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COMPUTER PROGRAMS FOR PLANE COLLISIONLESS SHEATHS BETWEEN FIELD-MODIFIED EMITTER AND THERMALLY IONIZED PLASMA EXEMPLIFIED BY CESIUM

By Susan L. Button and James F. Morris

Lewis Research Center
Cleveland, Ohio

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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SUMMARY

Two computer programs coded in FORTRAN IV are described for plane collisionless positive-ion and electron emission sheaths. Given the emitter temperature, emitter work function, atomic ionization potential, plasma electron and ion number density, and plasma electron, ion, and atom temperatures, the programs compute current densities, potential drop through the sheath, charge density, electron field, and sheath distance.

INTRODUCTION

Methods to calculate the properties of sheaths between a thermally ionized plasma and a field-modified emitter of electrons, ions, and atoms are programmed in FORTRAN IV for the IBM 7094. References 1 and 2 give the background, theory, and many results for emission sheaths and also graphic correlations for sheath characteristics in cesium plasmas. The examples herein are specific for a cesium plasma. The programs are general and convert readily to other plasmas by replacing the minimum mean free path, vapor pressure, ionization potential, and masses of the atom and ion of cesium with those of the desired chemical. Computing procedures for the positive-ion and electron sheaths appear as FORTRAN programs in appendixes A and B. Appendix C defines the FORTRAN variables and corresponding output labels. Appendix D defines additional FORTRAN variables and constants. Flow diagrams of the programs appear in figures 1 and 2.

SYMBOLS

E	electric field
e	electronic unit charge
h	Planck's constant
I	ionization potential
J	overall net current
j	current density or net particle current density
m	particle mass
N	particle number density
p	pressure
T	temperature
V	potential
ΔV	potential relative to plasma potential
X	distance from emitter
κ	Boltzmann constant
λ	mean free path for charge exchange in emitter temperature range
λ_D	plasma Debye length, $\approx 6.9\,(T_{ep}/N_{ep})^{1/2}$
λ_{DE}	emission Debye length, $\approx 6.0\,(T_E/N_{ep})^{1/2}$
φ	work function
φ_o	plasma potential for near-equilibrium positive-ion sheath

Subscripts:

a	atom
E	emitter
e	electron
i	ion
p	plasma
S	overall sheath
ΔV	potential relative to plasma potential
vp	vapor pressure

DESCRIPTION OF INPUT

The input for one case requires one value each of T_E, φ, N_{ep}, T_{ep}, and T_{ip}. The ranges of the conditions used in the calculations for cesium plasmas are 1400° to 2400° K for the electrode temperature, 1600° to 2400° K for the plasma atom and ion temperatures, 1700° to 2700° K for the plasma electron temperature, 10^{12} to 10^{15} for electron number density, and 1.5 to 5.0 volts for the work function. The work function is an assigned variable; the equilibrium value for no sheath was obtained by solving for the Saha-Langmuir null point

$$\varphi_o = \frac{\kappa T}{e}\left(\frac{3}{2} \ln T - \ln N_{ep} + \frac{3}{2} \ln \frac{2\pi m_e \kappa}{h^2} + \ln 2\right) \tag{1}$$

and choosing three or four values of φ above this point for the positive ion sheath calculations, and three or four values below the null point for the electron sheath calculations.

More than one case can be run during one machine access. On the 7094 II-DCS, approximately six cases can be run in 1 minute.

Input card preparations for the Positive-Ion and Electron Sheath Programs are identical. A single digit integer in column 5 of the first card is IWRITE, the variable that controls the desired output. If IWRITE = 0, results for Richardson-Dushman (refs. 3 to 5) and Schottky (ref. 6) are printed. If IWRITE = 1, the Richardson-Dushman output is eliminated. The remaining cards are in five groups. In each group the first card (an integer in cc4-5) indicates the number of values to be read from the successive cards of that group (Format 8E10.2):

Group	Fortran variable name of count ($\leq$10)	Fortran array variable	Description	Equation variable
I	II	TE	Emitter temperature	T_E
II	JJ	PHI	Emitter work function	$e\varphi$
III	KK	EPN	Plasma electron number density	N_{ep}
IV	LL	TEP	Plasma electron temperature	T_{ep}
V	LA	TIPP	Plasma ion temperature	T_{ip}

A second set of five groups of input data cards may follow; IWRITE is not included after the first set is read in.

In order to convert the programs from a cesium plasma to a plasma of another element, replace the ionization potential, AI, (FORTRAN statement 301; mass of the atom, AM, (302); vapor pressure, PTEST, (303); and minimum mean free path, AMTEST, (304) with those of the desired element.

METHOD OF CALCULATION

The programs described deal specifically with a cesium plasma; therefore, the tests and constants used are characteristic of cesium. As mentioned earlier in the section DESCRIPTION OF INPUT, the programs can be converted to handle another chemical if desired. The calculations in the programs assume $m_i = m_a$ and $N_{ip} = N_{ep}$.

Before major calculations begin, the input values must satisfy two tests. First, the Debye shielding length (AMDA) must be less than the low-energy mean free path for cesium charge exchange (AMTEST). This enables the model to be collisionless. Second, the vapor pressure of cesium at the emitter temperature (PTEST) must be less than the effective plasma pressure (PPT). The equations for these variables are as follows:

$$\mathrm{AMDA} = \left[\frac{\kappa}{(4\pi)(0.511\times 10^{6})(2.82\times 10^{-13})}\right]^{1/2}\left(\frac{T_{ep}}{N_{ep}}\right)^{1/2}, \ \mathrm{cm} \tag{2}$$

$$\mathrm{AMTEST} = 10^{12}\ N_{ap}^{-1}, \ \mathrm{cm} \tag{3}$$

$$\mathrm{PTEST} = \frac{\mathrm{anti\ log}\left(-\dfrac{3920.38}{T_E} - 0.51978 \log T_E + 10.71914\right)}{133.322}, \ \mathrm{torr} \tag{4}$$

$$\mathrm{PPT} = \frac{(82.06)(760)}{6.023\times 10^{23}}\left(2N_{ep}T_{ip} + N_{ap}T_{ap}\right), \ \mathrm{torr} \tag{5}$$

$$(133.322\ (\mathrm{N/m^2})/\mathrm{torr})$$

If the input for one case passes the preceding tests, calculations continue; otherwise, another case with a new N_{ep} is begun.

The Richardson-Dushman equation and $e\varphi' = e\varphi$ yield the current densities if the effects of the sheath field at the emitter, E_E are omitted.
Electron emission current density:

$$j_{eE} = 120\, T_E^2 \exp\left(- \frac{e\varphi'}{\kappa T_E}\right) \tag{6}$$

Plasma current density:

Electron:

$$j_{ep} = \frac{1.602\times10^{-19}\, N_{ep}}{2}\left(\frac{2\kappa T_{ep}}{\pi m_e}\right)^{1/2} \tag{7}$$

Ion:

$$j_{ip} = \frac{1.602\times10^{-19}\, N_{ip}}{2}\left(\frac{2\kappa T_{ip}}{\pi m_i}\right)^{1/2} \tag{8}$$

Atom:

$$j_{ap} = \frac{1.602\times10^{-19}\, N_{ep}^2\left(\frac{2\kappa T_{ap}}{\pi m_a}\right)^{1/2}}{2\left(\frac{2\pi m_e \kappa T_{ep}}{h^2}\right)^{3/2} \exp\left(- \frac{eI}{\kappa T_{ep}}\right)} \tag{9}$$

Equations (6) to (9) are the same for positive-ion and electron sheaths.

In order to calculate the current densities through the sheath, a need arises for the overall potential sheath drop ΔV_S. A first approximation is made by using the charge density equations $\rho_{\Delta V}$ and conditions at the plasma, sheath interface, where $\Delta V = 0$. The following equations define the charge density, equation (10) for the positive-ion sheath and equation (11) for the electron sheath.

Positive-ion sheath (ΔV_S positive):

$$\rho_{\Delta V} = \frac{j_{eE}\left\{1 - \operatorname{erf}\left[\frac{e(\Delta V_S - \Delta V)}{\kappa T_E}\right]^{1/2}\right\}\exp\left[\frac{e(\Delta V_S - \Delta V)}{\kappa T_E}\right]}{\left(\frac{2\kappa T_E}{\pi m_e}\right)^{1/2}}$$

$$+ \frac{j_{ep}\left\{1 + \operatorname{erf}\left[\frac{e(\Delta V_S - \Delta V)}{\kappa T_{ep}}\right]^{1/2}\right\}\exp\left(-\frac{e\,\Delta V}{\kappa T_{ep}}\right)}{\left(\frac{2\kappa T_{ep}}{\pi m_e}\right)^{1/2}}$$

$$- \frac{j_{iE}\left[1 + \operatorname{erf}\left(\frac{e\,\Delta V}{\kappa T_E}\right)^{1/2}\right]\exp\left[-\frac{e(\Delta V_S - \Delta V)}{\kappa T_E}\right]}{\left(\frac{2\kappa T_E}{\pi m_i}\right)^{1/2}}$$

$$- \frac{j_{ip}\left[1 - \operatorname{erf}\left(\frac{e\,\Delta V}{\kappa T_{ip}}\right)^{1/2}\right]\exp\left(\frac{e\,\Delta V}{\kappa T_{ip}}\right)}{\left(\frac{2\kappa T_{ip}}{\pi m_i}\right)^{1/2}} \tag{10}$$

Electron sheath (ΔV_S negative):

$$\rho_{\Delta V} = \frac{j_{eE}\left[1 + \mathrm{erf}\left(-\frac{e\,\Delta V}{\kappa T_E}\right)^{1/2}\right]\exp\left[\frac{e(\Delta V_S - \Delta V)}{\kappa T_E}\right]}{\left(\frac{2\kappa T_E}{\pi m_e}\right)^{1/2}}$$

$$+ \frac{j_{ep}\left[1 - \mathrm{erf}\left(-\frac{e\,\Delta V}{\kappa T_{ep}}\right)^{1/2}\right]\exp\left(-\frac{e\,\Delta V}{\kappa T_{ep}}\right)}{\left(\frac{2\kappa T_{ep}}{\pi m_e}\right)^{1/2}}$$

$$- \frac{j_{iE}\left\{1 - \mathrm{erf}\left[-\frac{e(\Delta V_S - \Delta V)}{\kappa T_E}\right]^{1/2}\right\}\exp\left[-\frac{e(\Delta V_S - \Delta V)}{\kappa T_E}\right]}{\left(\frac{2\kappa T_E}{\pi m_i}\right)^{1/2}}$$

$$- \frac{j_{ip}\left\{1 + \mathrm{erf}\left[-\frac{e(\Delta V_S - \Delta V)}{\kappa T_{ip}}\right]^{1/2}\right\}\exp\left(\frac{e\,\Delta V}{\kappa T_{ip}}\right)}{\left(\frac{2\kappa T_{ip}}{\pi m_i}\right)^{1/2}} \qquad (11)$$

When $\Delta V = 0$, equations (10) and (11) reduce to the charge density in the plasma $\rho_p = 0$.

Positive-ion sheath:

$$\rho_p = 0 = \frac{j_{eE}\left[1 - \mathrm{erf}\left(\frac{e\,\Delta V_S}{\kappa T_E}\right)^{1/2}\right]\exp\left(\frac{e\,\Delta V_S}{\kappa T_E}\right)}{\left(\frac{2\kappa T_E}{\pi m_e}\right)^{1/2}} + \frac{j_{ep}\left[1 + \mathrm{erf}\left(\frac{e\,\Delta V_S}{\kappa T_{ep}}\right)^{1/2}\right]}{\left(\frac{2\kappa T_{ep}}{\pi m_e}\right)^{1/2}}$$

$$- \frac{j_{iE}\exp\left(-\frac{e\,\Delta V_S}{\kappa T_E}\right)}{\left(\frac{2\kappa T_E}{\pi m_i}\right)^{1/2}} - \frac{j_{ip}}{\left(\frac{2\kappa T_{ip}}{\pi m_i}\right)^{1/2}} \qquad (12)$$

Electron sheath:

$$\rho_p = 0 = \frac{j_{eE}\exp\left(\frac{e\,\Delta V_S}{\kappa T_E}\right)}{\left(\frac{2\kappa T_E}{\pi m_e}\right)^{1/2}} + \frac{j_{ep}}{\left(\frac{2\kappa T_{ep}}{\pi m_e}\right)^{1/2}} - \frac{j_{iE}\left[1 - \mathrm{erf}\left(-\frac{e\,\Delta V_S}{\kappa T_E}\right)^{1/2}\right]\exp\left(-\frac{e\,\Delta V_S}{\kappa T_E}\right)}{\left(\frac{2\kappa T_E}{\pi m_i}\right)^{1/2}}$$

$$- \frac{j_{ip}\left[1 + \mathrm{erf}\left(-\frac{e\,\Delta V_S}{\kappa T_{ip}}\right)^{1/2}\right]}{\left(\frac{2\kappa T_{ip}}{\pi m_i}\right)^{1/2}} \qquad (13)$$

In equation (12), the third term equals one-half the ion charge density N_{ip}; equation (16) is substituted for j_{iE}. In equation (13), the first term equals one-half the electron charge density N_{ep}; therefore, an approximation of ΔV_S can be made.

Positive-ion sheath:

$$\Delta V_S = e\varphi' - eI + \frac{\kappa T_E}{e} \ln\left[\frac{\left(\frac{T_{ip}}{T_E}\right)^{1/2} + \frac{N_{ap}}{N_{ep}}\left(\frac{T_{ap}}{T_E}\right)^{1/2} - 1}{2}\right] \tag{14}$$

Electron sheath:

$$\Delta V_S = \kappa T_E \ln\left[\frac{1.602\times10^{-19} N_{ep}\left(\frac{2\kappa T_E}{\pi m_e}\right)^{1/2}}{2 j_{eE}}\right] \tag{15}$$

A test is made on ΔV_S to assure that it is positive for the ion sheath and negative for the electron sheath. If the test is not satisfied, a new case is begun by using another value of φ.

With the first estimate of ΔV_S, one can solve for the current densities from the emitter and the net negative current densities through the sheath into the plasma.

Ion current density from emitter:

Positive-ion sheath:

$$j_{iE} = \frac{j_{ip} + j_{ap}}{2 \exp\left[\frac{e(I - \varphi')}{\kappa T_E}\right] + \exp\left(- \frac{e\,\Delta V_S}{\kappa T_E}\right)} \tag{16}$$

Electron sheath:

$$j_{iE} = \frac{j_{ap} + j_{ip} \exp\left(\frac{e\,\Delta V_S}{\kappa T_{ip}}\right)}{1 + 2 \exp\left[\frac{e(I - \varphi')}{\kappa T_E}\right]} \tag{17}$$

Atom current density from emitter:

Positive-ion sheath:

$$j_{aE} = \frac{j_{ip} + j_{ap}}{1 + \frac{1}{2} \exp\left[-\frac{e(\Delta V_S - \varphi' + I)}{\kappa T_E}\right]} \tag{18}$$

Electron sheath:

$$j_{aE} = \frac{j_{ap} + j_{ip} \exp\left(\frac{e\,\Delta V_S}{\kappa T_{ip}}\right)}{1 + \frac{1}{2} \exp\left[-\frac{e(I - \varphi')}{\kappa T_E}\right]} \tag{19}$$

Net negative current density through sheath into plasma:

Electron:

Positive-ion sheath:

$$j_e = j_{eE} - j_{ep} \exp\left(-\frac{e\,\Delta V_S}{\kappa T_{ep}}\right) \tag{20}$$

Electron sheath:

$$j_e = j_{eE} \exp\left(\frac{e\,\Delta V_S}{\kappa T_E}\right) - j_{ep} \tag{21}$$

Ion:

Positive-ion sheath:

$$j_i = j_{ip} - j_{iE} \exp\left(-\frac{e\,\Delta V_S}{\kappa T_E}\right) \tag{22}$$

Electron sheath:

$$j_i = j_{ip} \exp\left(\frac{e\,\Delta V_S}{\kappa T_{ip}}\right) - j_{iE} \tag{23}$$

Atom:

Positive-ion and electron sheath:

$$j_a = j_{aE} - j_{ap} \tag{24}$$

Overall:

$$J = j_e + j_i \tag{25}$$

The overall potential drop ΔV_S is then divided into 20 equal increments ΔV, and the net negative charge density in the sheath equations (10) or (11) is calculated for increasing potentials. The error function in equations (10) and (11) was evaluated by using the Lewis library subroutine for error functions.

Integration of the net negative charge density yields the electron field in the sheath $E_{\Delta V}$. The calculations use the sheath fields and voltages given in terms of electron potential; therefore, positive signs correspond to ion sheath and negative signs correspond to electron sheath:

$$E_{\Delta V} = \pm\left(-72\,\pi\times10^{11} \int_0^{\pm\Delta V} \rho_{\Delta V}\, d\Delta V\right)^{1/2} \tag{26}$$

The numerical integration of $\rho_{\Delta V}$ is performed by using the trapezoidal rule based on 20 equal increments of ΔV from 0.0 to ΔV_S.

With the field at the Schottky emitter $E_E = E_{\Delta V_S}$, a Schottky correction $e\varphi' = e\varphi - e\left[(0.511\times10^{6})(2.82\times10^{-13}\,E_E)\right]^{1/2}$ is used in equation (6) for the ion sheath program, and $e\varphi' = e\varphi + e\left[(-0.511\times10^{6})(2.82\times10^{-13}\,E_E)\right]^{1/2}$ is substituted in equation (17) for the electron sheath program. The Schottky correction is used in the recalculation of the values of current densities, overall potential drop, charge density, and electron field. This cycle continues until no boundary current density affected by the Schottky correction (for example CAT in the Positive-Ion Sheath Program) changes by more than 0.1 percent of the smallest boundary (plasma or emitter) current density (TENT). Once the preceding test is satisfied, the sheath distances X are computed:

$$X_{\Delta V} = -\int_{\Delta V_S}^{0} \frac{d\Delta V}{E} + \int_{\Delta V}^{0} \frac{d\Delta V}{E} \qquad (27)$$

As in the electron field calculations, the trapezoidal rule is used for numerical integration. However, at zero ΔV, E equals zero, and equation (27) is not defined. The programs deal with this singularity by using $E/2$ at $\Delta V_S/20$ as the average for the first increment and compute a finite X at this point.

DESCRIPTION OF OUTPUT

Examples of the output are shown in figure 3 for the positive-ion sheath and in figure 4 for the electron sheath. Following the numerical values (figs. 3(a) and 4(a)) are plots which show sheath voltages, fields, and charge densities as functions of distances from the electrode. The sheath properties vary with the plasma electron concentration N_{ep}, electron and ion temperatures T_{ep} and T_{ip}, electrode work function φ, and emitter temperature T_E. The first set of five plots (plotted by the method of ref. 7) shows the Richardson-Dushman and Schottky results (figs. 3(b) and 4(b)); the second set shows only the Schottky results (figs. 3(c) and 4(c)). If IWRITE = 1, the second set of five plots is eliminated. The sample output corresponds to the input listed at the end of the Fortran programs (appendixes A and B).

An explanation of the output labels and corresponding FORTRAN variables is given in appendix C. Appendix D gives an alphabetical listing of important FORTRAN variables, not defined in appendix C. The recorded plasma and electrode properties, overall sheath characteristics, and tabulated and graphic incremental data are sufficient to detail the structure and transport of an emission sheath.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, December 4, 1967,
120-33-02-01-22.

