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# Intensity Ratios of Emission Lines from OV Ions for Temperature and Density Diagnostics

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Abstract

Intensity ratios of emission lines from OV ions are calculated for use in temperature and density diagnostics. The dependence on temperature and density of the intensity ratios is shown in graphs. The excitation rate coefficients among n = 2 and n = 3 levels are fitted to an analytical formula and the fitting parameters are tabulated. The rate coefficients are shown graphically.

Keywords

OV ion, line emission, intensity ratio, temperature and density diagnostics, excitation rate coefficients, inner sub-shell ionization

CONTENT



## 1.Introduction

Spectral line emissions of OV ions have been measured from the solar transition region[1,2] and from laboratory plasmas such as from tokamaks.[3,4,5,6] Theoretical calculations have been done to interpret line intensities.[7,8,9] We present here the calculation of the intensity ratios of emission lines using new data for electron impact excitation calculated by Berrington and Kingston[10] by the R-matrix method including 26 states( $2s^2$, 2 x 2s2p, 3 x $2p^2$, 2 x 2s3s, 2 x 2s3p, 2 x 2s3d, 2 x 2p3s, 6 x 2p3p, 6 x 2p3d). We include in our calculation the ionization and recombination processes from/to excited levels which are important in a transient plasma.

## 2.Atomic Data

### i)Energy Levels

The levels of the $2s^2$, 2s2p, $2p^2$, 2s3s, 2s3p and 2s3d configurations for OV[11](20 levels) and the n=2 levels for OIV[12] (6 states) and OVI[13] (2 states) ions are considered in our model. They are listed in Table 1. For OIV and OV ions the fine

structure levels are combined to one state for the calculation of the population densities as indicated in Table 1 by arabic numerals. For OV Fig. 1 shows the relevant part of the energy level diagram.

ii) Transition Probabilities

The data for transition probabilities among n = 2 and n = 3 levels are taken from ref.14 for OV. For OIV and OVI ions, the data from ref. 15 and from ref. 16, respectively, are used.

iii) Excitation rate coefficients by electron impact

Effective collision strengths $\gamma$ have been calculated using the R-matrix method including 26 states by Berrington and Kingston[10] in the electron temperature range from $3 \times 10^4$K $< T_e <$ $1.3 \times 10^6$K . These data are fitted to an empirical formula for collision strength $\Omega$ as given in refs. 17 and 18 as follows,

$$\Omega = a_1 + a_2/X + a_3/X^2 + a_4/X^3 + a_5 \ln X , \qquad (1)$$

where X is the energy of the incident electron in units of transition energy, $X=E/\Delta E$. The effective collision strength is defined as

$$\gamma = y\, e^y \int_1^\infty \Omega\, e^{-yX}\, dX , \qquad (2)$$

and can be written

$$\gamma = y\{(a_1/y+a_3)+a_4(1-y)/2 + e^y E_1(y)(a_2-a_3y+a_4y^2/2+a_5/y)\}, \qquad (3)$$

where

$$E_1(y) = \int_y^\infty e^{-t}/t\, dt, \qquad (4)$$

and $y = \Delta E/T_e$. The parameter $a_5$ in eq.(1) is derived from the Bethe limit as $a_5 = 4w_i f_{ij}/\Delta E$ for the allowed transitions where $w_i$ is the statistical weight of the lower level i, $f_{ij}$ is the absorption oscillator strength from level i to j and $\Delta E$ the excitation energy in Rydbergs units.

For the fine structure transitions where the transition energy is very small compared to the electron temperature, the effective collision strengths are fitted by the following formula

$$\log \gamma = b_1 + b_2/TL + b_3/TL^2 + b_4/TL^3, \qquad (5)$$

where TL = logT(K) and T indicates the electron temperature in degrees Kelvin.

The excitation rate coefficients can then be calculated using the formula (with $T_e$ in eV units),

$$R = 8.01 \times 10^{-8} e^{-y} \gamma/(w_i T_e^{1/2}) \quad cm^3 s^{-1}. \qquad (6)$$

The derived parameters $a_i$ and $b_i$ ($i = 1 - 5$) are listed in Table I and the calculated rate coefficients are given as in Fig.III. The evaluated values in ref.17 are plotted by dashed lines for comparison. The excitation rate coefficients for the $2s^2 - 2p^2$ ($^3P$, $^1D$ and $^1S$) transitions differ from those in ref. 17 by 30 - 100 % . The excitation rate coefficient for $2s^2\ ^1S - 2s3p\ ^1P$ is larger by 40 % at 20 eV compared to that calculated by Mann(as quated in Ref.17) using the Distorted Wave method, but agrees well at temperatures higher than 80 eV. For the $2s^2\ ^1S - 2s3s\ ^1S$ and $2s3d\ ^1D$ transitions, the new data are smaller by about 50 % and 30 %, respectively, as shown in Fig. III.

The validity range of the given rate coefficients is $3 \times 10^4 K < T_e < 1.3 \times 10^6 K$. It is risky to simple extend the formulas outside of their validity range. Extrapolation is permissible to some extent, but its accuracy depends on the transition. Since the parameters are derived to fit the effective collision strength $\Upsilon$, the collision strength $\Omega$, calculated from the fit parameters, has no real meaning.

For OIV and OVI ions, the data recommended in ref.17 are used.

iv) Ionization and recombination

The ionization process from ground and metastable levels becomes important when the electron temperature $T_e$ is higher than the equilibrium temperature $T_z$(Ref.5). The ionization rate coefficients are calculated by the Lotz formula[19], dividing through by statistical weights as in ref.9.

The recombination process is also included in our calculation for excited levels as well as for the ground level. The data from ref.20 are used for the ground state and are extrapolated for excited levels. Actually the recombination process has no effect in our calculation.

## 3.Population density

The population densities are calculated for the 20 levels shown in Table 1 under the assumption that all transitions considered are optically thin. All the possible ionization and recombination processes from other ionic levels and/or to other ionic levels are taken into account. The rate equations for the

population densities including ionization and recombination processes are described in ref.9.

Be-like OV ions have metastable levels $2s2p\ ^3P_{0,1,2}$ for which the population density is comparable to the ground level for an electron density $n_e$ greater than $10^{12}$ $cm^{-3}$ as shown in Fig.2. The populations of these levels relative to that of the ground level tend to be constant for $n_e > 10^{13}$ $cm^{-3}$ because of the small value of the transition probability from $2s2p\ ^3P$ to the $2s^2\ ^1S$ ground level. The calculated values of the populations at 20 eV agree well (within 10%) with those calculated by Keenan et al.[8]

Ionization processes from OV $2s2p\ ^3P$ to OVI 2s or 2p decrease the population of $2s2p\ ^3P$, whereas those from OIV $2s^22p$ to OV $2s2p\ ^3P$ and from OIV $2s2p^2$ to OV $2s2p\ ^3P$ increase it. Ionization from OIV $2s^22p$ populates also the ground level of OV $2s^2\ ^1S$. Ionization rate coefficients are compared to excitation rate coefficents in Fig.3. It is shown that for the $2s2p\ ^3P$ the ionization rate coefficient exceeds the excitation one when the temperature range is above 100 eV. This effect is not important in an ionization equilibrium plasma where the electron temperature is as low as 20 - 30 eV. In an ionizing plasma at higher temperature such as in a tokamak or a solar flare, this effect becomes important. The population of $2s2p\ ^3P$ relative to $2s^2\ ^1S$ is decreased by about 60% by the inclusion of the ionization process from OV as shown in Fig.2 for $T_e$ = 100 eV by the dashed curve. Then taking into account the ionization from OIV ions to all the levels of OV ions assuming n(OIV) = n(OV), where n(OIV) represents the density of OIV ions, the relative population of $2s2p\ ^3P$ increases by 50% for $T_e$ = 100 eV as shown in Fig.2 by a dashed - dotted curve. The recombination process is not important for plasmas of $T_e > 5$ eV, but would be effective in a strongly recombining plasma at low temperatures.

The populations of the triplet levels are mainly excited from the metastable levels $2s2p\ ^3P$ for $n_e > 10^{10}$ $cm^{-3}$ where the population of the metastable levels are comparable to that of the ground level, since the excitation rate coefficients from the $2s^2\ ^1S$ ground level to the triplet levels are small. At densities $10^{10} < n_e < 10^{12}$ $cm^{-3}$, the population densities of such levels

are approximately proportional to $n_e^2$ , while at higher densities where the populations of the metastable levels are determined only by collisional processes, this changes to a linear dependence. Then the ratio of the intensity of a line excited from the metastable levels to a line excited from the ground level is density dependent at $10^{10} < n_e < 10^{13}$ $cm^{-3}$.

The temperature dependence of the excitation rate coefficients to n = 3 levels from the ground or metastable levels is different from those to n = 2 levels because of the difference in the excitation energies. This result is used for temperature diagnostics.

We have included proton excitation which is comparable to the electron excitation between fine structure transitions for 2s2p $^3P$ and $2p^2$ $^3P$ levels[21], because the effect in the populations is found to be large in high temperature and low density regions; the population of 2s2p $^3P_2$ decreases by 35 % at $T_e$ = 100 eV and $n_e = 10^9$ $cm^{-3}$. But the effect is within 10 % for $n_e > 10^{11}$ $cm^{-3}$and negligibly small for $n_e > 10^{12}$ $cm^{-3}$. At temperature lower than 50 eV the effect is also wthin 10%.

## 4. Line intensity ratios

We present in this section the line intensity ratios of OV ions for density and temperature diagnostics. The spectral lines emitted from OV ions related to our calculations are listed in Table 2( taken from Ref.11) whose visible wavelengths are those in the air.

As we have discussed in the previous section, the metastable 2s2p $^3P$ levels and other triplet levels have varying electron density dependence and this is utilised for density diagnostics by the line ratio method. The most commonly used line ratio for density diagnostics is I( 760.45, 760.23, 762.00, 761.13, 758.68, 759.44 2s2p $^3P$ - $2p^2$ $^3P$)/ I( 629.73 $2s^2$ $^1S$ - 2s2p $^1P$). This intensity ratio is plotted in Fig. 4 as a function of electron density for $T_e$ = 20 and 100 eV. The intensity ratio I( 1218 $2s^2$ $^1S$ - 2s2p $^3P$)/ I (629.73) is also plotted in Fig.4. The density dependent intensity ratios I(192.90 2s2p$^3P_2$- 2s3d $^3D_{2,3}$)/ I(248.46 2s2p $^1P$ - 2s3s $^1S$), I(215.25 2s2p $^3P_2$- 2s3s $^3S_1$)/

I(220.35 $2s2p\ ^1P - 2s3d\ ^1D$), I(192.80 $2s2p\ ^3P_{0,1} - 2s3d\ ^3D_{1,2}$)/ I(220.35 ) are shown in Fig.5. The above calculations do not include any ionization processes to allow a comparison of our calculations with others who do not include ionization processes. In Fig.4, the intensity ratio for I(760)/I(630) is compared with those by Doyle et al.[1] and by Finkenthal et al.[3] The results in ref.3 give agreement to within 10 % but those of ref.1 are smaller by more than 40 % at $n_e = 10^{12}$ $cm^{-3}$. Both works used R-matrix calculations for electron excitation rate coefficients.[7, 8] We have found differences between our calculations and those by Widing et al [2] for triplet lines (see Fig.5); their values are smaller than ours by 50 % and 70 % for I(192.90)/I(248.46) and I(192.80)/I(220.35) at $n_e = 10^9$ $cm^{-3}$, although the rate coefficients used are not that different. However at densities higher than $10^{11}$ $cm^{-3}$, the agreement is good, within 10 % as shown in Fig.5. The calculations by Huang et al.[4] agree with our calculations to within 30 %.

Our calculations <u>including</u> ionization and recombination processes are presented in Figs.I and II. The line intensities for multiplets are summed up for the triplet system, except when the wavelength is written to be full precision of its value in Table 2, in which case it is calculated only for one line.

The ratios of lines from levels excited from the same levels are a sensitive function of temperautre when the difference in their excitation energy is greater than the electron temperature. In Fig.I, the ratios of I(172)/ I(630), I(193)/ I(760) and I(220)/I(248) are shown for $n_e = 10^9$ (solid line), $10^{11}$ (dashed - dotted line) and $10^{13}$ $cm^{-3}$ (dashed line) as a function of electron temperature for n(OIV) = 0.0. The dotted line shows the result for $n_e = 10^{13}$ $cm^{-3}$ assuming n(OIV) = n(OV). The contribution of the ionization from OIV ions is negligible in this case. When the cross sections have different energy dependence even though the excitation energies are nearly the same, the line ratio is also sensitive to the electron temperature. In this case the ratio is also density dependent as shown in Fig.I for I(215)/ I(220), I(215)/I(193) and I(220)/I(193).

The intensity ratios in the singlet system such as I(220)/I(172) and I(220)/I(248) exhibit small density and temperature dependence as shown in Fig.II. The intensity ratios for $T_e$ = 20 eV (solid line), 40 eV (dashed dotted line) and 100 eV (dashed line) are shown as a function of the electron density assuming n(OIV) = 0.0. For the case of n(OIV) = n(OV) for $T_e$ = 100 eV, the ratios are also plotted as dotted lines. These ratios can be used to cross check the spectrometer sensitivity calibration. (It can be noted that on the scale of these figures, the dashed and the dotted lines nearly coincide.)

Density dependent line ratios involving the triplet system are also shown in Fig. II. Plots are given for the followings; I(760)/I(630), I(1218)/ I(630), I(193)/I(248), I(193)/I(220), I(215)/I(220), I(193)/I(172), I(215)/ I(193), I(271)/ I(215), I(2781.01)/ I(193), I(2781.01)/ I(215), I(760.45)/ I(630) and I(270.98)/ I(215). As indicated by the truncations of the wavelength values the intensities are for the multiplet for the triplet transition except for the last four sets, where particular single lines are being represented.

## 5. Conclusions

The ionization process from the metastable OV 2s2p $^3$P state to the OVI 2s and 2p states decreases the relative population to the ground state n( 2s2p $^3$P)/n( 2s$^2$ $^1$S) as the temperature increases; 10 %, 40% and 60 % at $T_e$ = 50 eV, 80 eV and 100 eV, respectively. On the other hand the ionization from OIV ions to OV 2s2p $^3$P increases the relative population of the metastable state by 10%, 30% and 50% at $T_e$ = 50 eV, 80 eV and 100 eV for the ion density n(OIV) = n(OV).

The changes in population caused by the inclusion of ionization processes can thus be substantial and are important in an ionizing plasma such as a tokamak where the temperature is comparatively higher than that for ionization equilibrium. Proton excitation is also important for high temperature and low density plasmas.

The detailed analysis of measurements obtained from the tokamaks will be published in a separate paper.

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Table 1

Energy levels of OV

| level No. | Configuration | J | Energy ($cm^{-1}$) | (eV) |
|---|---|---|---|---|
| 1 | $2s^2\ ^1S$ | 0 | 0 | 0 |
| 2 | $2s2p\ ^3P$ | 0 | 81942.5 | 10.16 |
| 3 | | 1 | 82078.6 | 10.18 |
| 4 | | 2 | 82385.3 | 10.21 |
| 5 | $2s2p\ ^1P$ | 1 | 158797.1 | 19.69 |
| 6 | $2p^2\ ^3P$ | 0 | 213462.5 | 26.47 |
| 7 | | 1 | 213618.2 | 26.49 |
| 8 | | 2 | 213887.0 | 26.52 |
| 9 | $^1D$ | 2 | 231721.4 | 28.73 |
| 10 | $^1S$ | 0 | 287910.3 | 35.70 |
| 11 | $2s3s\ ^3S$ | 1 | 546972.7 | 67.82 |
| 12 | $^1S$ | 0 | 561276.4 | 69.59 |
| 13 | $2s3p\ ^1P$ | 1 | 580824.9 | 72.01 |
| 14 | $^3P$ | 0 | 582806.4 | 72.26 |
| 15 | | 1 | 582843.1 | 72.26 |
| 16 | | 2 | 582920.3 | 72.27 |
| 17 | $2s3d\ ^3D$ | 1 | 600748.9 | 74.48 |
| 18 | | 2 | 600758.9 | 74.49 |
| 19 | | 3 | 600779.2 | 74.49 |
| 20 | $^1D$ | 2 | 612615.6 | 75.96 |

Energy levels of OIV

| | | | |
|---|---|---|---|
| 1 | $2s^22p\ ^2P$ | 1/2 | 0 ($cm^{-1}$) |
| | | 3/2 | 385.9 |
| 2 | $2s2p^2\ ^4P$ | 1/2 | 71439.8 |
| | | 3/2 | 71570.1 |
| | | 5/2 | 71755.5 |
| 3 | $2s2p^2\ ^2D$ | 5/2 | 126936.3 |
| | | 3/2 | 126950.2 |
| 4 | $2s2p^2\ ^2S$ | 1/2 | 164366.4 |
| 5 | $2s2p^2\ ^2P$ | 1/2 | 180480.8 |
| | | 3/2 | 180724.2 |
| 6 | $2p^3\ ^4S$ | 3/2 | 231537.5 |

Energy levels of OVI

| | | | |
|---|---|---|---|
| 1 | $2s\ ^2S$ | 1/2 | 0.0($cm^{-1}$) |
| 2 | $2p\ ^2P$ | 1/2 | 96375. |
| | | 3/2 | 96907.5 |

Table II

Prominant emission lines from OV ions

| Wavelength(A)(Ref.11) | Transition |
|---|---|
| 172.17 | $2s^2\ ^1S$ - $2s3p\ ^1P$ |
| 192.8 | $2s2p\ ^3P_{0,1}$ - $2s3d\ ^3D_{1,2}$ |
| 192.9 | " $^3P_2$ - " $^3D_{2,3}$ |
| 215.245 | $2s2p\ ^3P_2$ - $2s3s\ ^3S_1$ |
| 215.103 | " $^3P_1$ - " $^3S_1$ |
| 215.040 | " $^3P_0$ - " $^3S_1$ |
| 220.35 | $2s2p\ ^1P_1$ - $2s3d\ ^1D_2$ |
| 248.46 | $2s2p\ ^1P$ - $2s3s\ ^1S$ |
| 270.98 | $2p^2\ ^3P_2$ - $2s3p\ ^3P_2$ |
| 286.45 | $2p^2\ ^1D$ - $2s3p\ ^1P$ |
| 629.73 | $2s^2\ ^1S$ - $2s2p\ ^1P$ |
| 760.45 | $2s2p\ ^3P_2$ - $2p^2\ ^3P_2$ |
| 760.23 | $2s2p\ ^3P_1$ - $2p^2\ ^3P_1$ |
| 762.00 | $2s2p\ ^3P_2$ - $2p^2\ ^3P_1$ |
| 761.13 | $2s2p\ ^3P_1$ - $2p^2\ ^3P_0$ |
| 758.68 | $2s2p\ ^3P_1$ - $2p^2\ ^3P_2$ |
| 759.44 | $2s2p\ ^3P_0$ - $2p^2\ ^3P_1$ |
| 774.52 | $2s2p\ ^1P$ - $2p^2\ ^1S$ |
| 1218.34 | $2s^2\ ^1S$ - $2s2p\ ^3P_1$ |
| 1371.29 | $2s2p\ ^1P$ - $2p^2\ ^1D$ |
| 2781.01(air) | $2s3s\ ^3S_1$ - $2s3p\ ^3P_2$ |
| 2786.99(air) | $2s3s\ ^3S_1$ - $2s3p\ ^3P_1$ |
| 2789.85(air) | $2s3s\ ^3S_1$ - $2s3p\ ^3P_0$ |
| 5114.07(air) | $2s3s\ ^1S$ - $2s3p\ ^1P$ |
| 5597.91 - 5607.41(air) | $2s3p\ ^3P$ - $2s3d\ ^3D$ |

Figure captions

Fig.1 Schematic energy level diagram for OV. The term designations are shown across the top of the figure; the level numbers are same as those in Table 1; the wavelengths are approximate values in A.

Fig.2 Population density of the metastable level 2s2p $^3P_1$ for $T_e$ = 20 and 100 eV as a function of electron density. Solid, dashed and dash - dotted curves indicate the results without ionization processes ( $T_e$ = 20 and 100 eV), with ionization from OV to OVI ions ( $T_e$ = 100 eV) and with ionization both from OV to OVI and OIV to OV ions ( $T_e$ = 100 eV), respectively. The values from Keenan et al.[8] for 20 eV are shown by triangles.

Fig.3 Rate coefficients for excitation, recombination ($\alpha$) and ionization processes (S). The dotted portions extending the solid lines represent the extraporated values from ref.10.

Fig.4 Density dependent line ratios for I(760) /I(630), I( 1218)/ I(630) without ionization processes for $T_e$ = 20 (solid line) and 100 eV (dashed line). The calculated results from ref.1 (dotted line) and ref.3 (dashed dotted line) for 22 eV are also shown.

Fig.5 Density dependent line ratios for I(192.90A)/ I(248.46A), I( 215.25A)/ I(220.35A) and I( 192.80A)/ I(220.35A) for $T_e$ = 20 eV (solid line) and 100 eV (dashed line) without ionization processes. Dashed dotted lines are results from ref.2 for $T_e$ = 17 eV.

