO DO
C NOT PLOT IF (PLOT.GT.0) (I.E. AN X-Y PLOT)
C
      IF ((IPLUT.GT.1).AND.(SMAX.GT.1000)) GO TO 100
C
      IF (SMAX.LT.1000.) NRAY=NRAY+1
      SVEC=0.
C      IF ((CLK+LE).GT.0) CALL DOT
C      IF (SMAX.GT.1000.) CALL DOT
      IF ((CLK+LE).LT.2).OR.(SMAX.GT.1000.))
1  CALL CURVE(XI,YI,NPTS,0)
      CALL RESET("DOT")
C

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XLAB=X1(NPTS)+.1
CALL HEIGHT(.1)
IF((CLK+LE).EQ.0).AND.(SMAX.LT.1000.))
1 CALL RLINT(IRAY,XLAB,Y1(NPTS))
CALL RESET('HEIGHT')

C
C      ADD A MESSAGE AND NUMBER ASSOCIATED WITH EACH
C      RAY AS IT IS TRACED OUT.
C      CURRENTLY SET UP TO PRINT OUT V(7) AT END OF RAY, WHICH IS
C      GO TO 6725
C      ELECTRON LANDAU DAMPING
      IF(IRAY.EQ.1)
1 CALL MESSAG('ELECTRON LANDAU DAMPING$',100,XMARR,YMARR)
      YMARR=YMARR-DELR
      CALL MESSAG('RAY #$',100,XMARR,YMARR)
      CALL INTNO(IRAY,'ABUT','ABUT')
      CALL REALNO(V(7),-3,XMAR2,YMARR)
      IRAY=IRAY+1
6725      CONTINUE
      GO TO 100
500      IF (IPILOT.GT.1) GO TO 1000
C
      OPEN (UNIT=10,FILE='FOR21.DAT',DEVICE='DSK:')
      XMARL=-2.05
      XMAR2=-1.40
      XMAR3=-1.25
      YMAR=7.1
      NSIG=3
      DEL=.5
      IF(ISGN.LT.0) CALL MESSAG('MINUS BRANCH$',100,XMARL,YMAR)
      IF(ISGN.GT.0) CALL MESSAG('PLUS BRANCH$',100,XMARL,YMAR)
C      CALL MESSAG('INPUT DATA$',100,XMARL,YMAR)
      YMAR=YMAR-1.9*DEL
      CALL MESSAG('PFE0$',100,XMARL,YMAR)
      CALL REALNO(PFE0,3,XMAR2,YMAR)
      YMAR=YMAR-DEL
      CALL MESSAG('CFE0$',100,XMARL,YMAR)
      CALL REALNO(CFE0,3,XMAR2,YMAR)
      YMAR=YMAR-DEL
      CALL MESSAG('FIU $',100,XMARL,YMAR)
      CALL REALNO(FIU,3,XMAR2,YMAR)
      YMAR=YMAR-DEL
      CALL MESSAG('TE $',100,XMARL,YMAR)
      CALL REALNO(TE,3,XMAR2,YMAR)
      YMAR=YMAR-DEL
      CALL MESSAG('RM $',100,XMARL,YMAR)
      CALL REALNO(RI,3,XMAR2,YMAR)
      YMAR=YMAR-DEL
      CALL MESSAG('TE $',100,XMARL,YMAR)
      CALL REALNO(TE,3,XMAR2,YMAR)
      YMAR=YMAR-DEL
      CALL MESSAG('PFEH $',100,XMARL,YMAR)
      CALL REALNO(PFEH,3,XMAR2,YMAR)
      YMAR=YMAR-DEL
      CALL MESSAG('NZ0 $',100,XMARL,YMAR)
      CALL REALNO(RZ0,3,XMAR2,YMAR)
      YMAR=YMAR-DEL
      CALL MESSAG('DNE0$',100,XMARL,YMAR)
      CALL REALNO(DNE0,3,XMAR2,YMAR)