APPENDIX A

POSITIVE-ION SHEATH PROGRAM LISTING

```
$IBFTC ION
C
C       A PLANAR ION SHEATH BETWEEN AN EMITTER AND A
C         NEAR - EQUILIBRIUM PLASMA
C
      COMMON /MV/ PI,EM,AK,AM
      COMMON /MP/ XDV(50),XDS(50),RHODOP(50),RHDS(50),EDV(50),EDS(50),
     1DV(50),DVSAVE(50),RHOEOP(50),RHES(50),RHOIOP(50),RHIS(50),NBB
     2,IWRITE
      DIMENSION TE(10),PHI(10),EPN(10),TEP(10),EJ(30),EPJ(30),PIJ(30),
     1APJ(30),PP(30),DVS(100),EIJ(30),AEJ(30),CJ(30),RHOD(40),
     2ESAVE(40),XSAVE(40),RHOE(40),TIPP(10),EJS(50),AMDA(10),SJE(20),
     3SJA(20),SDJA(20),SDJE(20),SDJI(20),          J1(100),J2(100),
     4J3(100),J4(100),RHOI(40),AMDATE(10),Y(40),SJI(20)
      REAL J1,J2,J3,J4,JA,JB,JC
C
C       AI , IONIZATION POTENTIAL
C
  301 AI = 3.893
      AK   = 8.617E-5
      AKT  = 2.0*AK
      EM   = .511E+6/((2.998E+10)**2)
      PI   = 3.14159
      PIEM = PI*EM
      SE   = 1.602E-19
C
C       MA , MASS OF ATOM
C
  302 AM = 931.478E+6*132.9/((2.998E+10)**2)
      PIAM = PI*AM
      AP1  = 6.6256E-34/SE
      AP2  = AM
      C1   = SQRT(AK/(4.0*PI*.511E+6*2.82E-13))
      C2   = AP1**2
      C3   = 82.06*760./6.023E+23
      C4   = .511E+6*2.82E-13
      C5   = -72.0*PI*1.0E+11
C
C       IWRITE = 1 FOR SCHOTTKY OUTPUT
C       IWRITE = 0 FOR RICHARDSON - DUSHMAN AND SCHOTTKY OUTPUT
C
      READ (5,12) IWRITE
C
C       READ INPUT  TE   , PHI  , EPN  , TEP  , TIP
C
    1 READ (5,2) II,(TE(I),I=1,II)
      READ (5,2) JJ,(PHI(J),J=1,JJ)
      READ (5,2) KK,(EPN(K),K=1,KK)
      READ (5,2) LL,(TEP(L),L=1,LL)
      READ (5,2) LA,(TIPP(LB),LB=1,LA)
      DO 1000  I =1,II
C
C       COMPUTE PTEST , VAPOR PRESSURE
C
  303 PTEST = 10.**(-3920.38/TE(I)-.519781*ALOG10(TE(I))+10.71914)/
     1 133.322
      AKTE = AK*TE(I)
```

```
      TAKTE = 2.0*AKTE
      SA =  SQRT(TAKTE/PIAM)
      FD = SA**2
      CI1 = PIEM*TAKTE
      CI2 = SQRT(TAKTE/PIEM)
      TES = TE(I)**2
      DO 995 LB = 1,LA
      TIP = TIPP(LB)
      CLB1 = SQRT(AKT*TIP/PIAM)
C
C     SET TAP = TIP FOR THESE SOLUTIONS
C
      TAP = TIP
      DO 990  L=1,LL
      AKTP = AK*TEP(L)
      TAKTP = 2.0*AKTP
      SB = TAKTP*PIEM
      SB15 = SB**1.5
      CL1 = EXP(AI/AKTP)
      CL2 = SQRT(TAKTP/PIEM)
      FB = CL2**2
      DO 980  K=1,KK
C
C     COMPUTE PHIZZ , AMDA , AMDATE , APN , AMTEST , PPT
C
      APN = (EPN(K)*C2)*(EPN(K)*(AP1))*CL1/SB15
      CK1 = AKTE*ALOG(.5*((TIP/TE(I))**.5+(APN/EPN(K))*(TAP/TE(I))**.5
     1-1.0))
      SEE = SE*EPN(K)
      PHIZZ = -AKTE*ALOG((SEE/(240.*TES))*CI2)
      AMDA(K) = C1*SQRT(TEP(L)/EPN(K))
      AMDATE(K) = C1*SQRT(TE(I)/EPN(K))
C
C     AMTEST, MINIMUM MEAN FREE PATH
C
  304 AMTEST = 1.0E+12/APN
      PPT = C3*(2.0*EPN(K)*TIP+APN*TAP)
C
C     TEST ON AMDA , AND AMTEST
C
      IF (AMDA(K).LT.AMTEST) GO TO 9
      WRITE (6,7) AMDA(K),AMTEST,TE(I),EPN(K),TEP(L)
      GO TO 980
C
C     TEST ON PPT  AND  PTEST
C
    9 IF (PPT  -PTEST) 40,40,5
    5 WRITE (6,6) PPT  ,PTEST,TE(I),EPN(K),TEP(L)
      GO TO 980
   40 CONTINUE
      DO 970 J = 1,JJ
      KOUNT = 0
      METS = 0
      IPRINT = IWRITE
    3 PHD = PHI(J)
C
C     COMPUTE EJ , EPJ , PIJ , APJ , PP
C
      EJ(J) = 120.*TES*EXP(-PHD/AKTE)
      EPJ(J) = SEE*.5*CL2
```

```
      PIJ(J) = .5*SEE*CLB1
      APJ(J) = (SE*EPN(K)**2*AP1)*(CL1*C2    )*SQRT(AKT   *TAP/(PI*AP2))
     1/(SB15*2.0)
      PP(J) = C3*(EPN(K)*(TEP(L)+TIP*1.0+TAP*((EPN(K)*C2)*CL1*AP1)/SB15)
     1)
      IF (IWRITE.EQ.1.OR.METS.EQ.1) GO TO 38
      WRITE (6,799)
    8 WRITE (6,800) AI,TE(I),PHI(J),EPN(K),TEP(L),TIP,AMDA(K),PTEST
     1,AMDATE(K)
   38 CONTINUE
      KOUNT = KOUNT + 1
C
C     COMPUTE DVS
C
  105 DVS(J) = CK1+PHD-AI
      IF (METS.EQ.0) DVSRD = DVS(J)
      PHIZ = PHI(J) - DVSRD
      DRDK = ABS(DVSRD/AKTP)
      DVSPZ = DVS(J)/DVSRD
  115 IF (DVS(J )) 108,106,102
  108 WRITE (6,109)
      GO TO 970
  106 WRITE (6,107)
      GO TO 970
C
C     COMPUTE EIJ , AEJ , SJE , SJI , CJ , SDJA , SDJE , SDJI , J1
C     J2 , J3 , J4, SJA
C
  102 EIJ(J) = (PIJ(J)+APJ(J))/(2.0*EXP((AI-PHD)/AKTE)+EXP(-DVS(J)/AKTE)
     1)
      AEJ(J) = (PIJ(J)+APJ(J))/(1.0+.5*EXP(-(DVS(J)-PHD+AI)/AKTE))
      SJE(J) = EJ(J)-EPJ(J)*EXP(-DVS(J)/AKTP)
      SJI(J) = -EIJ(J)*EXP(-DVS(J)/AKTE)+PIJ(J)
      CJ(J) = SJE(J)+SJI(J)
      SJA(J) = AEJ(J)-APJ(J)
      SDJA(J) = SJA(J)/APJ(J)
      SDJE(J) = SJE(J)/EPJ(J)
      SDJI(J) = SJI(J)/PIJ(J)
      J1(KOUNT) = EJ(J)
      J2(KOUNT) = EPJ(J)*EXP(-DVS(J)/AKTP)
      J3(KOUNT) = EIJ(J)*EXP(-DVS(J)/AKTE)
      J4(KOUNT) = PIJ(J)
C
C     IN = 20
C     COMPUTE - IN - VALUES OF DV FROM 0.0 TO DVS
C
      IN = 20
  112 DVI = DVS(J)/FLOAT(IN)
      DV(1) = 0.0
      DO 120 NB = 1,IN
      NBB = NB + 1
      DV(NBB) = DV(NB) + DVI
  120 CONTINUE
C
C     COMPUTE RHOEOP , RHOIOP , RHODOP
C     ERF IS THE ERROR FUNCTION  SUBROUTINE
C      VIN IS A SUBROUTINE TO CALCULATE SQRT(2KT/PI*M)*EXP(-DV/KT)/
C             (1.0-ERF(SQRT(DV/KT)))
C
  121 DO 200 NB = 1,NBB
```

```
      X = SQRT (DV(NB)/AKTE)
      ERC = ERF(X)
      X = SQRT ((DVS(J)-DV(NB))/AKTP)
      ERD = ERF(X)
      DVP = DVS(J)-DV(NB)
      IF (DVP.EQ.0.0) GO TO 160
      CALL VIN (1,DVP,TE(I),ANS)
      AV1 = ANS
      GO TO 161
  160 AV1 = CI2
  161 CONTINUE
      DVP = DV(NB)
      IF (DVP.EQ.0.0) GO TO 165
      CALL VIN (2,DVP,TIP,ANS)
      AV2 = ANS
      GO TO 166
  165 AV2 = CLB1
  166 CONTINUE
      FA = EXP(-DV(NB)/AKTP)
      AE1 = EPJ(J)*FA*(1.0+ERD)/(FB**.5)
      FC = EXP(-(DVS(J)-DV(NB))/AKTE)
      AE2 = EIJ(J)*FC*(1.0+ERC)/(FD**.5)
      AE3 = EJ(J)/AV1
      AE4 = PIJ(J)/AV2
  185 RHOE(NB) = AE3+AE1
      RHOI(NB) = -AE2-AE4
      RHOD(NB) = RHOE(NB)+RHOI(NB)
      IF (DV(NB).EQ.0.0) RHOD(NB) = 0.0
      RHOEOP(NB) = RHOE(NB)/SE
      RHODOP(NB) = RHOD(NB)/SE
      RHOIOP(NB) = RHOI(NB)/SE
  200 CONTINUE
      WNEPA = RHOEOP(1)
C
C     COMPUTE EDV BY INTEGRATING RHOD (TRAPEZOIDAL RULE)
C
  202 CALL TRAP(RHOD,DV,NBB,EDV)
      DO 210 NB = 1,NBB
      IF (EDV(NB).GT.0.0) EDV(NB)=0.0
      EDV(NB) = SQRT(C5*EDV(NB))
  210 CONTINUE
      EDVS = EDV(NBB)
      EDPZL = EDVS/(DVSRD/AMDA(K))
      EE = EDVS
      IF (METS.EQ.0) GO TO 400
C
C     COMPUTE SC , EJS , TENT
C
  260 SC = SQRT(C4*EE)
      PHD = -SC + PHI(J)
      EJS(J) = 120.*TES*EXP(-PHD/AKTE)
      TENT = .001*AMIN1(J1(KOUNT),J2(KOUNT),J3(KOUNT),J4(KOUNT),APJ(J),
     1 AEJ(J))
      IF (KOUNT.EQ.1) GO TO 340
      JA = J1(KOUNT)-J1(KOUNT-1)
      JB = J2(KOUNT)-J2(KOUNT-1)
      JC = J3(KOUNT) - J3(KOUNT-1)
      CAT = AMAX1(JA,JB,JC)
      IF (CAT.LE.TENT)  GO TO 400
      GO TO 350
```

```
  340 IF (ABS(EJ(J)-EJS(J)).LE.TENT) GO TO 400
C
C     IF TEST IS NOT SATISFIED SET EJ = EJS
C     RETURN TO COMPUTE A NEW DVS
C
  350 EJ(J) = EJS(J)
      GO TO 38
  400 DO 405 NB = 1,NBB
      IF (EDV(NB).EQ.0.0)  GO TO 403
      ESAVE(NB) = 1.0/EDV(NB)
      GO TO 405
  403 ESAVE(NB) = 0.0
  405 CONTINUE
C
C      COMPUTE XDVS BY INTEGRATING 1.0/EDV (TRAPEZOIDAL RULE)
C
      CALL TRAP (ESAVE,DV,NBB,XSAVE)
C
C     COMPUTE XLAM , TPN , CEN , TNE , PHAT , XAMTE , EAMPHZ
C
      XDVS = XSAVE(NBB)
      XLAM = XDVS/AMDA(K)
      TPN = 2.0*EPN(K) + APN
      CEN = ABS(RHOIOP(NBB)) + ABS(RHOEOP(NBB))
      TNE = CEN + APN
      PHAT = (PHI(J)-PHIZ)/(AK*TE(I))
      XAMTE = XDVS/AMDATE(K)
      EAMPHZ = EDVS*AMDATE(K)/(PHI(J)-PHIZ)
C
C      COMPUTE XDVS
C
      DO 460 NB = 1,NBB
      XDV(NB) = XDVS - XSAVE(NB)
      IF (NB.EQ.NBB) XDV(NB) = 0.0
  460 CONTINUE
      IF (IPRINT.EQ.1) GO TO 496
      IF (METS.EQ.0)  GO TO 480
      WRITE (6,798)
      WRITE (6,800) AI,TE(I),PHI(J),EPN(K),TEP(L),TIP,AMDA(K),PTEST
     1,AMDATE(K)
  480 WRITE (6,810)
      WRITE (6,820) (DV(NB),RHODOP(NB),RHOEOP(NB),RHOIOP(NB),EDV(NB),XDV
     1(NB),NB=1,NBB)
      IF (METS.EQ.1) GO TO 490
      WRITE (6,830) EJ(J),EPJ(J),PIJ(J),APJ(J),CJ(J),PP(J),EIJ(J),AEJ(J)
     1,SJA(J),SJI(J),SJE(J),SDJA(J),SDJE(J),SDJI(J),DVS(J),XDVS    ,APN
     2,XLAM,PHIZZ,EDVS
     3,TPN,CEN,TNE,PHAT,XAMTE,EAMPHZ,WNEPA
      GO TO 496
  490 WRITE (6,831) EJ(J),EPJ(J),PIJ(J),APJ(J),CJ(J),PP(J),EIJ(J),AEJ(J)
     1,SJA(J),SJI(J),SJE(J),SDJA(J),SDJE(J),SDJI(J),DVS(J),XDVS    ,APN
     2,XLAM,SC,PHIZ  ,EDVS,DVSRD,DVSPZ,EDPZL,PHIZZ,DRDK
     3,TPN,CEN,TNE,PHAT,XAMTE,EAMPHZ,WNEPA
  496 IF (METS.EQ.1) GO TO 599
C
C     SAVE RICHARDSON - DUSHMAN VALUES OF DV , RHODOP , RHOEOP , EDV ,
C     XDV , RHOIOP
C
      DO 870 NB = 1,NBB
      DVSAVE(NB) = DV(NB)
```

```
      RHDS(NB) = RHODOP(NB)
      RHES(NB) = RHOEOP(NB)
      EDS(NB) = EDV(NB)
      XDS(NB) = XDV(NB)
      RHIS(NB) = RHOIOP(NB)
  870 CONTINUE
      METS = 1
      IPRINT = 2
      GO TO 260
C
C     CALL PLOTTING SUBROUTINE
C
  599 CALL PLOT
  970 CONTINUE
  980 CONTINUE
  990 CONTINUE
  995 CONTINUE
 1000 CONTINUE
      GO TO 1
    2 FORMAT (I5/(8E10.2))
    6 FORMAT (1H1,10X,90HPLASMA TEST PRESSURE(PPT) IS GREATER THAN THE V
     1APOR PRESSURE OF THE PLASMA CHEMICAL(PTEST)/1H0,10X,6HPPT = ,E12.5
     2,10X,8HPTEST = ,E12.5/1H0,10X,5HTE = ,F8.0,10X,6HNEP = ,E8.1,10X,6
     3HTEP = ,F8.0)
    7 FORMAT (1H1,10X,99HDEBYE LENGTH(LAMBDA) LONGER THAN MINIMUM MEAN F
     1REE PATH OF THE CHEMICAL(AMTEST) -- COLLISIONAL CASE/1H0,10X,10HLA
     2MBDA = ,E15.8,10X,9HAMTEST = ,E15.8/1H0,10X,5HTE = ,F8.0,6HNEP = ,
     3E8.1,10X,6HTEP = ,F8.0)
   12 FORMAT (I5)
  107 FORMAT (1H0,20X,11HDVS IS ZERO)
  109 FORMAT (1H0,20X,20HDVS IS NEGATIVE STOP)
  798 FORMAT (1H1,54X,8HSCHOTTKY)
  799 FORMAT          (1H1,48X,18HRICHARDSON-DUSHMAN)
  800 FORMAT (1H0,2X,4HI = ,F5.3,5X,5HTE = ,F5.0,5X,6HPHI = ,F5.3,5X,6HN
     1EP = ,1PE8.2,5X,6HTEP = ,1PE8.2,5X,6HTIP = ,0PF7.1,5X,9HLAMBDA = ,
     21PE11.4/1H0,1X,5HPV = ,1PE13.6,5X,12HLAMBDA(TE) =,1PE11.4)
  801 FORMAT (1H1,2X,4HI = ,F5.3,5X,5HTE = ,F5.0,5X,6HPHI = ,F5.3,5X,6HN
     1EP = ,1PE8.2,5X,6HTEP = ,1PE8.2,5X,6HTIP = ,0PF7.1,5X,9HLAMBDA = ,
     21PE11.4/1H0,1X,5HPV = ,1PE13.6,5X,12HLAMBDA(TE) =,1PE11.4)
  810 FORMAT (1HL,10X,2HDV,12X,6HND(DV),12X,6HNE(DV),12X,6HNI(DV),12X,5H
     2E(DV),12X,5HX(DV)/1H0)
  820 FORMAT (0PF16.5,1PE19.6,1P2E18.6,1PE17.6,1PE18.6)
  830 FORMAT (1HL,2X,9HJEE      = ,1PE13.6,4X,9HJEP      = ,1PE13.6,4X,6HJIP
     1 = ,1PE13.6,4X,9HJAP      = ,1PE13.6/
     23X,9HJ        = ,1PE13.6,4X,9HPP       = ,1PE13.6,4X,6HJIE = ,1PE13.6,
     34X,9HJAE      = ,1PE13.6/
     43X,9HJA       = ,1PE13.6,4X,9HJI       = ,1PE13.6,4X,6HJE   = ,1PE13.6,
     54X,9HJA/JAP = ,1PE13.6/
     63X,9HJE/JEP = ,1PE13.6,4X,9HJI/JIP = ,1PE13.6,4X,6HDVS = ,0PF8.5,9
     7X,9HXDVS     = ,1PE13.6/3X,9HNAP      = ,1PE13.6,4X,9HXD/LAM = ,1PE13.
     86,4X,6HPHZZ= ,0PF8.5,9X,9HEDVS     = ,1PE13.6/
     93X,9HNTP      = ,1PE13.6,4X,9HNCE      = ,1PE13.6,4X,6HNTE = ,1PE13.6,
     14X,9HRD/KTE = ,1PE13.6/3X,9HX/LMTE = ,1PE13.6,4X,9HELT/RD = ,1PE13
     2.6,4X,6HNEPA= ,1PE13.6)
  831 FORMAT (1HL,2X,9HJEE      = ,1PE13.6,4X,9HJEP      = ,1PE13.6,4X,6HJIP
     1 = ,1PE13.6,4X,9HJAP      = ,1PE13.6/
     23X,9HJ        = ,1PE13.6,4X,9HPP       = ,1PE13.6,4X,6HJIE = ,1PE13.6,
     34X,9HJAE      = ,1PE13.6/
     43X,9HJA       = ,1PE13.6,4X,9HJI       = ,1PE13.6,4X,6HJE   = ,1PE13.6,
     54X,9HJA/JAP = ,1PE13.6/
```

```
     63X,9HJE/JEP = ,1PE13.6,4X,9HJI/JIP = ,1PE13.6,4X,6HDVS = ,0PF8.5,9
     7X,9HXDVS    = ,1PE13.6/3X,9HNAP     = ,1PE13.6,4X,9HXD/LAM = ,1PE13.
     86,4X,6HSC   = ,1PE13.6,4X,9HPHZ     = ,0PF8.5/
     93X,9HEDVS    = ,1PE13.6,4X,9HDVSRD   = ,1PE13.6,27X,9HDVS/RD = ,1PE1
     13.6/
     23X,9HELM/RD = ,1PE13.6,4X,9HPHZZ    = ,1PE13.6,27X,9HDRD/KT = ,1PE1
     33.6/
     43X,9HNTP     = ,1PE13.6,4X,9HNCE     = ,1PE13.6,4X,6HNTE = ,1PE13.6,
     54X,9HRD/KTE = ,1PE13.6/3X,9HX/LMTE = ,1PE13.6,4X,9HELT/RD = ,1PE13
     6.6,4X,6HNEPA= ,1PE13.6)
  840 FORMAT (1HL,2X,9HRHO(DV)= ,1PE13.6,3H + ,1PE13.6,6H*DV + ,1PE13.6,
     19H*DV**2 + ,1PE13.6,9H*DV**3 + ,1PE13.6,6H*DV**4)
  850 FORMAT (1H1)
  860 FORMAT (1HL/1HL,2X,4HI = ,F5.3,5X,5HTE = ,F5.0,5X,6HPHI = ,F5.3,5X
     1,6HNEP = ,1PE8.2,5X,6HTEP = ,1PE8.2,5X,6HTIP = ,0PF7.1,5X,9HLAMBDA
     2 = ,1PE11.4/1H0,1X,5HPV = ,1PE13.6,5X,12HLAMBDA(TE) =,1PE11.4)
      END
$IBFTC PLOTA
      SUBROUTINE PLOT
      COMMON /MP/ XDV(50),XDS(50),RHODOP(50),RHDS(50),EDV(50),EDS(50),
     1DV(50),DVSAVE(50),RHOEOP(50),RHES(50),RHOIOP(50),RHIS(50),NBB
     2,IWRITE
      DIMENSION KKK(14),P(10),Z(100),ZA(100),ZB(100),ZC(100),ZD(100),
     1 ZE(100)
  599 ND = 0
      DO 600 NB = 1,NBB
      NE = NBB - ND
      NET = 2*NBB - ND
      ND = ND + 1
      Z(NE ) = XDV(NB)
      Z(NET) = XDS(NB)
      ZA(NE ) = RHODOP(NB)
      ZA(NET) = RHDS(NB)
      ZB(NE ) = EDV(NB)
      ZB(NET) = EDS(NB)
      ZC(NE ) = DV(NB)
      ZC(NET) = DVSAVE(NB)
      ZD(NE ) = RHOEOP(NB)
      ZD(NET) = RHES(NB)
      ZE(NE) = RHOIOP(NB)
      ZE(NET) = RHIS(NB)
  600 CONTINUE
      P(1) = 5.0
      KKK(1) = 64
      KKK(2) = 2
      KKK(3) = NBB
      KKK(5) = NBB
      NB2 = 2*NBB
      CALL SCALE (NB2,ZA,KRSTR)
      CALL PLOTMY (Z,ZA,KKK,P)
      WRITE (6,602) KRSTR
      ND = 0
      DO 607 NB = 1,NBB
      NE = NBB - ND
      NET = 2*NBB - ND
      Z(NE) = XDV(NB)
      Z(NET) = XDS(NB)
      ND = ND + 1
  607 CONTINUE
      CALL SCALE (NB2,ZD,KRSTR)
```

```
      CALL PLOTMY (Z,ZD,KKK,P)
      WRITE (6,603) KRSTR
      ND = 0
      DO 601 NB = 1,NBB
      NE = NBB - ND
      NET = 2*NBB - ND
      ND = ND + 1
      Z(NE) = XDV(NB)
      Z(NET) = XDS(NB)
  601 CONTINUE
      CALL SCALE (NB2,ZE,KRSTR)
      CALL PLOTMY(Z,ZE,KKK,P)
      WRITE (6,610) KRSTR
      ND = 0
      DO 611 NB = 1,NBB
      NE = NBB-ND
      NET = 2*NBB-ND
      ND = ND+1
      Z(NE) = XDV(NB)
      Z(NET) = XDS(NB)
  611 CONTINUE
      CALL SCALE (NB2,ZB,KRSTR)
      CALL PLOTMY (Z,ZB,KKK,P)
      WRITE (6,604) KRSTR
      ND = 0
      DO 606 NB = 1,NBB
      NE = NBB - ND
      NET = 2*NBB - ND
      ND = ND + 1
      Z(NE) = XDV(NB)
      Z(NET) = XDS(NB)
  606 CONTINUE
      CALL SCALE (NB2,ZC,KRSTR)
      CALL PLOTMY (Z,ZC,KKK,P)
      WRITE (6,605) KRSTR
      IF (IWRITE.EQ.1) RETURN
      P(1) = NBB
      KODE = 64
      ND = 0
      DO 500 NB = 1,NBB
      NE = NBB - ND
      Z(NE) = XDV(NB)
      ZA(NE) = RHODOP(NB)
      ZD(NE) = RHOEOP(NB)
      ZB(NE) = EDV(NB)
      ZC(NE) = DV(NB)
      ZE(NE) = RHOIOP(NB)
      ND = ND + 1
  500 CONTINUE
      WRITE (6,501)
      CALL SCALE (NBB,ZA,KRSTR)
      CALL PLOTXY (Z,ZA,KODE,P)
      WRITE (6,502) KRSTR
      WRITE (6,501)
      CALL SCALE (NBB,ZD,KRSTR)
      CALL PLOTXY(Z,ZD,KODE,P)
      WRITE (6,505) KRSTR
      WRITE (6,501)
      CALL SCALE (NBB,ZE,KRSTR)
      CALL PLOTXY (Z,ZE,KODE,P)
```

```
      WRITE (6,510) KRSTR
      WRITE (6,501)
      CALL SCALE (NBB,ZB,KRSTR)
      CALL PLOTXY (Z,ZB,KODE,P)
      WRITE (6,503) KRSTR
      WRITE (6,501)
      CALL SCALE (NBB,ZC,KRSTR)
      CALL PLOTXY (Z,ZC,KODE,P)
      WRITE (6,504) KRSTR
  501 FORMAT (2HPT)
  502 FORMAT (2HPL,47X,8HND(X10**,I3,6H) VS X)
  503 FORMAT (2HPL,47X,7HE(X10**,I3,6H) VS X)
  504 FORMAT (2HPL,47X,8HDV(X10**,I3,6H) VS X)
  505 FORMAT (2HPL,47X,8HNE(X10**,I3,6H) VS X)
  510 FORMAT (2HPL,47X,8HNI(X10**,I3,6H) VS X)
  602 FORMAT (2HPL,47X,8HND(X10**,I3,6H) VS X/
     12HPL,44X,20H+ RICHARDSON-DUSHMAN/2HPL,44X,10H* SCHOTTKY)
  603 FORMAT (2HPL,47X,8HNE(X10**,I3,6H) VS X/
     12HPL,44X,20H+ RICHARDSON-DUSHMAN/2HPL,44X,10H* SCHOTTKY)
  604 FORMAT (2HPL,47X,7HE(X10**,I3,6H) VS X/
     12HPL,44X,20H+ RICHARDSON-DUSHMAN/2HPL,44X,10H* SCHOTTKY)
  605 FORMAT (2HPL,47X,8HDV(X10**,I3,6H) VS X/
     12HPL,44X,20H+ RICHARDSON-DUSHMAN/2HPL,44X,10H* SCHOTTKY)
  610 FORMAT (2HPL,47X,8HNI(X10**,I3,6H) VS X/
     12HPL,44X,20H+ RICHARDSON-DUSHMAN/2HPL,44X,10H* SCHOTTKY)
      RETURN
      END
$IBFTC VINE
      SUBROUTINE VIN (NV,DVV,T,ANS)
      COMMON /MV/ PI,EM,AK,AM
C
C        IF NV  =  1  COMPUTATIONS FOR ELECTRONS
C        IF  NV  =  2  COMPUTATIONS FOR ATOMS AND IONS
C       THE PROPER T AND DV IS SPECIFIED IN MAIN PROGRAM
C
      IF (NV.EQ.1) GO TO 10
      C = SQRT(2.0*AK*T/(PI*AM))
      GO TO 20
   10 C = SQRT(2.0*AK*T/(PI*EM))
   20 XE = SQRT(DVV/(AK*T))
      Y = ERF(XE)
      ERFC = 1.0-Y
      ANS = C*EXP(-DVV/(AK*T))/ERFC
      RETURN
      END
$IBFTC TRAPE
      SUBROUTINE TRAP (X,DV,NBB,ANS)
      DIMENSION X(40),DV(50),ANS(40)
C
C       SUBROUTINE TO INTEGRATE TRAPEZOIDALLY
C
      H = DV(2) /2.0
      SUME = 0.0
      DO 60 NB = 1,NBB
      IF (NB.EQ.1) GO TO 50
      SUME = SUME+X(NB-1)+X(NB)
      ANS(NB) = SUME*H
      GO TO 60
   50 ANS(NB) = 0.0
   60 CONTINUE
```

```
      RETURN
      END
$DATA

    1
    2.4E+3
    1
    4.0E+0
    1
    1.E+13
    1
    2.5E+3
    1
    2.4E+3
```