Fig.1

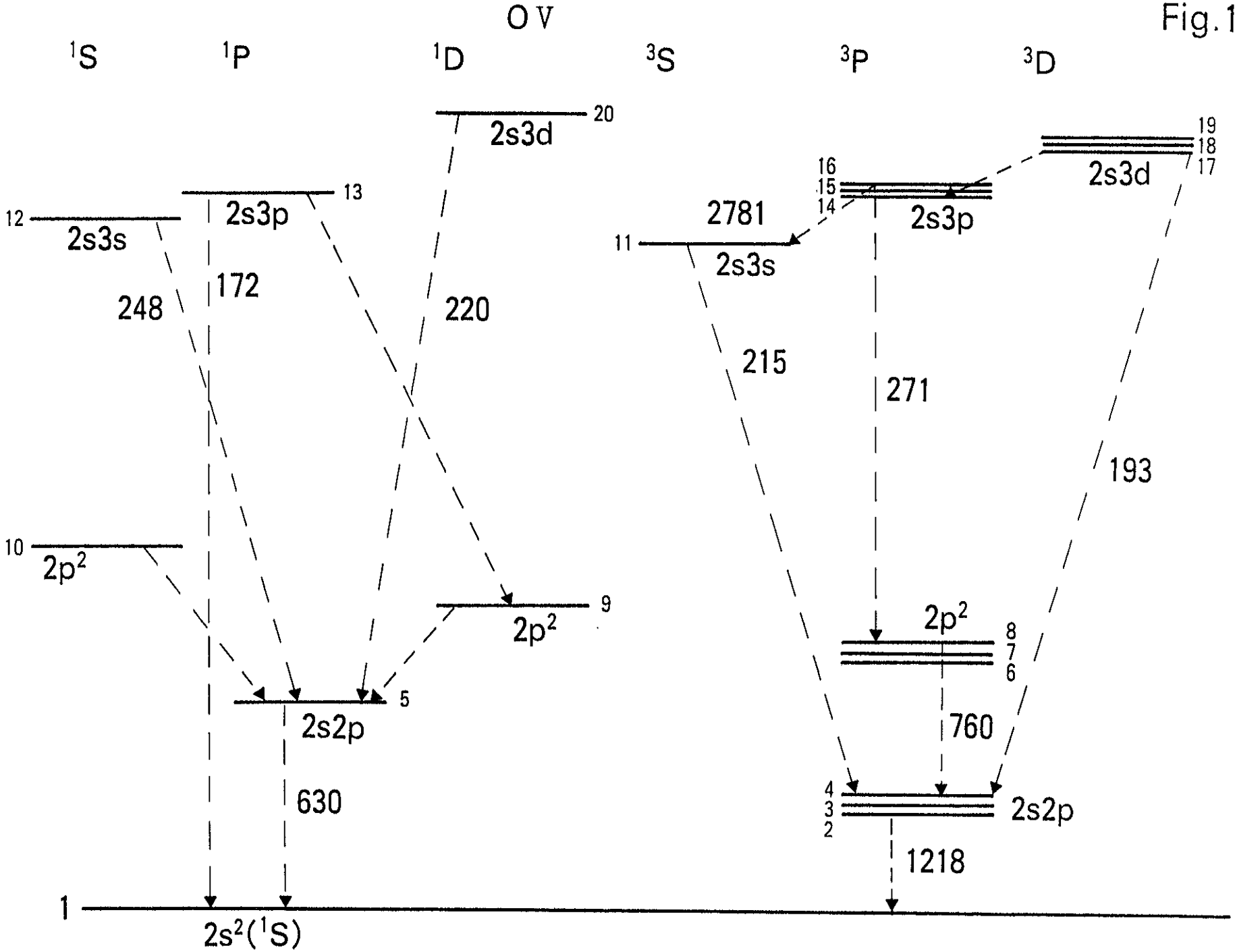

O V
1S
1P
1D
3S
3P
3D
20
2s3d
19
18
17
16
15
14
2s3p
13
12
2s3s
11
2781
248
172
220
215
271
193
10
2p2
9
2p2
8
7
6
2p2
5
2s2p
760
4
3
2
2s2p
630
1218
1
2s2(1S)

Fig.2

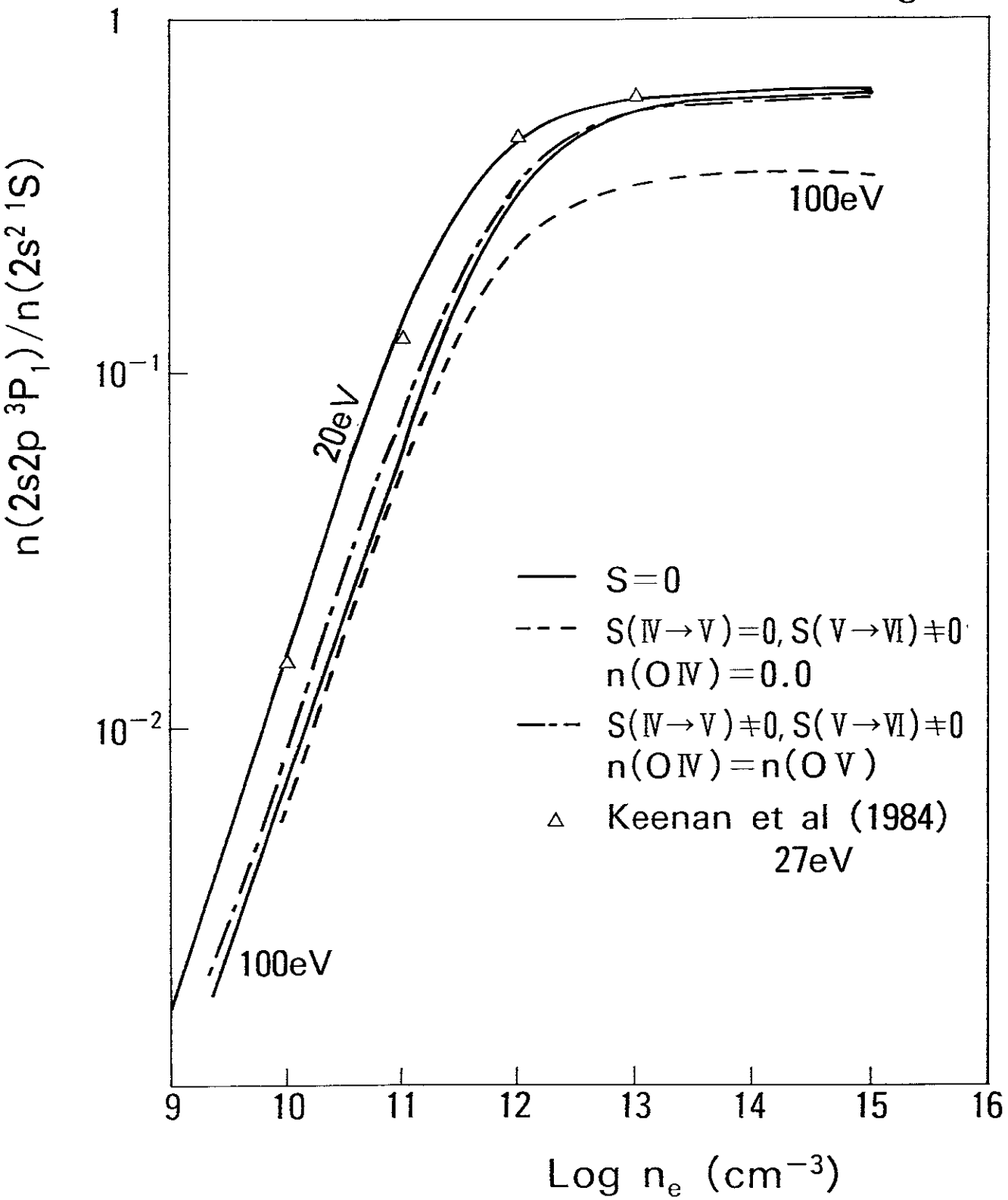

1
$10^{-1}$
$10^{-2}$
$n(2s2p\ ^3P_1)/n(2s^2\ ^1S)$
20eV
100eV
100eV
S=0
S(Ⅳ→Ⅴ)=0, S(Ⅴ→Ⅵ)≠0
n(OⅣ)=0.0
S(Ⅳ→Ⅴ)≠0, S(Ⅴ→Ⅵ)≠0
n(OⅣ)=n(OⅤ)
Keenan et al (1984)
27eV
9
10
11
12
13
14
15
16
Log $n_e$ ($cm^{-3}$)

Fig.3

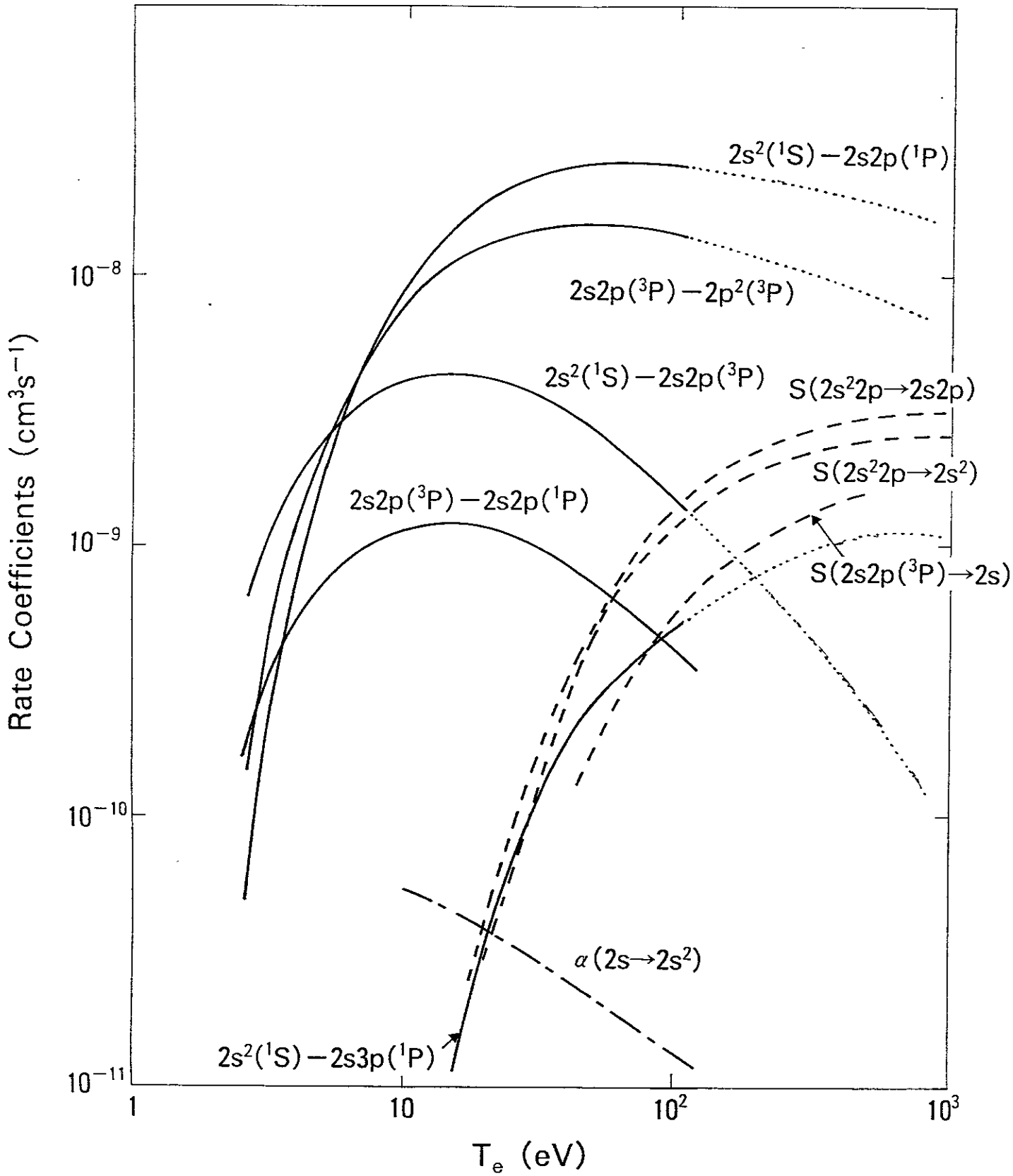

Rate Coefficients (cm³s⁻¹)
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁻¹¹
1
10
10²
10³
Tₑ (eV)
2s²(¹S)−2s2p(¹P)
2s2p(³P)−2p²(³P)
2s²(¹S)−2s2p(³P)
S(2s²2p→2s2p)
S(2s²2p→2s²)
2s2p(³P)−2s2p(¹P)
S(2s2p(³P)→2s)
α(2s→2s²)
2s²(¹S)−2s3p(¹P)

Fig.4

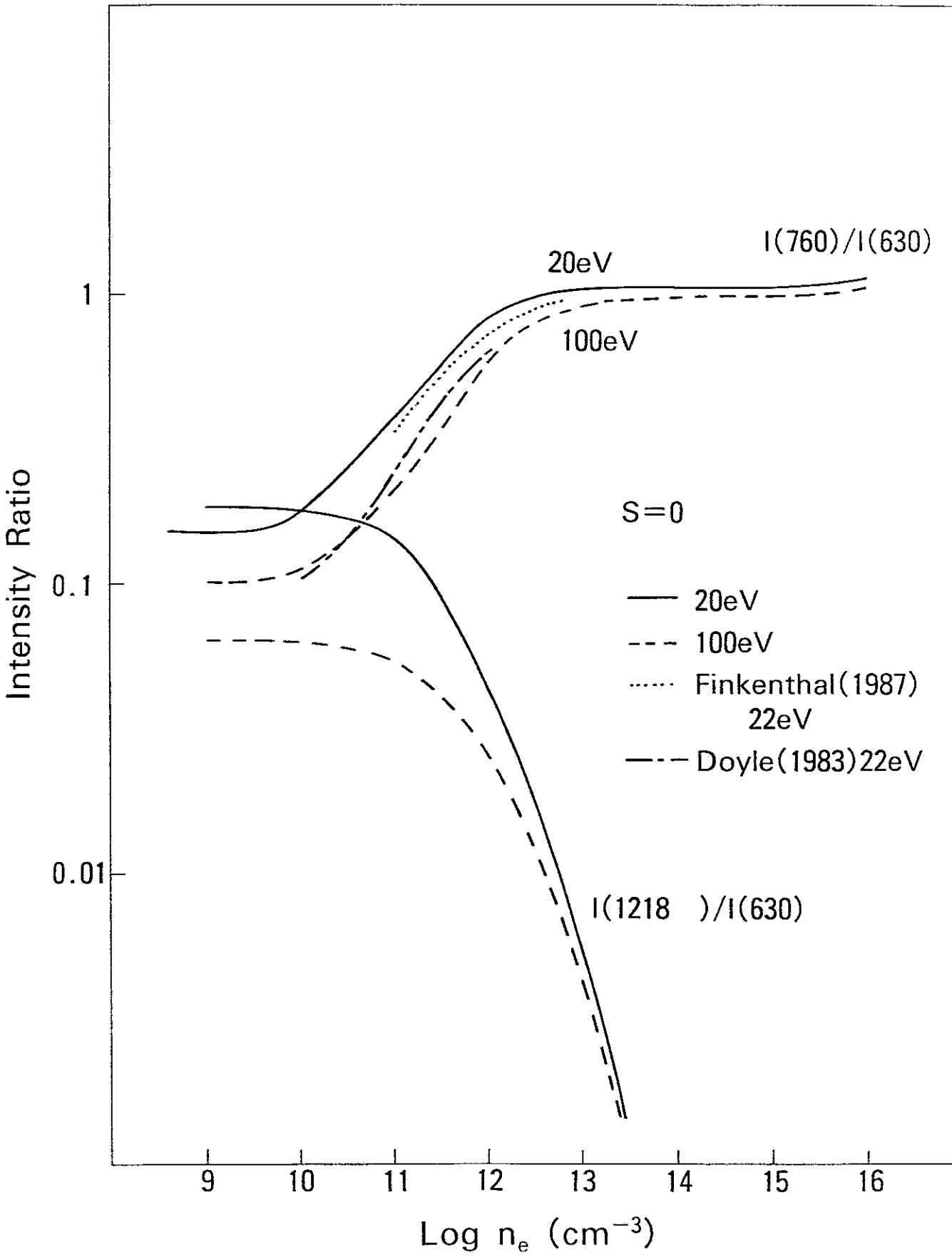
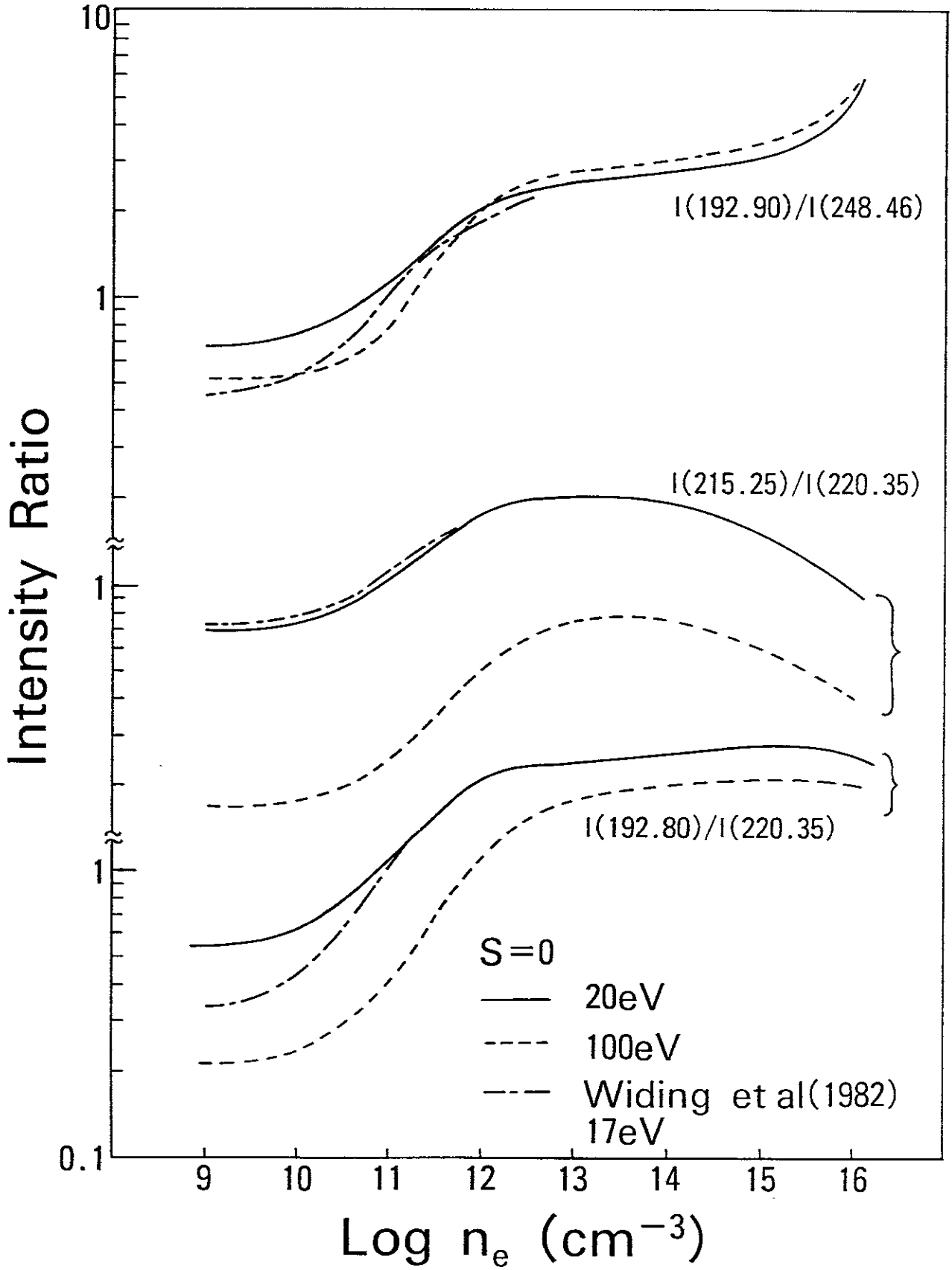

I(760)/I(630)
20eV
100eV
1
0.1
0.01
Intensity Ratio
S=0
20eV
100eV
Finkenthal(1987)
22eV
Doyle(1983)22eV
I(1218 )/I(630)
9
10
11
12
13
14
15
16
Log $n_e$ ($cm^{-3}$)

Fig.5


10
1
1
1
0.1
Intensity Ratio
I(192.90)/I(248.46)
I(215.25)/I(220.35)
I(192.80)/I(220.35)
S=0
20eV
100eV
Widing et al(1982)
17eV
9
10
11
12
13
14
15
16
Log $n_e$ ($cm^{-3}$)

Appendix

## Explanation of Tables

### Table I. Fit parameters for the Recommended Rate Coefficients

Fit parameters are tabulated for each excitation process of OV. Transitions between energy terms are listed first, followed by transition between the triplet fine structure levels. The notation $2s^2\ ^1S - 2s2p\ ^3P$, for example, means the excitation from the lower state $2s^2\ ^1S$ to the upper triplet term $2s2p\ ^3P$, while $2s2p\ ^3P_0 - 2p^2\ ^3P_2$ indicates a transition between fine structure levels.

| | |
|---|---|
| $\Delta E$ | Excitation energy in eV |
| $a_1, a_2, a_3, a_4, a_5$ | Fit parameters in Eq.(3) ($\Delta E \neq 0$ ) |
| $b_1, b_2, b_3, b_4$ | Fit parameters in Eq.(5) for transitions between fine structure levels belonging to the same term ($\Delta E = 0$ ). |