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      YMAR=YMAR-3.*DEL
      CALL MESSAG('MODELS USED:$',100,XMARL,YMAR)
      YMAR=YMAR-.4*DEL
C      READ IN LITERAL INFO. TELLING WHICH MODELS USED.
      READ(10,DATA)
      READ(10,26) (XNAME(I),I=1,10)
26      FORMAT(IX,A5)
      DO 125 I=1,10,2
      YMAR=YMAR-.6*DEL
      DUM=XNAME(I)
      CALL MESSAG(DUM,5,XMARL,YMAR)
      DUM=XNAME(I+1)
      CALL MESSAG(DUM,5,XMAR3,YMAR)
125      CONTINUE
C      IF NEXT THREE LINES ARE COMMENTED OUT, THEN BOTH X-Z
C      AND X-Y PLOTS WILL BE CREATED. IF ALLOWED TO BE EXECUTED, THE
C      NEXT THREE LINES ALLOW ONLY THE X-Z PLOT TO BE MADE.
C      CALL ENDPL(1)
C      CALL DONEPL
C      RETURN
      CALL ENDPL(1)
      CALL DGNPL(2)
      CALL MIXALF('L/CSTD')
C      CALL CROSS
      CALL TITLE(1H,-1.6HX(CM),6
1,6HY(CID,6:6,6)
      CALL HDG(1SGN,LK,LE)
      YMIN=YMAX
      DELY=YMAX/4.
      CALL GRAF(XMIN,DELY,XMAX,YMIN,DELY,YMAX)
C
      XLAB=X*DSN('LEFT','LOWER')+.87
      YLAB=Y*DSN('LEFT','LOWER')+.87
      CALL MESSAG(LABE,100,XLAB,YLAB)
C
      OPEN(UNIT=10,FILE='FOR21.DAT',DEVICE='DSK:')
      READ(10,DATA)
      READ(10,26) (XNAME(I),I=1,10)
C
C
C      *** SKIP FOR SLAB ***
C      GO TO 700
      DO 600 I=1,201
      X(I)=XMIN+XMAX/100.*(I-1)
      Y(I)=YMIN+YMAX/100.*(I-1)
      ZERO(I)=0.
      T=3.14159*(I-1)/100.
      X1(I)=XMAX*COS(T)
600      Y1(I)=YMAX*SIN(T)
C
      CALL DASH
      CALL CURVE(X1,Y1,201,0)
      CALL CURVE(X,ZERO,201,0)
      CALL CURVE(ZERO,Y,201,0)
      CALL RESET('DASH')
700      CONTINUE
C      *****
      IPLOT=IPLOT+1
      GO TO J

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```

      IVEC=0
      SVEC=0.
      GO TO 100
C
1000 CONTINUE
      CALL DUNEPL
      END
C
C PLOT HEADINGS
C
      SUBROUTINE HDG(ISGN,LK,LE)
      NLIN=LK+LE+1
      IF -(ISGN.I.T.0) CALL HEADIN ('MINUS BRANCH
1 PROPAGATIONS',-100,1.3,NLIN)
      IF (ISGN.GT.0) CALL HEADIN ('PLUS BRANCH
1 PROPAGATIONS',-100,1.3,NLIN)
      IF (LK.GT.0) CALL HEADIN('DOTTED VECTORS=WAVE
1 VECTORS',100,1.,NLIN)
      IF (LE.GT.0) CALL HEADIN(' SOLID VECTORS=ELECTRIC FIELD
1 POLARIZATIONS',100,1.,NLIN)
      RETURN
      END
C
CC TEST FRDCHT
C
C COMPLEX Z,F
C
C X=0.0E+0
C
C DO 1 I=1,11
C
C Y=0.0E+0
C
C DO 2 J=1,11
C
C Z=CMPLX(X,Y)
C
C CALL FRDCHT(Z,F)
C
C PRINT 100,Z,F
C
C 100 FORMAT(1H,2F10.3,5X,2E16.0)
C
C 2 Y=Y+2.0E+0
C
C 1 X=X+2.0E+0
C
C STOP
C
C END