APPENDIX B

ELECTRON SHEATH PROGRAM LISTING

```
$IBFTC ELECT
C
C     A PLANAR ELECTRON SHEATH BETWEEN AN EMITTER AND A
C        NEAR-EQUILIBRIUM PLASMA
C
      COMMON /MV/ PI,EM,AK,AM
      COMMON /MP/ XDV(50),XDS(50),RHODUP(50),RHDS(50),EDV(50),EDS(50),
     1DV(50),DVSAVE(50),RHOEOP(50),RHES(50),RHOIOP(50),RHIS(50),NBB,
     2IWRITE
      DIMENSION TE(10),PHI(10),EPN(10),TEP(10),TIPP(10),EJ(10),EPJ(10),
     1PIJ(10),APJ(10),PP(10),DVS(10),EIJ(10),AEJ(10),SJE(10),SJI(10),
     2SJA(10),CJ(10),SDJA(10),SDJI(10),SDJE(10),RHOD(50),RHOI(50),
     3RHOE(50),          ESAVE(50),XSAVE(50),           EIJS(10),AMDA(10),
     4AMDATE(10)
C
C     AI , IONIZATION POTENTIAL
C
  301 AI = 3.893
      AK = 8.617E-5
      AKT = 2.0*AK
      EM = .511E+6/((2.998E+10)**2)
      PI = 3.14159
      PIEM = PI*EM
      SE = 1.602E-19
C
C     MA , MASS OF ATOM
C
  302 AM = 931.478E+6*132.9/((2.998E+10)**2)
      PIAM = PI*AM
      AP1 = 6.6256E-34/SE
      AP2 = AM
      C1 = SQRT(AK/(4.0*PI*.511E+6*2.82E-13))
      C2 = AP1**2
      C3 = 82.06*760./6.023E+23
      C5 = -72.0*PI*1.0E+11
C
C     IWRITE = 1   FOR SCHOTTKY OUTPUT
C     IWRITE = 0 FOR RICHARDSON-DUSHMAN AND SCHOTTKY OUTPUT
C
      READ (5,12) IWRITE
C
C     READ INPUT VALUES OF TE , PHI , EPN , TEP , TIP
C
    1 READ (5,2) II,(TE(I),I=1,II)
      READ (5,2) JJ,(PHI(J),J=1,JJ)
      READ (5,2) KK,(EPN(K),K=1,KK)
      READ (5,2) LL,(TEP(L),L=1,LL)
      READ (5,2) LA,(TIPP(LB),LB=1,LA)
      DO 1000 I = 1,II
C
C     COMPUTE PTEST , VAPOR PRESSURE
C
  303 PTEST = 10.**(-3920.38/TE(I)-.519781*ALOG10(TE(I))+10.71914)/
     1133.322
      AKTE = AK*TE(I)
      TAKTE = 2.0*AKTE
```

```
      TES = TE(I)*TE(I)
      SB = SQRT(TAKTE/PIEM)
      DO 960 LB = 1,LA
      TIP = TIPP(LB)
      AKTP = AK*TIP
      TAKTIP = AKT*TIP
C
C     SET  TAP = TIP FOR THESE SOLUTIONS
C
      TAP = TIP
      TAKTAP = AKT*TAP
      SI = SQRT(TAKTIP/PIAM)
      SIA = SQRT(TAKTAP/PIAM)
      DO 990 L = 1,LL
      AKTEP = AK*TEP(L)
      TAKTEP = 2.0*AKTEP
      SA = SQRT(TAKTEP/PIEM)
      CL1 = TAKTEP*PIEM
      DO 980 K = 1,KK
      SEE = SE*EPN(K)
C
C     COMPUTE PHIZZ , AMDA , AMDATE , APN , PPT , AMTEST
C
      PHIZZ = -AKTE*ALOG((SEE/(240.*TES))*SB)
      AMDA(K) = C1*SQRT(TEP(L)/EPN(K))
      AMDATE(K) = C1*SQRT(TE(I)/EPN(K))
      APN = (EPN(K)*C2)*(EPN(K)*(AP1))*EXP(AI/AKTEP)/(CL1**1.5)
      PPT = C3*(2.0*EPN(K)*TIP+APN*TAP)
C
C     AMTEST, MINIMUM MEAN FREE PATH
C
  304 AMTEST = 1.0E+12/APN
C
C     TEST ON  AMDA  AND  AMTEST
C
      IF (AMDA(K).LT.AMTEST)  GO TO 9
      WRITE (6,7) AMDA(K),AMTEST,TE(I),EPN(K),TEP(L)
      GO TO 980
C
C     TEST ON PPT  AND  PTEST
C
    9 IF (PPT  -PTEST) 40,40,5
    5 WRITE (6,6) PPT,PTEST,TE(I),EPN(K),TEP(L)
      GO TO 980
   40 CONTINUE
      DO 970 J = 1,JJ
      METS = 0
      IPRINT = IWRITE
    3 PHD = PHI(J)
C
C     COMPUTE  EPJ , PIJ , APJ , PP
C
      EPJ(J) = SEE*.5*SA
      PIJ(J) = SEE*.5*SI
      APJ(J) = SE*APN*SIA/2.0
      PP(J) = C3*(EPN(K)*TEP(L)+EPN(K)*TIP+TAP*APN)
      IF (IWRITE.EQ.1.OR .METS.EQ.1) GO TO 38
      WRITE (6,799)
    8 WRITE (6,800) AI,TE(I),PHI(J),EPN(K),TEP(L),TIP,AMDA(K) ,PTEST
     1,AMDATE(K)
```

```
   38 CONTINUE
C
C     COMPUTE  EJ
C
      EJ(J) = 120.*TES*EXP((-PHD)/AKTE)
C
C     COMPUTE DVS
C
      DVS(J) = AKTE*ALOG(SEE*SB/(2.0*EJ(J)))
      IF (METS.EQ.0) DVSRD = DVS(J)
      PHIZ = PHI(J) - DVSRD
      DRDK = ABS(DVSRD/AKTEP)
      DVSPZ = DVS(J)/DVSRD
  115 IF (DVS(J ))102,106,108
  108 WRITE (6,109)
      GO TO 970
  106 WRITE (6,107)
      GO TO 970
C
C     COMPUTE EIJ , AEJ , SJE , SJI , SJA , CJ , SDJI , SDJE , SDJA
C
  102 EIJ(J) = (APJ(J)+PIJ(J)*EXP(DVS(J)/AKTP    ))/(1.0+2.0*EXP((
     1AI-PHD)/AKTE))
      AEJ(J) = (APJ(J)+PIJ(J)*EXP(DVS(J)/AKTP    ))/(1.0+.5*EXP(-(
     1(AI-PHD)/AKTE)))
      SJE(J) = EJ(J)*EXP(DVS(J)/AKTE       )-EPJ(J)
      SJI(J) = PIJ(J)*EXP(DVS(J)/AKTP    ) - EIJ(J)
      SJA(J) = AEJ(J) - APJ(J)
      CJ(J) = SJE(J) + SJI(J)
      SDJI(J) = SJI(J) / PIJ(J)
      SDJE(J) = SJE(J) / EPJ(J)
      SDJA(J) = SJA(J) / APJ(J)
C
C     IN = 20
C     COMPUTE - IN - VALUES OF DV FROM 0.0 TO DVS
C
      IN = 20
  112 DVI = DVS(J)/FLOAT(IN)
      DV(1) = 0.0
      DO 120 NB = 1,IN
      NBB = NB + 1
      DV(NBB) = DV(NB) + DVI
  120 CONTINUE
C
C     COMPUTE RHOEOP , RHOIOP , RHODOP
C     ERF IS THE ERROR FUNCTION SUBROUTINE
C      VIN IS A SUBROUTINE TO CALCULATE SQRT(2KT/PI*M)*EXP(-DV/KT)/
C             (1.0-ERF(SQRT(DV/KT)))
C
  121 DO 200 NB = 1,NBB
      X = SQRT(-DV(NB)/AKTE)
      ERA = ERF(X)
      X = SQRT(-(DVS(J)-DV(NB))/AKTP)
      ERB = ERF(X)
      DVP = DV(NB)
      IF (DVP.EQ.0.0) GO TO 160
      CALL VIN (1,DVP,TEP(L),ANS)
      AV1 = ANS
      GO TO 161
  160 AV1 = SQRT(TAKTEP/PIEM)
```

```
  161 CONTINUE
      DVP = DVS(J) - DV(NB)
      IF (DVP.EQ.0.0) GO TO 165
      CALL VIN (2,DVP,TE(I),ANS)
      AV2 = ANS
      GO TO 166
  165 AV2 = SQRT(TAKTE/PIAM)
  166 CONTINUE
      FA = EXP((DVS(J)-DV(NB))/AKTE)
      AE1 = EJ(J)*FA*(1.0+ERA)/SB
      AE2 = EPJ(J)/AV1
      AE3 = EIJ(J)/AV2
      FB = EXP(DV(NB)/AKTP)
      AE4 = PIJ(J)*FB*(1.0+ERB)/SI
      RHOE(NB) = AE1+AE2
      RHOI(NB) = -AE3-AE4
      RHOD(NB) = RHOE(NB)+RHOI(NB)
      IF (DV(NB).EQ.0.0) RHOD(NB) = 0.0
      RHOEOP(NB) = RHOE(NB)/SE
      RHODOP(NB) = RHOD(NB)/SE
      RHOIOP(NB) = RHOI(NB)/SE
  200 CONTINUE
      WNIPA = RHOIOP(1)
C
C       COMPUTE EDV BY INTEGRATING RHOD (TRAPEZOIDAL RULE)
C
  202 CALL TRAP(RHOD,DV,NBB,EDV)
      DO 210 NB = 1,NBB
      IF (EDV(NB).GT.0.0) EDV(NB) = 0.0
      EDV(NB) = -SQRT(C5*EDV(NB))
  210 CONTINUE
      EDVS = EDV(NBB)
      EDPZL = EDVS/(DVSRD/AMDA(K))
      EE = EDVS
      IF (METS.EQ.0) GO TO 402
C
C       COMPUTE SC , EIJS
C
  260 SC = SQRT(-.511E+6*2.82E-13*EE)
      PHD = SC + PHI(J)
      EIJS(J) = (APJ(J)+PIJ(J)*EXP(DVS(J)/AKTP     ))/(1.0+2.0*EXP((AI-
     1PHD)/AKTE))
      TENT=.001   *AMIN1(EJ(J),EPJ(J),PIJ(J),EIJ(J),APJ(J),AEJ(J))
      IF (ABS(EIJ(J)-EIJS(J)     ).LE.TENT) GO TO 402
C
C       IF TEST IS NOT SATISFIED SET EIJ = EIJS AND RETURN
C       TO COMPUTE A NEW DVS
C
      EIJ(J) = EIJS(J)
      GO TO 38
  402 DO 405 NB = 1,NBB
      IF (EDV(NB).EQ.0.0) GO TO 403
      ESAVE(NB) = 1.0/EDV(NB)
      GO TO 405
  403 ESAVE(NB) = 0.0
  405 CONTINUE
C
C       COMPUTE  XDVS  BY INTEGRATING 1.0/EDV  (TRAPEZOIDAL RULE)
C
      CALL TRAP (ESAVE,DV,NBB,XSAVE)
```

```
      XDVS = XSAVE(NBB)
C
C     COMPUTE XLAM , TPN , CEN , TNE , PHAT , XAMTE , EAMPHZ
C
      XLAM = XDVS/AMDA(K)
      TPN = APN+2.0*EPN(K)
      CEN = RHOEOP(NBB)+ABS(RHOIOP(NBB))
      TNE = CEN + APN
      PHAT = (PHI(J)-PHIZ)/(AK*TE(I))
      XAMTE = XDVS/AMDATE(K)
      EAMPHZ = EDVS*AMDATE(K)/(PHI(J)-PHIZ)
C
C      COMPUTE XDV
C
      DO 460 NB = 1,NBB
      XDV(NB) = XDVS - XSAVE(NB)
      IF (NB.EQ.NBB) XDV(NB) = 0.0
  460 CONTINUE
      IF (IPRINT.EQ.1) GO TO 496
      IF (METS.EQ.0) GO TO 480
      WRITE (6,798)
      WRITE (6,800) AI,TE(I),PHI(J),EPN(K),TEP(L),TIP,AMDA(K),PTEST
     1,AMDATE(K)
  480 WRITE (6,810)
      WRITE (6,820) (DV(NB),RHODOP(NB),RHOEOP(NB),RHOIOP(NB),EDV(NB)
     1,XDV(NB),NB=1,NBB)
      IF (METS.EQ.1) GO TO 490
      WRITE (6,830) EJ(J),EPJ(J),PIJ(J),APJ(J),CJ(J),PP(J),EIJ(J),AEJ(J)
     1,SJA(J),SJI(J),SJE(J),SDJA(J),SDJE(J),SDJI(J),DVS(J),XDVS    ,APN
     2,XLAM,PHIZZ,EDVS
     3,TPN,CEN,TNE,PHAT,XAMTE,EAMPHZ,WNIPA
      GO TO 496
  490 WRITE (6,831) EJ(J),EPJ(J),PIJ(J),APJ(J),CJ(J),PP(J),EIJ(J),AEJ(J)
     1,SJA(J),SJI(J),SJE(J),SDJA(J),SDJE(J),SDJI(J),DVS(J),XDVS    ,APN,
     2XLAM,SC,PHIZ  ,EDVS,DVSRD,DVSPZ,EDPZL,PHIZZ,DRDK
     3,TPN,CEN,TNE,PHAT,XAMTE,EAMPHZ,WNIPA
  496 IF (METS.EQ.1) GO TO 599
C
C     SAVE RICHARDSON - DUSHMAN VALUES FOR DV , RHODOP , RHOEOP ,
C     RHOIOP , EDV , XDV
C
      DO 870 NB = 1,NBB
      DVSAVE(NB) = DV(NB)
      RHDS(NB) = RHODOP(NB)
      RHES(NB) = RHOEOP(NB)
      EDS(NB) = EDV(NB)
      XDS(NB) = XDV(NB)
      RHIS(NB) = RHOIOP(NB)
  870 CONTINUE
      METS = 1
      IPRINT = 2
      GO TO 260
C
C      CALL PLOTTING SUBROUTINE
C
  599 CALL PLOT
  970 CONTINUE
  980 CONTINUE
  990 CONTINUE
  960 CONTINUE
```

```
1000 CONTINUE
     GO TO 1
   2 FORMAT (I5/(8E10.2))
   6 FORMAT (1H1,10X,90HPLASMA TEST PRESSURE(PPT) IS GREATER THAN THE V
    1APOR PRESSURE OF THE PLASMA CHEMICAL(PTEST)/1H0,10X,6HPPT = ,E12.5
    2,10X,8HPTEST = ,E12.5/1H0,10X,5HTE = ,F8.0,10X,6HNEP = ,E8.1,10X,6
    3HTEP = ,F8.0)
   7 FORMAT (1H1,10X,99HDEBYE LENGTH(LAMBDA) LONGER THAN MINIMUM MEAN F
    1REE PATH OF THE CHEMICAL(AMTEST) -- COLLISIONAL CASE/1H0,10X,10HLA
    2MBDA = ,E15.8,10X,9HAMTEST = ,E15.8/1H0,10X,5HTE = ,F8.0,6HNEP = ,
    3E8.1,10X,6HTEP = ,F8.0)
  12 FORMAT (I5)
 107 FORMAT (1H0,20X,11HDVS IS ZERO)
 109 FORMAT (1H1,20X,20HDVS IS POSITIVE STOP)
 798 FORMAT (1H1,54X,8HSCHOTTKY)
 799 FORMAT (1H1,48X,18HRICHARDSON-DUSHMAN)
 800 FORMAT (1H0,2X,4HI = ,F5.3,5X,5HTE = ,F5.0,5X,6HPHI = ,F5.3,5X,6HN
    1EP = ,1PE8.2,5X,6HTEP = ,0PF7.1,5X,6HTIP = ,0PF7.1,5X,9HLAMBDA = ,
    21PE11.4/1H0,1X,5HPV = ,1PE13.6,5X,12HLAMBDA(TE) =,1PE11.4)
 801 FORMAT (1H1,2X,4HI = ,F5.3,5X,5HTE = ,F5.0,5X,6HPHI = ,F5.3,5X,6HN
    1EP = ,1PE8.2,5X,6HTEP = ,0PF7.1,5X,6HTIP = ,0PF7.1,5X,9HLAMBDA = ,
    21PE11.4/1H0,1X,5HPV = ,1PE13.6,5X,12HLAMBDA(TE) =,1PE11.4)
 810 FORMAT (1HL,10X,2HDV,12X,6HND(DV),12X,6HNE(DV),12X,6HNI(DV),12X,5H
    1E(DV),12X,5HX(DV)/1H0)
 820 FORMAT (0PF16.5,1PE19.6,1P2E18.6,1PE17.6,1PE18.6)
 830 FORMAT (1HL,2X,9HJEE     = ,1PE13.6,4X,9HJEP     = ,1PE13.6,4X,6HJIP
    1 = ,1PE13.6,4X,9HJAP     = ,1PE13.6/
    23X,9HJ       = ,1PE13.6,4X,9HPP      = ,1PE13.6,4X,6HJIE = ,1PE13.6,
    34X,9HJAE     = ,1PE13.6/
    43X,9HJA      = ,1PE13.6,4X,9HJI      = ,1PE13.6,4X,6HJE  = ,1PE13.6,
    54X,9HJA/JAP = ,1PE13.6/
    63X,9HJE/JEP = ,1PE13.6,4X,9HJI/JIP = ,1PE13.6,4X,6HDVS = ,0PF8.5,9
    7X,9HXDVS    = ,1PE13.6/3X,9HNAP     = ,1PE13.6,4X,9HXD/LAM = ,1PE13.
    86,4X,6HPHZZ= ,0PF8.5,9X,9HEDVS    = ,1PE13.6/
    93X,9HNTP     = ,1PE13.6,4X,9HNCE     = ,1PE13.6,4X,6HNTE = ,1PE13.6,
    14X,9HRD/KTE = ,1PE13.6/3X,9HX/LMTE = ,1PE13.6,4X,9HELT/RD = ,1PE13
    2.6,4X,6HNIPA= ,1PE13.6)
 831 FORMAT (1HL,2X,9HJEE     = ,1PE13.6,4X,9HJEP     = ,1PE13.6,4X,6HJIP
    1 = ,1PE13.6,4X,9HJAP     = ,1PE13.6/
    23X,9HJ       = ,1PE13.6,4X,9HPP      = ,1PE13.6,4X,6HJIE = ,1PE13.6,
    34X,9HJAE     = ,1PE13.6/
    43X,9HJA      = ,1PE13.6,4X,9HJI      = ,1PE13.6,4X,6HJE  = ,1PE13.6,
    54X,9HJA/JAP = ,1PE13.6/
    63X,9HJE/JEP = ,1PE13.6,4X,9HJI/JIP = ,1PE13.6,4X,6HDVS = ,0PF8.5,9
    7X,9HXDVS    = ,1PE13.6/3X,9HNAP     = ,1PE13.6,4X,9HXD/LAM = ,1PE13.
    86,4X,6HSC  = ,1PE13.6,4X,9HPHZ     = ,0PF8.5/
    93X,9HEDVS    = ,1PE13.6,4X,9HDVSRD  = ,1PE13.6,27X,9HDVS/RD = ,1PE1
    13.6/
    23X,9HELM/RD = ,1PE13.6,4X,9HPHZZ    = ,1PE13.6,27X,9HDRD/KT = ,1PE1
    33.6/
    43X,9HNTP     = ,1PE13.6,4X,9HNCE     = ,1PE13.6,4X,6HNTE = ,1PE13.6,
    54X,9HRD/KTE = ,1PE13.6/3X,9HX/LMTE = ,1PE13.6,4X,9HELT/RD = ,1PE13
    6.6,4X,6HNIPA= ,1PE13.6)
 840 FORMAT (1HL,2X,9HRHO(DV)= ,1PE13.6,3H + ,1PE13.6,6H*DV + ,1PE13.6,
    19H*DV**2 + ,1PE13.6,9H*DV**3 + ,1PE13.6,6H*DV**4)
 850 FORMAT (1H1)
 860 FORMAT (1HL/1HL,2X,4HI = ,F5.3,5X,5HTE = ,F5.0,5X,6HPHI = ,F5.3,5X
    1,6HNEP = ,1PE8.2,5X,6HTEP = ,0PF7.1,5X,6HTIP = ,0PF7.1,5X,9HLAMBDA
    2 = ,1PE11.4/1H0,1X,5HPV = ,1PE13.6,5X,12HLAMBDA(TE) =,1PE11.4)
     END
```

```
$IBFTC PLOTA
      SUBROUTINE PLOT
      COMMON /MP/ XDV(50),XDS(50),RHODOP(50),RHDS(50),EDV(50),EDS(50),
     1DV(50),DVSAVE(50),RHOEOP(50),RHES(50),RHOIOP(50),RHIS(50),NBB,
     2IWRITE
      DIMENSION KKK(14),P(10),Z(100),ZA(100),ZB(100),ZC(100),ZD(100),
     1ZE(100)
  599 ND = 0
      DO 600 NB = 1,NBB
      NE = NBB - ND
      NET = 2*NBB - ND
      ND = ND + 1
      Z(NE) = XDV(NB)
      Z(NET) = XDS(NB)
      ZA(NE) = RHODOP(NB)
      ZA(NET) = RHDS(NB)
      ZB(NE) = EDV(NB)
      ZB(NET) = EDS(NB)
      ZC(NE) = DV(NB)
      ZC(NET) = DVSAVE(NB)
      ZD(NE) = RHOEOP(NB)
      ZD(NET) = RHES(NB)
      ZE(NE) = RHOIOP(NB)
      ZE(NET) = RHIS(NB)
  600 CONTINUE
      P(1) = 5.0
      KKK(1) = 64
      KKK(2) = 2
      KKK(3) = NBB
      KKK(5) = NBB
      NB2 = 2*NBB
      CALL SCALE (NB2,ZA,KRSTR)
      CALL PLOTMY (Z,ZA,KKK,P)
      WRITE (6,602) KRSTR
      ND = 0
      DO 606 NB = 1,NBB
      NE = NBB - ND
      NET = 2*NBB - ND
      Z(NE) = XDV(NB)
      Z(NET) = XDS(NB)
      ND = ND + 1
  606 CONTINUE
      CALL SCALE (NB2,ZD,KRSTR)
      CALL PLOTMY (Z,ZD,KKK,P)
      WRITE (6,603) KRSTR
      ND = 0
      DO 601 NB = 1,NBB
      NE = NBB - ND
      NET = 2*NBB - ND
      ND = ND + 1
      Z(NE) = XDV(NB)
      Z(NET) = XDS(NB)
  601 CONTINUE
      CALL SCALE (NB2,ZE,KRSTR)
      CALL PLOTMY (Z,ZE,KKK,P)
      WRITE (6,610) KRSTR
      ND = 0
      DO 611 NB = 1,NBB
      NE = NBB - ND
      NET = 2*NBB - ND
```

```
      ND = ND + 1
      Z(NE) = XDV(NB)
      Z(NET) = XDS(NB)
  611 CONTINUE
      CALL SCALE (NB2,ZB,KRSTR)
      CALL PLOTMY (Z,ZB,KKK,P)
      WRITE (6,604) KRSTR
      ND = 0
      DO 608 NB = 1,NBB
      NE = NBB - ND
      NET = 2*NBB - ND
      Z(NE) = XDV(NB)
      Z(NET) = XDS(NB)
      ND = ND + 1
  608 CONTINUE
      CALL SCALE (NB2,ZC,KRSTR)
      CALL PLOTMY (Z,ZC,KKK,P)
      WRITE (6,605) KRSTR
      IF (IWRITE.EQ.1) RETURN
      P(1) = NBB
      KODE = 64
      ND = 0
      DO 500 NB = 1,NBB
      NE = NBB - ND
      Z(NE) = XDV(NB)
      ZA(NE) = RHODOP(NB)
      ZD(NE) = RHOEOP(NB)
      ZB(NE) = EDV(NB)
      ZC(NE) = DV(NB)
      ZE(NE) = RHOIOP(NB)
      ND = ND + 1
  500 CONTINUE
      WRITE (6,501)
      CALL SCALE (NBB,ZA,KRSTR)
      CALL PLOTXY (Z,ZA,KODE,P)
      WRITE (6,502) KRSTR
      WRITE (6,501)
      CALL SCALE (NBB,ZD,KRSTR)
      CALL PLOTXY(Z,ZD,KODE,P)
      WRITE (6,505) KRSTR
      WRITE (6,501)
      CALL SCALE (NBB,ZE,KRSTR)
      CALL PLOTXY (Z,ZE,KODE,P)
      WRITE (6,510) KRSTR
      WRITE (6,501)
      CALL SCALE (NBB,ZB,KRSTR)
      CALL PLOTXY (Z,ZB,KODE,P)
      WRITE (6,503) KRSTR
      WRITE (6,501)
      CALL SCALE (NBB,ZC,KRSTR)
      CALL PLOTXY (Z,ZC,KODE,P)
      WRITE (6,504) KRSTR
  501 FORMAT (2HPT)
  502 FORMAT (2HPL,47X,8HND(X10**,I3,6H) VS X)
  503 FORMAT (2HPL,47X,7HE(X10**,I3,6H) VS X)
  504 FORMAT (2HPL,47X,8HDV(X10**,I3,6H) VS X)
  505 FORMAT (2HPL,47X,8HNE(X10**,I3,6H) VS X)
  510 FORMAT (2HPL,47X,8HNI(X10**,I3,6H) VS X)
  602 FORMAT (2HPL,47X,8HND(X10**,I3,6H) VS X/
     12HPL,44X,20H+ RICHARDSON-DUSHMAN/2HPL,44X,10H* SCHOTTKY)
```

```
  603 FORMAT (2HPL,47X,8HNE(X10**,I3,6H) VS X/
     12HPL,44X,20H+ RICHARDSON-DUSHMAN/2HPL,44X,10H* SCHOTTKY)
  604 FORMAT (2HPL,47X,7HE(X10**,I3,6H) VS X/
     12HPL,44X,20H+ RICHARDSON-DUSHMAN/2HPL,44X,10H* SCHOTTKY)
  605 FORMAT (2HPL,47X,8HDV(X10**,I3,6H) VS X/
     12HPL,44X,20H+ RICHARDSON-DUSHMAN/2HPL,44X,10H* SCHOTTKY)
  610 FORMAT (2HPL,47X,8HNI(X10**,I3,6H) VS X/
     12HPL,44X,20H+ RICHARDSON-DUSHMAN/2HPL,44X,10H* SCHOTTKY)
      RETURN
      END
$IBFTC VINE
      SUBROUTINE VIN (NV,DVV,T,ANS)
      COMMON /MV/ PI,EM,AK,AM
C
C        IF NV  =  1  COMPUTATION FOR ELECTRONS
C         IF  NV  =  2  COMPUTATIONS FOR ATOMS AND IONS
C       THE PROPER T AND DV IS SPECIFIED IN THE MAIN PROGRAM
C
      IF (NV.EQ.1) GO TO 10
      C = SQRT (2.0*AK*T/(PI*AM))
      GO TO 20
   10 C = SQRT (2.0*AK*T/(PI*EM))
   20 XE =ASQRT(DVV/(AK*T))
      Y = ERF(XE)
      ERFC = 1.0-Y
      ANS = C*EXP(-ABS(DVV)/(AK*T))/ERFC
      RETURN
      END
$IBFTC TRAPE
      SUBROUTINE TRAP (X,DV,NBB,ANS)
      DIMENSION X(40),DV(50),ANS(40)
C
C        SUBROUTINE TO INTEGRATE TRAPEZOIDALLY
C
      H = DV(2)/2.0
      SUME = 0.0
      DO 60 NB = 1,NBB
      IF (NB.EQ.1) GO TO 50
      SUME = SUME+X(NB-1)+X(NB)
      ANS(NB) = SUME*H
      GO TO 60
   50 ANS(NB) = 0.0
   60 CONTINUE
      RETURN
      END
$DATA

    1
    2.4E+3
    1
    3.0E+0
    1
    1.E+13
    1
    2.5E+3
    1
    2.4E+3
```