Table I

| | ΔE(eV) | $a_1$ | $a_2$ | $a_3$ | $a_4$ | $a_5$ |
|---|---|---|---|---|---|---|
| $2s^2\ ^1S - 2s2p\ ^3P$ | 1.02E+01 | -2.52E-02 | 2.07E+00 | -3.71E+00 | 2.49E+00 | 0.0 |
| $2s^2\ ^1S - 2s2p\ ^1P$ | 2.06E+01 | 1.66E+00 | 6.65E-01 | 2.75E-01 | 0.0 | 1.40E+00 |
| $2s^2\ ^1S - 2p^2\ ^3P$ | 2.66E+01 | -8.40E-05 | 1.44E-02 | 4.82E-02 | -5.63E-02 | 0.0 |
| $2s^2\ ^1S - 2p^2\ ^1D$ | 2.96E+01 | 1.06E-02 | 4.25E-01 | -4.85E-01 | 1.54E-01 | 0.0 |
| $2s^2\ ^1S - 2p^2\ ^1S$ | 3.69E+01 | -6.91E-04 | 9.27E-02 | -6.46E-03 | -6.44E-02 | 0.0 |
| $2s^2\ ^1S - 2s3s\ ^3S$ | 6.78E+01 | -8.79E-03 | 1.73E-01 | -5.98E-01 | 5.58E-01 | 0.0 |
| $2s^2\ ^1S - 2s3s\ ^1S$ | 6.96E+01 | 3.12E-02 | 1.32E+00 | -2.87E+00 | 1.75E+00 | 0.0 |
| $2s^2\ ^1S - 2s3p\ ^1P$ | 7.20E+01 | -2.08E-01 | 1.19E-01 | 1.71E-01 | 0.0 | 2.95E-01 |
| $2s^2\ ^1S - 2s3p\ ^3P$ | 7.22E+01 | 1.08E-03 | 3.55E-02 | -7.44E-02 | 1.30E-01 | 0.0 |
| $2s^2\ ^1S - 2s3d\ ^3D$ | 7.46E+01 | 2.50E-03 | 3.10E-02 | 1.08E-01 | -8.69E-03 | 0.0 |
| $2s^2\ ^1S - 2s3d\ ^1D$ | 7.64E+01 | 4.51E-01 | -4.31E-01 | 2.59E-02 | 6.76E-02 | 0.0 |
| $2s2p\ ^3P - 2s2p\ ^1P$ | 1.04E+01 | 1.04E-02 | 3.87E+00 | -6.00E+00 | 4.23E+00 | 0.0 |
| $2s2p\ ^3P - 2p^2\ ^3P$ | 1.64E+01 | 2.55E+01 | -3.91E+01 | 4.37E+01 | -1.73E+01 | 0.0 |
| $2s2p\ ^3P - 2p^2\ ^1D$ | 1.94E+01 | -4.21E-02 | 2.39E+00 | -2.85E+00 | 8.74E-01 | 0.0 |
| $2s2p\ ^3P - 2p^2\ ^1S$ | 2.67E+01 | -1.14E-03 | 2.60E-02 | 5.92E-01 | -5.87E-01 | 0.0 |
| $2s2p\ ^3P - 2s3s\ ^3S$ | 5.76E+01 | 1.37E+00 | 4.72E+04 | -4.72E+04 | 0.0 | 4.61E-02 |
| $2s2p\ ^3P - 2s3s\ ^1S$ | 5.94E+01 | 7.81E-03 | 3.05E-01 | -1.62E+00 | 1.74E+00 | 0.0 |

| | ΔE(eV) | $a_1$ | $a_2$ | $a_3$ | $a_4$ | $a_5$ |
|---|---|---|---|---|---|---|
| $2s2p\ ^3P - 2s3p\ ^1P$ | 6.19E+01 | -2.42E-02 | 6.73E-01 | -2.06E+00 | 1.89E+00 | 0.0 |
| $2s2p\ ^3P - 2s3p\ ^3P$ | 6.20E+01 | -6.99E-01 | 1.71E+01 | -3.74E+01 | 2.40E+01 | 0.0 |
| $2s2p\ ^3P - 2s3d\ ^3D$ | 6.44E+01 | 8.11E+00 | -1.24E+01 | 7.63E+00 | 0.0 | 5.38E-01 |
| $2s2p\ ^3P - 2s3d\ ^1D$ | 6.62E+01 | -1.01E-03 | 1.12E-01 | -1.30E-01 | 5.01E-01 | 0.0 |
| $2s2p\ ^1P - 2p^2\ ^3P$ | 6.04E+00 | -5.62E-02 | 3.91E+00 | -1.05E+01 | 8.77E+00 | 0.0 |
| $2s2p\ ^1P - 2p^2\ ^1D$ | 8.98E+00 | 9.62E+00 | -1.00E+01 | 9.38E+00 | 0.0 | 1.94E+00 |
| $2s2p\ ^1P - 2p^2\ ^1S$ | 1.63E+01 | 4.61E+00 | -5.66E+00 | 3.70E+00 | 0.0 | 2.06E-01 |
| $2s2p\ ^1P - 2s3s\ ^3S$ | 4.73E+01 | -1.06E-02 | 2.59E-01 | -1.07E+00 | 1.24E+00 | 0.0 |
| $2s2p\ ^1P - 2s3s\ ^1S$ | 4.90E+01 | 1.80E-01 | -1.06E-02 | 1.31E-02 | 0.0 | 4.71E-02 |
| $2s2p\ ^1P - 2s3p\ ^1P$ | 5.15E+01 | 4.60E-02 | 2.02E+00 | -5.34E+00 | 3.95E+00 | 0.0 |
| $2s2p\ ^1P - 2s3p\ ^3P$ | 5.16E+01 | -2.54E-04 | 2.13E-01 | -7.59E-01 | 1.08E+00 | 0.0 |
| $2s2p\ ^1P - 2s3d\ ^3D$ | 5.40E+01 | -4.02E-03 | 5.46E-01 | -1.42E+00 | 1.65E+00 | 0.0 |
| $2s2p\ ^1P - 2s3d\ ^1D$ | 5.58E+01 | 2.37E+00 | -3.34E+00 | 2.04E+00 | 0.0 | 5.41E-01 |
| $2p^2\ ^3P - 2p^2\ ^1D$ | 2.94E+00 | 6.18E-02 | 1.99E+01 | -6.37E+01 | 5.16E+01 | 0.0 |
| $2p^2\ ^3P - 2p^2\ ^1S$ | 1.03E+01 | -2.12E-02 | 1.20E+00 | -1.61E+00 | 5.52E-01 | 0.0 |
| $2p^2\ ^3P - 2s3s\ ^3S$ | 4.12E+01 | -4.04E-03 | 1.60E-01 | -8.83E-01 | 1.17E+00 | 0.0 |
| $2p^2\ ^3P - 2s3s\ ^1S$ | 4.30E+01 | -2.45E-03 | 8.44E-02 | -4.51E-01 | 5.44E-01 | 0.0 |

| | ΔE(eV) | $a_1$ | $a_2$ | $a_3$ | $a_4$ | $a_5$ |
|---|---|---|---|---|---|---|
| $2p^2\ ^3P$ - $2s3p\ ^1P$ | 4.54E+01 | -2.75E-02 | 9.65E-01 | -4.07E+00 | 4.05E+00 | 0.0 |
| $2p^2\ ^3P$ - $2s3p\ ^3P$ | 4.56E+01 | -8.76E-02 | 2.00E+00 | -8.27E+00 | 8.87E+00 | 0.0 |
| $2p^2\ ^3P$ - $2s3d\ ^3D$ | 4.80E+01 | 1.98E-01 | 3.56E-01 | -5.08E+00 | 7.16E+00 | 0.0 |
| $2p^2\ ^3P$ - $2s3d\ ^1D$ | 4.97E+01 | -1.74E-02 | 4.20E-01 | -1.82E+00 | 1.99E+00 | 0.0 |
| $2p^2\ ^1D$ - $2p^2\ ^1S$ | 7.36E+00 | 3.92E-01 | -1.83E-01 | 5.00E-02 | 1.33E-02 | 0.0 |
| $2p^2\ ^1D$ - $2s3s\ ^3S$ | 3.83E+01 | -7.35E-03 | 2.56E-01 | -1.30E+00 | 1.61E+00 | 0.0 |
| $2p^2\ ^1D$ - $2s3s\ ^1S$ | 4.00E+01 | -1.13E-04 | 6.19E-01 | -2.51E+00 | 2.49E+00 | 0.0 |
| $2p^2\ ^1D$ - $2s3p\ ^1P$ | 4.25E+01 | 6.64E-01 | -2.55E+00 | 2.70E+00 | 0.0 | 2.30E-02 |
| $2p^2\ ^1D$ - $2s3p\ ^3P$ | 4.27E+01 | -1.44E-02 | 4.80E-01 | -2.32E+00 | 2.74E+00 | 0.0 |
| $2p^2\ ^1D$ - $2s3d\ ^3D$ | 4.50E+01 | -2.06E-02 | 6.31E-01 | -3.00E+00 | 3.46E+00 | 0.0 |
| $2p^2\ ^1D$ - $2s3d\ ^1D$ | 4.68E+01 | 2.24E-01 | -8.46E-03 | -1.21E+00 | 2.18E+00 | 0.0 |
| $2p^2\ ^1S$ - $2s3s\ ^3S$ | 3.09E+01 | -1.73E-04 | 2.13E-02 | -1.68E-01 | 3.10E-01 | 0.0 |
| $2p^2\ ^1S$ - $2s3s\ ^1S$ | 3.27E+01 | 1.25E-03 | 2.35E-02 | -2.27E-02 | 1.03E-01 | 0.0 |
| $2p^2\ ^1S$ - $2s3p\ ^1P$ | 3.51E+01 | 1.55E-01 | -8.50E-01 | 9.99E-01 | 0.0 | 1.11E-02 |
| $2p^2\ ^1S$ - $2s3p\ ^3P$ | 3.53E+01 | -4.76E-03 | 1.59E-01 | -7.33E-01 | 8.54E-01 | 0.0 |
| $2p^2\ ^1S$ - $2s3d\ ^3D$ | 3.77E+01 | -3.13E-03 | 1.06E-01 | -5.13E-01 | 6.59E-01 | 0.0 |
| $2p^2\ ^1S$ - $2s3d\ ^1D$ | 3.94E+01 | 5.86E-02 | 8.49E-02 | -3.65E-01 | 4.97E-01 | 0.0 |

| | ΔE(eV) | $a_1$ | $a_2$ | $a_3$ | $a_4$ | $a_5$ |
|---|---|---|---|---|---|---|
| 2s3s $^3$S - 2s3s $^1$S | 1.77E+00 | 2.98E-02 | 8.25E-02 | 5.45E+00 | -3.94E+00 | 0.0 |
| 2s3s $^3$S - 2s3p $^1$P | 4.22E+00 | -1.03E-02 | 1.18E+00 | -2.33E+00 | 2.78E+00 | 0.0 |
| 2s3s $^3$S - 2s3p $^3$P | 4.39E+00 | 3.18E+01 | -4.96E+01 | 7.07E+01 | 0.0 | 1.63E+01 |
| 2s3s $^3$S - 2s3d $^3$D | 6.76E+00 | 6.64E+00 | -6.92E+00 | 1.20E+01 | -5.69E+00 | 0.0 |
| 2s3s $^3$S - 2s3d $^1$D | 8.53E+00 | 3.54E-03 | 6.17E-01 | -1.29E-01 | 1.59E-01 | 0.0 |
| 2s3s $^1$S - 2s3p $^1$P | 2.45E+00 | 1.17E+01 | -3.78E+01 | 5.23E+01 | 0.0 | 4.59E+00 |
| 2s3s $^1$S - 2s3p $^3$P | 2.63E+00 | -5.96E-03 | 1.32E+00 | -2.51E-01 | -3.41E-01 | 0.0 |
| 2s3s $^1$S - 2s3d $^3$D | 4.99E+00 | 1.95E-02 | 7.83E-01 | 3.89E-01 | -5.31E-01 | 0.0 |
| 2s3s $^1$S - 2s3d $^1$D | 6.76E+00 | 1.80E+00 | -1.12E+00 | 1.13E+00 | 0.0 | 1.61E-02 |
| 2s3p $^1$P - 2s3p $^3$P | 1.77E-01 | 2.30E-01 | 3.36E+01 | -6.41E+01 | 1.43E+01 | 0.0 |
| 2s3p $^1$P - 2s3d $^3$D | 2.54E+00 | 2.51E-02 | 3.17E+00 | 5.37E+00 | -6.95E+00 | 0.0 |
| 2s3p $^1$P - 2s3d $^1$D | 4.31E+00 | 3.75E+01 | -7.87E+01 | 7.47E+01 | 0.0 | 2.27E+00 |
| 2s3p $^3$P - 2s3d $^3$D | 2.37E+00 | 1.90E+02 | -6.90E+02 | 7.81E+02 | 0.0 | 2.37E+00 |
| 2s3p $^3$P - 2s3d $^1$D | 4.14E+00 | -4.54E-03 | 2.54E+00 | 2.56E+00 | -3.48E+00 | 0.0 |
| 2s3d $^3$D - 2s3d $^1$D | 1.77E+00 | -1.52E-02 | 1.92E+01 | -1.06E+01 | -8.95E+00 | 0.0 |
| 2s2p $^3P_0$ - 2p$^2$ $^3P_0$ | 1.64E+01 | 6.65E-02 | -3.53E-01 | 6.91E-01 | -3.93E-01 | 0.0 |
| 2s2p $^3P_0$ - 2p$^2$ $^3P_1$ | 1.64E+01 | 1.14E+00 | -1.44E-01 | 3.97E-01 | 0.0 | 5.96E-01 |

| | ΔE(eV) | $a_1$ | $a_2$ | $a_3$ | $a_4$ | $a_5$ |
|---|---|---|---|---|---|---|
| $2s2p\ ^3P_0 - 2p^2\ ^3P_2$ | 1.64E+01 | 1.05E-01 | -5.08E-01 | 9.97E-01 | -5.77E-01 | 0.0 |
| $2s2p\ ^3P_0 - 2s3p\ ^3P_0$ | 6.20E+01 | 9.12E-02 | 3.42E-01 | -8.11E-01 | 5.15E-01 | 0.0 |
| $2s2p\ ^3P_0 - 2s3p\ ^3P_1$ | 6.20E+01 | -2.78E-03 | 8.77E-02 | -2.76E-01 | 2.66E-01 | 0.0 |
| $2s2p\ ^3P_0 - 2s3p\ ^3P_2$ | 6.20E+01 | 2.23E-03 | 2.94E-01 | -8.31E-01 | 6.31E-01 | 0.0 |
| $2s2p\ ^3P_0 - 2s3d\ ^3D_1$ | 6.44E+01 | -4.22E-01 | 1.16E+00 | -4.96E-01 | 0.0 | 5.38E-01 |
| $2s2p\ ^3P_0 - 2s3d\ ^3D_2$ | 6.44E+01 | 1.52E-02 | -6.61E-03 | -2.55E-02 | 8.47E-02 | 0.0 |
| $2s2p\ ^3P_0 - 2s3d\ ^3D_3$ | 6.44E+01 | 3.85E-02 | -7.45E-02 | 5.94E-02 | 3.14E-02 | 0.0 |
| $2s2p\ ^3P_1 - 2p^2\ ^3P_0$ | 1.64E+01 | 2.25E+00 | -2.46E+00 | 1.66E+00 | 0.0 | 1.99E-01 |
| $2s2p\ ^3P_1 - 2p^2\ ^3P_1$ | 1.64E+01 | 1.69E+00 | -1.57E+00 | 1.05E+00 | 0.0 | 1.49E-01 |
| $2s2p\ ^3P_1 - 2p^2\ ^3P_2$ | 1.64E+01 | 2.84E+00 | -2.95E+00 | 1.99E+00 | 0.0 | 2.48E-01 |
| $2s2p\ ^3P_1 - 2s3p\ ^3P_0$ | 6.20E+01 | -5.64E-04 | 6.62E-02 | -2.28E-01 | 2.37E-01 | 0.0 |
| $2s2p\ ^3P_1 - 2s3p\ ^3P_1$ | 6.20E+01 | 1.27E-01 | 2.25E+00 | -4.96E+00 | 3.15E+00 | 0.0 |
| $2s2p\ ^3P_1 - 2s3p\ ^3P_2$ | 6.20E+01 | 1.23E-02 | 7.55E-01 | -2.26E+00 | 1.80E+00 | 0.0 |
| $2s2p\ ^3P_1 - 2s3d\ ^3D_1$ | 6.44E+01 | 4.21E-01 | -5.42E-01 | 3.99E-01 | 0.0 | 1.35E-01 |
| $2s2p\ ^3P_1 - 2s3d\ ^3D_2$ | 6.44E+01 | 1.20E+00 | -1.39E+00 | 8.19E-01 | 0.0 | 4.03E-01 |
| $2s2p\ ^3P_1 - 2s3d\ ^3D_3$ | 6.44E+01 | 3.04E-02 | 1.94E-01 | -4.65E-01 | 4.46E-01 | 0.0 |
| $2s2p\ ^3P_2 - 2p^2\ ^3P_0$ | 1.64E+01 | 1.01E-01 | -4.67E-01 | 8.93E-01 | -5.06E-01 | 0.0 |

| | ΔE(eV) | $a_1$ | $a_2$ | $a_3$ | $a_4$ | $a_5$ |
|---|---|---|---|---|---|---|
| $2s2p\ ^3P_2$ - $2p^2\ ^3P_1$ | 1.64E+01 | 3.23E+00 | -3.89E+00 | 2.58E+00 | 0.0 | 1.49E-01 |
| $2s2p\ ^3P_2$ - $2p^2\ ^3P_2$ | 1.64E+01 | 9.61E+00 | -1.18E+01 | 7.89E+00 | 0.0 | 4.64E-01 |
| $2s2p\ ^3P_2$ - $2s3p\ ^3P_0$ | 6.20E+01 | -2.82E-03 | 2.53E-01 | -6.79E-01 | 5.22E-01 | 0.0 |
| $2s2p\ ^3P_2$ - $2s3p\ ^3P_1$ | 6.20E+01 | 5.23E-03 | 7.47E-01 | -2.19E+00 | 1.75E+00 | 0.0 |
| $2s2p\ ^3P_2$ - $2s3p\ ^3P_2$ | 6.20E+01 | -5.09E-02 | 5.83E+00 | -1.26E+01 | 7.99E+00 | 0.0 |
| $2s2p\ ^3P_2$ - $2s3d\ ^3D_1$ | 6.44E+01 | 1.23E-01 | -2.76E-01 | 2.93E-01 | 0.0 | 5.36E-03 |
| $2s2p\ ^3P_2$ - $2s3d\ ^3D_2$ | 6.44E+01 | 6.46E-01 | -1.02E+00 | 7.89E-01 | 0.0 | 8.05E-02 |
| $2s2p\ ^3P_2$ - $2s3d\ ^3D_3$ | 6.44E+01 | 2.38E+00 | -2.31E+00 | 1.22E+00 | 0.0 | 4.51E-01 |
| $2p^2\ ^3P_0$ - $2s3p\ ^3P_0$ | 4.56E+01 | 4.55E-01 | -2.03E+00 | 2.80E+00 | -1.20E+00 | 0.0 |
| $2p^2\ ^3P_0$ - $2s3p\ ^3P_1$ | 4.56E+01 | -3.60E-03 | 1.04E-01 | -3.99E-01 | 4.21E-01 | 0.0 |
| $2p^2\ ^3P_0$ - $2s3p\ ^3P_2$ | 4.56E+01 | -3.49E-03 | 1.07E-01 | -4.65E-01 | 4.91E-01 | 0.0 |
| $2p^2\ ^3P_0$ - $2s3d\ ^3D_1$ | 4.80E+01 | -1.36E-03 | 4.42E-02 | -1.86E-01 | 2.32E-01 | 0.0 |
| $2p^2\ ^3P_0$ - $2s3d\ ^3D_2$ | 4.80E+01 | -2.88E-03 | 7.04E-02 | -2.78E-01 | 3.21E-01 | 0.0 |
| $2p^2\ ^3P_0$ - $2s3d\ ^3D_3$ | 4.80E+01 | -1.46E-03 | 3.83E-02 | -2.06E-01 | 2.56E-01 | 0.0 |
| $2p^2\ ^3P_1$ - $2s3p\ ^3P_0$ | 4.56E+01 | -2.50E-03 | 9.75E-02 | -3.88E-01 | 4.16E-01 | 0.0 |
| $2p^2\ ^3P_1$ - $2s3p\ ^3P_1$ | 4.56E+01 | -6.90E-03 | 1.66E-01 | -7.67E-01 | 8.78E-01 | 0.0 |
| $2p^2\ ^3P_1$ - $2s3p\ ^3P_2$ | 4.56E+01 | 2.74E+00 | -1.27E+01 | 1.77E+01 | -7.28E+00 | 0.0 |

| | ΔE(eV) | $a_1$ | $a_2$ | $a_3$ | $a_4$ | $a_5$ |
|---|---|---|---|---|---|---|
| $2p^2\ ^3P_1$ - $2s3d\ ^3D_1$ | 4.80E+01 | -5.91E-04 | 9.05E-02 | -4.34E-01 | 5.57E-01 | 0.0 |
| $2p^2\ ^3P_1$ - $2s3d\ ^3D_2$ | 4.80E+01 | -8.18E-03 | 1.69E-01 | -7.12E-01 | 8.65E-01 | 0.0 |
| $2p^2\ ^3P_1$ - $2s3d\ ^3D_3$ | 4.80E+01 | -4.95E-03 | 1.24E-01 | -6.51E-01 | 8.55E-01 | 0.0 |
| $2p^2\ ^3P_2$ - $2s3p\ ^3P_0$ | 4.56E+01 | 1.13E+00 | -4.86E+00 | 6.28E+00 | -2.40E+00 | 0.0 |
| $2p^2\ ^3P_2$ - $2s3p\ ^3P_1$ | 4.56E+01 | -2.52E-03 | 1.57E-01 | -9.53E-01 | 1.22E+00 | 0.0 |
| $2p^2\ ^3P_2$ - $2s3p\ ^3P_2$ | 4.56E+01 | -1.77E-01 | 6.17E+00 | -2.65E+00 | 2.88E+00 | 0.0 |
| $2p^2\ ^3P_2$ - $2s3d\ ^3D_1$ | 4.80E+01 | -1.37E-03 | 6.42E-02 | -4.02E-01 | 5.47E-01 | 0.0 |
| $2p^2\ ^3P_2$ - $2s3d\ ^3D_2$ | 4.80E+01 | -3.05E-03 | 1.40E-01 | -7.93E-01 | 1.08E+00 | 0.0 |
| $2p^2\ ^3P_2$ - $2s3d\ ^3D_3$ | 4.80E+01 | -5.14E-03 | 1.26E-01 | -9.24E-01 | 1.56E+00 | 0.0 |
| $2s3p\ ^3P_0$ - $2s3d\ ^3D_1$ | 2.37E+00 | 2.50E+01 | -1.57E+02 | 3.57E+02 | -2.34E+02 | 0.0 |
| $2s3p\ ^3P_0$ - $2s3d\ ^3D_2$ | 2.37E+00 | -1.17E-02 | 1.24E+00 | 2.52E-01 | -1.46E+00 | 0.0 |
| $2s3p\ ^3P_0$ - $2s3d\ ^3D_3$ | 2.37E+00 | 2.29E-01 | -8.81E-01 | 5.56E+00 | -5.28E+00 | 0.0 |
| $2s3p\ ^3P_1$ - $2s3d\ ^3D_1$ | 2.37E+00 | 1.91E+01 | -1.23E+02 | 2.83E+02 | -1.86E+02 | 0.0 |
| $2s3p\ ^3P_1$ - $2s3d\ ^3D_2$ | 2.37E+00 | 4.35E+01 | -1.49E+02 | 1.38E+02 | 0.0 | 1.77E+00 |
| $2s3p\ ^3P_1$ - $2s3d\ ^3D_3$ | 2.37E+00 | 1.55E+00 | -1.52E+01 | 5.20E+01 | -4.03E+01 | 0.0 |
| $2s3p\ ^3P_2$ - $2s3d\ ^3D_1$ | 2.37E+00 | 1.38E+00 | -3.92E+00 | 5.33E+00 | 0.0 | 3.88E-02 |
| $2s3p\ ^3P_2$ - $2s3d\ ^3D_2$ | 2.37E+00 | 1.66E+01 | -5.70E+01 | 5.48E+01 | 0.0 | 3.50E-01 |

| | ΔE(eV) | $a_1$ | $a_2$ | $a_3$ | $a_4$ | $a_5$ |
|---|---|---|---|---|---|---|
| $2s3p\ ^3P_2 - 2s3d\ ^3D_3$ | 2.37E+00 | 7.70E+01 | -2.41E+02 | 2.18E+02 | 0.0 | 1.98E+00 |

| | ΔE(eV) | $b_1$ | $b_2$ | $b_3$ | $b_4$ | $b_5$ |
|---|---|---|---|---|---|---|
| $2s2p\ ^3P_0 - 2s2p\ ^3P_1$ | 0.00E+00 | -6.47E+00 | 6.52E+01 | -2.07E+02 | 1.94E+02 | 0.0 |
| $2s2p\ ^3P_0 - 2s2p\ ^3P_2$ | 0.00E+00 | -2.23E+00 | -1.29E+01 | 2.46E+02 | -6.49E+02 | 0.0 |
| $2s2p\ ^3P_1 - 2s2p\ ^3P_2$ | 0.00E+00 | -1.42E+01 | 1.83E+02 | -7.65E+02 | 1.07E+03 | 0.0 |
| $2p^2\ ^3P_0 - 2p^2\ ^3P_1$ | 0.00E+00 | -2.13E+01 | 3.09E+02 | -1.53E+03 | 2.53E+03 | 0.0 |
| $2p^2\ ^3P_0 - 2p^2\ ^3P_2$ | 0.00E+00 | -1.58E+01 | 2.23E+02 | -1.10E+03 | 1.80E+03 | 0.0 |
| $2p^2\ ^3P_1 - 2p^2\ ^3P_2$ | 0.00E+00 | -2.98E+01 | 4.47E+02 | -2.25E+03 | 3.75E+03 | 0.0 |
| $2s3p\ ^3P_0 - 2s3p\ ^3P_1$ | 0.00E+00 | -1.41E+01 | 1.58E+02 | -5.84E+02 | 7.36E+02 | 0.0 |
| $2s3p\ ^3P_0 - 2s3p\ ^3P_2$ | 0.00E+00 | -1.20E+01 | 1.54E+02 | -6.46E+02 | 9.08E+02 | 0.0 |
| $2s3p\ ^3P_1 - 2s3p\ ^3P_2$ | 0.00E+00 | -9.74E+00 | 1.21E+02 | -4.58E+02 | 5.78E+02 | 0.0 |
| $2s3d\ ^3D_1 - 2s3d\ ^3D_2$ | 0.00E+00 | -1.96E+01 | 2.64E+02 | -1.16E+03 | 1.69E+03 | 0.0 |
| $2s3d\ ^3D_1 - 2s3d\ ^3D_3$ | 0.00E+00 | -9.71E+00 | 9.16E+01 | -2.17E+02 | 2.48E+01 | 0.0 |
| $2s3d\ ^3D_2 - 2s3d\ ^3D_3$ | 0.00E+00 | -1.86E+01 | 2.49E+02 | -1.08E+03 | 1.56E+03 | 0.0 |

## Explanation of Figures

Figure I. Line Intensity Ratios vs. Temperature

Ionization processes are included in the line intensity calculations. The curves shown are for electron densities $n_e$ = $10^9$ $cm^{-3}$(solid line), $10^{11}$ $cm^{-3}$(dash - dotted line) and $10^{13}$ $cm^{-3}$(dashed line) for n(OIV)=0 and $10^{13}$ $cm^{-3}$ assuming n(OIV) = n(OV) (dotted line). Plots are given for I(172)/I(630), I(193)/ I(760), I(220)/I(248), I(215)/ I(220), I(215)/I(193) and I(193/I(220).