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>ZFUN.RAY
SUBROUTINE ZFUN(Z,FU)
C
C ROUTINE WHICH EVALUATES THE PLASMA DISPERSION FUNCTION. USES
C NUMERICAL INTEGRATION (ABSOLUTE VALUE OF THE COMPLEX ARGUMENT, Z,
C LESS THAN 5) OR ASYMPTOTIC EXPANSION.
C
C COMPLEX Z,FU,TEMP1,TEMP2,Z2,TP10D
C DIMENSION C(21),D(21),E(21),F(21),W(21)
C DATA DELTA/5.0E-1/, Y1/-1.0E+0/, N/21/, ITEST/0/
C DATA ZERO/0.0E+0/, OSUPI/5.6418958355E-1/, TP1/6.28318530718E+0/
C
C IF (ITEST .EQ. 1) GO TO 1
ITEST=1
C*** DEFINE WEIGHTS AND STORE CONSTANTS USED FOR INTEGRATION.
C*** WEIGHTS ARE DERIVED FROM A 3 POINT INTEGRATION SCHEME.
NM3=N-3
CONO1=DELTA*OSUPI
W(1)=CONO1*3.75E-1
W(2)=CONO1*1.1666666667E+0
W(3)=CONO1*9.5833333333E-1
DO 20 I=1,3
20 W(N-1+I)=W(I)
DO 30 I=4,NM3
30 W(I)=CONO1
N02=N/2
N02P1=N02+1
X=ZERO
Y=Y1
E(N02P1)=X
F(N02P1)=Y
TEMP1=CMPLX(X,Y)
TEMP2=CEXP(-TEMP1*TEMP1)
C(N02P1)=REAL(TEMP2)*W(N02P1)
D(N02P1)=AIMAG(TEMP2)*W(N02P1)
DO 200 I=1,N02
X=DELTA*FLOAT(I)
NP1=N02P1+I
NM1=N02P1-I
TEMP1=CMPLX(X,Y)
TEMP2=CEXP(-TEMP1*TEMP1)
C(NP1)=REAL(TEMP2)*W(NP1)
C(NM1)=REAL(TEMP2)*W(NM1)
D(NP1)=AIMAG(TEMP2)*W(NP1)
D(NM1)=AIMAG(TEMP2)*W(NM1)*(-1.0E+0)
E(NM1)=-X
E(NP1)=X
F(NP1)=Y
F(NM1)=Y
200 CONTINUE
TP10D=TP1/DELTA
TP10D=CMPLX(ZERO,TP10D)
C*** BEGIN CALCULATIONS.
1 G=REAL(Z)
Y=AIMAG(Z)
H=ABS(Z)
Z2=Z*CONJUG(Z)
IF (Z2 .GE. 2.5E+1) GO TO 5
Z=Z*Z

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```

C*** NUMERICAL INTEGRATION.
C*** F=1/SQRT(PI)*SUM OF...U(I)*EXP(-X(I)**2)/(X(I)-Z)...I=1,N.
C*** INTEGRATION IS ALONG A LINE X(I) IN THE COMPLEX PLANE, WHERE
C*** THE IMAGINARY PART OF X(I)=YI AND THE DIFFERENCE BETWEEN
C*** SUCCESSIVE REAL PARTS OF X(I)=DELTA. LIMITS OF INTEGRATION
C*** ARE FROM -DELTA**1/2 TO DELTA**1/2.
C*** COMPUTE THE INTEGRAL BY TAKING THE SUM FROM 1 TO N OF THE
C*** CONSTANTS DIVIDED BY X(I)-Z. USES REAL ARITHMETIC.
      ZR=0.0E+0
      ZI=0.0E+0
      DO 7 I=1,N
        A=E(I)-G
        B=F(I)-H
        DEN=A**2+D**2
        ODEN=1.0E+0/DEN
        ZR=ZR+(A**2+D**2)*ODEN
        ZI=ZI+(A*D(I)-B*C(I))*ODEN
      7 CONTINUE
C*** ADD THE CORRECTION TERM.
      FU=CMPLX(ZR,ZI)+(0.0E+0,-3.5449877018E+0)*CEXP(-Z2-TP10D*
      * (H-YI)+TP110D*G)
      IF (YY .GE. ZERO) GO TO 6
C*** IMAGINARY PART OF ARGUMENT IS NEGATIVE.
      FU=CONJG(FU)+(0.0E+0,3.5449877018E+0)*CEXP(-Z2)
      GO TO 6
C*** MAGNITUDE OF ARGUMENT IS GREATER THAN 5, USE
C*** ASYMPTOTIC EXPANSION.
      5 CALL AEXPAN(Z,G,H,YY,FU)
      6 RETURN
      END
      SUBROUTINE AEXPAN(Z,G,H,YY,FU)
C
C ROUTINE WHICH COMPUTES THE PLASMA DISPERSION FUNCTION USING
C ASYMPTOTIC EXPANSION. IF THE IMAGINARY PART OF THE ARGUMENT, YY,
C IS EQUAL TO ZERO REAL ARITHMETIC IS USED.
C
      COMPLEX Z,FU,A,Z2,OZ2
      DATA ZERO/0.0E+0/, N/8/
C
      IF (YY .EQ. ZERO) GO TO 1
C*** COMPLEX ARITHMETIC.
      Z2=Z**2
      OZ2=1.0E+0/Z2
      FU=-1.0E+0/Z2
      A=FU
      EN=5.0E-1
      DO 10 I=1,N
        A=EN*A+OZ2
        FU=FU+A
      10 EN=EN+1.0E+0
      IF (YY .GT. ZERO) GO TO 30
      IF (H .GT. SQRT(EN**2+1.77E+2)) GO TO 20
      FU=FU+(0.0E+0,3.5449877018E+0)*CEXP(-Z2)
      GO TO 30
C*** ERROR STOP TO AVOID OVERFLOW.
      20 PRINT *,(51,100) Z
      103 FORMAT('X',F14.6,'Y',F14.6,'E',F14.6)
      * * 100 STOP, ARG =',IP2E14.6)
      * *

```

C*** REAL ARITHMETIC.