APPENDIX C

SYMBOLS FOR IBM OUTPUT SHEETS AND FORTRAN IV LISTING

The symbols are presented here in the order of appearance on the output sheets.

Output labels	FORTRAN variables	Symbols	Description	Units
I	AI	I	ionization potential for plasma atoms	V
TE	TE	T_E	emitter temperature	^oK
PHI	PHI	$e\varphi$	work function	V
NEP	EPN	N_{ep}	plasma electron number density	cm^{-3}
TEP	TEP	T_{ep}	plasma electron temperature	^oK
TIP	TIP, TIPP	T_{ip}	plasma ion temperature	^oK
LAMBDA	AMDA	$\lambda_{DT_{ep}}$	plasma Debye length	cm
PV	PTEST	p_{vp}	vapor pressure of plasma element at T_E	torr (133.322 (N/m^2)/torr)
LAMBDA(TE)	AMDATE	λ_{DT_E}	emission Debye length	cm
DV	DV	ΔV	sheath potential measured from plasma electron potential	V
ND(DV)	RHODOP	$\rho_{\Delta V}$	net number density of charge at ΔV	cm^{-3}
NE(DV)	RHOEOP	ρ_e	electron number density at ΔV	cm^{-3}

Output labels	FORTRAN variables	Symbols	Description	Units
NI(DV)	RHOIOP	ρ_i	ion number density at ΔV	cm^{-3}
E(DV)	EDV	$E_{\Delta V}$	electron electrostatic field at ΔV	V/cm
X(DV)	XDV	$X_{\Delta V}$	distance from emitter to ΔV	cm
JEE	EJ	j_e	emitted electron current density	A/cm^2
JEP	EPJ	j_{ep}	plasma electron random current density	A/cm^2
JIP	PIJ	j_{ip}	plasma ion random current density	A/cm^2
JAP	APJ	j_{ap}	plasma atom equivalent random current density	A/cm^2
J	CJ	J	net current density through sheath	A/cm^2
PP	PP	p_p	plasma pressure	torr (133.322 (N/m^2)/torr)
JIE	EIJ	j_{iE}	emitted ion current density	A/cm^2
JAE	AEJ	j_{aE}	emitted equivalent atom current density	A/cm^2
JA	SJA	j_a	net equivalent atom current density	A/cm^2
JI	SJI	j_i	net ion current density	A/cm^2
JE	SJE	j_e	net electron current density	A/cm^2

Output labels	FORTRAN variables	Symbols	Description	Units
JA/JAP	SDJA	---------------------	j_a/j_{ap}	------------
JE/JEP	SDJE	---------------------	j_e/j_{ep}	------------
JI/JIP	SDJI	---------------------	j_i/j_{ip}	------------
DVS	DVS	ΔV_S	overall sheath voltage drop	V
XDVS	XDVS	$X_{\Delta V_S}$	effective sheath thickness	cm
NAP	APN	N_{ap}	plasma atom number density	cm^{-3}
XD/LAM	XLAM	---------------------	X_S/λ_D	------------
SC	SC	$(\pm 0.511 \times 10^6 \times 2.82 \times 10^{-13}\ E_E)^{1/2}$	Schottky depression of work function	V
PHZ	PHIZ	φ_o	plasma potential (work function for no sheath)	V
EDVS	EDVS	$E_{\Delta V_S} = E_E$	electrostatic field at emitter	V/cm
DVSRD	DVSRD	$\varphi - \varphi_o$	Richardson-Dushman overall sheath voltage drop	V
DVS/RD	DVSPZ	---------------------	$\Delta V_S/\Delta V_o = \Delta V_S/(\varphi - \varphi_o)$	
ELM/RD	EDPZL	---------------------	$E_E\lambda_D/(\varphi - \varphi_o)$	
PHZZ	PHIZZ	($\varphi_{oo} = \varphi_o$ for equilibrium and electron sheath)	plasma potential at equilibrium (work function for no sheath and no net current)	V
DRD/KT	DRDK	---------------------	$e\lvert\varphi - \varphi_o\rvert/\kappa T_e$	------------
NTP	TPN	---------------------	total particle number density in plasma	cm^{-3}

Output labels	FORTRAN variables	Symbols	Description	Units
NCE	CEN	---------------------	total charge number density at emitter	cm^{-3}
NTE	TNE	---------------------	total particle number density at emitter	cm^{-3}
RD/KTE	PHAT	---------------------	$e\lvert\varphi - \varphi_o\rvert/\kappa T_E$	------------
X/LMTE	XAMTE	---------------------	x_S/λ_{DE}	------------
ELT/RD	EAMPHZ	---------------------	$E_E\lambda_{DE}/(\varphi - \varphi_o)$	------------
NEPA	WNEPA	---------------------	NE(ΔV) at $\Delta V = 0.0$, approximate value of N_{ep} from sheath calculations (Positive-Ion Sheath Program)	------------
NIPA	WNIPA	---------------------	NI(ΔV) at $\Delta V = 0.0$, approximate value of N_{ip} from sheath calculations (Electron Sheath Program)	------------
-----------	---------	---------------------	ND, NE, NI, E, DV, and X on plots correspond to ND(DV), NE(DV), NI(DV), E(DV), DV, and X(DV) in the preceding list.	------------

APPENDIX D

IMPORTANT VARIABLES AND CONSTANTS IN FORTRAN IV LISTING

The variables given in the following list are not included in the output.

AK	Boltzmann constant, κ
AM	atom particle mass, m_a
AP1	(Planck's constant)/(electronic charge), h/e
C3	gas constant
C4	electronic charge, e
CAT	value of JA, JB, JC whichever is largest (Positive-Ion Sheath Program)
DVSAVE	Richardson-Dushman value of ΔV
EDS	Richardson-Dushman value of $E_{\Delta V}$
EE	field at Schottky emitter, E_E or $E_{\Delta V_S}$
EIJS	emitted ion current density j_{ie} with Schottky correction (Electron Sheath Program)
EJS	emitted electron current density j_{eE} with Schottky correction (Positive-Ion Sheath Program)
EM	electron particle mass, m_e
J1	emitted electron current density, j_{eE}
J2	electron current from plasma that reaches emitter, $j_{ep} \exp(-\Delta V_S/\kappa T_{ep})$
J3	ion current from emitter that reaches plasma, $j_{ie} \exp(-\Delta V_S/\kappa T_E)$
J4	plasma ion random current density, j_{ip}
JA	$J1_{kount} - J1_{kount-1}$
JB	$J2_{kount} - J2_{kount-1}$
JC	$J3_{kount} - J3_{kount-1}$
KOUNT	counter
PHD	work function with or without Schottky correction, $e\varphi$ or $e\varphi \pm e\,(\pm eE_E)^{1/2}$
PI	3.14159
RHDS	Richardson-Dushman value of $\rho_{\Delta V}$

RHES	Richardson-Dushman value of ρ_e
RHIS	Richardson-Dushman value of ρ_i
RHOD	(Net number density of charge) (Electronic charge)
RHOE	(Electron number density) (Electronic charge)
RHOI	(Ion number density) (Electronic charge)
SE	electronic charge
TAP	plasma atom temperature, $T_{ap} = T_{ip}$
TENT	0.1 percent of either J1, J2, J3, J4, j_{ap}, j_{ae} whichever is smallest (Positive-Ion Sheath Program); 0.1 percent of either j_e, j_{ep}, j_{ip}, j_{ie}, j_{ep}, j_{ae} whichever is smallest (Electron Sheath Program)

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3. Richardson, O. W.: Negative Radiation from Hot Platinum. Cambridge Phil. Soc. Proc., vol. 11, Feb. 1902, pp. 286-295.

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6. Schottky, W.: Emission of Electrons from an Incandescent Filament Under the Action of a Retarding Potential. Ann. d. Physik, vol. 44, no. 7, July 17, 1914, pp. 1011-1032.

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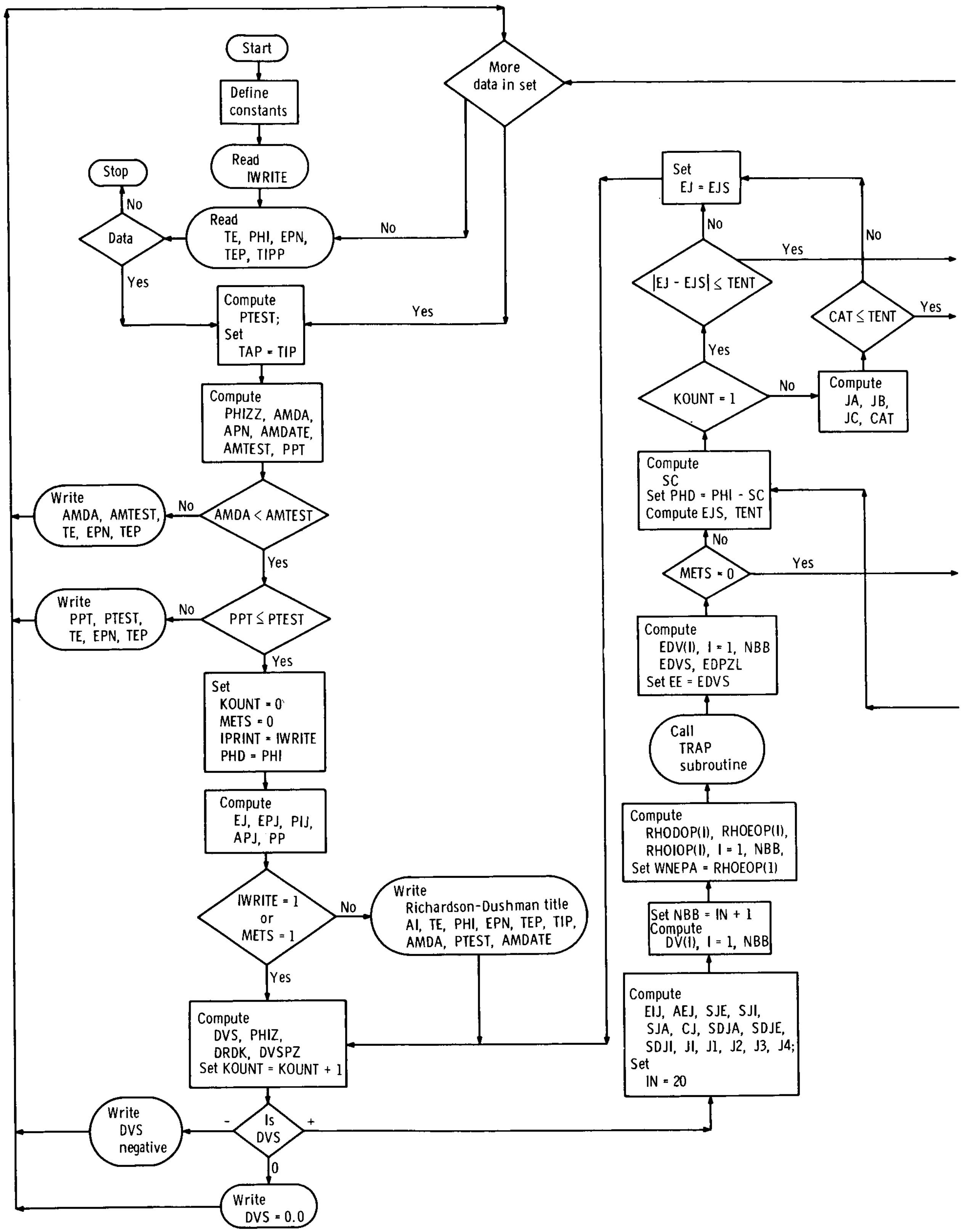
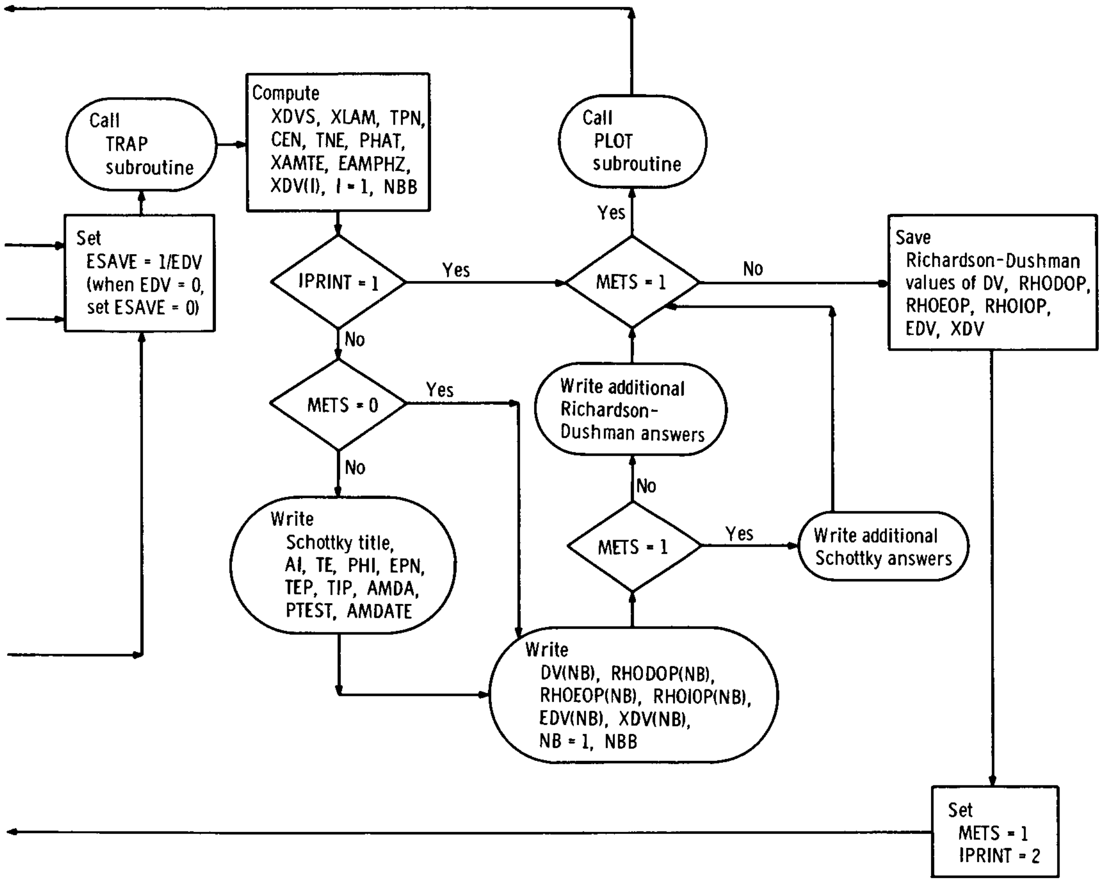


Figure 1. - Flow diagram for



Positive-Ion Sheath Program.

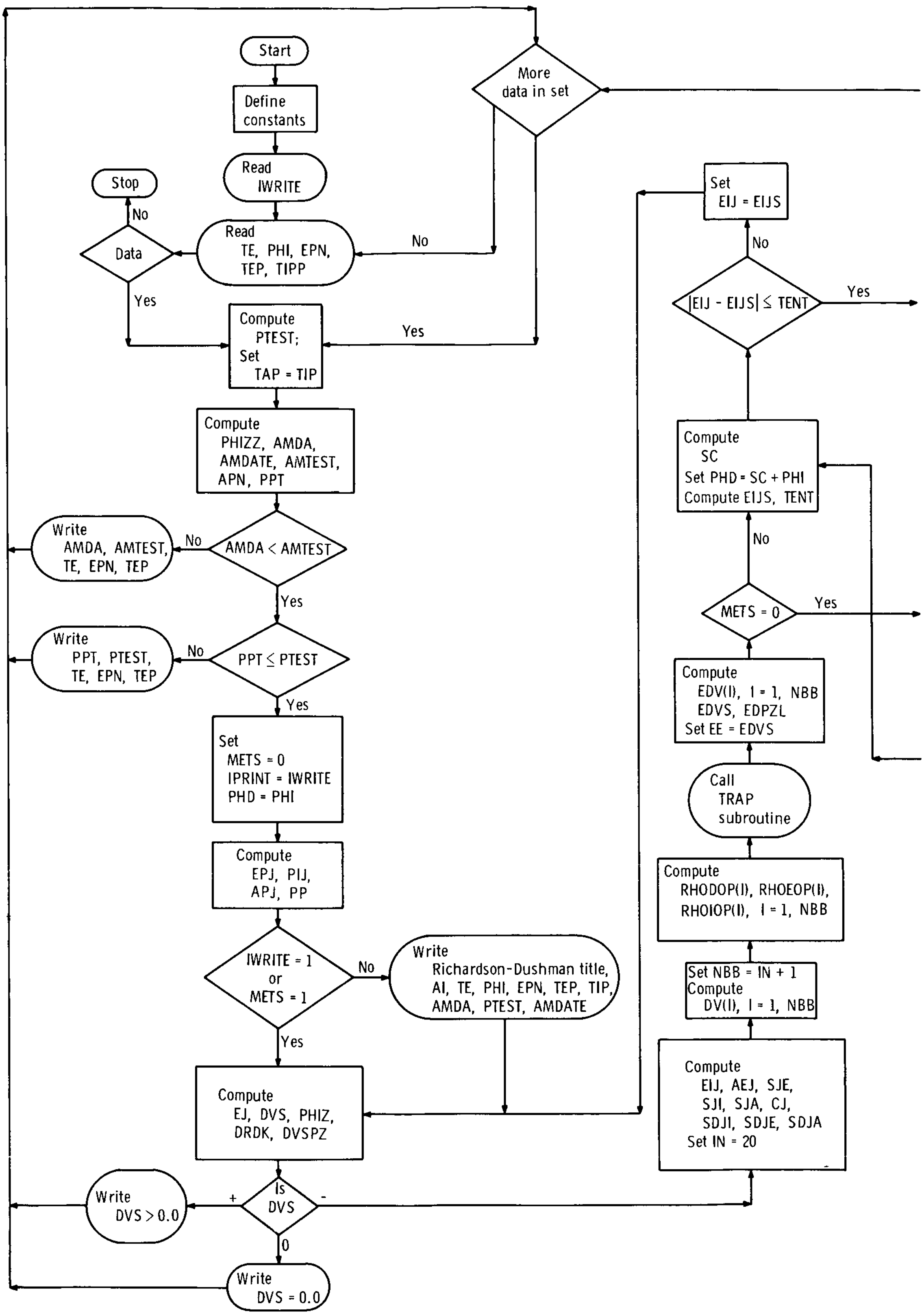
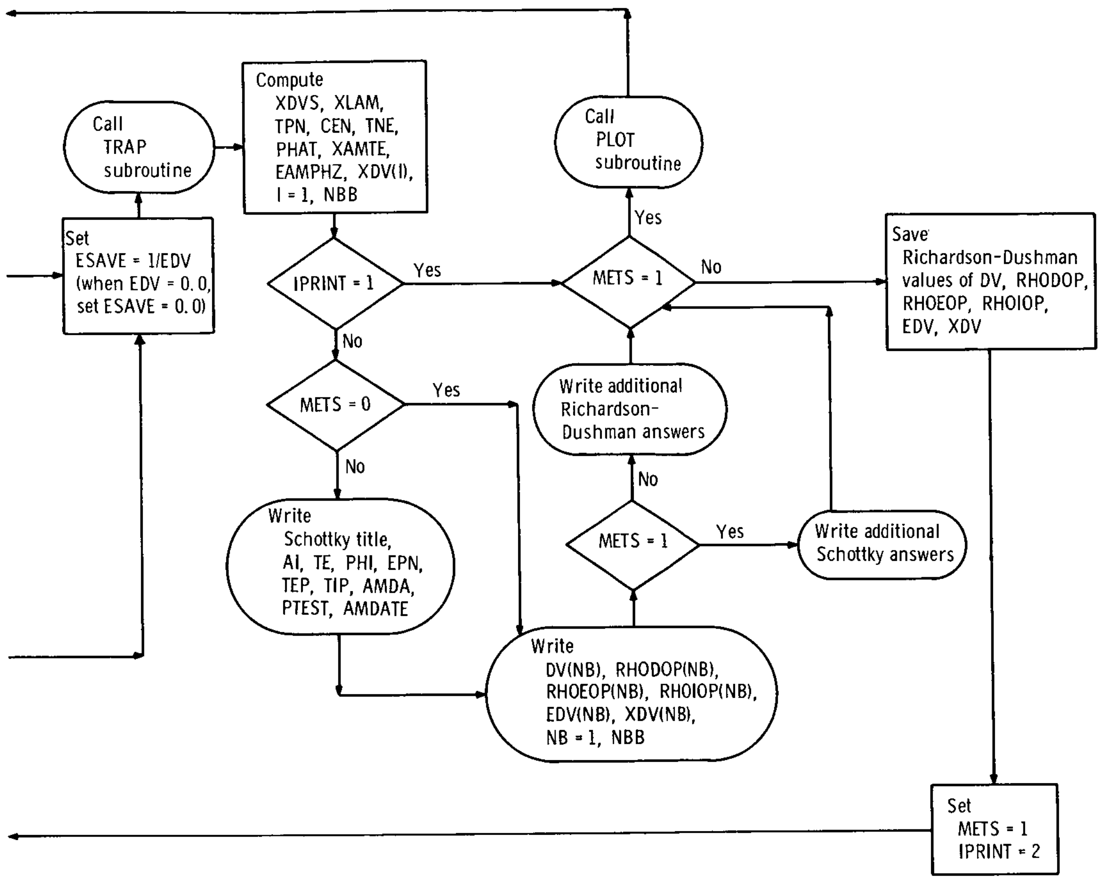


Figure 2. - Flow diagram for



Electron Sheath Program.