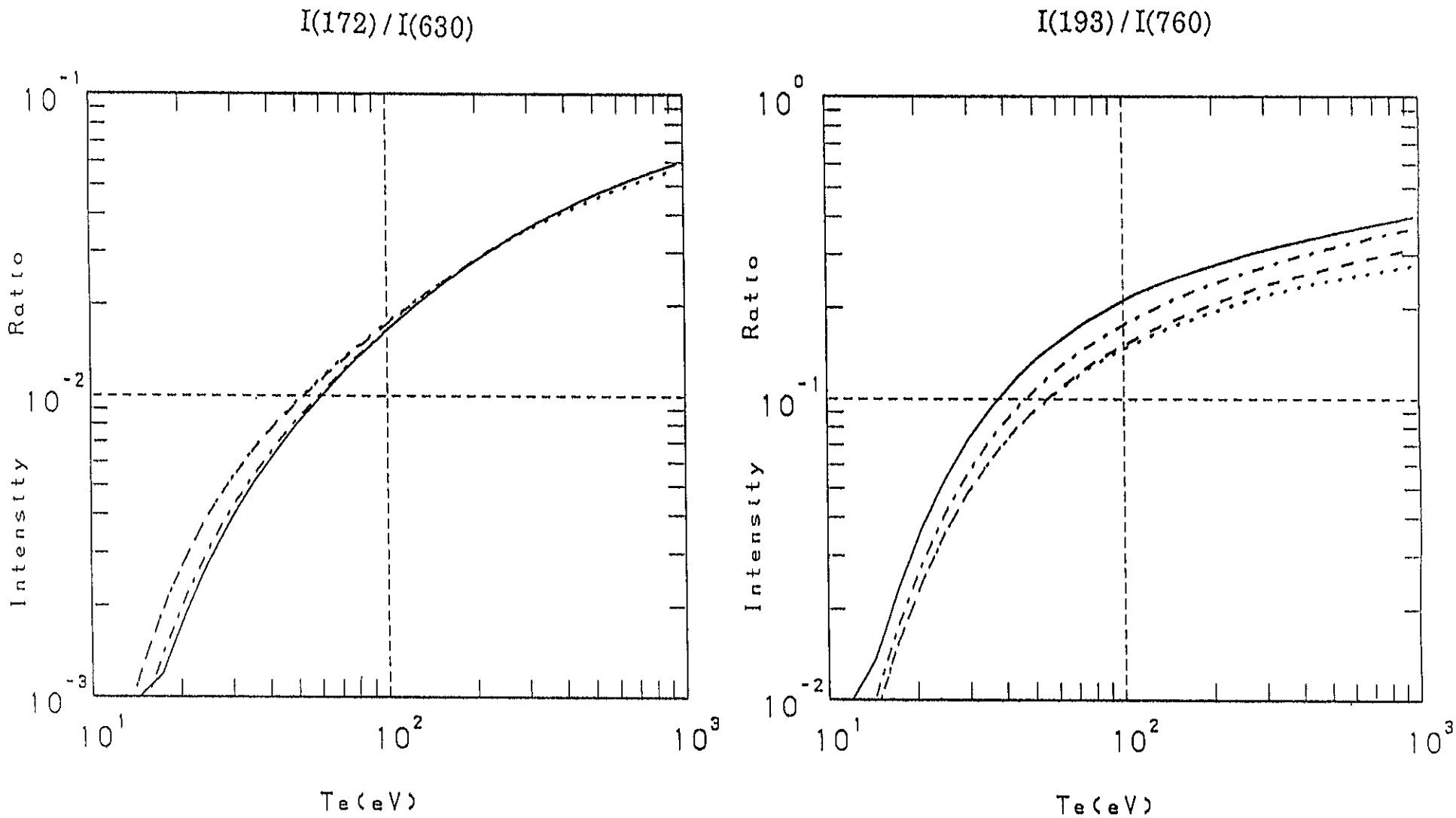
Figure II. Line Intensity Ratios vs. Density

Ionization processes are included in the line intensity calculations. The curves shown are for electron temperature $T_e$ = 20 eV (solid line), 40 eV (dash - dotted line) and 100 eV (dashed line) for n(OIV)=0 and 100eV assuming n(OIV) = n(OV) (dotted line). Plots are given for I(220)/ I(172) and I(220)/ I(248) in the singlet system and for the following cases involving the triplet system: I(760)/ I(630), I(1218)/I(630), I(193)/I(248), I(193)/ I(220), I(215)/ I(220), I(193)/ I(172), I(215)/ I(193), I(271)/ I(215), I(2781.01)/ I(193), I(2781.01)/ I(215), I(760.45)/I(630) and I(270.98)/ I(215).

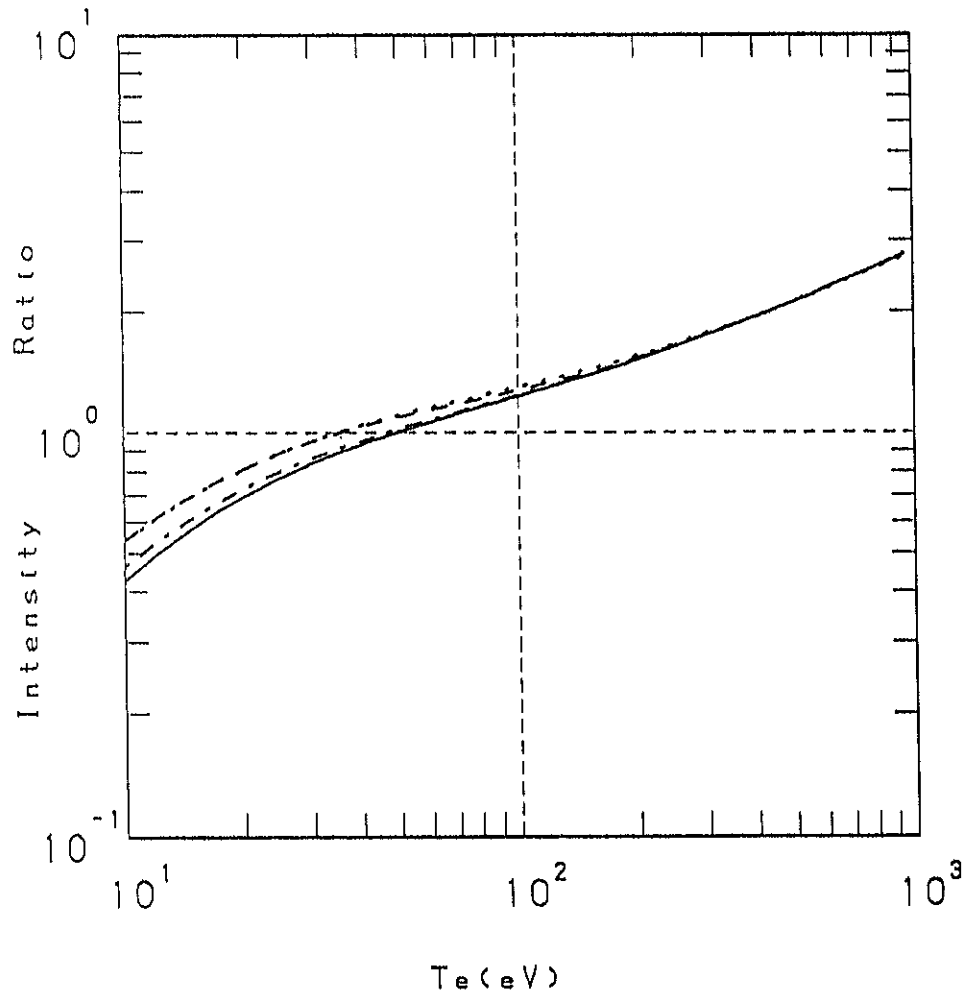
Ordinate — Line intensity ratio for the lines indicated at the top of the graph. Wavelengths (in angstrom) refer to transitions as indicated in Fig. 1 and Table 2 in the text. In the case of transitions involving triplets, truncation of the decimal in the wavelength indicates that line intensities for multiplets are summed.

Abscissa — Electron temperature $T_e$(in eV), or the electron density, $n_e$( in $cm^{-3}$).

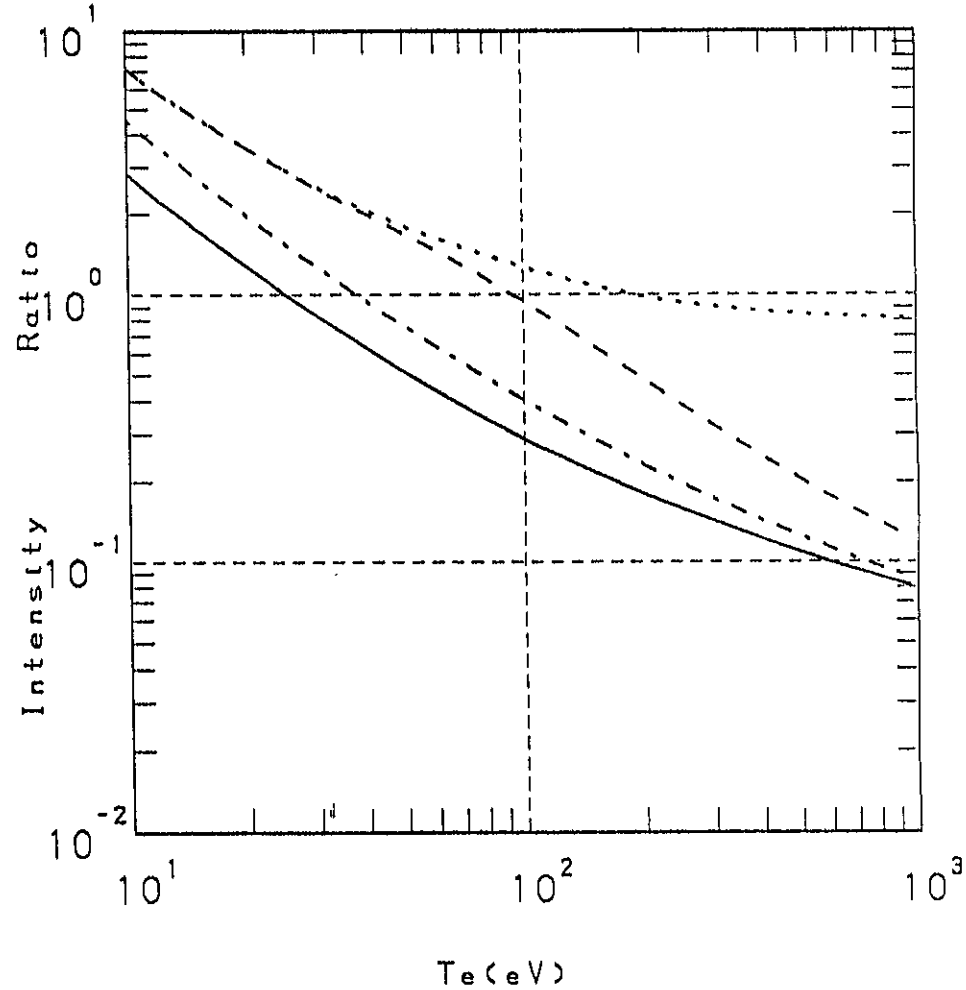
Figure I


I(172) / I(630)
Intensity Ratio
$10^{-1}$
$10^{-2}$
$10^{-3}$
$10^{1}$
$10^{2}$
$10^{3}$
Te(eV)
I(193) / I(760)
Intensity Ratio
$10^{0}$
$10^{-1}$
$10^{-2}$
$10^{1}$
$10^{2}$
$10^{3}$
Te(eV)

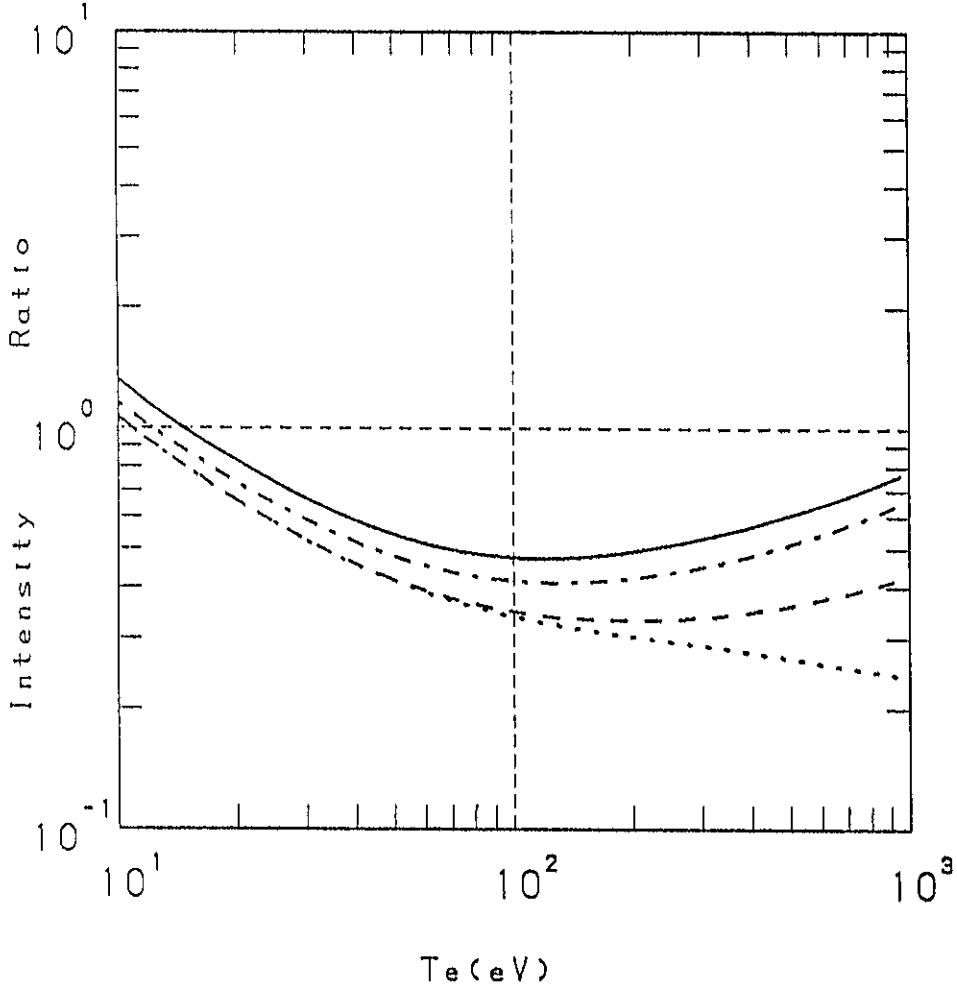
I(220) / I(248)




I(215) / I(220)



I(215) / I(193)




I(193) / I(220)