```
1 X2=4/G
  OX2=1.0E+0/X2
  F=-1.0E+0/G
  B=F
  EN=5.0E-1
  DO 11 I=1,N
    B=EN*B*OX2
    F=F+B
11 EN=EN+1.0E+0
  C=1.7724538509E+0*EXP(-X2)
  FU=CMPLX(F,C)
30 RETURN
  END
```

C

C

C TWO POL APPROXIMATION

C

```
  SUBROUTINE Z2P(Z,F)
    COMPLEX Z,F
    F=CMPLX(.5,.81)/(CMPLX(.51,-.81)-Z)-CMPLX(.5,-.81)
    1/(CMPLX(.51,.81)+Z)
    RETURN
  END
```

```

>DAMPEC.RAY
SUBROUTINE DAMP (ALFA,BETA,VTE,RZ,RX,R1)
COMPLEX Z,ZC,Z1,Z2,DWARM,RINDEX
COMMON NAMES,XNAME(10),NDRV,NDAMP
DATA XNAME(4) /'DAMP' /

C
C
R1=0.
RR=0.
ZETA=(1.-SQRT(BETA))/VTE/RZ
IF (ZETA.GT.5.) RETURN

C
C
RZ2=RZ**2
RX2=RX**2
R2=RZ2+RX2
R=SQRT(R2)

C
C
A1=1.-ALFA
B1=1.-BETA

C
C
A=A1-BETA
B=-(A1*A1+A1**2-BETA)+(A+A1*B1)*RZ2
C=A1*(A1**2-BETA+B1*RZ2**2-2.*A*RZ2)
D=A**2*RZ2**2+B*RX2+C

C
C
ZC=CMPLX(ZETA,0.)
CALL ZFUN (ZC,Z)
Z1=ZETA+1./Z
Z2=1.+ZETA*Z

C
C
BRT=SQRT(BETA)
Q1=ALFA/2./(1.+BRT)
Q1=1.-Q1
Q2=1.-2.*Q1

C
D0=R2*RX2-A1*(R2+RZ2)-2.*Q2*RX2+2.*A1*Q2
D1=Q1**2*RX2+A1*R2*RZ2-Q1*A1*(R2+RZ2)-Q2*RX2+Q2*A1
D2=ALFA/BRT*(R2*RX2-Q2*RX2)+ALFA**2-BETA/4.
D3=RX2/RZ2*((R2+RZ2)-2.*Q2)
D3=ALFA*(R2*RZ2-D1*(R2+RZ2)+Q2)
DPRIME=-ALFA*(1.+BRT)/2.*D0+D1*D1

C
C
DWARM=-(1.+BRT)*S2*VTE*(D1+D2+R*Z/RZ/2.*VTE*ZETA*D3)*Z1
DCX=2.*RX*(2.*A+Q2*RX2+B)
DCZ=2.*RZ*((A+B1*Q1)*RX2+A1*(2.*B1*RZ2-2.*A))

C
C
RINDEX= DWARM/(R*DCX+RZ*DCZ)*R+CMPLX(R,0.)
R1=LOG(RINDEX)
R2=REAL(RINDEX)
RETURN
END

```

>DAMPLH.RAY

C REFRACTIVE INDEX FOR TWO COMPONENT PLASMA WITH
C ELECTRON LANDAU DAMPING

C

SUBROUTINE DAMP(ALFA,BETA,VTE,RZ,RX,RXI)
COMMON/NAME5/NAME(10)
DATA NAME(4)/'DAMPLH'/
DATA FINITY/1.E38/,RM/5.4466231E-4/,RM1/1.00054466231/
DATA RM2/2.96E-70SE-7/

P=1.-RM1*ALFA
T=(1.-BETA)*(1.-RM2*BETA)
S=T-RM1*ALFA+RM*RM1*ALFA*BETA
Q=T-2.*RM1*ALFA*(1.-RM*BETA)+RM1**2*ALFA**2

C

RXS=RX**2
RYS=RZ**2
RS=RXS+RYS
SH=RXS/RS
CS=RYS/RS
A=1+P*CS+S*SH
B=-((1.+CS)*P+S+Q*SH)
C=P*Q
D=B**2-4.*A*C
KXK=SQRT(RS)
RXI=0.0
Z=1./VTE/RZ
IF (ABS(Z).GT.4.) RETURN

C

D1=T*CS*PS**2-(1.+CS)*S*RS+Q
D2=RXR*(4.*A*RS+2.*B)

C

RXI=-3.5449877*ALFA*D1**3*EXP(-Z**2)/D2
RETURN
END

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