RICHARDSON-DUSHMAN

I = 3.893 TE = 2400. PHI = 4.000 NEP = 1.00E 13 TEP = 2.50E 03 TIP = 2400.0 LAMBDA = 1.0907E-04

PV = 1.598737E 05 LAMBDA(TE) = 1.0687E-04

DV	ND(DV)	NE(DV)	NI(DV)	E(DV)	X(DV)
0.	0.	9.265926E 12	-1.000000E 13	-0.	2.165515E-04
0.00696	-1.404696E 12	8.937498E 12	-1.034219E 13	1.330774E 02	1.904072E-04
0.01392	-2.077485E 12	8.618612E 12	-1.069610E 13	2.482155E 02	1.502460E-04
0.02088	-2.753221E 12	8.308889E 12	-1.106211E 13	3.500196E 02	1.262889E-04
0.02783	-3.432695E 12	8.007952E 12	-1.144065E 13	4.477747E 02	1.085789E-04
0.03479	-4.116718E 12	7.715422E 12	-1.183214E 13	5.437654E 02	9.441045E-05
0.04175	-4.806115E 12	7.430912E 12	-1.223703E 13	6.388856E 02	8.256630E-05
0.04871	-5.501740E 12	7.154030E 12	-1.265577E 13	7.335736E 02	7.237770E-05
0.05567	-6.204476E 12	6.884366E 12	-1.308884E 13	8.280794E 02	6.343331E-05
0.06263	-6.915243E 12	6.621489E 12	-1.353673E 13	9.225624E 02	5.546050E-05
0.06958	-7.635015E 12	6.364936E 12	-1.399995E 13	1.017135E 03	4.826864E-05
0.07654	-8.364827E 12	6.114193E 12	-1.447902E 13	1.111881E 03	4.171890E-05
0.08350	-9.105809E 12	5.868672E 12	-1.497448E 13	1.206872E 03	3.570693E-05
0.09046	-9.859223E 12	5.627675E 12	-1.548690E 13	1.302167E 03	3.015222E-05
0.09742	-1.062652E 13	5.390328E 12	-1.601685E 13	1.397824E 03	2.499133E-05
0.10438	-1.140947E 13	5.155461E 12	-1.656493E 13	1.493897E 03	2.017335E-05
0.11134	-1.221039E 13	4.921382E 12	-1.713178E 13	1.590445E 03	1.565682E-05
0.11829	-1.303267E 13	4.685348E 12	-1.771801E 13	1.687532E 03	1.140752E-05
0.12525	-1.388219E 13	4.442123E 12	-1.832431E 13	1.785243E 03	7.396930E-06
0.13221	-1.477311E 13	4.178250E 12	-1.895136E 13	1.883709E 03	3.601048E-06
0.13917	-1.585036E 13	3.749501E 12	-1.959986E 13	1.983543E 03	0.

JEE =	2.752001E 00	JEP =	1.244062E 01	JIP =	2.476505E-02	JAP =	5.786600E-02
J =	-3.768474E 00	PP =	1.088042E-02	JIE =	4.853916E-02	JAE =	5.786600E-02
JA =	-4.190952E-09	JI =	-3.259629E-09	JE =	-3.768474E 00	JA/JAP =	-7.242511E-08
JE/JEP =	-3.029169E-01	JI/JIP =	-1.316221E-07	DVS =	0.13917	XDVS =	2.165515E-04
NAP =	2.336599E 13	XD/LAM =	1.985423E 00	PHZZ=	3.69222	EDVS =	1.983543E 03
NTP =	4.336599E 13	NCE =	2.334936E 13	NTE =	4.671535E 13	RE/KTE =	6.729372E-01
X/LMTE =	2.026364E 00	ELT/RD =	1.523154E 00	NEPA=	9.265926E 12		

SCHOTTKY

I = 3.893   TE = 2400.   PHI = 4.000   NEP = 1.00E 13   TEP = 2.50E 03   TIP = 2400.0   LAMBDA = 1.0907E-04

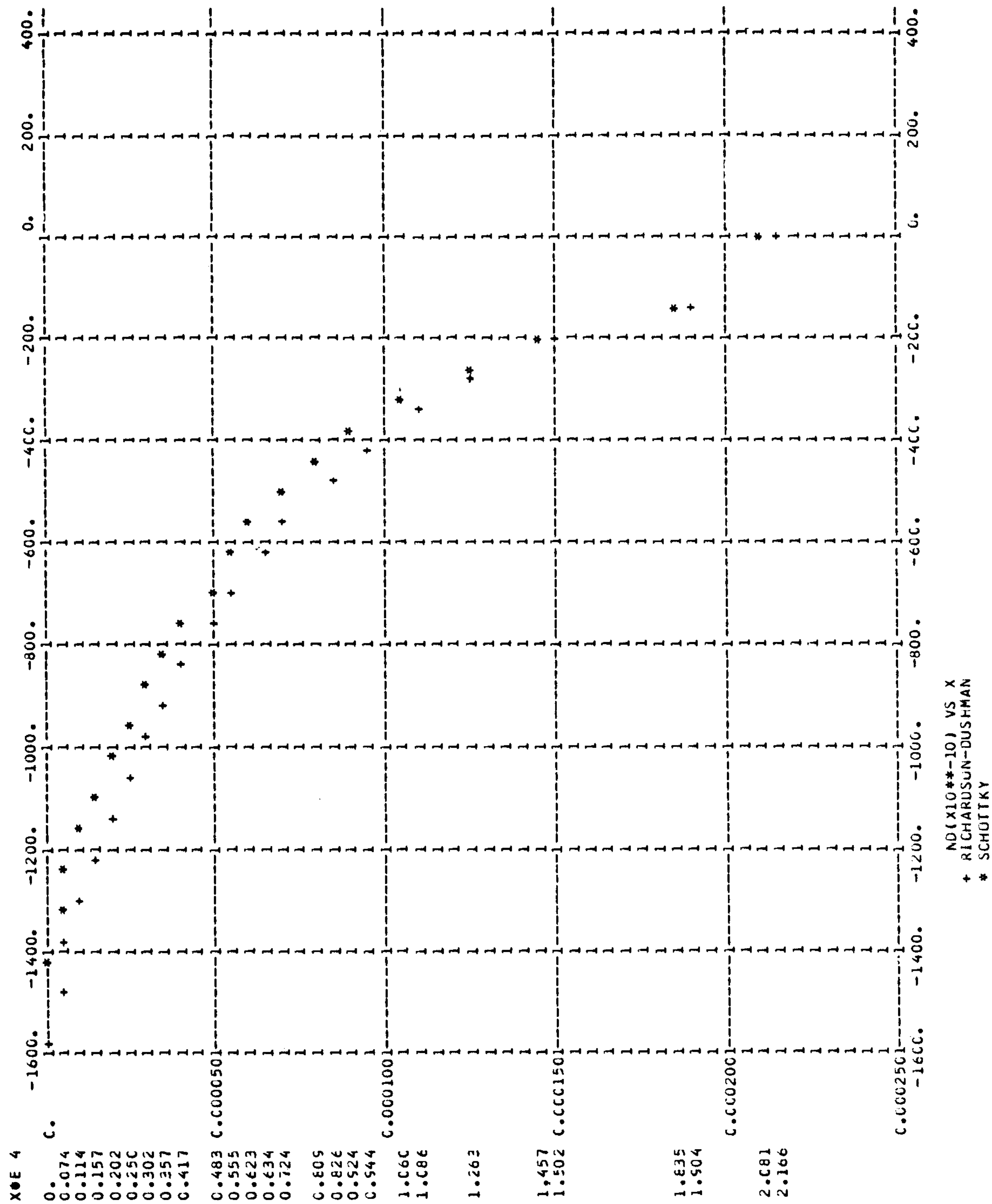
PV = 1.598737E 05   LAMBDA(TE) = 1.0687E-04

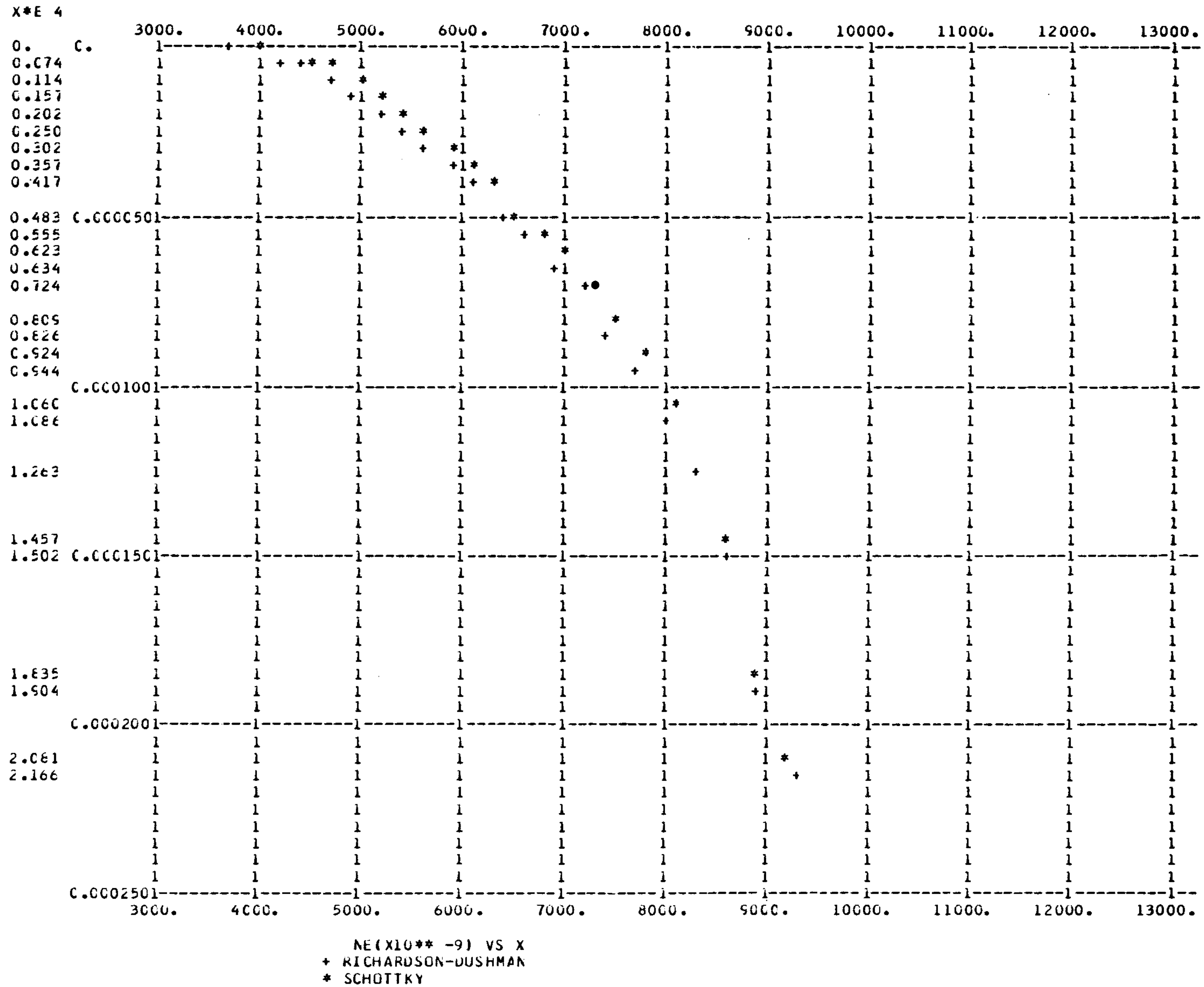
DV	ND(DV)	NE(DV)	NI(DV)	E(DV)	X(DV)
0.	0.	9.184470E 12	-1.000000E 13	-0.	2.080556E-04
0.00616	-1.411273E 12	8.891160E 12	-1.030243E 13	1.255216E 02	1.835106E-04
0.01232	-2.008800E 12	8.605214E 12	-1.061401E 13	2.322454E 02	1.456598E-04
0.01849	-2.608671E 12	8.326347E 12	-1.093502E 13	3.247893E 02	1.229480E-04
0.02465	-3.211457E 12	8.054272E 12	-1.126573E 13	4.128739E 02	1.060000E-04
0.03081	-3.817747E 12	7.788696E 12	-1.160644E 13	4.985389E 02	9.236287E-05
0.03697	-4.428144E 12	7.529316E 12	-1.195746E 13	5.839507E 02	8.091191E-05
0.04313	-5.043276E 12	7.275818E 12	-1.231909E 13	6.683852E 02	7.102640E-05
0.04929	-5.663798E 12	7.027866E 12	-1.269166E 13	7.525120E 02	6.232270E-05
0.05546	-6.290402E 12	6.785101E 12	-1.307550E 13	8.365004E 02	5.454540E-05
0.06162	-6.923825E 12	6.547125E 12	-1.347095E 13	9.204665E 02	4.751515E-05
0.06778	-7.564871E 12	6.313486E 12	-1.387836E 13	1.004496E 03	4.110088E-05
0.07394	-8.214430E 12	6.083656E 12	-1.429809E 13	1.088657E 03	3.520372E-05
0.08010	-8.873521E 12	5.856986E 12	-1.473051E 13	1.173008E 03	2.974718E-05
0.08627	-9.543358E 12	5.632650E 12	-1.517601E 13	1.257600E 03	2.467081E-05
0.09243	-1.022547E 13	5.409514E 12	-1.563498E 13	1.342462E 03	1.992602E-05
0.09859	-1.092192E 13	5.185911E 12	-1.610784E 13	1.427708E 03	1.547312E-05
0.10475	-1.163589E 13	4.959104E 12	-1.659499E 13	1.513338E 03	1.127932E-05
0.11091	-1.237306E 13	4.723820E 12	-1.709688E 13	1.599447E 03	7.317229E-06
0.11708	-1.314750E 13	4.468448E 12	-1.761395E 13	1.686163E 03	3.563802E-06
0.12324	-1.410559E 13	4.041058E 12	-1.814665E 13	1.774092E 03	0.

JEE =	2.972385E 00	JEP =	1.244062E 01	JIP =	2.476505E-02	JAP =	5.786600E-02
J =	-4.048585E 00	PP =	1.088042E-02	JIE =	4.494028E-02	JAE =	5.786600E-02
JA =	-1.862645E-09	JI =	-6.984919E-10	JE =	-4.048589E 00	JA/JAP =	-3.218894E-08
JE/JEP =	-3.254331E-01	JI/JIP =	-2.820474E-08	DVS =	0.12324	XDVS =	2.080556E-04
NAP =	2.326595E 13	XD/LAM =	1.907529E 00	SC =	1.598907E-02	PHZ =	3.86083
EDVS =	1.774092E 03	DVSRD =	1.391688E-01			DVS/RD =	8.855223E-01
ELM/RD =	1.390409E 00	PHZZ =	3.692223E 00			DRD/KT =	6.460197E-01
NTP =	4.326599E 13	NCE =	2.218771E 13	NTE =	4.555370E 13	RD/KTE =	6.729372E-01
X/LMTE =	1.946864E 00	ELT/RD =	1.362317E 00	NEPA=	9.184470E 12		

(a) Numerical values.

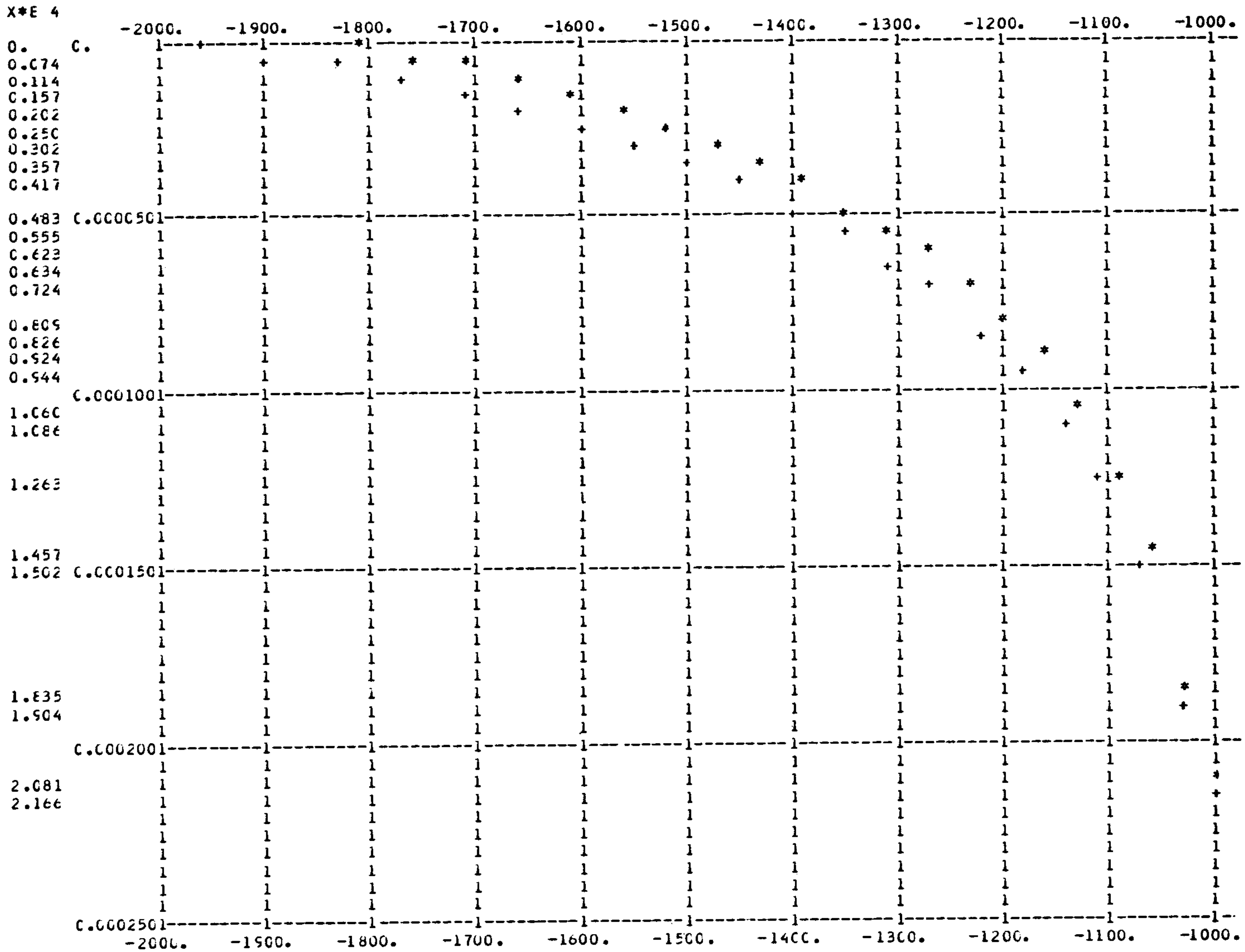
Figure 3. - Example output for Positive-Ion Sheath Program.


ND(X10**-10) VS X
+ RICHARDSON-DUSHMAN
* SCHOTTKY

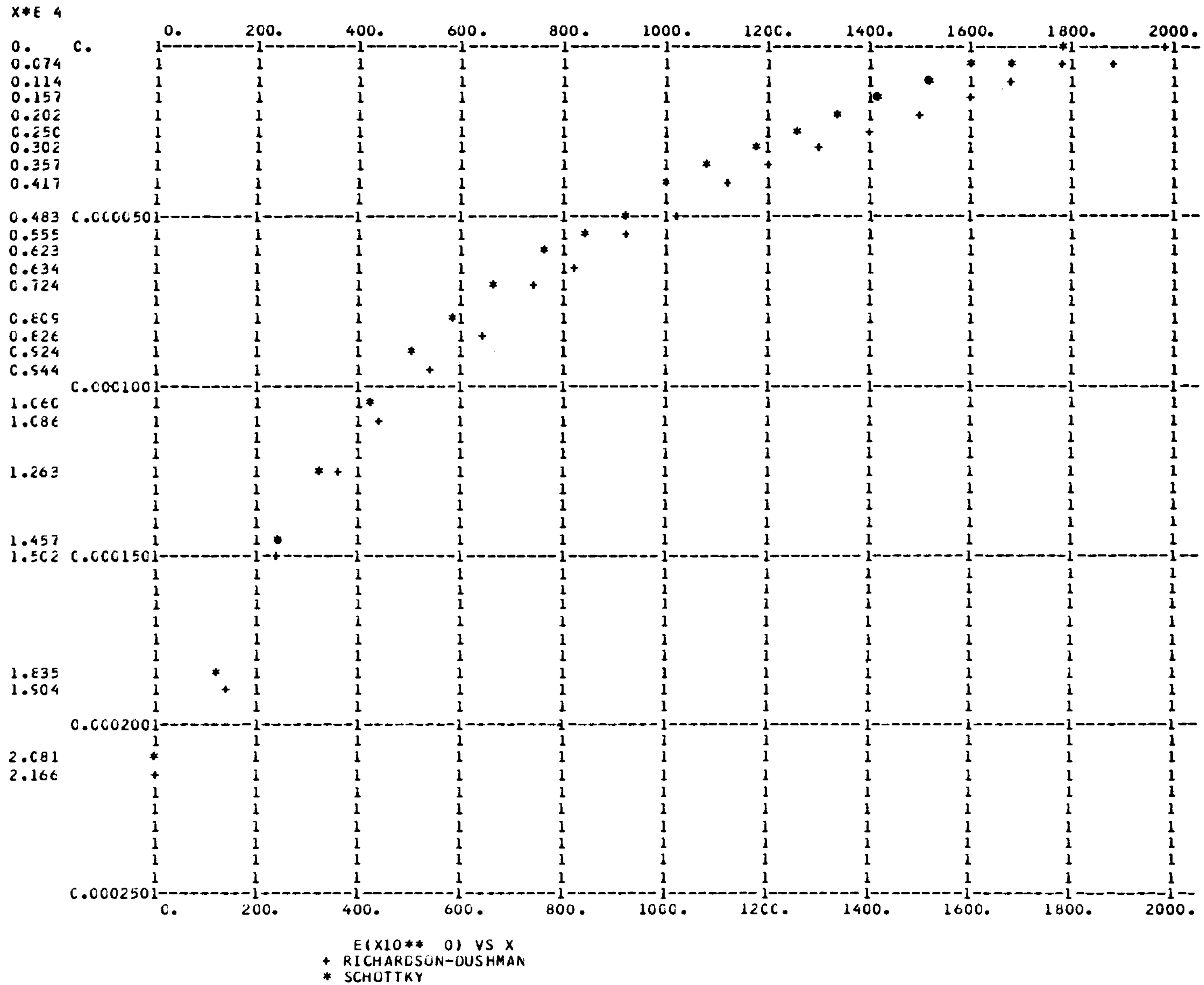


(b) Continued. Richardson-Dushman and Schottky results.