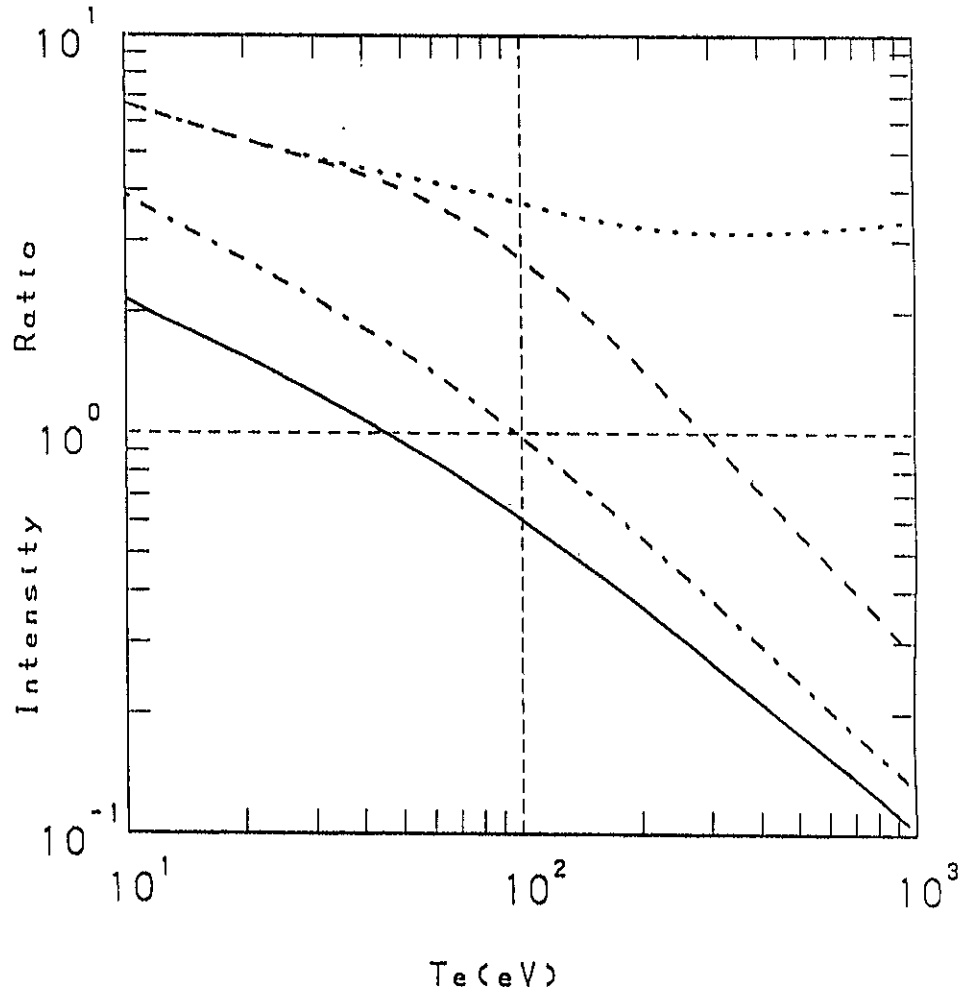
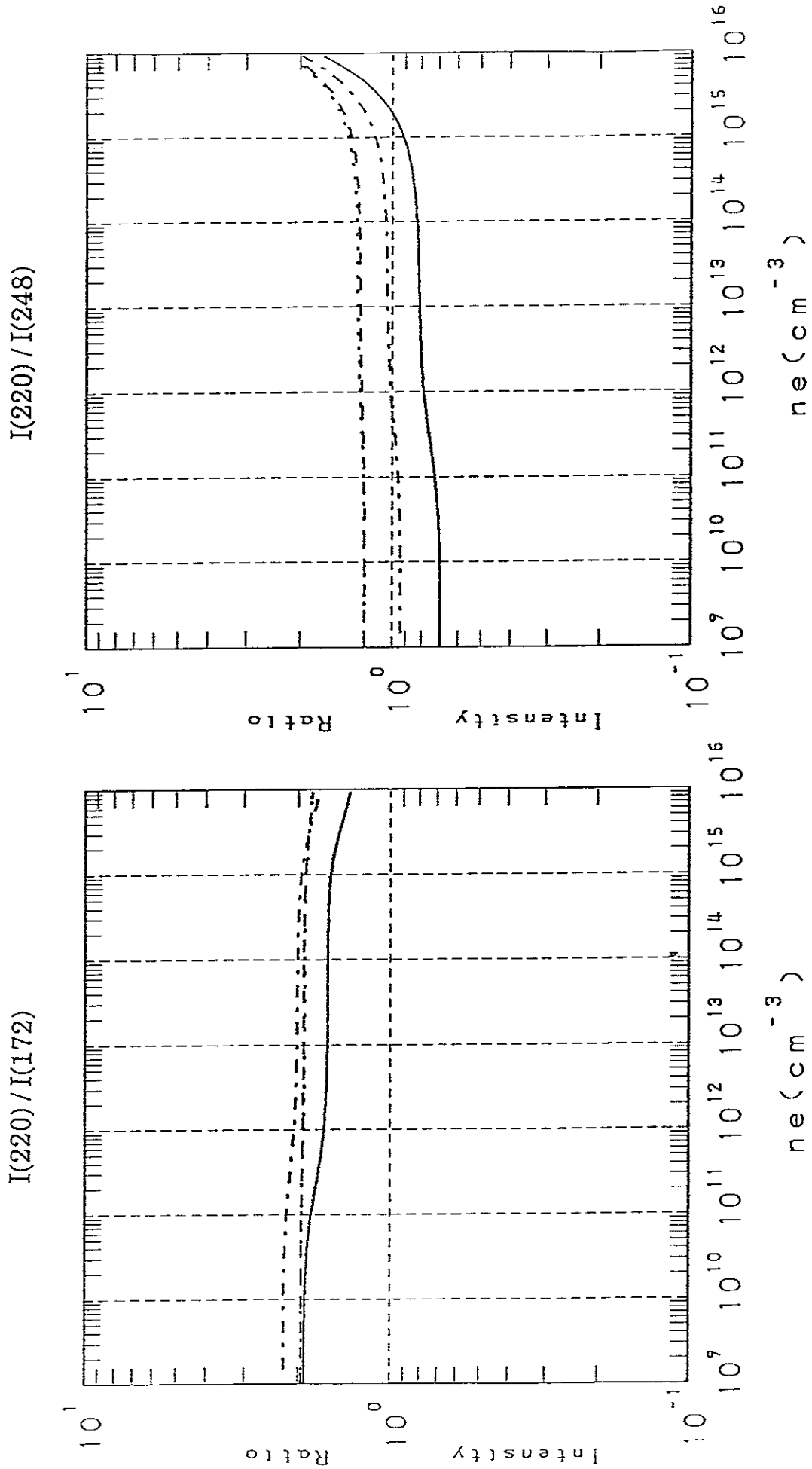
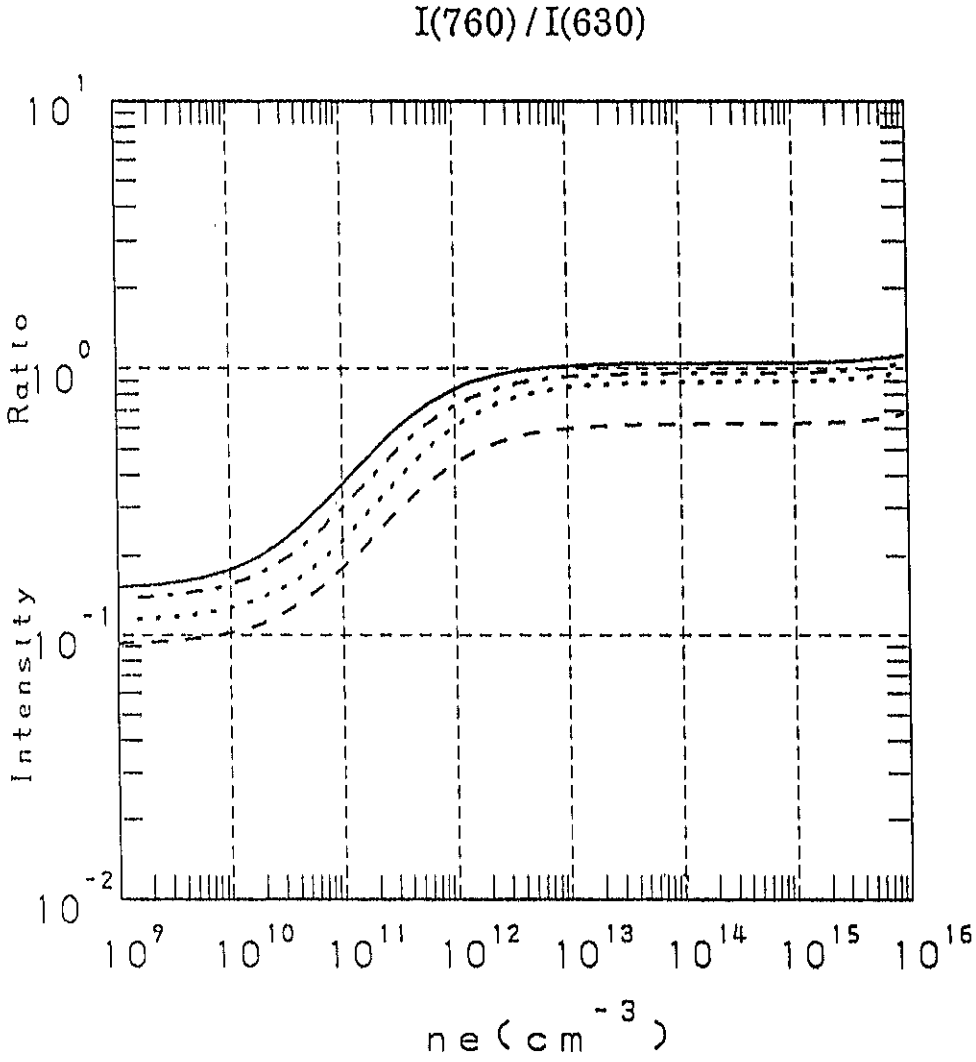
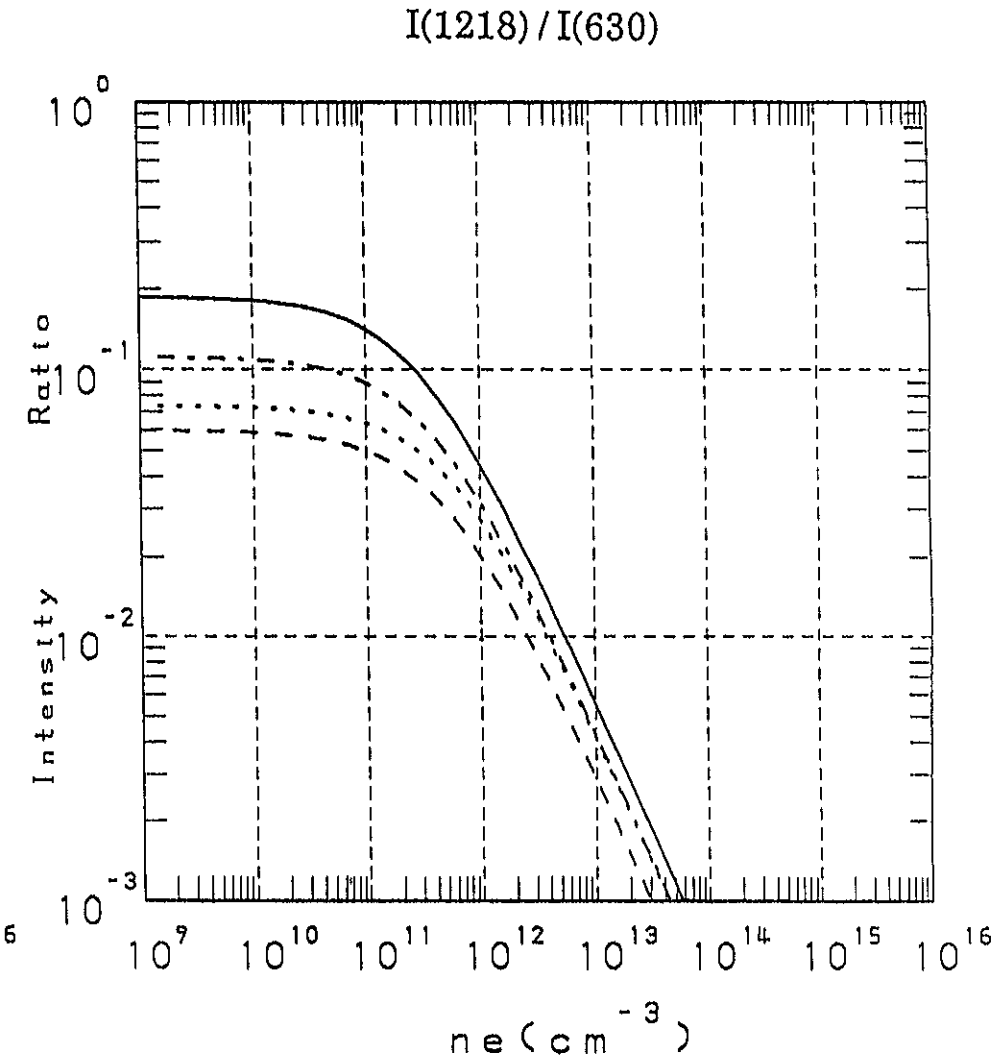
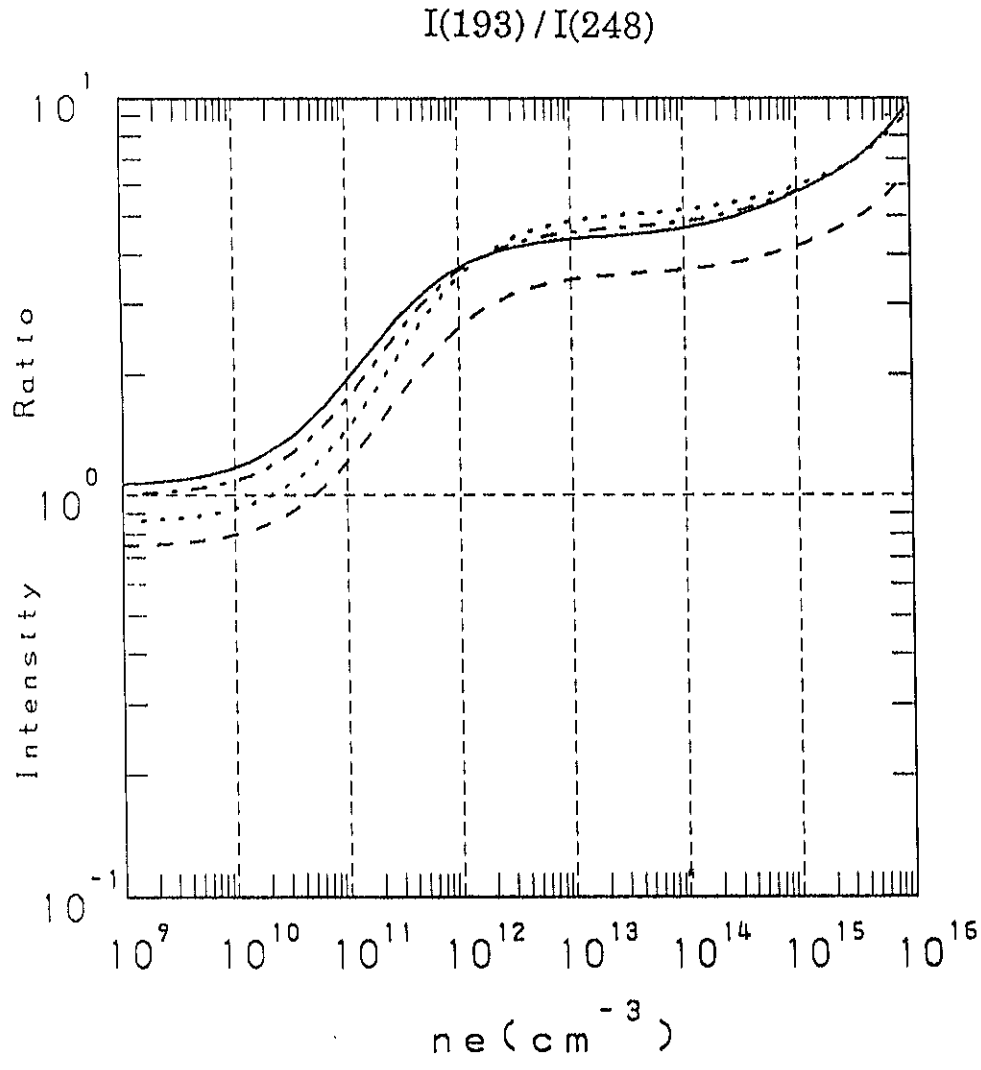


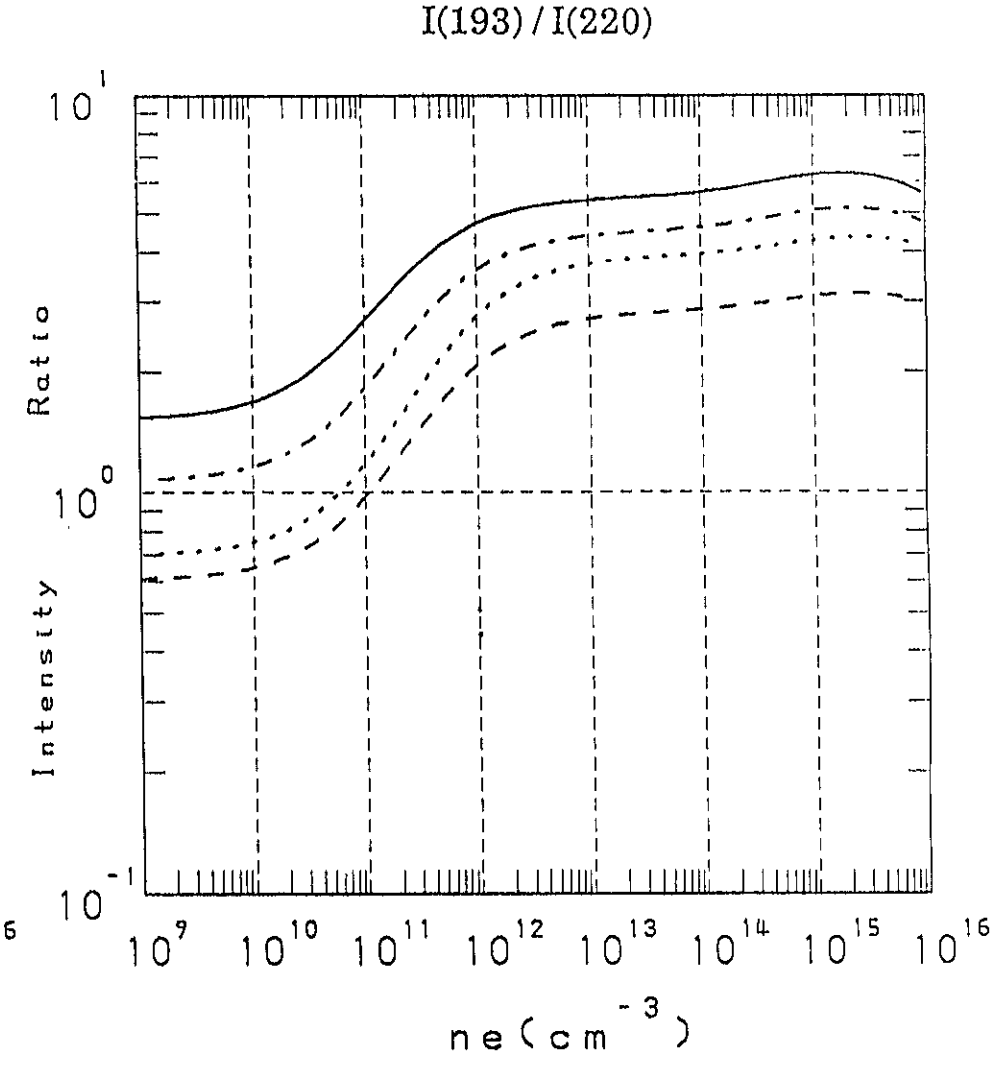
Figure II


I(220) / I(248)
Ratio
Intensity
ne(cm$^{-3}$)
I(220) / I(172)
Ratio
Intensity
ne(cm$^{-3}$)

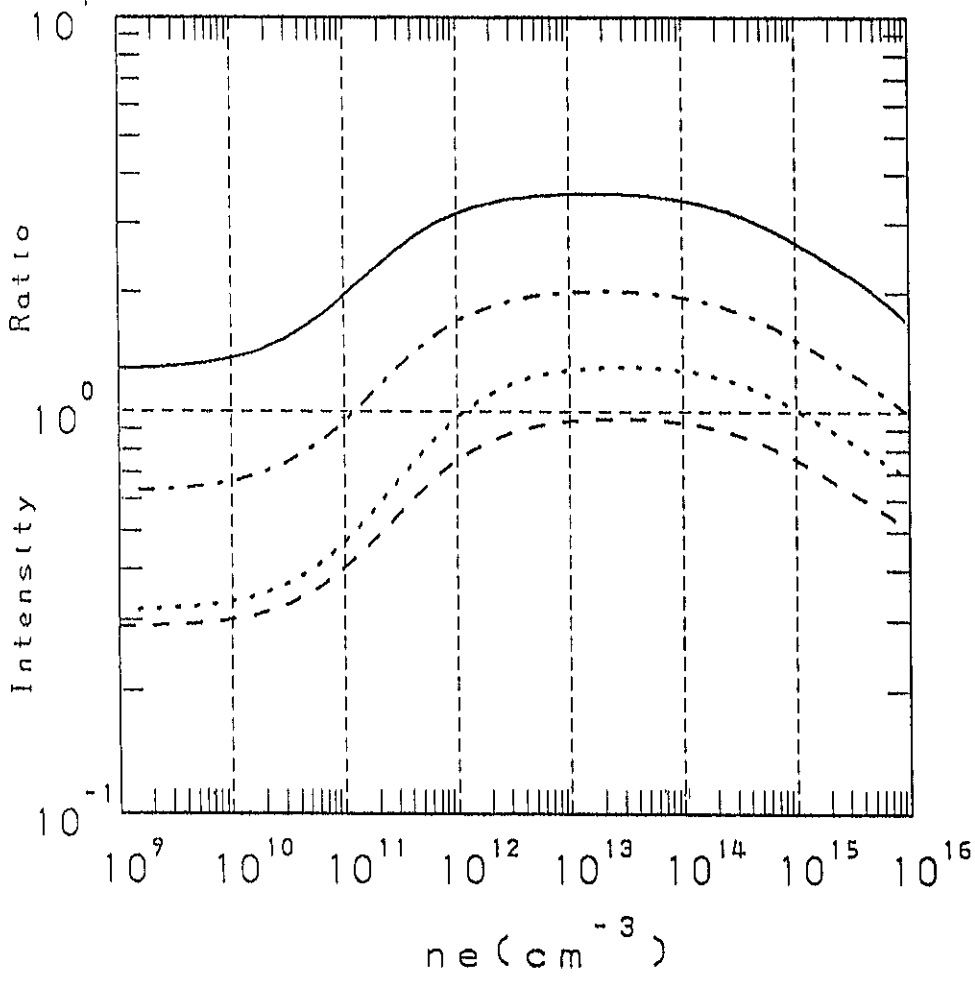

I(760) / I(630)
Intensity Ratio
$10^{1}$
$10^{0}$
$10^{-1}$
$10^{-2}$
$10^{9}$ $10^{10}$ $10^{11}$ $10^{12}$ $10^{13}$ $10^{14}$ $10^{15}$ $10^{16}$
ne(cm$^{-3}$)


I(1218) / I(630)
Intensity Ratio
$10^{0}$
$10^{-1}$
$10^{-2}$
$10^{-3}$
$10^{9}$ $10^{10}$ $10^{11}$ $10^{12}$ $10^{13}$ $10^{14}$ $10^{15}$ $10^{16}$
ne(cm$^{-3}$)

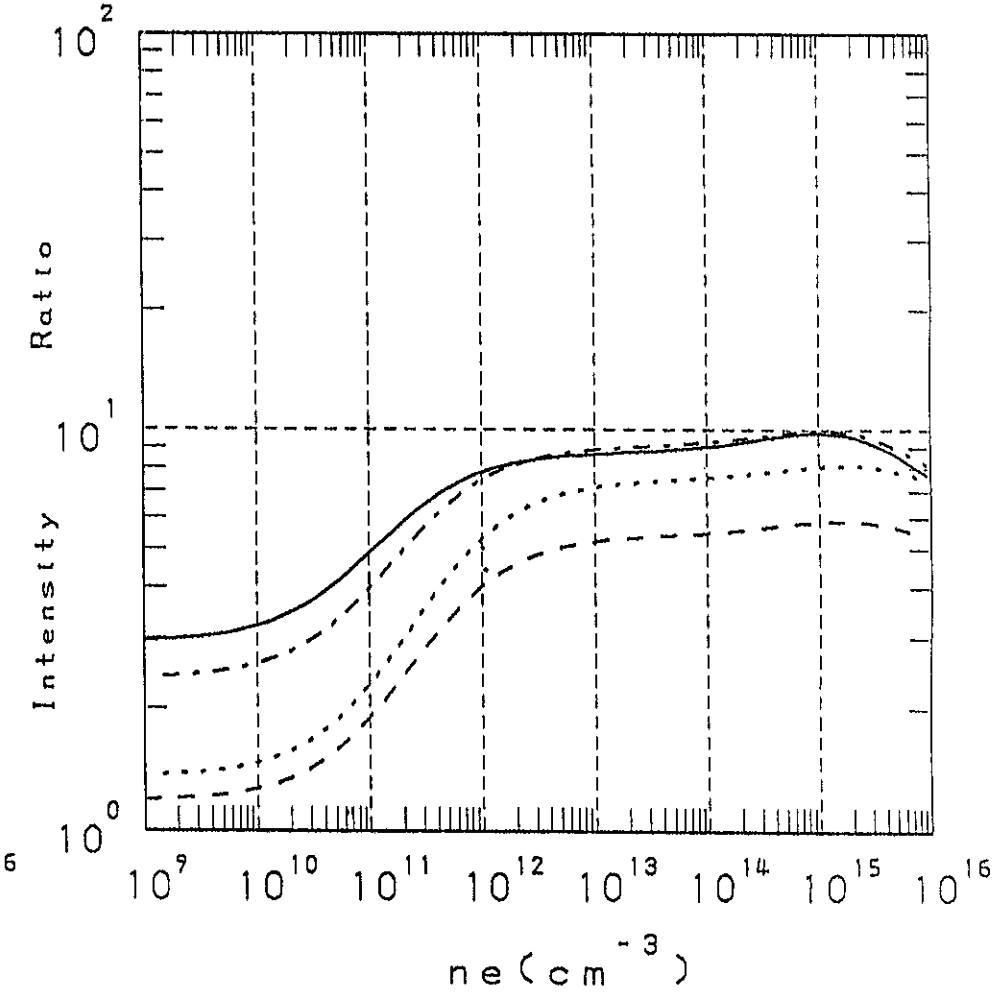

I(193) / I(248)
Intensity Ratio
$10^{1}$
$10^{0}$
$10^{-1}$
$10^{9}$ $10^{10}$ $10^{11}$ $10^{12}$ $10^{13}$ $10^{14}$ $10^{15}$ $10^{16}$
ne(cm$^{-3}$)