Figure 3. - Continued.

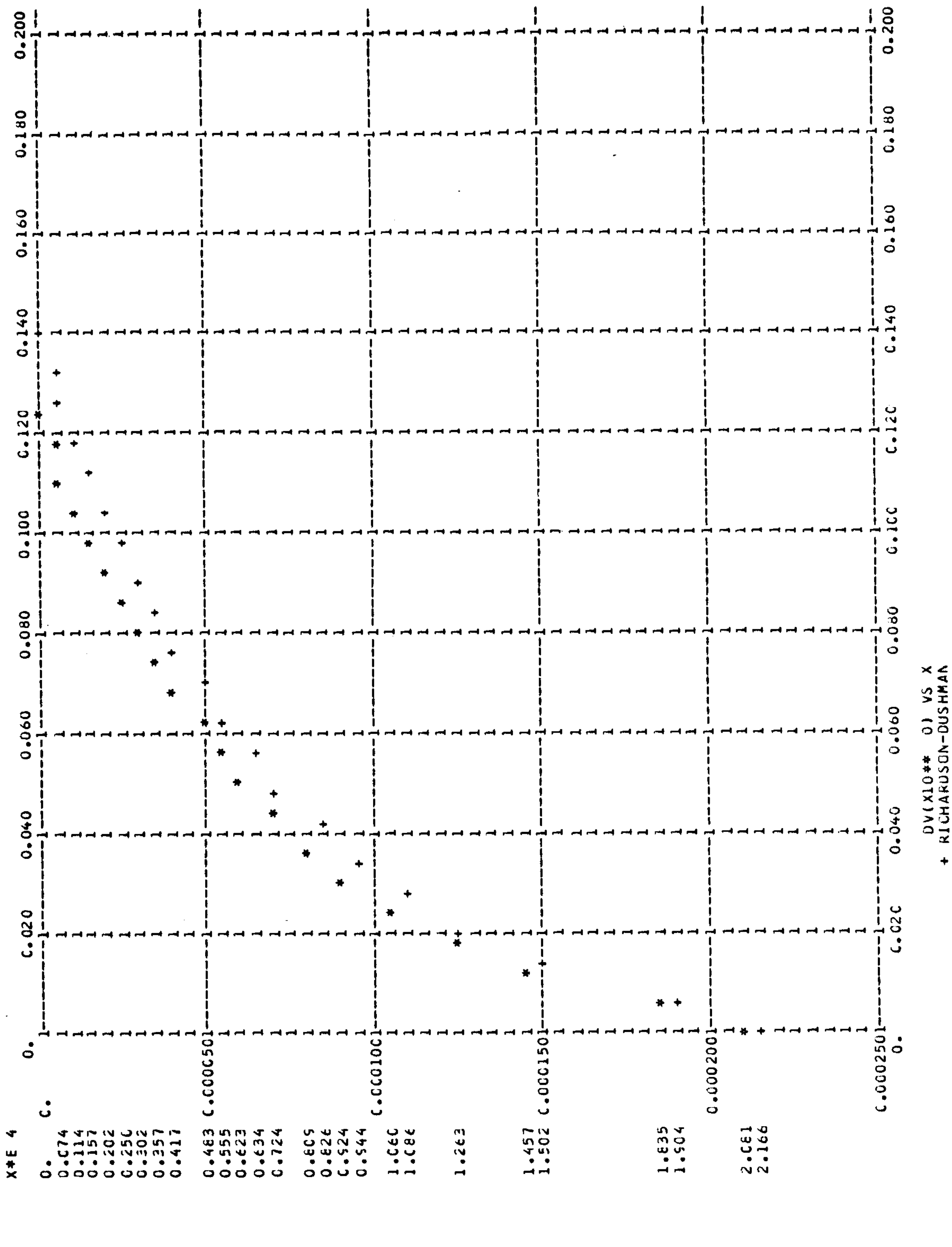


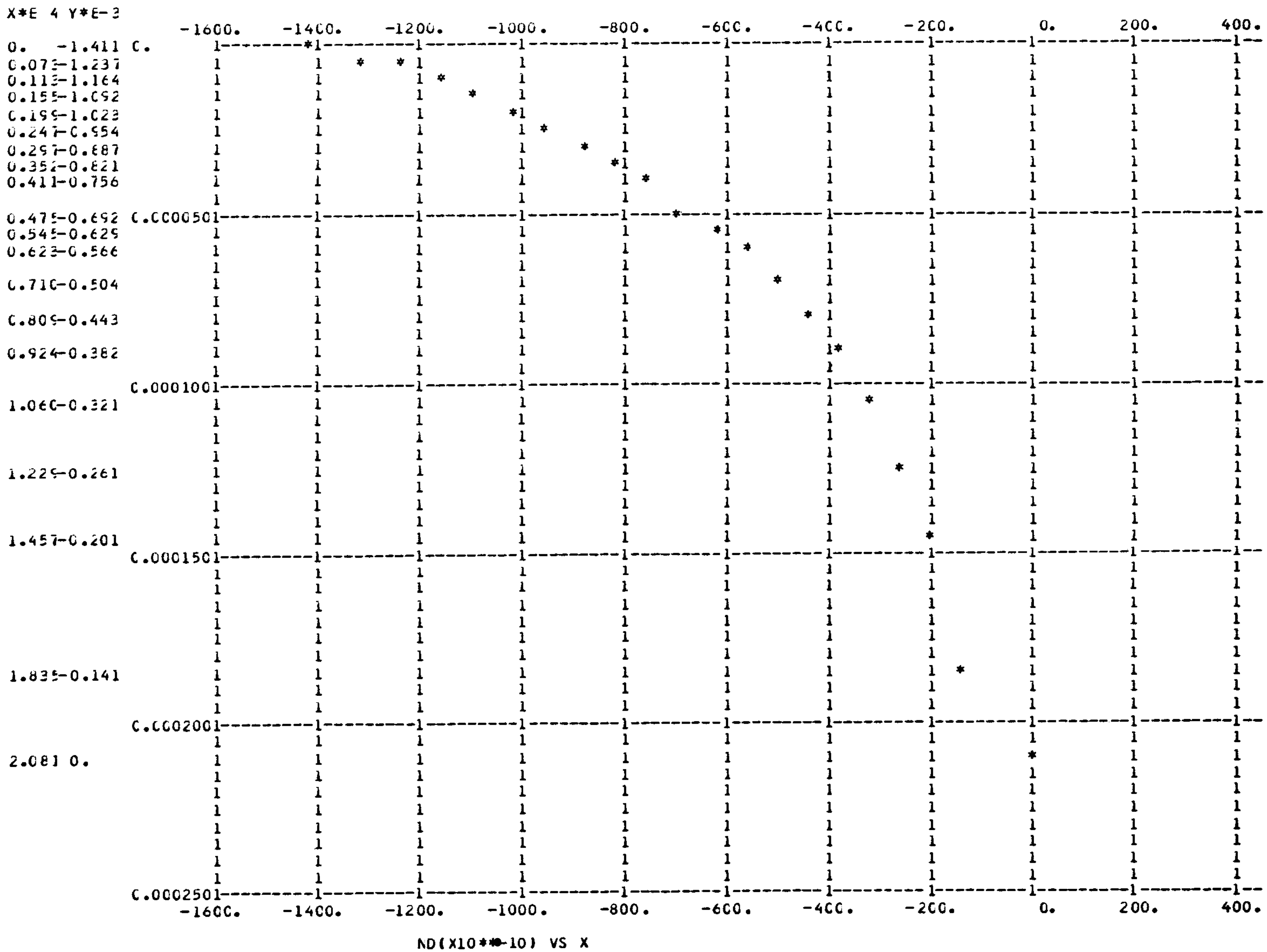
NI(X10**-10) VS X
+ RICHARDSON-DUSHMAN
* SCHOTTKY



(b) Continued. Richardson-Dushman and Schottky results.

Figure 3. - Continued.

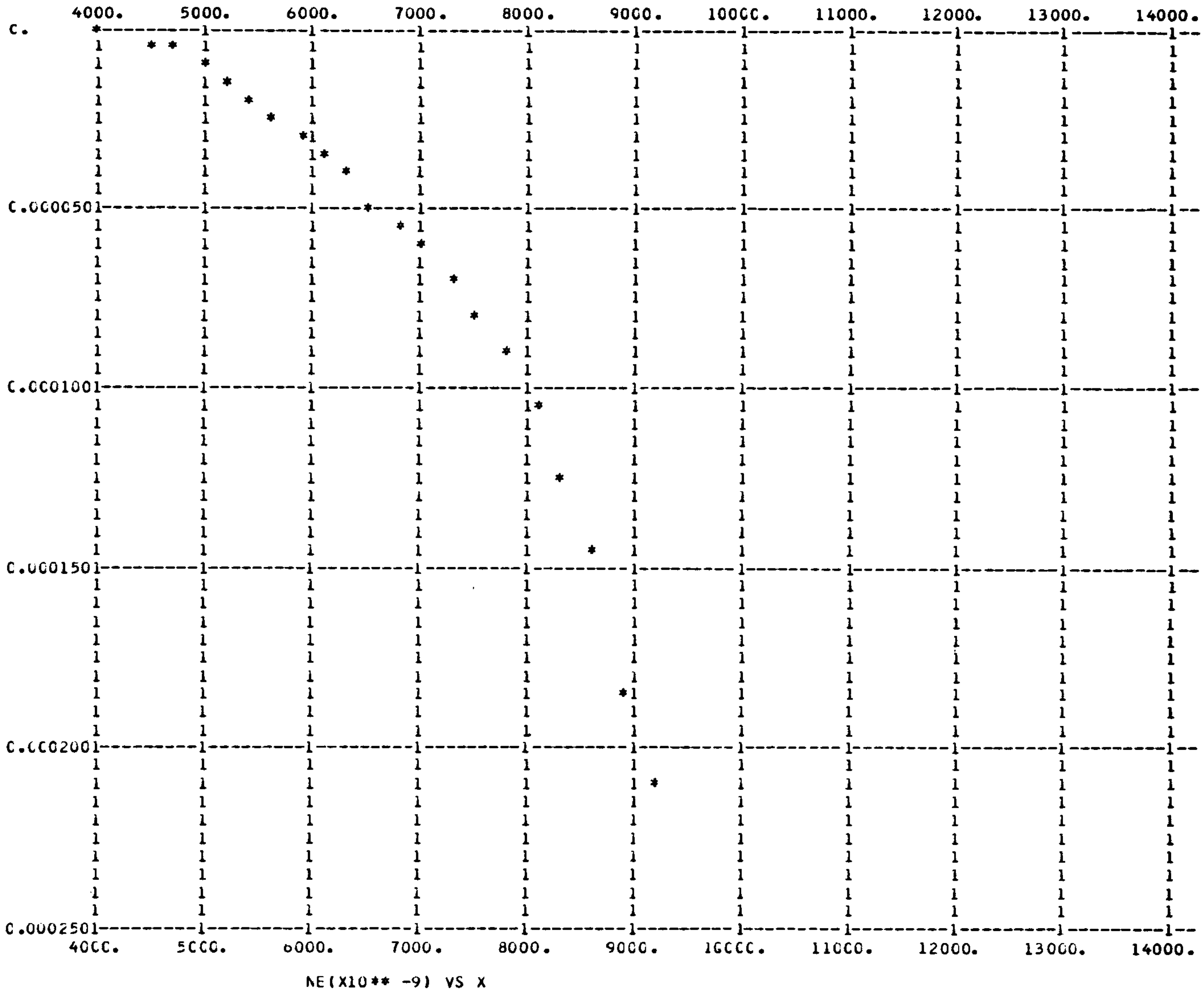

DV(X10** 0) VS X
+ RICHARDSON-DUSHMAN
* SCHOTTKY

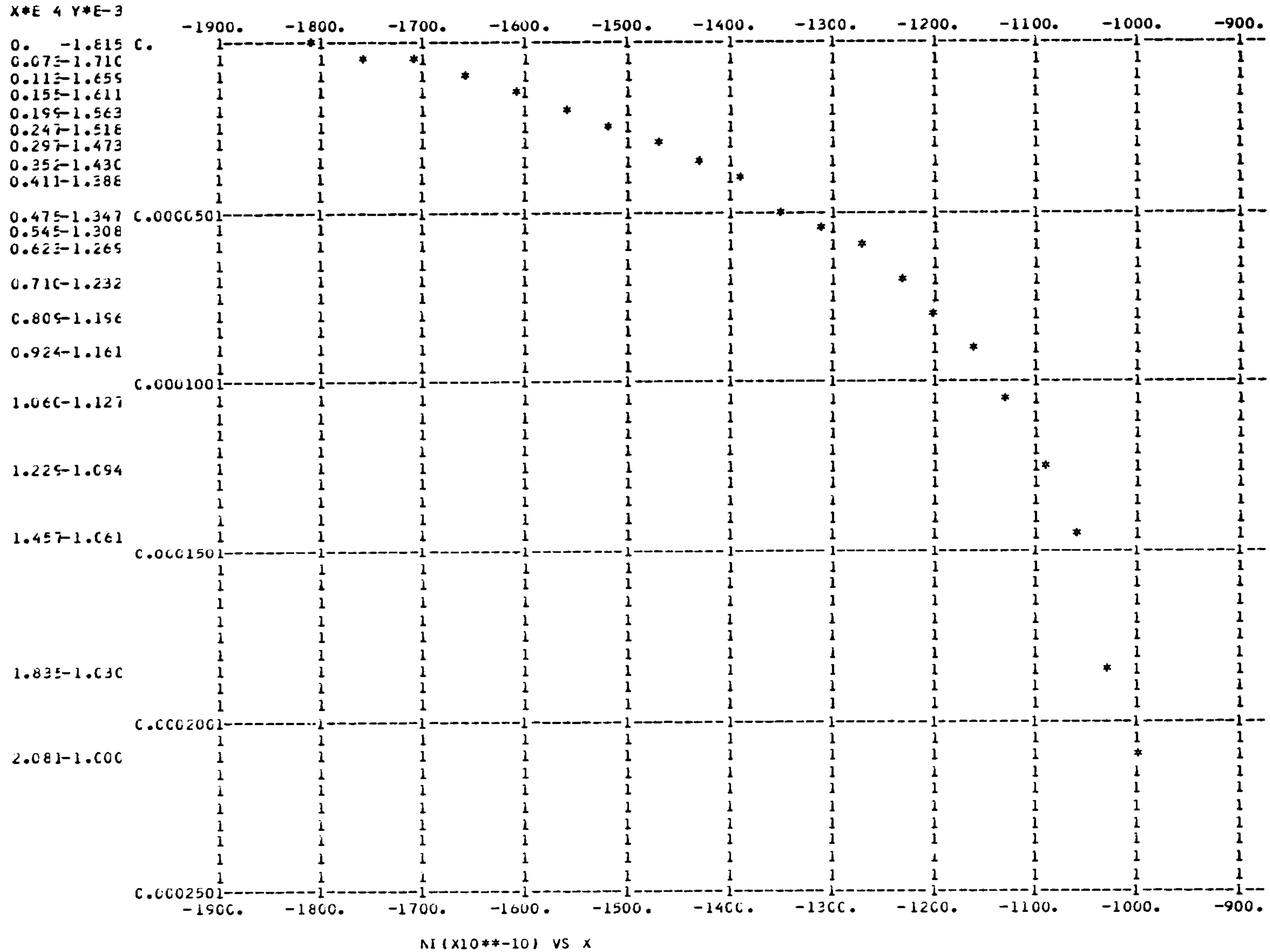


(c) Schottky results.

Figure 3. - Continued.

X*E 4	Y*E-3
0.	4.041
0.073	4.724
0.113	4.959
0.155	5.186
0.199	5.410
0.247	5.633
0.297	5.857
0.352	6.084
0.411	6.313
0.475	6.547
0.545	6.785
0.623	7.028
0.710	7.276
0.809	7.529
0.924	7.789
1.060	8.054
1.229	8.326
1.457	8.605
1.835	8.891
2.081	9.184

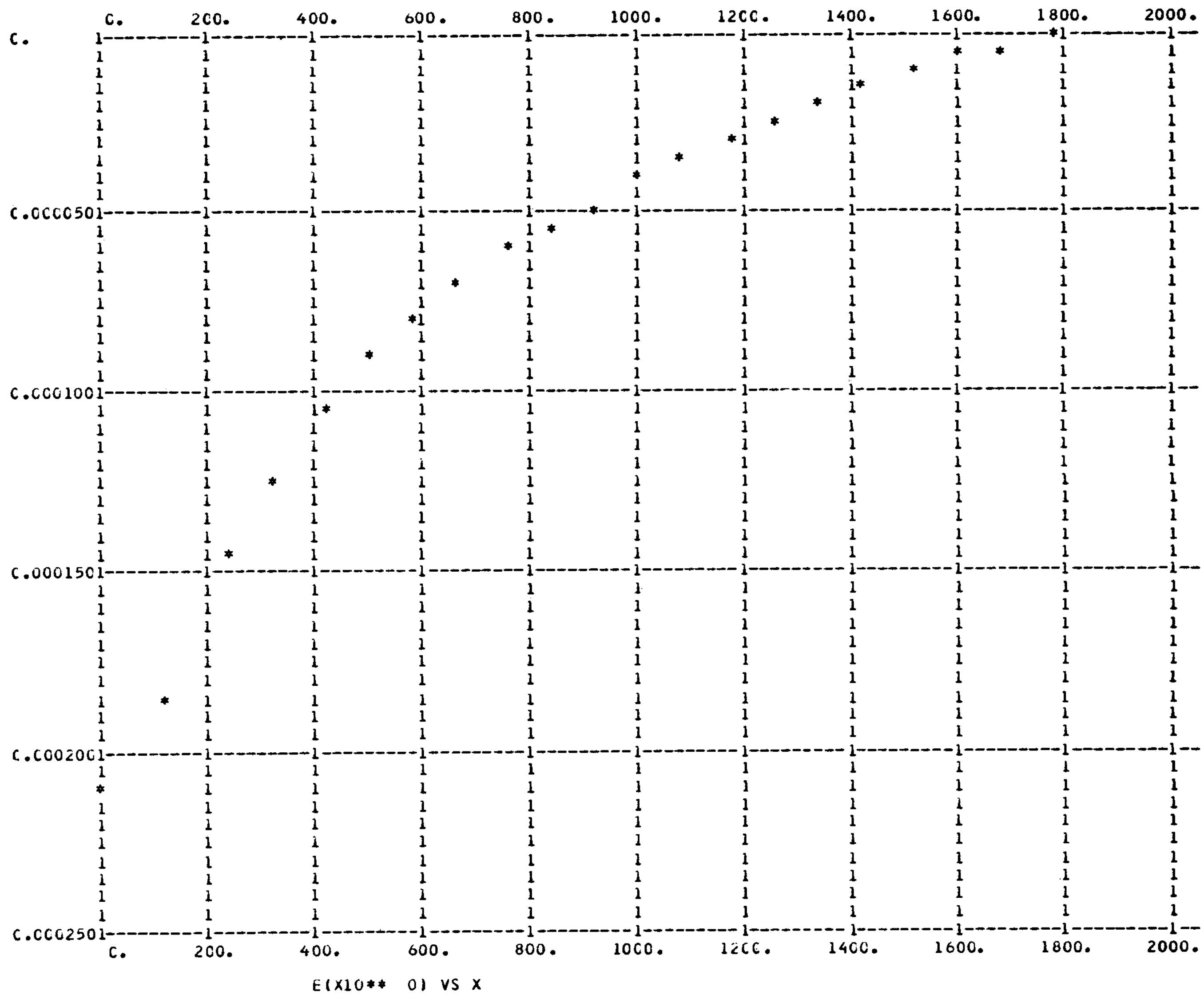




(c) Continued. Schottky results.

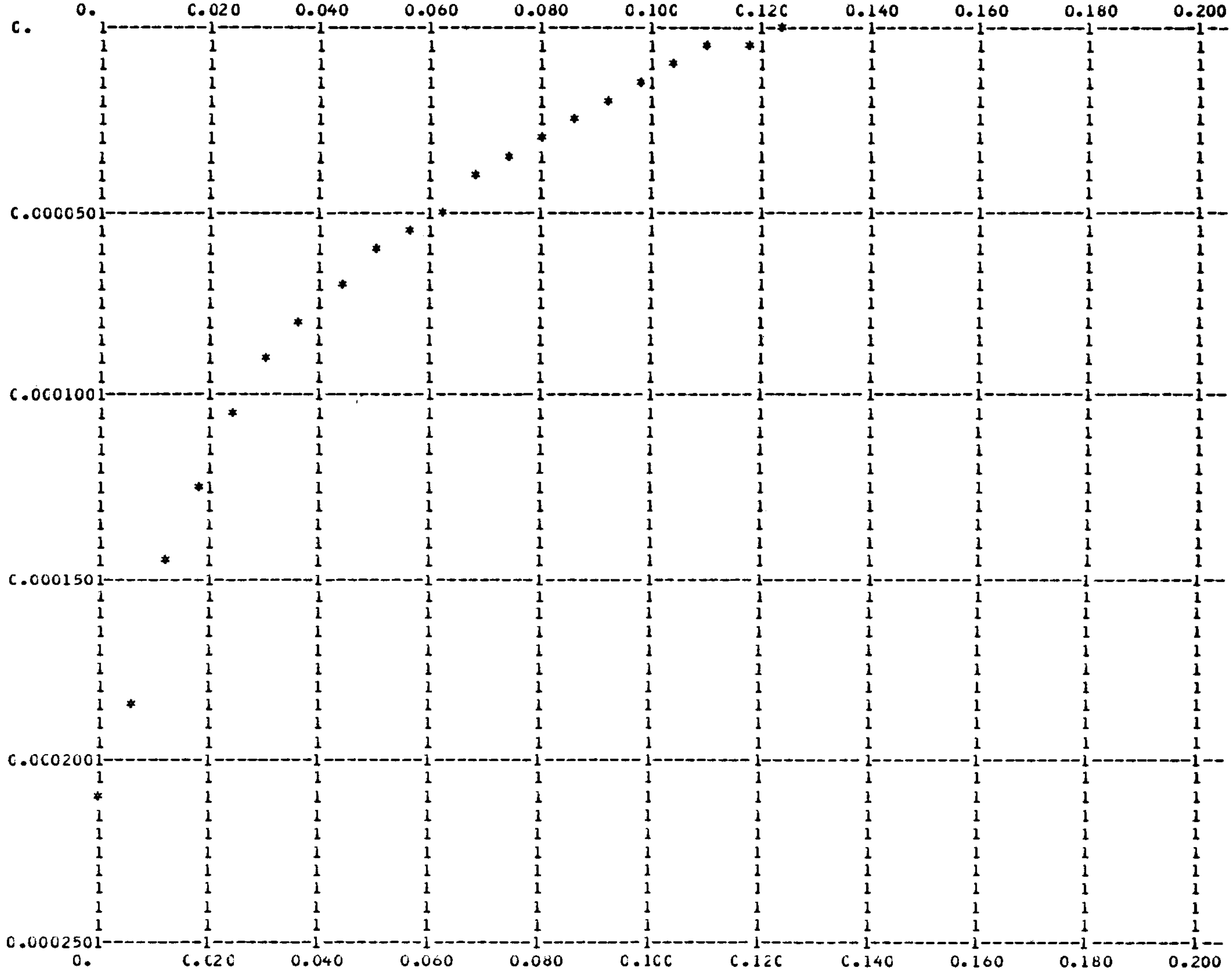
Figure 3. - Continued.

X*E 4	Y*E-3
0.	1.774
0.073	1.599
0.113	1.513
0.155	1.428
0.195	1.342
0.247	1.258
0.297	1.173
0.352	1.089
0.411	1.004
0.475	0.920
0.545	0.837
0.623	0.753
0.710	0.668
0.809	0.584
0.924	0.499
1.060	0.413
1.229	0.325
1.457	0.232
1.835	0.126
2.081	-0.