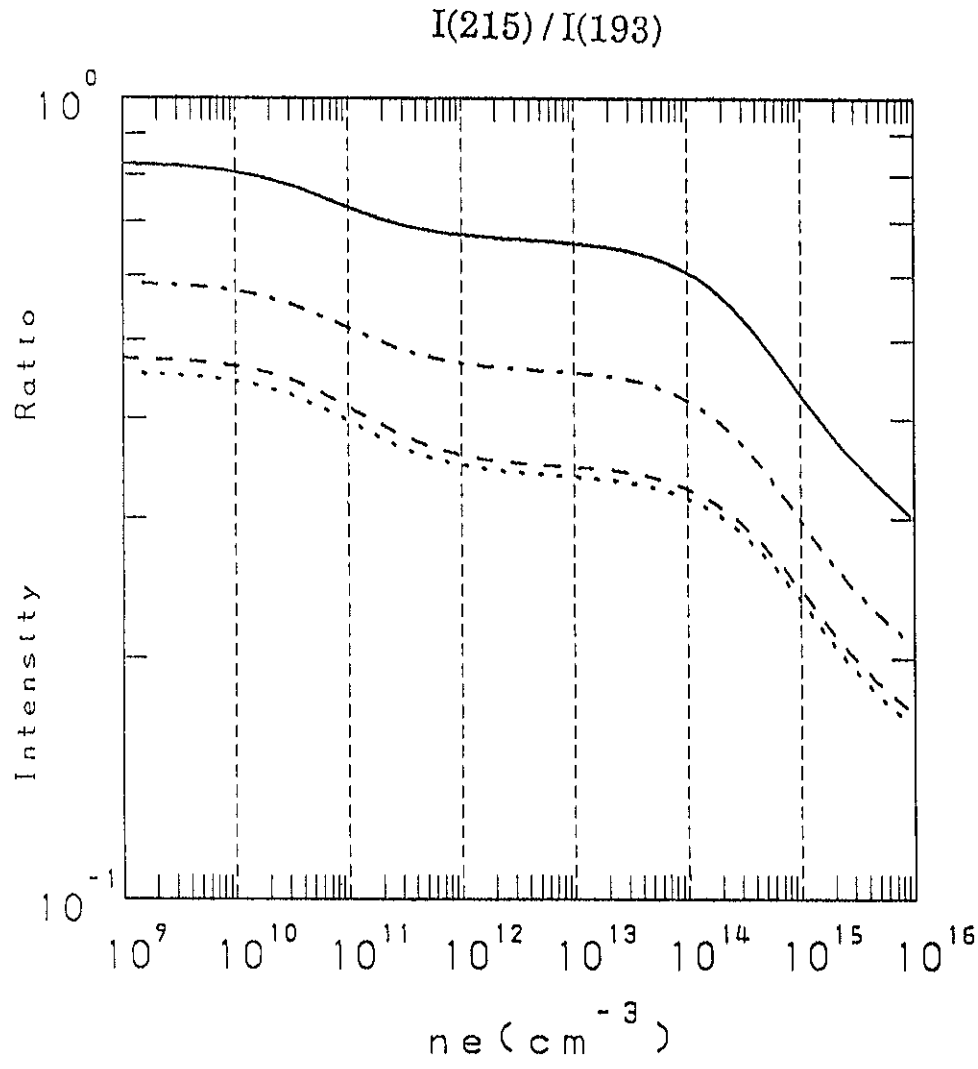

I(193) / I(220)
Intensity Ratio
$10^{1}$
$10^{0}$
$10^{-1}$
$10^{9}$ $10^{10}$ $10^{11}$ $10^{12}$ $10^{13}$ $10^{14}$ $10^{15}$ $10^{16}$
ne(cm$^{-3}$)

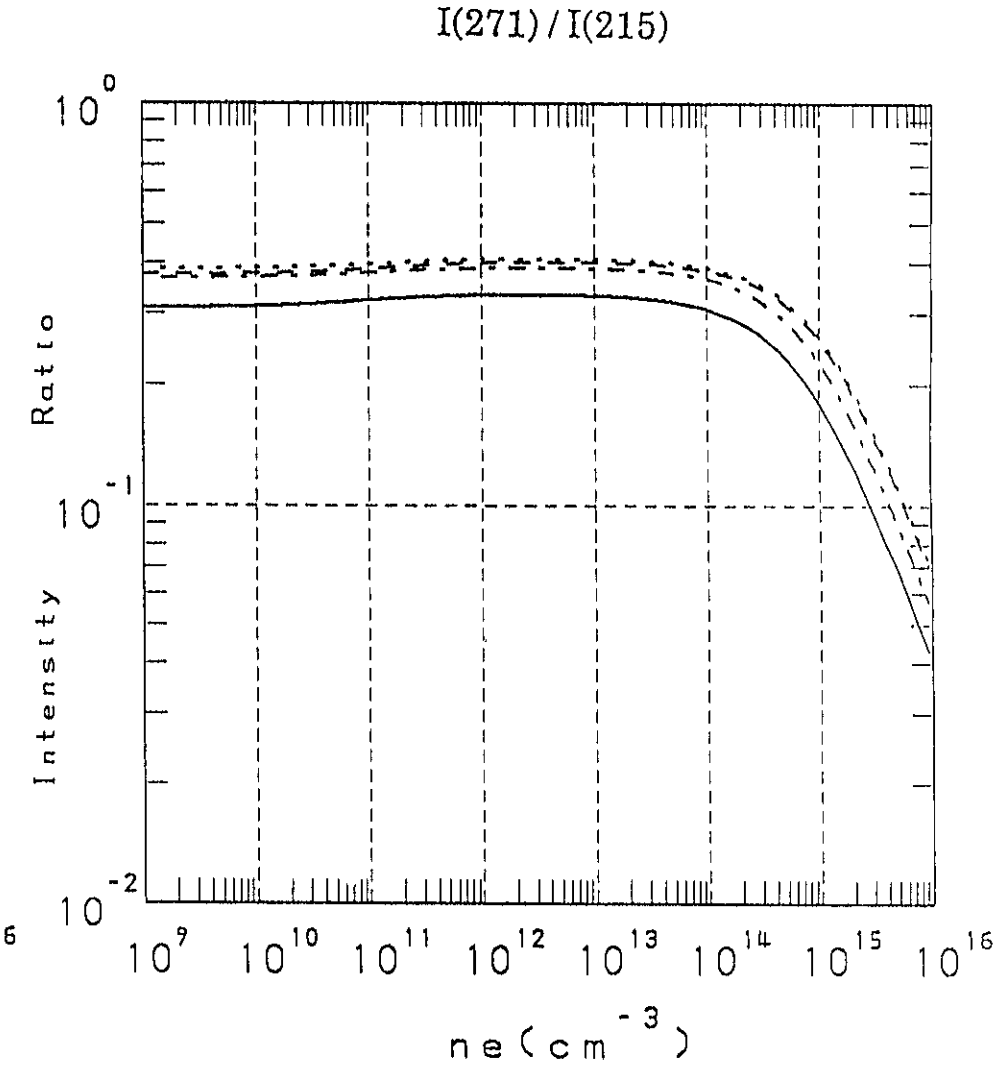
I(215) / I(220)

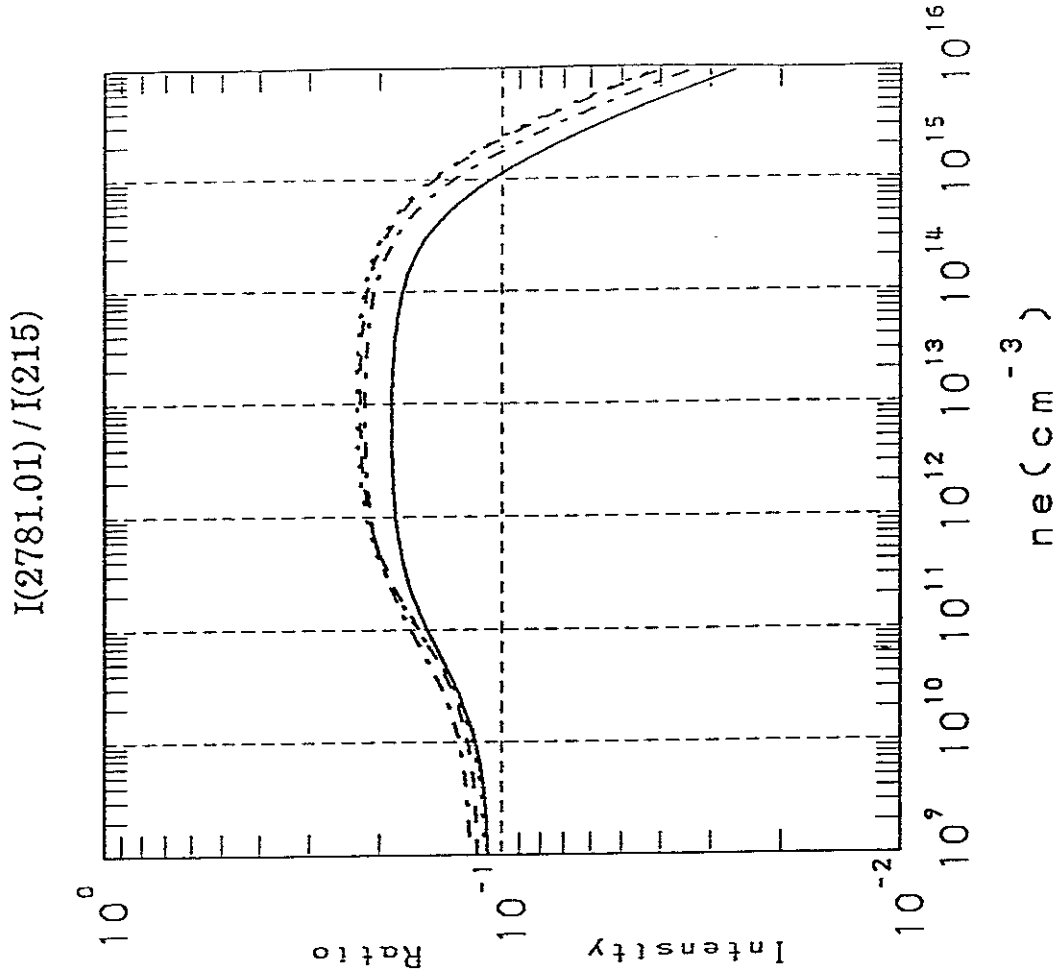


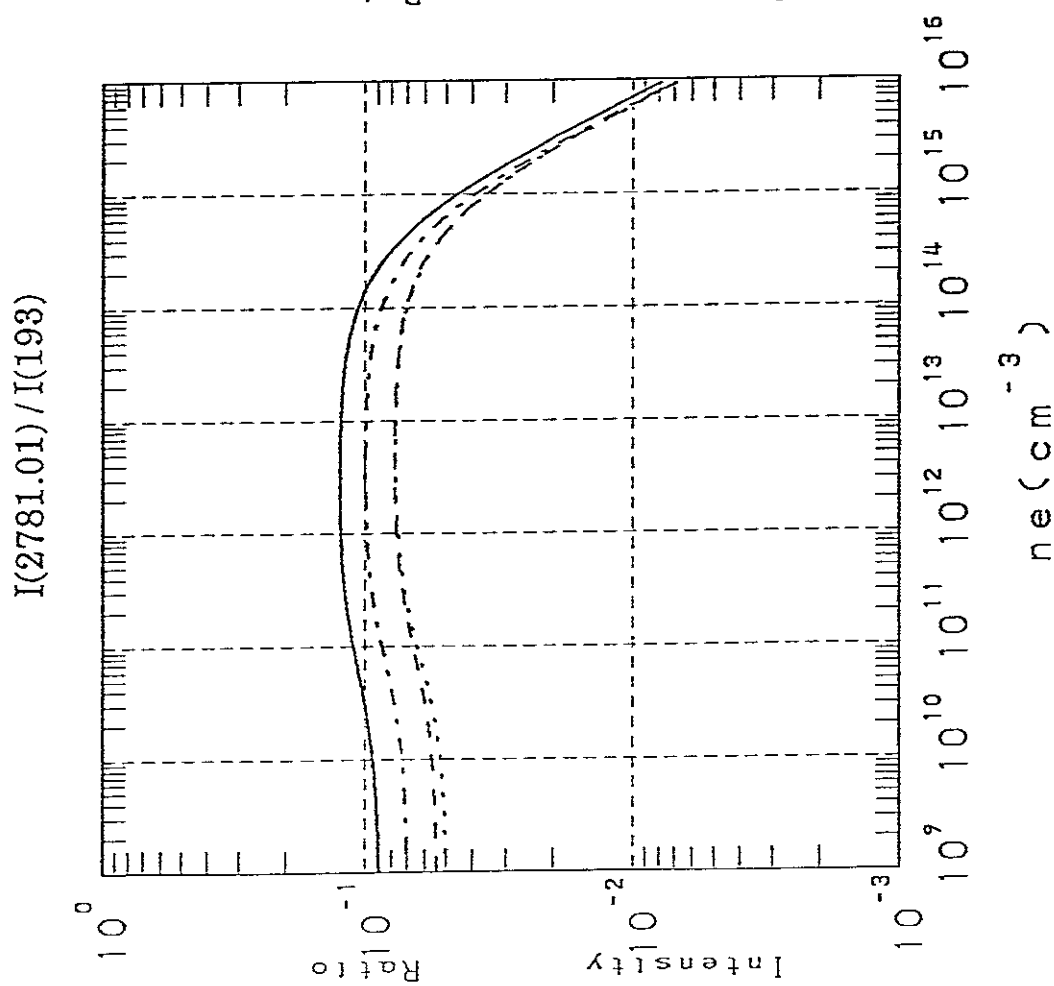

I(193) / I(172)




I(215) / I(193)
Intenstity Ratio
$10^{0}$
$10^{-1}$
$10^{9}$ $10^{10}$ $10^{11}$ $10^{12}$ $10^{13}$ $10^{14}$ $10^{15}$ $10^{16}$
ne(cm$^{-3}$)


I(271) / I(215)
Intenstity Ratio
$10^{0}$
$10^{-1}$
$10^{-2}$
$10^{9}$ $10^{10}$ $10^{11}$ $10^{12}$ $10^{13}$ $10^{14}$ $10^{15}$ $10^{16}$
ne(cm$^{-3}$)


I(2781.01) / I(215)
Ratio
Intensity
ne(cm$^{-3}$)


I(2781.01) / I(193)
Ratio
Intensity
ne(cm$^{-3}$)

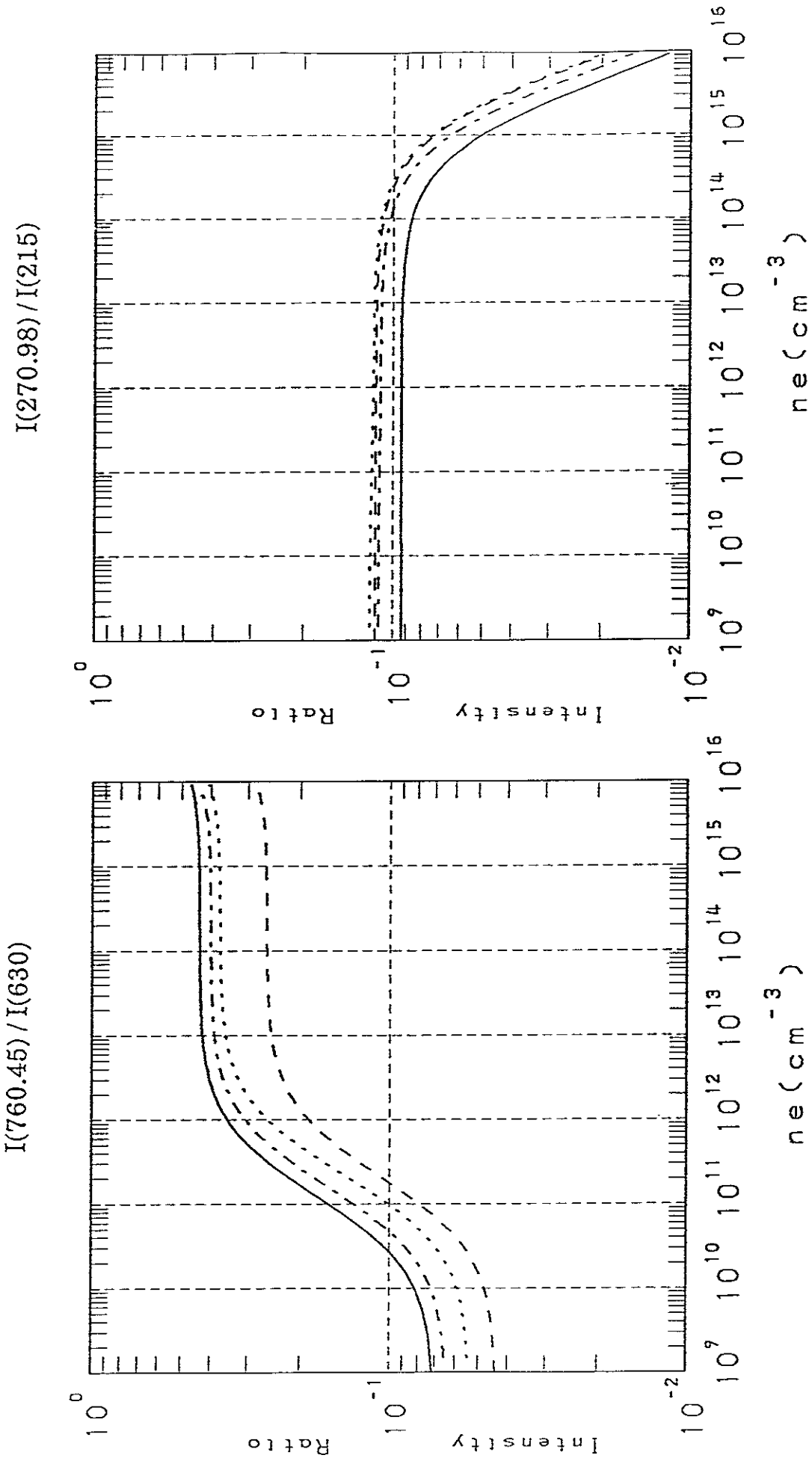
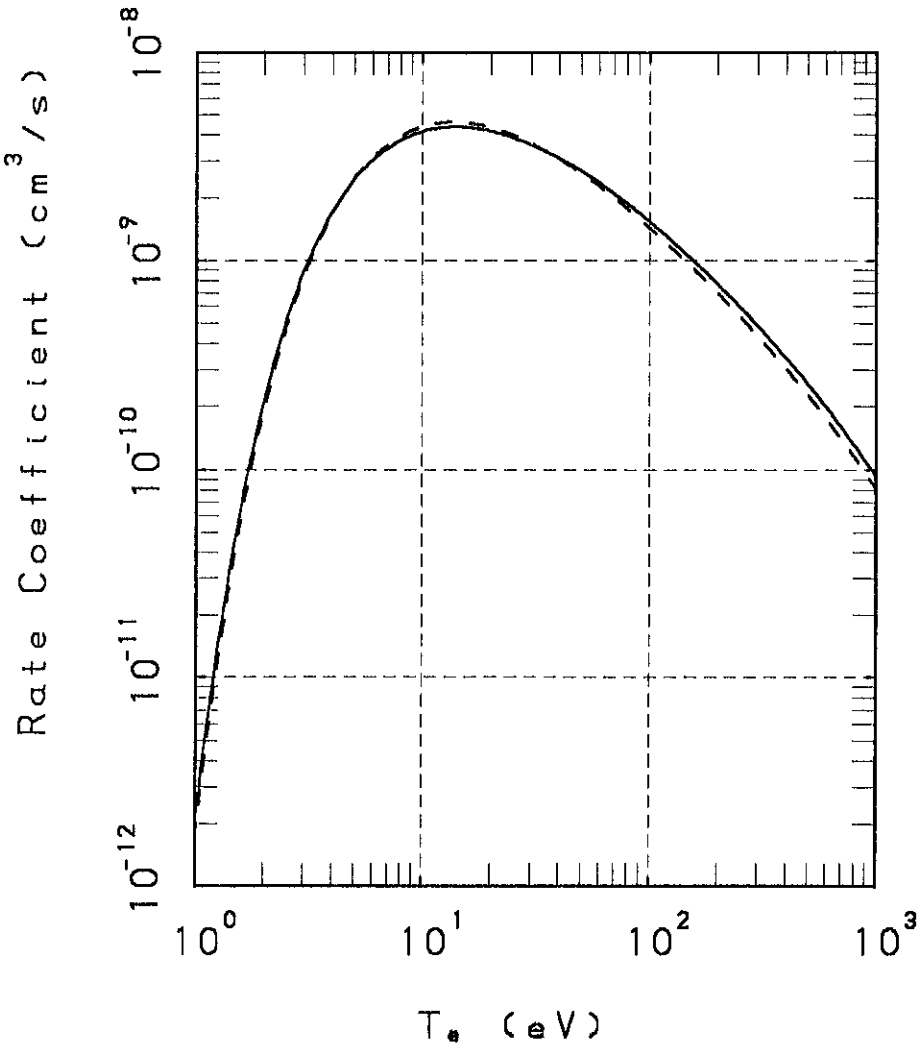
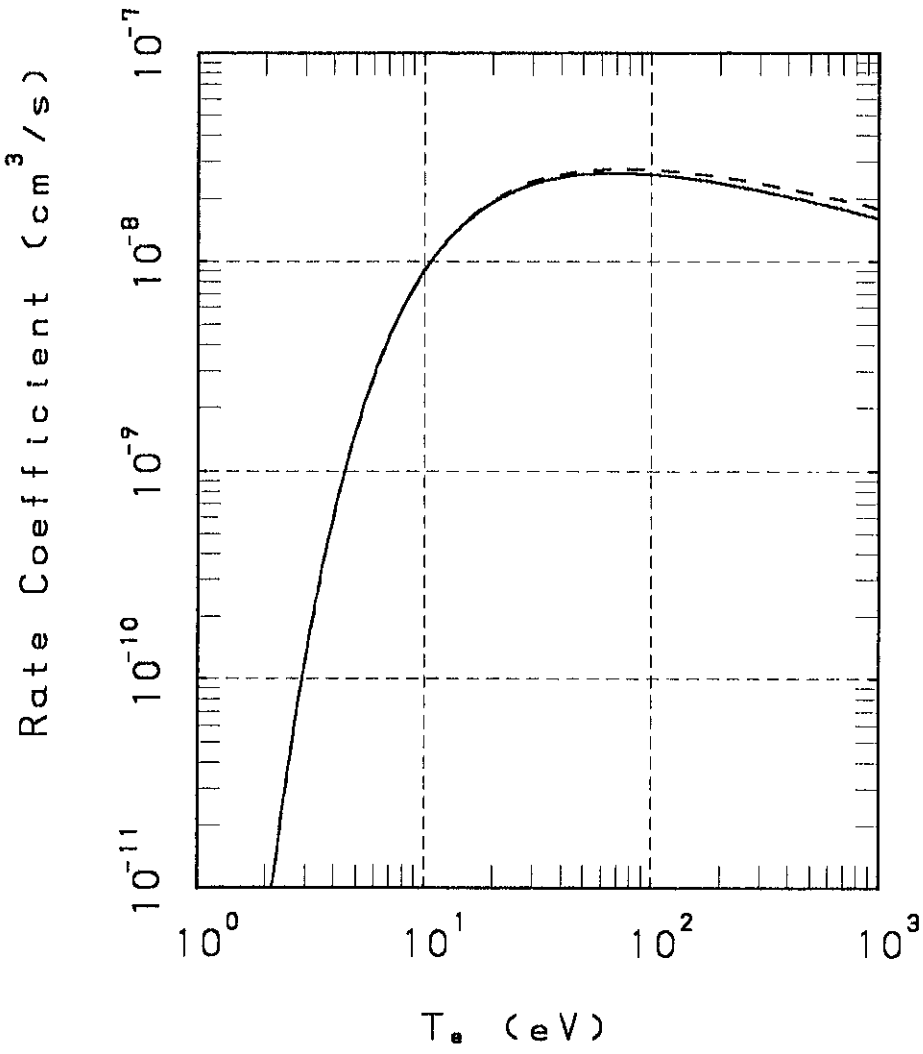
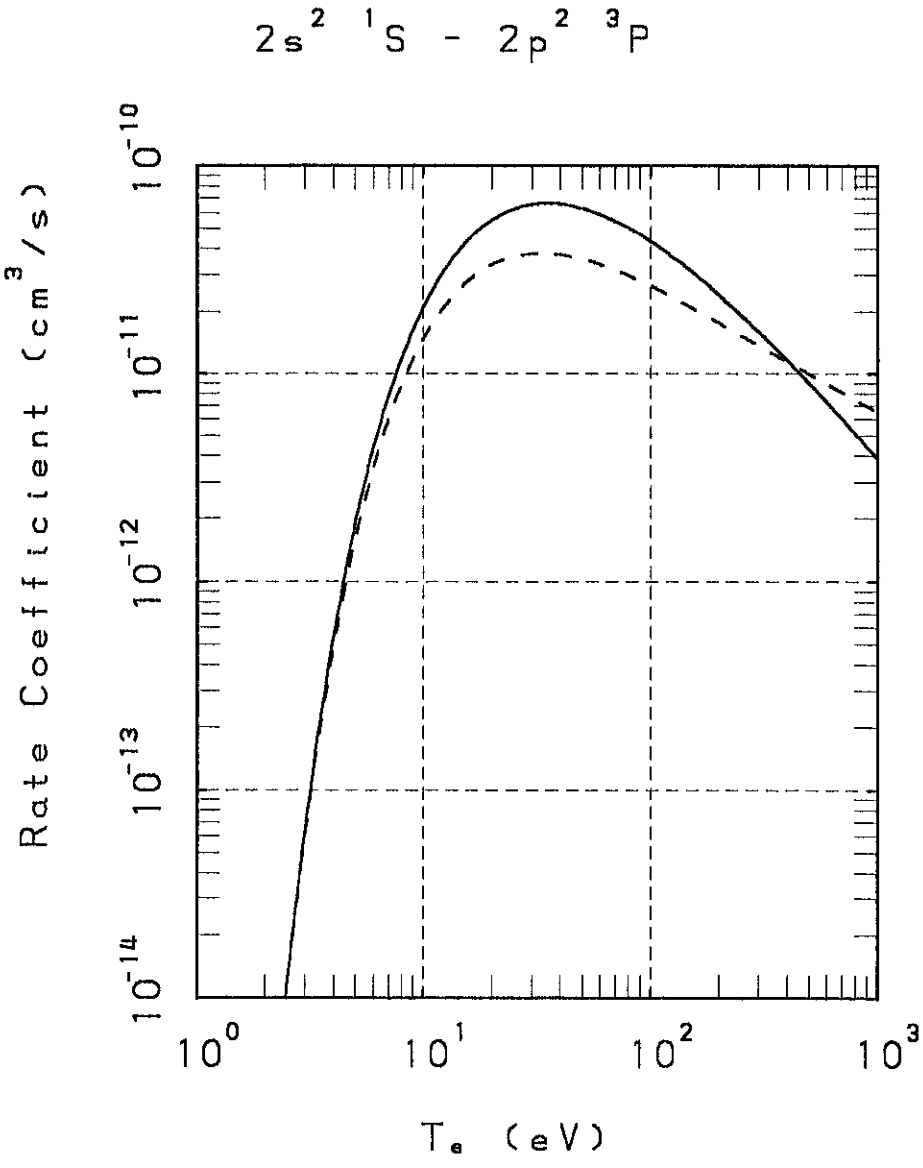

I(270.98) / I(215)
Ratio
Intensity
ne(cm$^{-3}$)
$10^{0}$
$10^{-1}$
$10^{-2}$
$10^{9}$ $10^{10}$ $10^{11}$ $10^{12}$ $10^{13}$ $10^{14}$ $10^{15}$ $10^{16}$
I(760.45) / I(630)
Ratio
Intensity
ne(cm$^{-3}$)
$10^{0}$
$10^{-1}$
$10^{-2}$
$10^{9}$ $10^{10}$ $10^{11}$ $10^{12}$ $10^{13}$ $10^{14}$ $10^{15}$ $10^{16}$

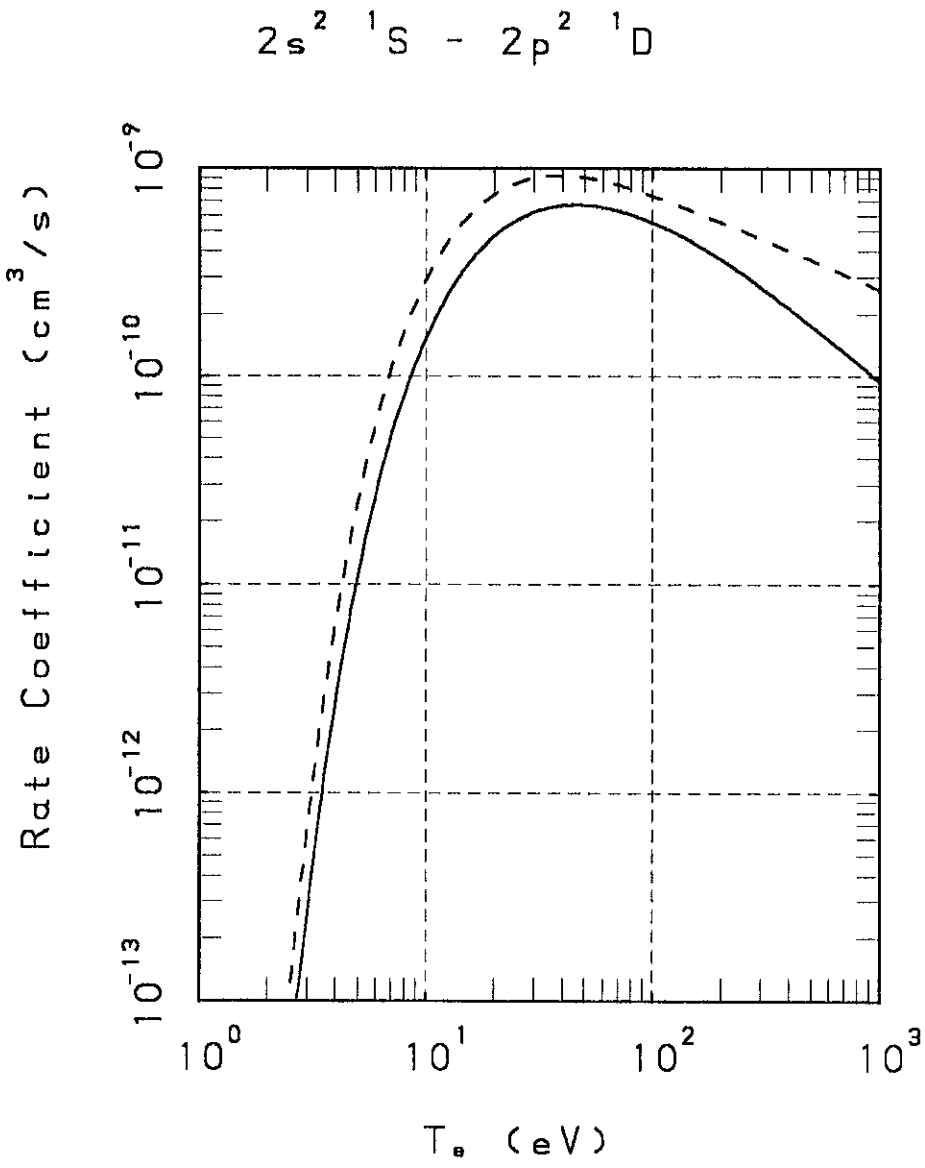
Figure III.Recommended Excitation Rate Coefficients

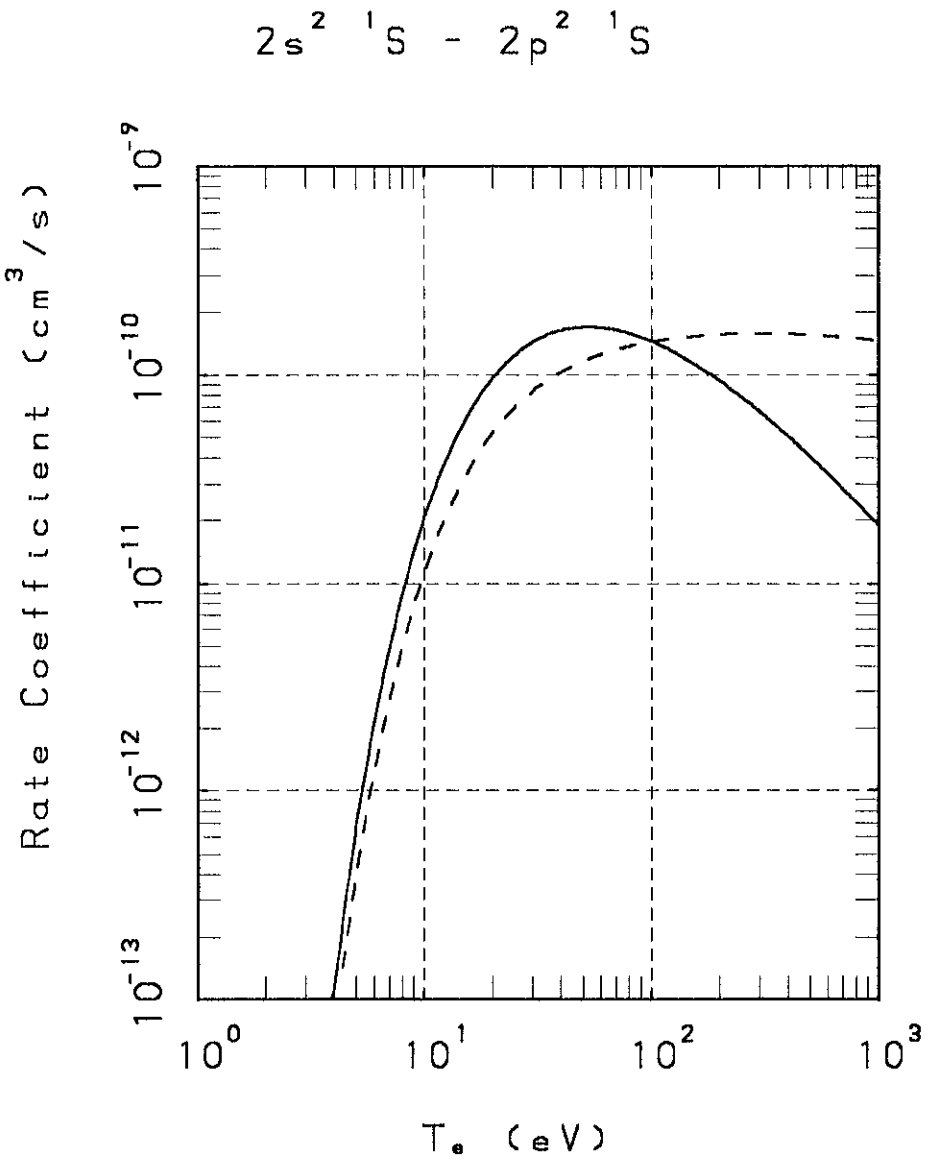
Excitation rate coefficients ($cm^3 s^{-1}$) are plotted against electron temperature $T_e$(eV). Transitions between energy terms are shown first, followed by transitions between the triplet fine structure levels. Dashed lines indicate values from Ref. 17. The initial and final states are given at the top of each figure using the same notation as that in Table I.

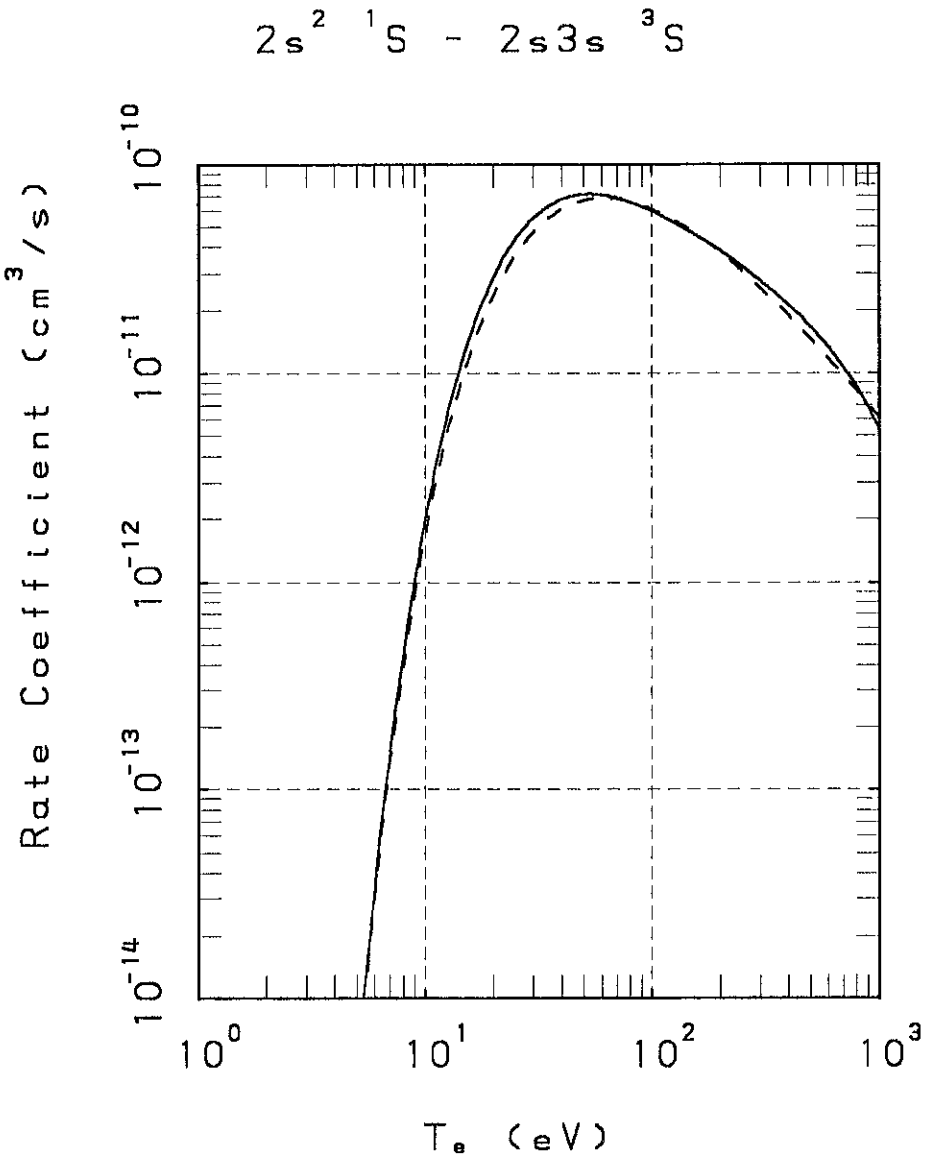

$2s^2\ ^1S - 2s2p\ ^3P$
Rate Coefficient (cm$^3$/s)
$10^{-8}$
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

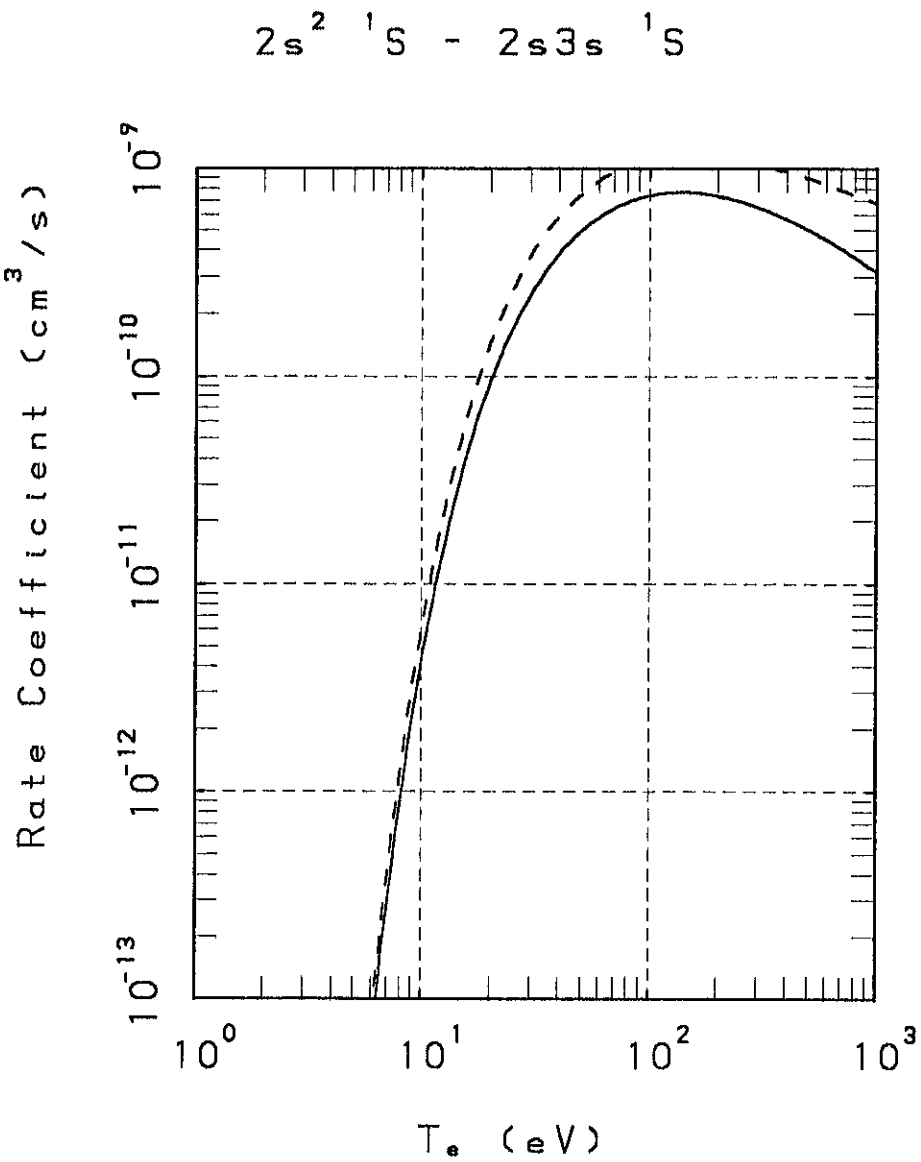

$2s^2\ ^1S - 2s2p\ ^1P$
Rate Coefficient (cm$^3$/s)
$10^{-7}$
$10^{-8}$
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

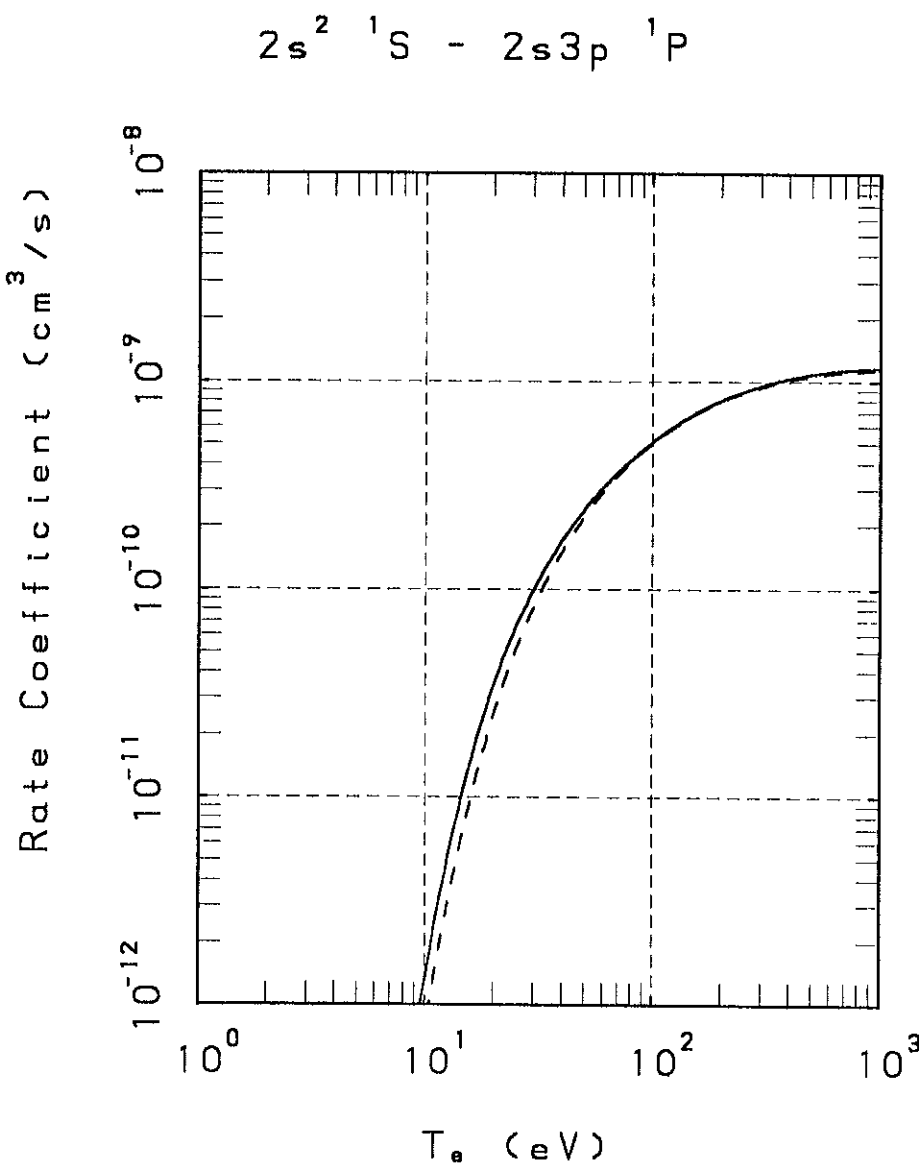

$2s^2\ ^1S - 2p^2\ ^3P$
Rate Coefficient ($cm^3/s$)
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^{-14}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