X*E 4 Y*E 1

0.	1.232
0.073	1.109
0.113	1.048
0.155	0.986
0.199	0.924
0.247	0.863
0.297	0.801
0.352	0.739
0.411	0.678
0.475	0.616
0.545	0.555
0.623	0.493
0.710	0.431
0.809	0.370
0.924	0.308
1.060	0.246
1.229	0.185
1.457	0.123
1.835	0.062
2.081	0.



DV(X10** 0) VS X

(c) Concluded. Schottky results.

Figure 3. - Concluded.

RICHARDSON-DUSHMAN

I = 3.893 TE = 2400. PHI = 3.000 NEP = 1.00E 13 TEP = 2500.0 TIP = 2400.0 LAMBDA = 1.0907E-04

PV = 1.598737E 05 LAMBDA(TE) = 1.0687E-04

DV	ND(DV)	NE(DV)	NI(DV)	E(CV)	X(DV)
0.	0.	1.000000E 13	-9.973218E 12	0.	2.532789E-04
-0.03461	3.414446E 12	1.184606E 13	-8.431615E 12	-4.627274E 02	2.158798E-04
-0.06922	6.875106E 12	1.400256E 13	-7.127454E 12	-9.270193E 02	1.598128E-04
-0.10383	1.052536E 13	1.654949E 13	-6.024134E 12	-1.396614E 03	1.287538E-04
-0.13844	1.446888E 13	1.955957E 13	-5.090691E 12	-1.875606E 03	1.071360E-04
-0.17306	1.881674E 13	2.311767E 13	-4.300933E 12	-2.367532E 03	9.059986E-05
-0.20767	2.369114E 13	2.732384E 13	-3.632702E 12	-2.875906E 03	7.727289E-05
-0.24228	2.922900E 13	3.229625E 13	-3.067249E 12	-3.404322E 03	6.617206E-05
-0.27689	3.558582E 13	3.817453E 13	-2.588713E 12	-3.956499E 03	5.671469E-05
-0.31150	4.294009E 13	4.512376E 13	-2.183672E 12	-4.536317E 03	4.852584E-05
-0.34611	5.149829E 13	5.333905E 13	-1.840764E 12	-5.147845E 03	4.134924E-05
-0.38072	6.150069E 13	6.305106E 13	-1.550370E 12	-5.795375E 03	3.500143E-05
-0.41533	7.322812E 13	7.453247E 13	-1.304341E 12	-6.483447E 03	2.934614E-05
-0.44994	8.700985E 13	8.810561E 13	-1.095765E 12	-7.216887E 03	2.427902E-05
-0.48456	1.032328E 14	1.041516E 14	-9.187677E 11	-8.000837E 03	1.971813E-05
-0.51917	1.223525E 14	1.231208E 14	-7.683330E 11	-8.840794E 03	1.559770E-05
-0.55378	1.449058E 14	1.455459E 14	-6.401391E 11	-9.742646E 03	1.186396E-05
-0.58839	1.715261E 14	1.720565E 14	-5.303731E 11	-1.071272E 04	8.472274E-06
-0.62300	2.029613E 14	2.033968E 14	-4.354417E 11	-1.175781E 04	5.385016E-06
-0.65761	2.400955E 14	2.404467E 14	-3.511035E 11	-1.288525E 04	2.570134E-06
-0.69222	2.839918E 14	2.842463E 14	-2.544639E 11	-1.410301E 04	0.

JEE = 3.464474E 02	JEP = 1.244062E 01	JIP = 2.476505E-02	JAP = 5.786600E-02
J = -2.506688E-01	PP = 1.088042E-02	JIE = 3.887854E-04	JAE = 5.834854E-02
JA = 4.825387E-04	JI = 4.825382E-04	JE = -2.513514E-01	JA/JAP = 8.338698E-03
JE/JEP = -2.020409E-02	JI/JIP = 1.948464E-02	DVS = -0.69222	XDVS = 2.532789E-04
NAP = 2.336599E 13	XD/LAM = 2.322152E 00	PHZZ= 3.69222	EDVS = -1.410301E 04
NTP = 4.336599E 13	NCE = 2.845007E 14	NTE = 3.078667E 14	RC/KTE = -3.347175E 00
X/LMTE = 2.370037E 00	ELT/RD = 2.177258E 00	NIPA= -9.973218E 12	

SCHOTTKY

I = 3.893 TE = 2400. PHI = 3.000 NEP = 1.00E 13 TEP = 2500.0 TIP = 2400.0 LAMBDA = 1.0907E-04

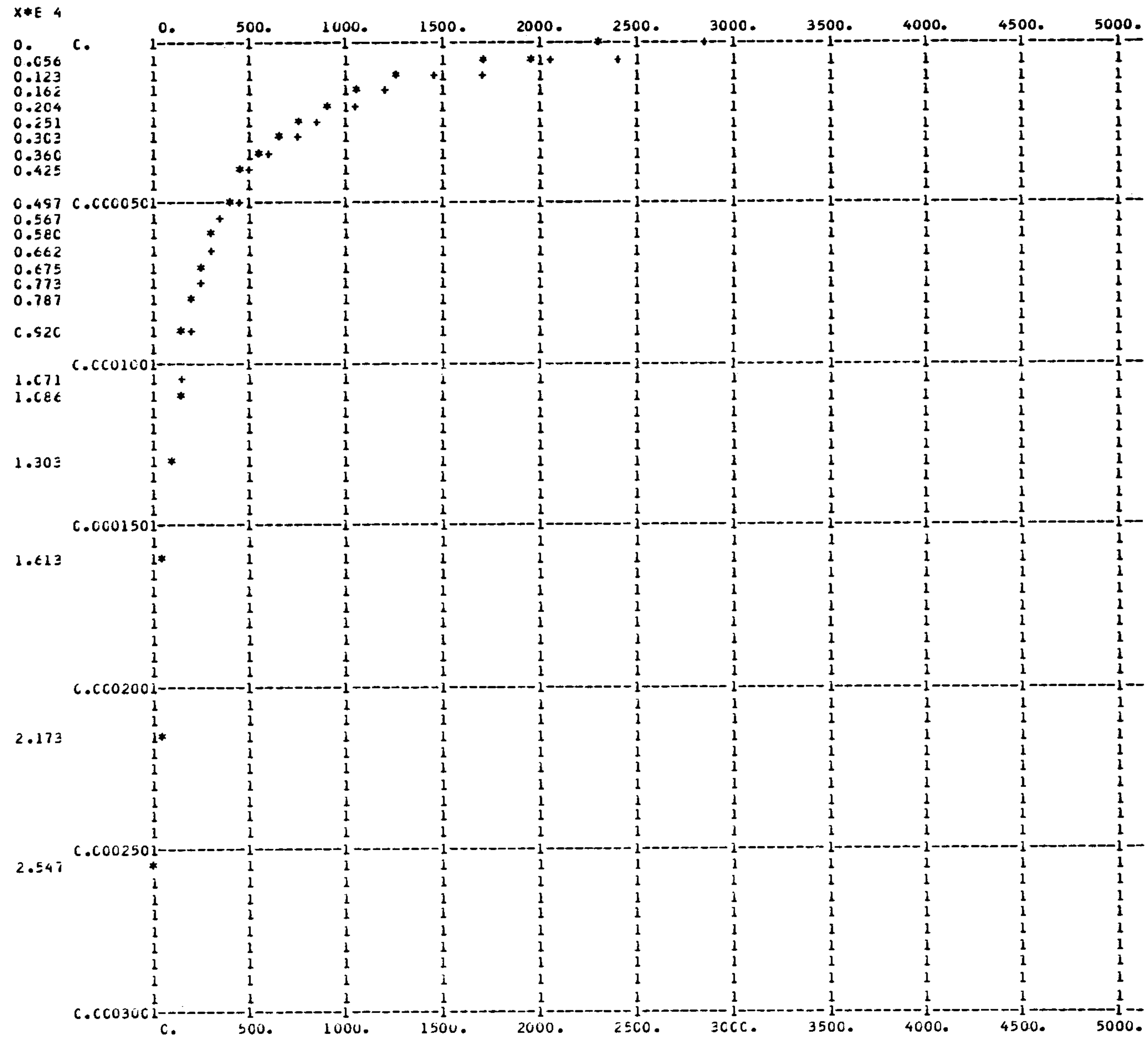
PV = 1.598737E 05 LAMBDA(TE) = 1.0687E-04

DV	ND(DV)	NE(DV)	NI(DV)	E(DV)	X(DV)
0.	0.	1.000000E 13	-9.966303E 12	0.	2.546730E-04
-0.03249	3.212968E 12	1.172489E 13	-8.511927E 12	-4.348701E 02	2.173214E-04
-0.06497	6.449273E 12	1.371809E 13	-7.268820E 12	-8.705294E 02	1.613111E-04
-0.09746	9.841624E 12	1.604788E 13	-6.206258E 12	-1.310224E 03	1.302550E-04
-0.12994	1.347510E 13	1.877308E 13	-5.297982E 12	-1.757579E 03	1.086162E-04
-0.16243	1.743989E 13	2.196143E 13	-4.521545E 12	-2.215560E 03	9.204307E-05
-0.19492	2.183418E 13	2.569194E 13	-3.857764E 12	-2.687069E 03	7.866681E-05
-0.22740	2.676669E 13	3.005693E 13	-3.290238E 12	-3.175049E 03	6.750606E-05
-0.25989	3.235942E 13	3.516437E 13	-2.804947E 12	-3.682531E 03	5.797937E-05
-0.29238	3.875068E 13	4.114058E 13	-2.389903E 12	-4.212660E 03	4.971275E-05
-0.32486	4.609851E 13	4.813336E 13	-2.034853E 12	-4.768715E 03	4.245080E-05
-0.35735	5.458460E 13	5.631562E 13	-1.731023E 12	-5.354133E 03	3.601089E-05
-0.38983	6.441879E 13	6.588969E 13	-1.470899E 12	-5.972534E 03	3.025752E-05
-0.42232	7.584428E 13	7.709232E 13	-1.248038E 12	-6.627737E 03	2.508712E-05
-0.45481	8.914361E 13	9.020051E 13	-1.056900E 12	-7.323791E 03	2.041850E-05
-0.48729	1.046457E 14	1.055384E 14	-8.926965E 11	-8.064955E 03	1.618664E-05
-0.51978	1.227340E 14	1.234852E 14	-7.512384E 11	-8.855929E 03	1.233847E-05
-0.55226	1.438559E 14	1.444847E 14	-6.287595E 11	-9.701478E 03	8.830037E-06
-0.58475	1.685345E 14	1.690562E 14	-5.216017E 11	-1.060687E 04	5.624377E-06
-0.61724	1.973819E 14	1.978071E 14	-4.252053E 11	-1.157770E 04	2.690045E-06
-0.64972	2.311358E 14	2.314485E 14	-3.126986E 11	-1.262003E 04	0.

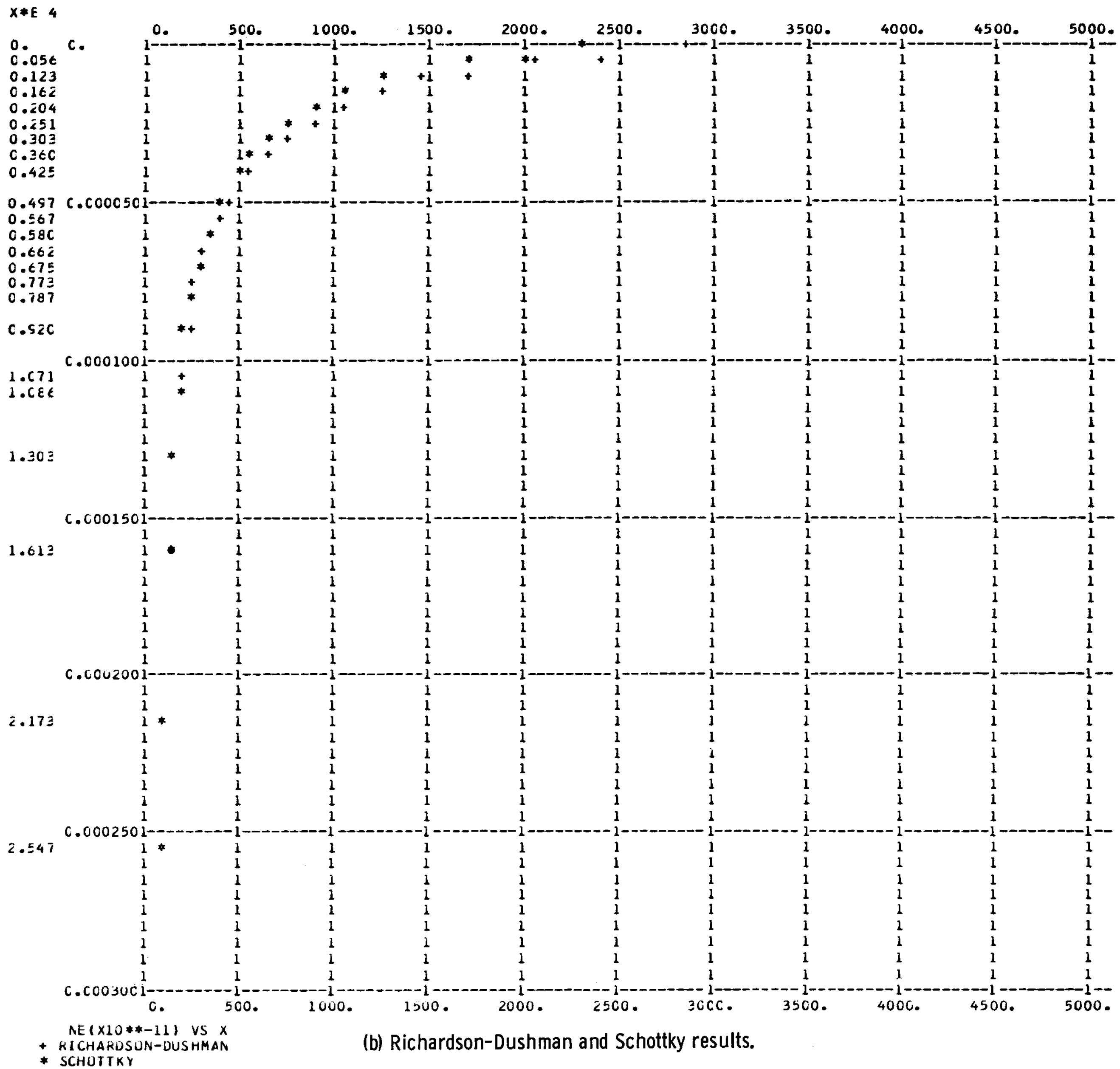
JEE	= 2.820903E 02	JEP	= 1.244062E 01	JIP	= 2.476505E-02	JAP	= 5.786600E-02
J	= -2.507594E-01	PP	= 1.088042E-02	JIE	= 4.783780E-04	JAE	= 5.645774E-02
JA	= 5.517330E-04	JI	= 5.917327E-04	JE	= -2.513511E-01	JA/JAP	= 1.022592E-02
JE/JEP	= -2.020407E-02	JI/JIP	= 2.389386E-02	DVS	= -0.64972	XDVS	= 2.546730E-04
NAP	= 2.336559E 13	XD/LAM	= 2.334934E 00	SC	= 4.264472E-02	PHZ	= 3.69222
EDVS	= -1.262003E 04	DVSRD	= -6.922226E-01			DVS/RD	= 9.386038E-01
ELM/RD	= 1.986488E 00	PHZZ	= 3.692223E 00			DRD/KT	= 3.213288E 00
NTP	= 4.336559E 13	NCE	= 2.317612E 14	NTE	= 2.551272E 14	RD/KTE	= -3.347175E 00
X/LMTE	= 2.383082E 00	ELT/RD	= 1.948312E 00	NIPA	= -9.966303E 12		

(a) Numerical values.

Figure 4. - Example output for Electron Sheath Program.

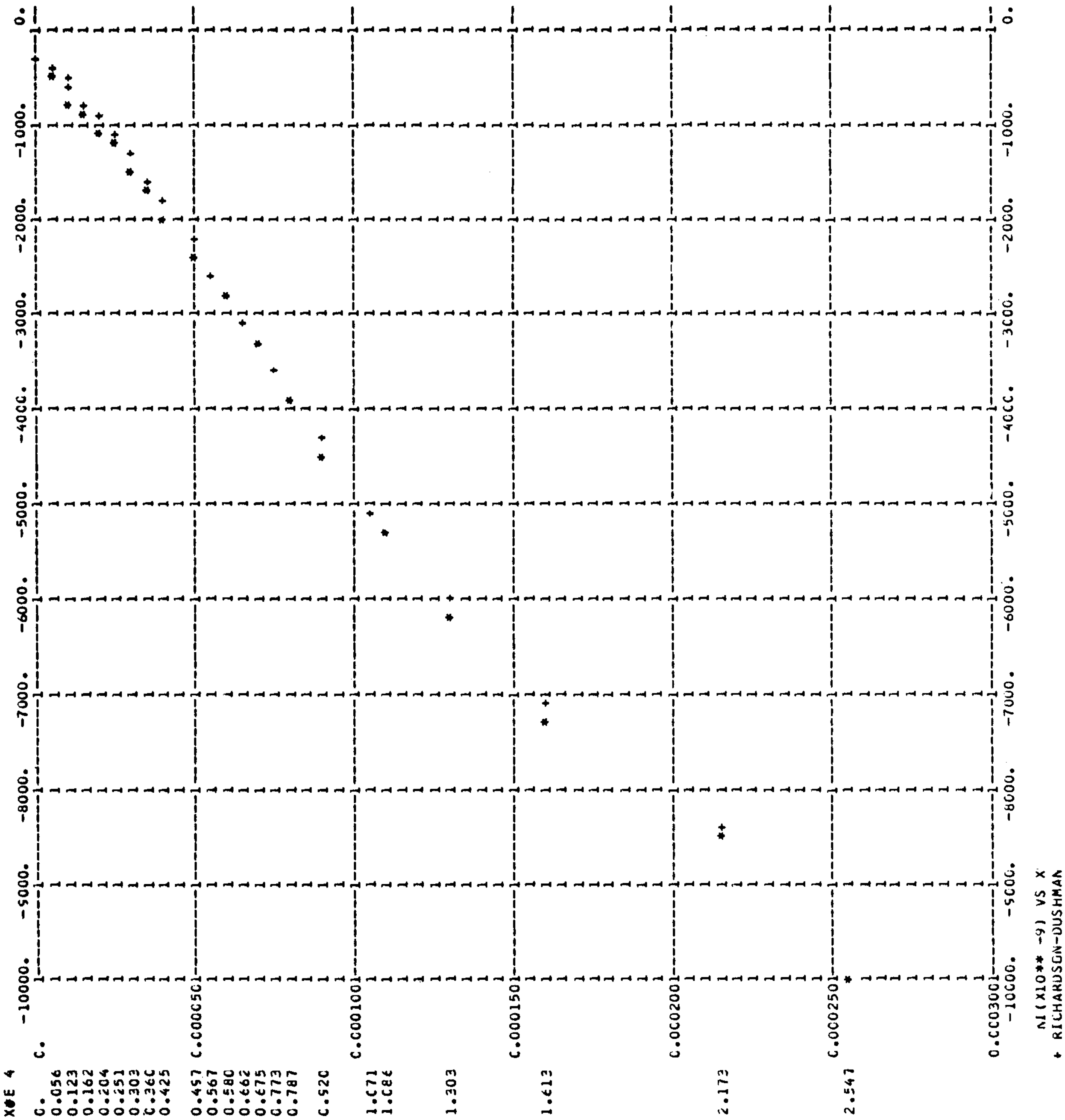


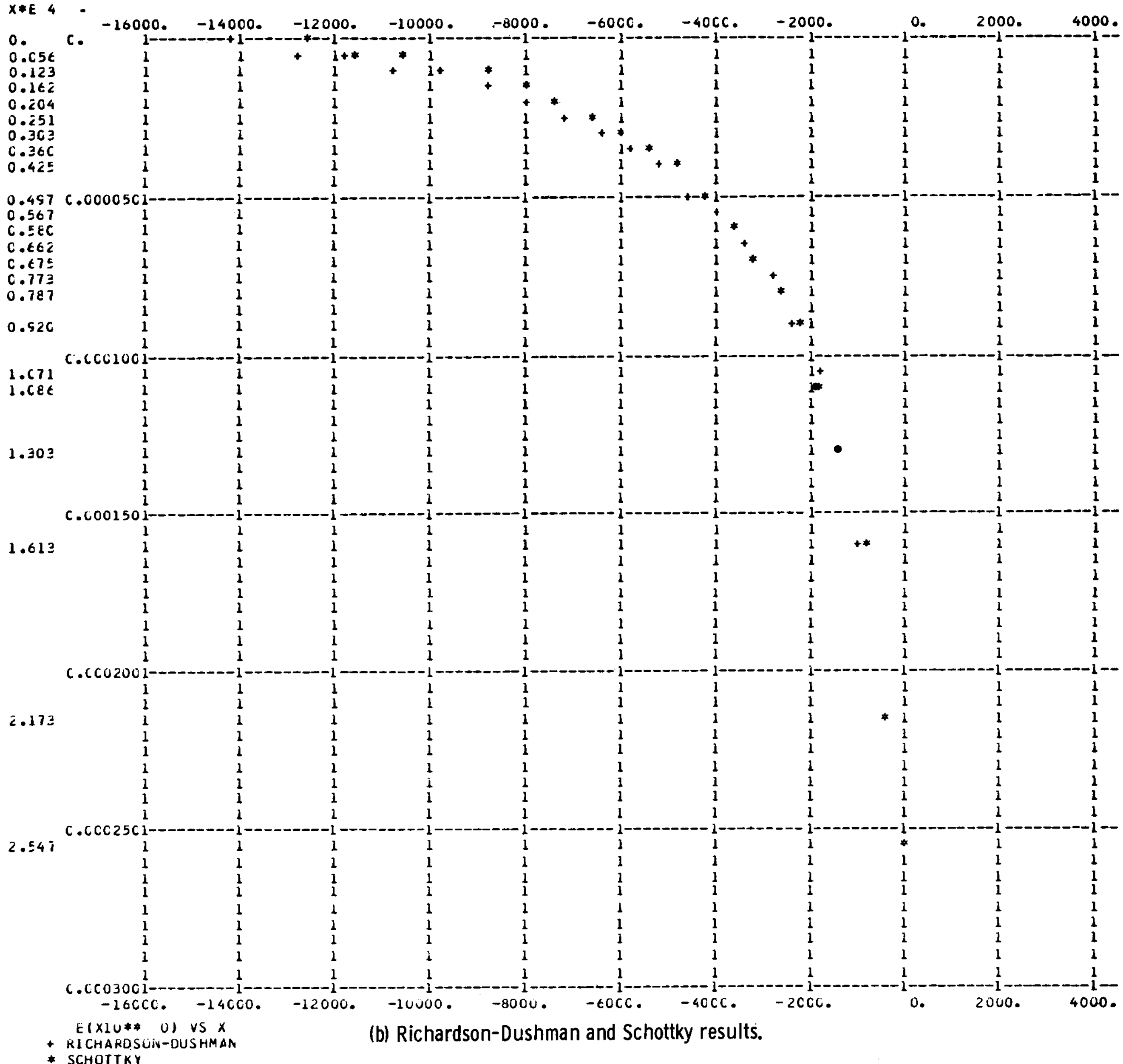
ND(X10**-11) VS X
+ RICHARDSON-DUSHMAN
* SCHOTTKY



(b) Richardson-Dushman and Schottky results.

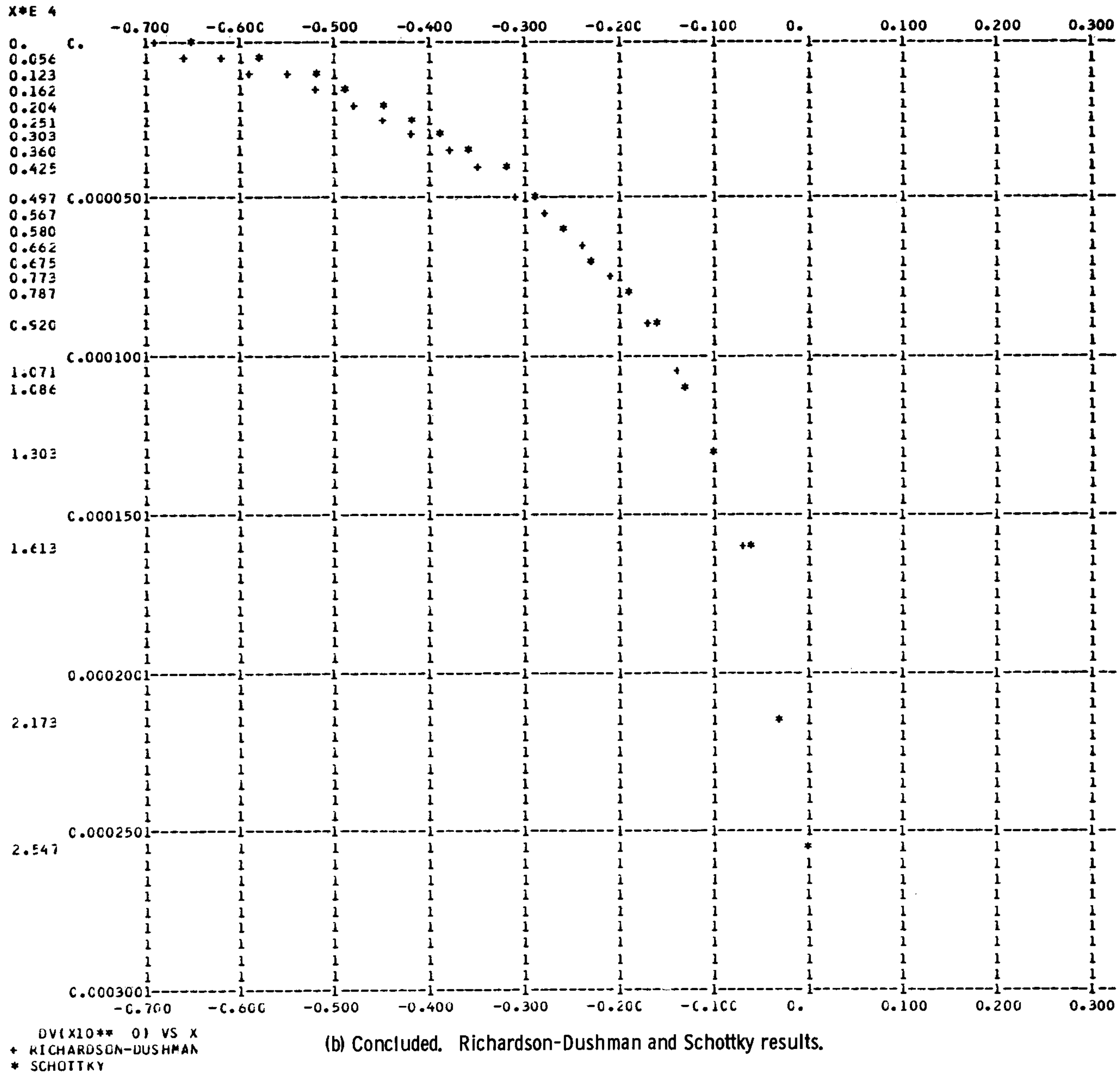
Figure 4. - Continued.


X*E 4
NI(X10** -9) VS X
+ RICHARDSON-DUSHMAN
* SCHOTTKY



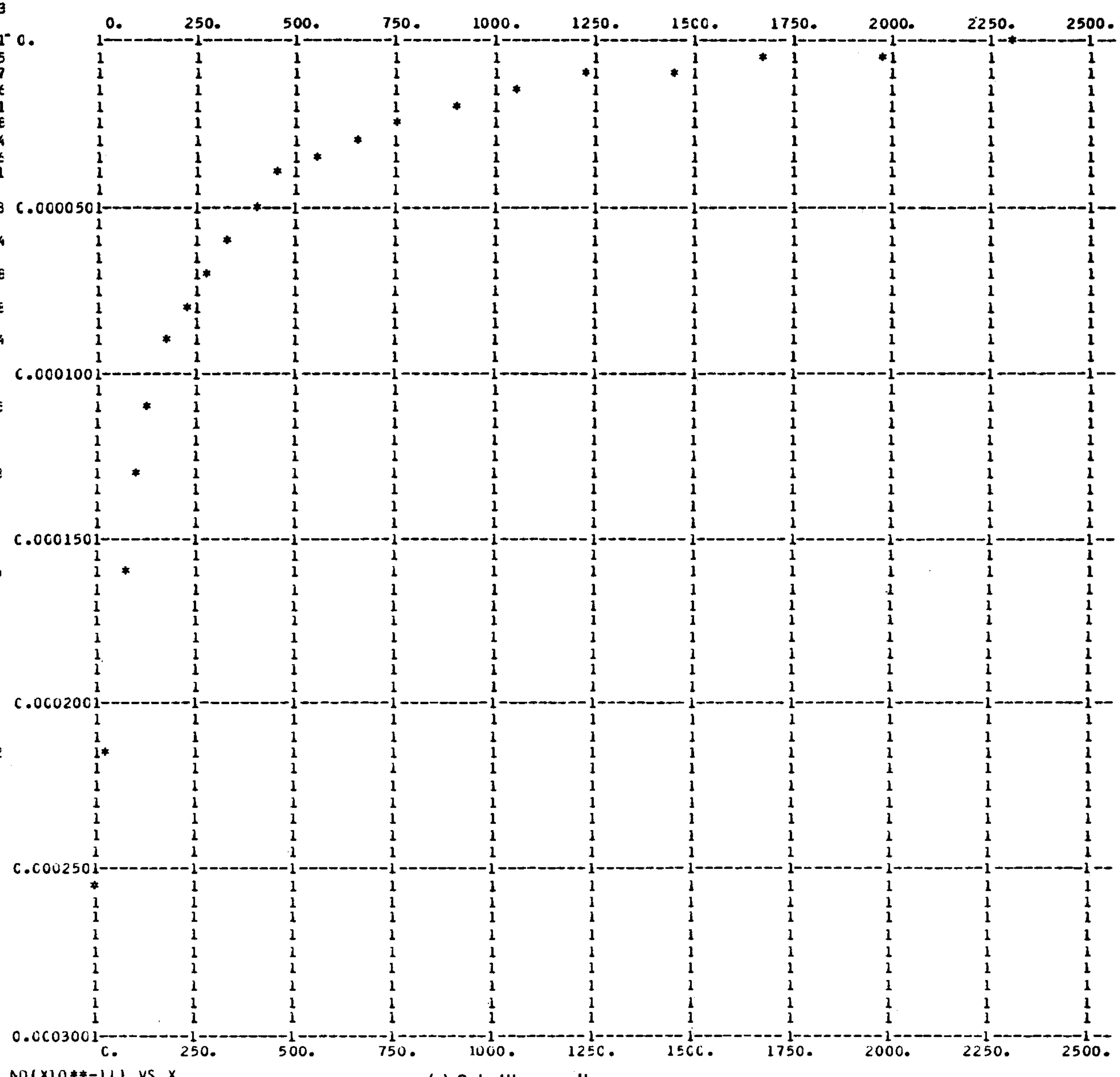
(b) Richardson-Dushman and Schottky results.

Figure 4. - Continued.



(b) Concluded. Richardson-Dushman and Schottky results.

X*E 4	Y*E-3
0.	2.311
0.056	1.685
0.123	1.227
0.162	1.046
0.204	0.891
0.251	0.758
0.303	0.644
0.360	0.546
0.425	0.461
0.497	0.388
0.580	0.324
0.675	0.268
0.787	0.218
0.920	0.174
1.066	0.135
1.303	0.098
1.613	0.064
2.173	0.032
2.547	0.

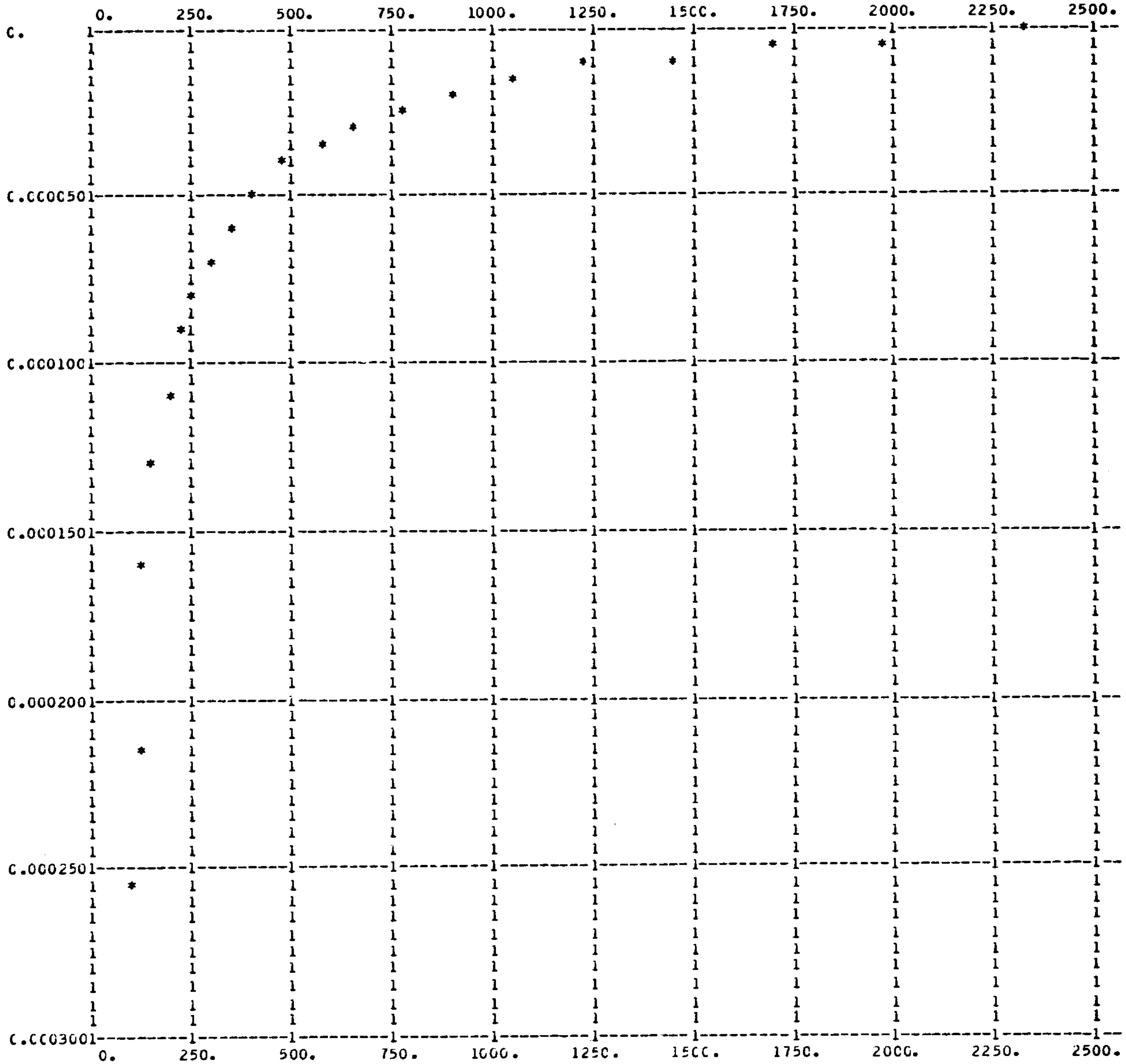


(c) Schottky results.

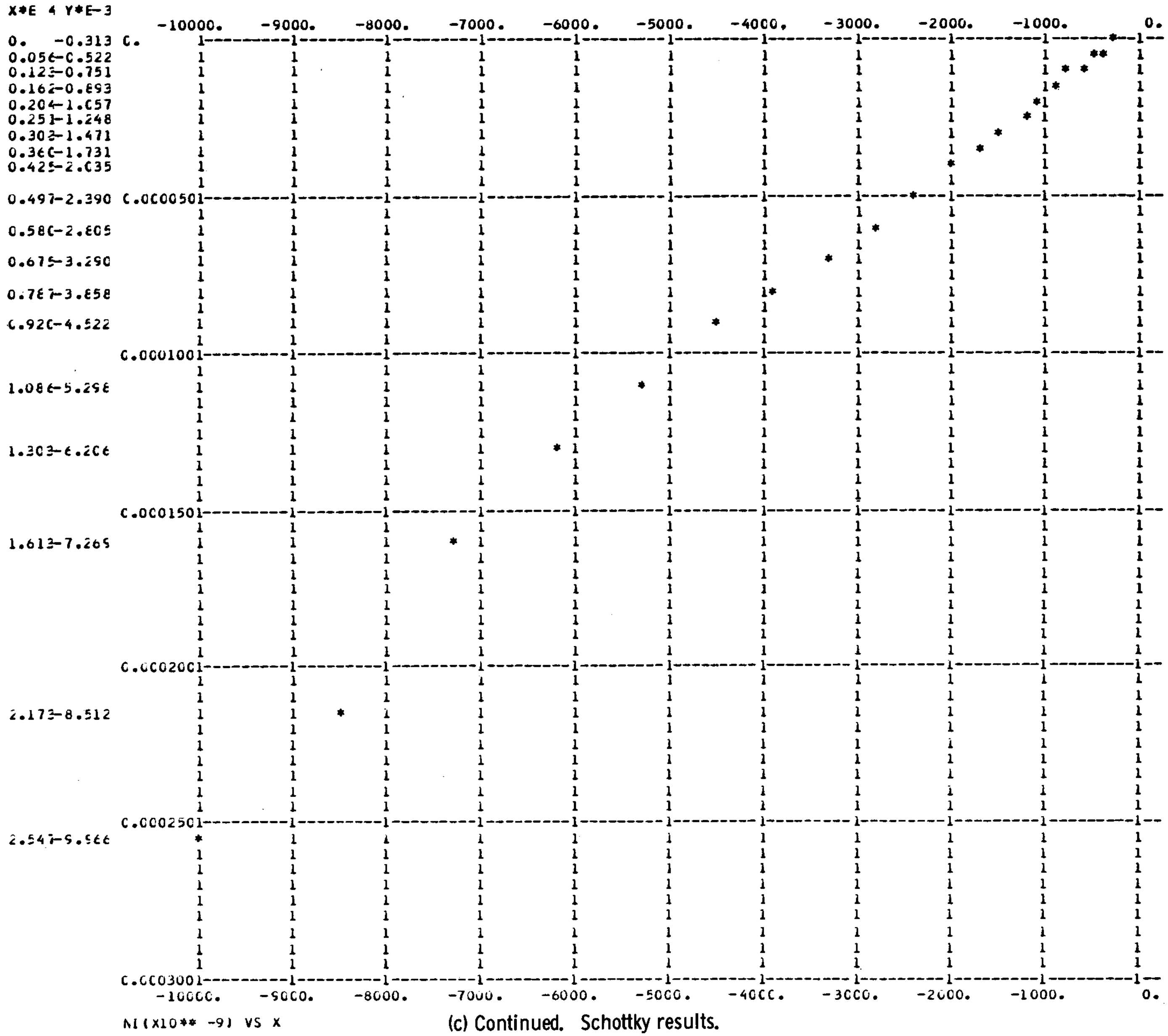
Figure 4. - Continued.

X*E 4 Y*E-3

X	Y
0.	2.314
0.056	1.691
0.123	1.235
0.162	1.055
0.204	0.902
0.251	0.771
0.303	0.659
0.360	0.563
0.425	0.481
0.497	0.411
0.580	0.352
0.675	0.301
0.787	0.257
0.920	0.220
1.086	0.188
1.303	0.160
1.613	0.137
2.173	0.117
2.547	0.100

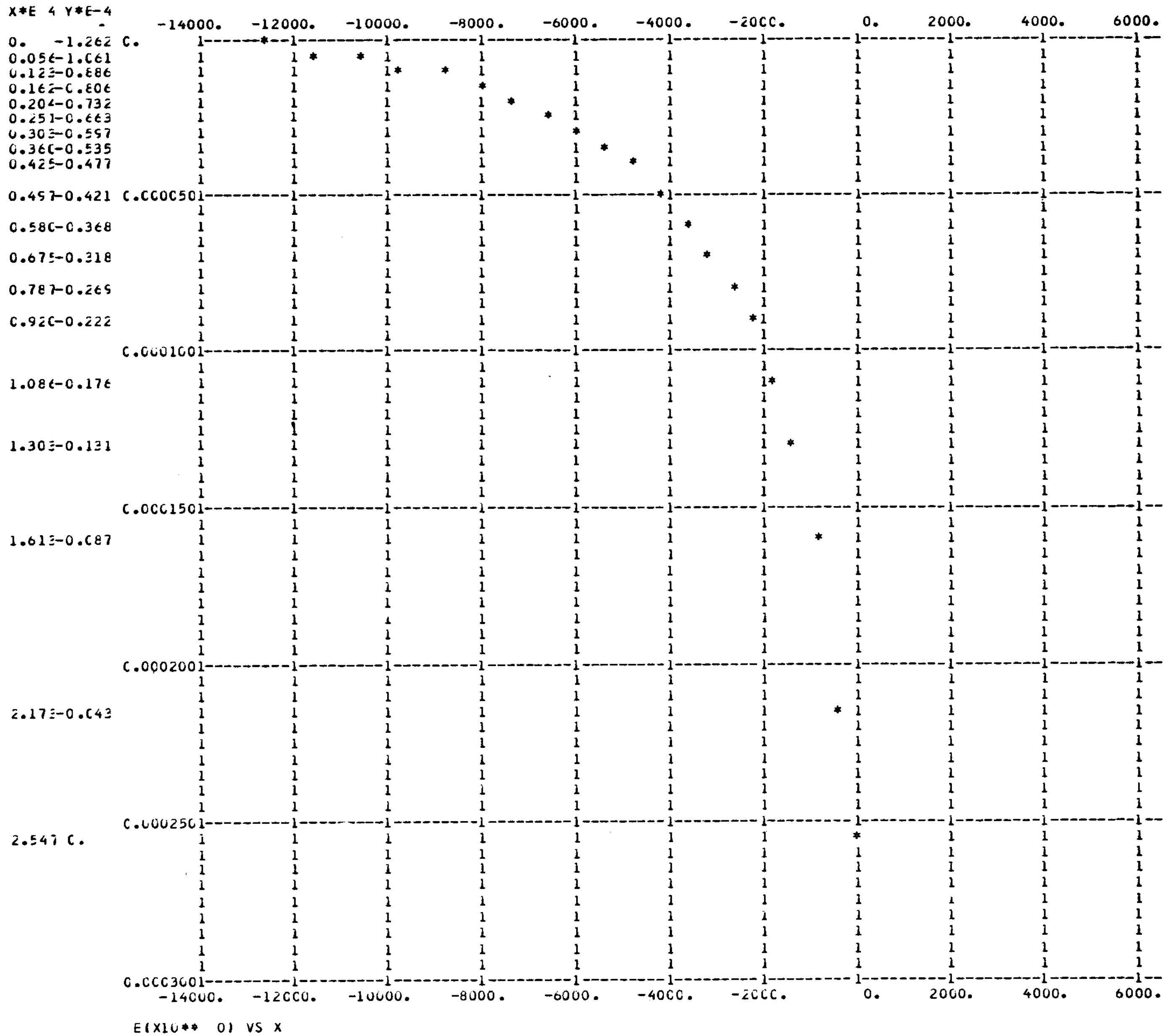


NE(X10**-11) VS X

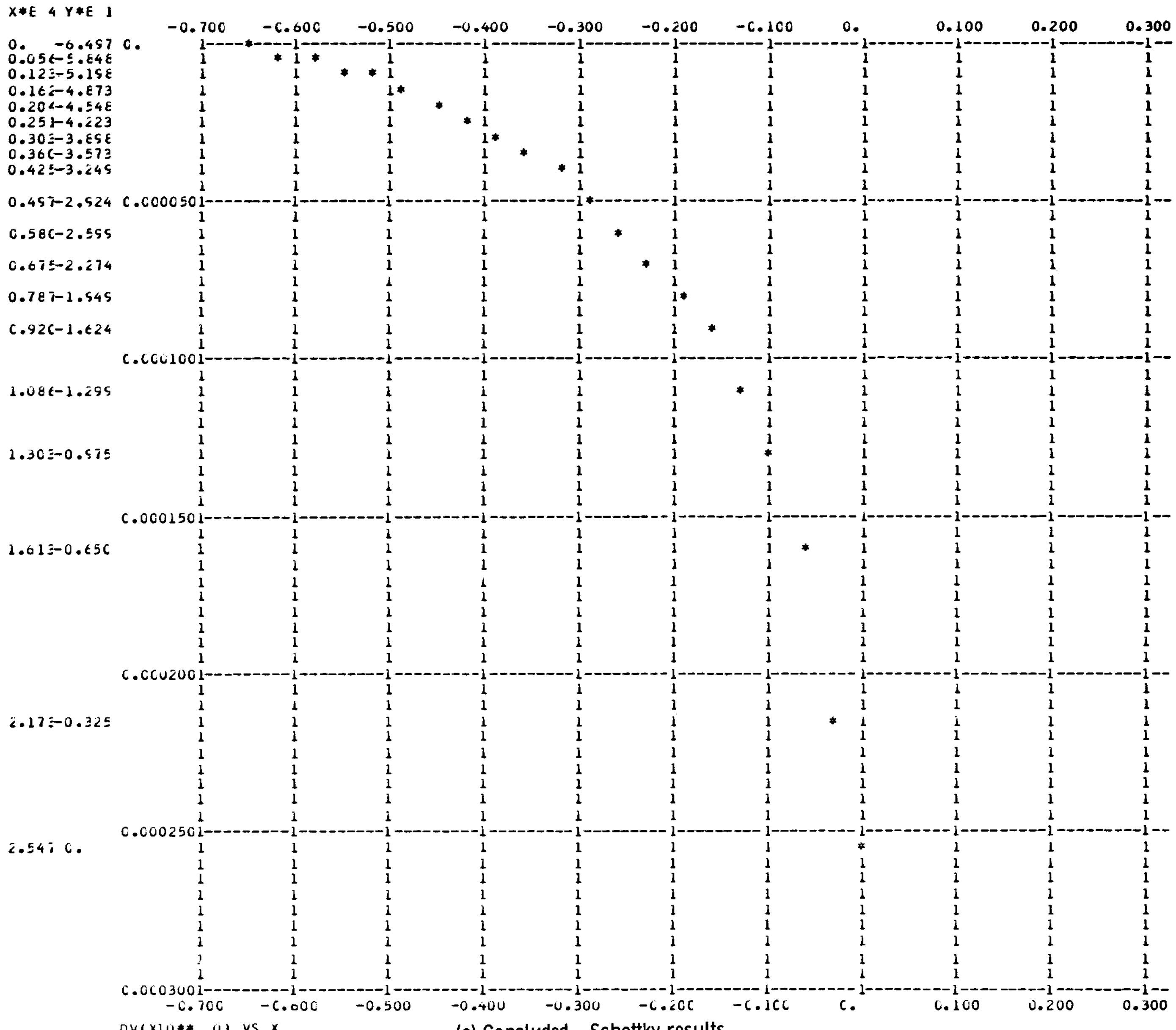


(c) Continued. Schottky results.

Figure 4. - Continued.



X*E 4 Y*E-4
0. -1.262 C.
0.056-1.C61
0.123-0.886
0.162-C.806
0.204-0.732
0.251-0.663
0.303-0.597
0.360-0.535
0.425-0.477
0.497-0.421 C.CC0C50
0.58C-0.368
0.675-0.318
0.787-0.269
C.92C-0.222
C.0001C0
1.086-0.176
1.303-0.131
C.0001500
1.613-0.C87
C.000200
2.173-0.C43
C.000250
2.547 C.
0.CCC300
-14000. -12000. -10000. -8000. -6000. -4000. -2000. 0. 2000. 4000. 6000.
E(X10** 0) VS X



(c) Concluded. Schottky results.

Figure 4. - Concluded.