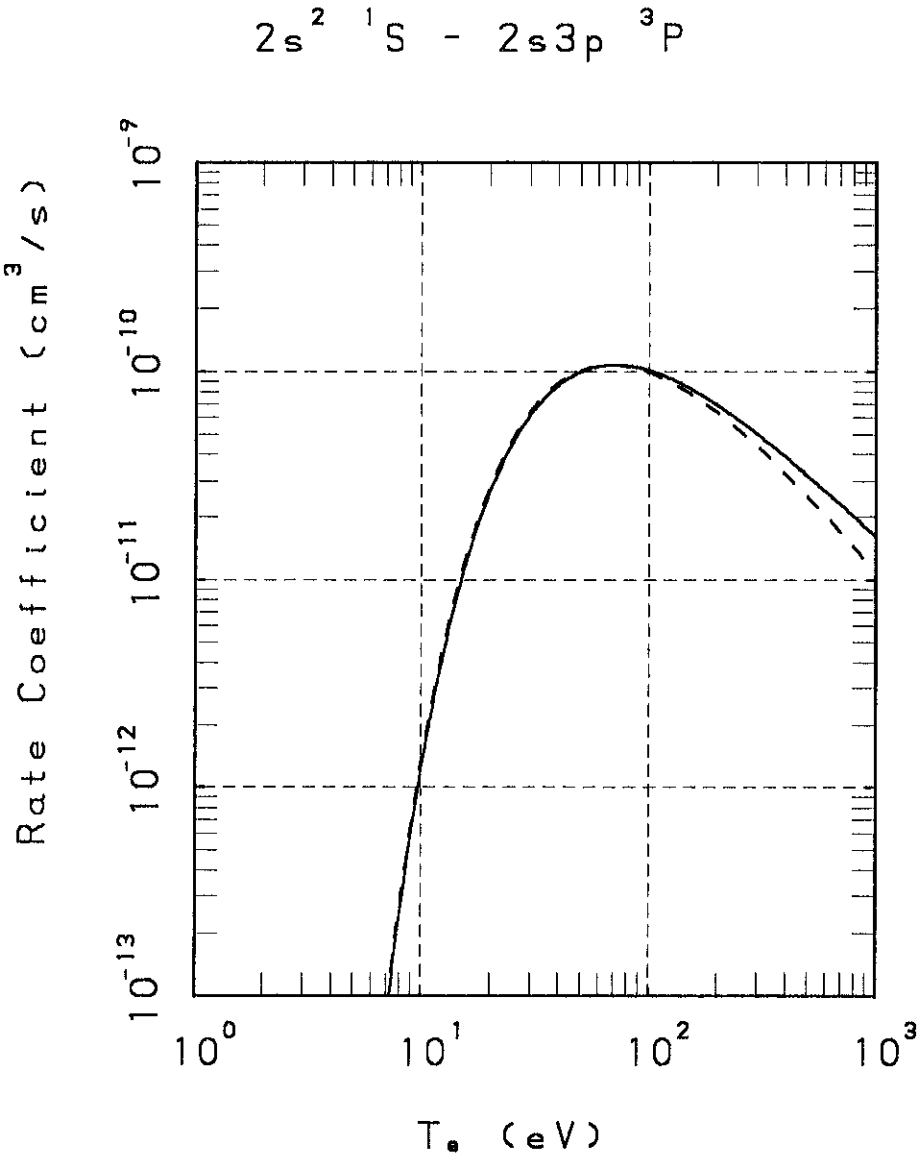

$2s^2\ ^1S - 2p^2\ ^1D$
Rate Coefficient ($cm^3/s$)
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

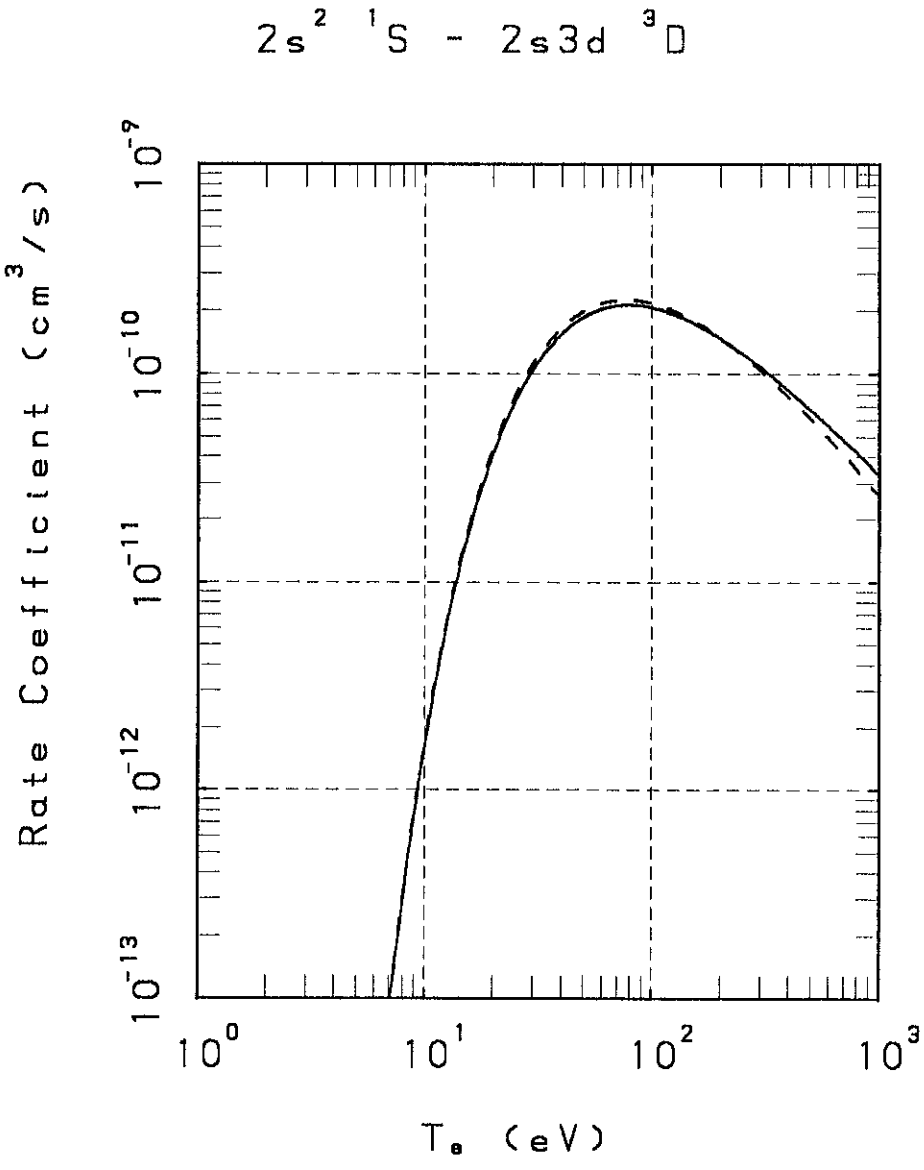

$2s^2\ ^1S - 2p^2\ ^1S$
Rate Coefficient ($cm^3/s$)
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

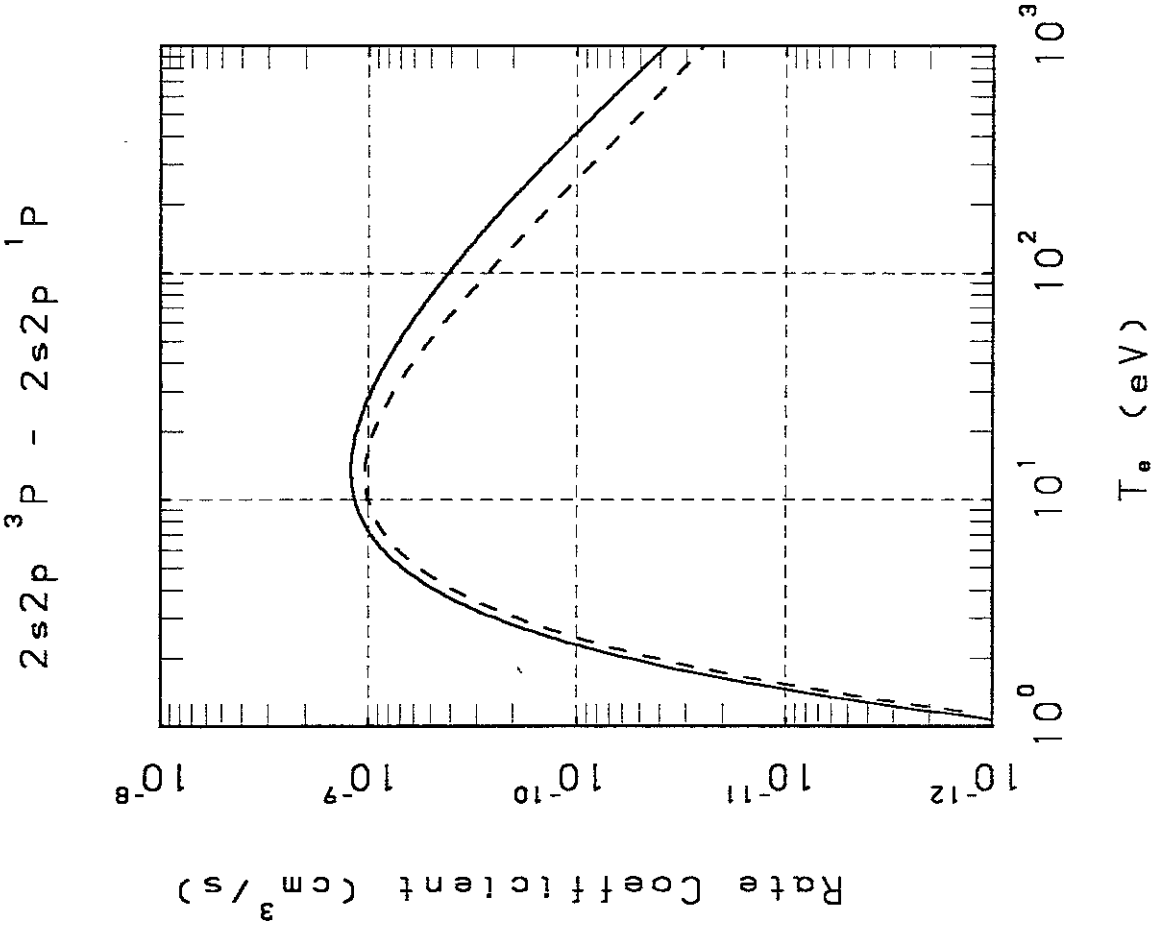

$2s^2\ ^1S - 2s3s\ ^3S$
Rate Coefficient ($cm^3/s$)
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^{-14}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

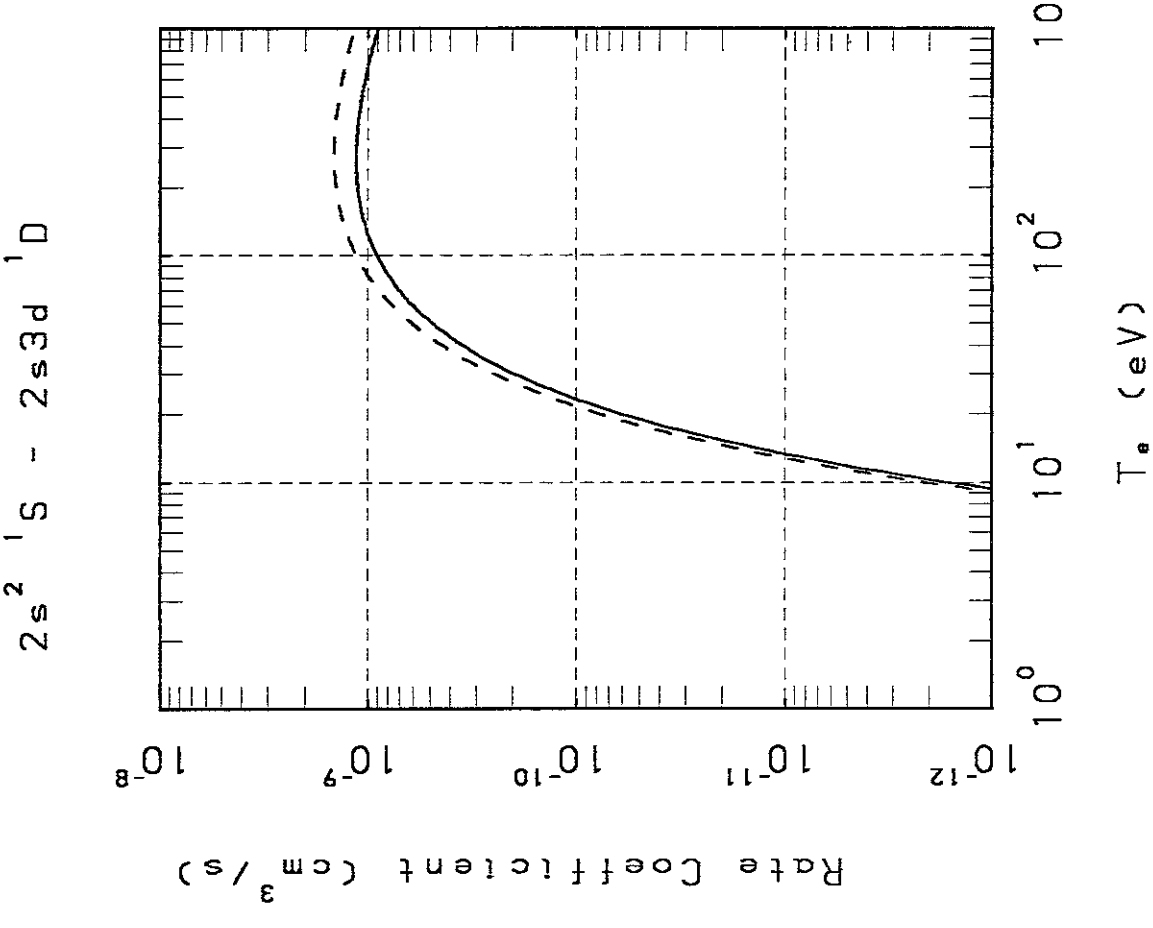

2s² ¹S - 2s3s ¹S
Rate Coefficient (cm³/s)
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁻¹³
10⁰
10¹
10²
10³
Tₑ (eV)

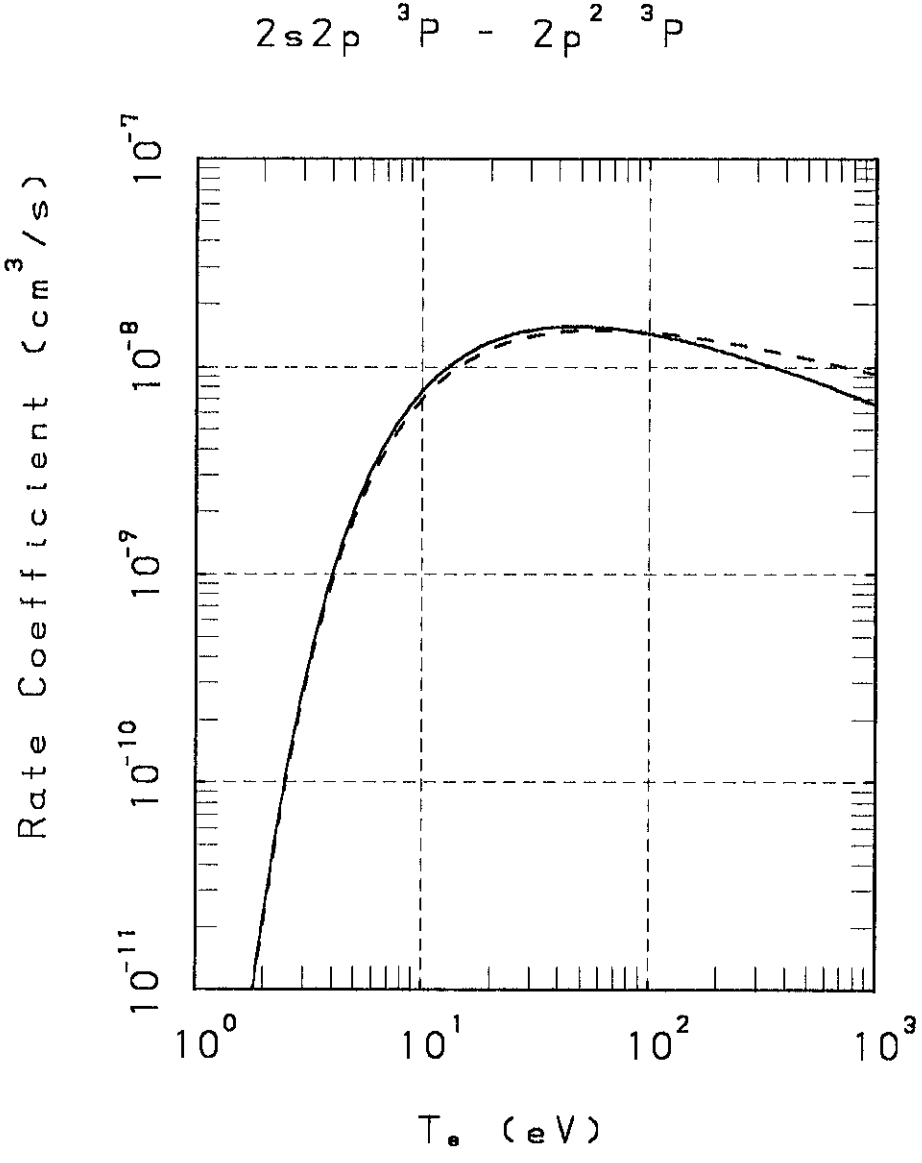

2s² ¹S - 2s3p ¹P
Rate Coefficient (cm³/s)
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁰
10¹
10²
10³
Tₑ (eV)

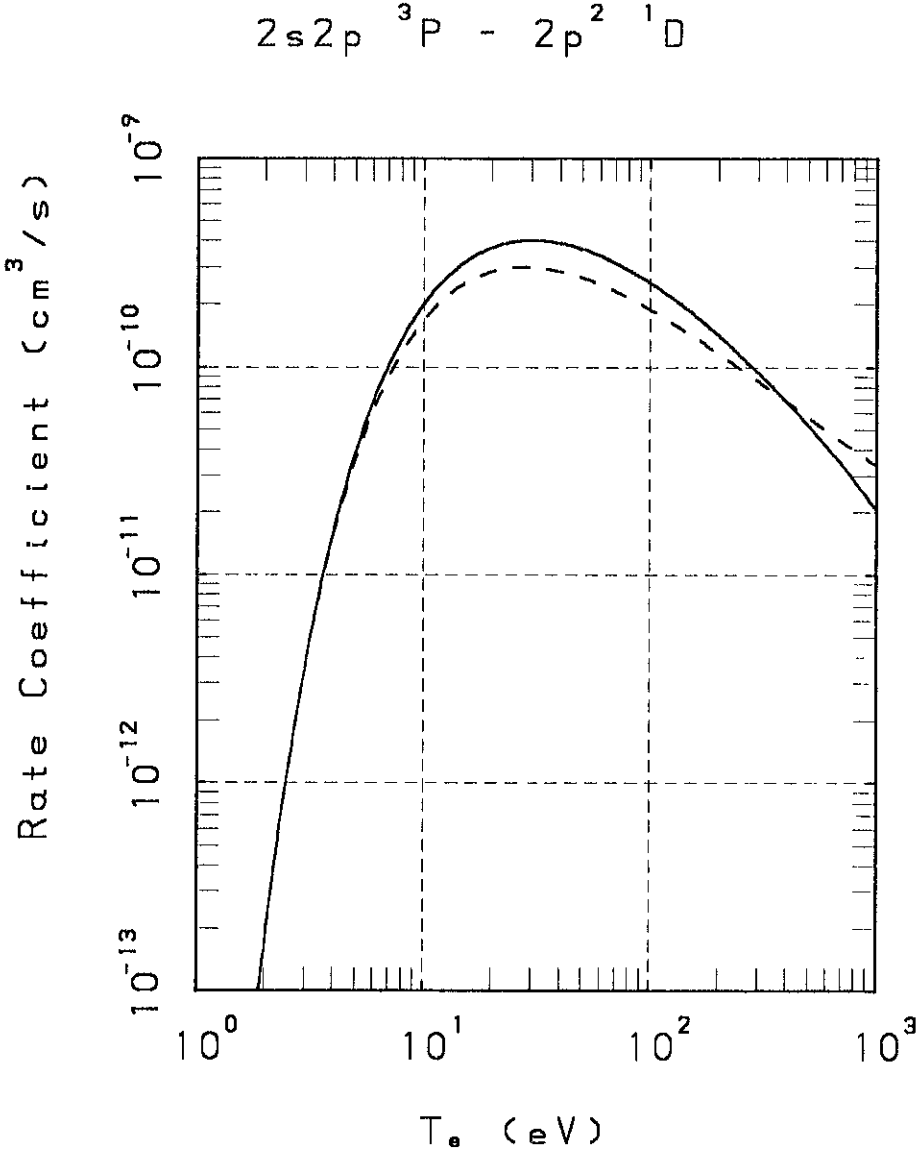

$2s^2\ ^1S - 2s3p\ ^3P$
Rate Coefficient ($cm^3/s$)
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

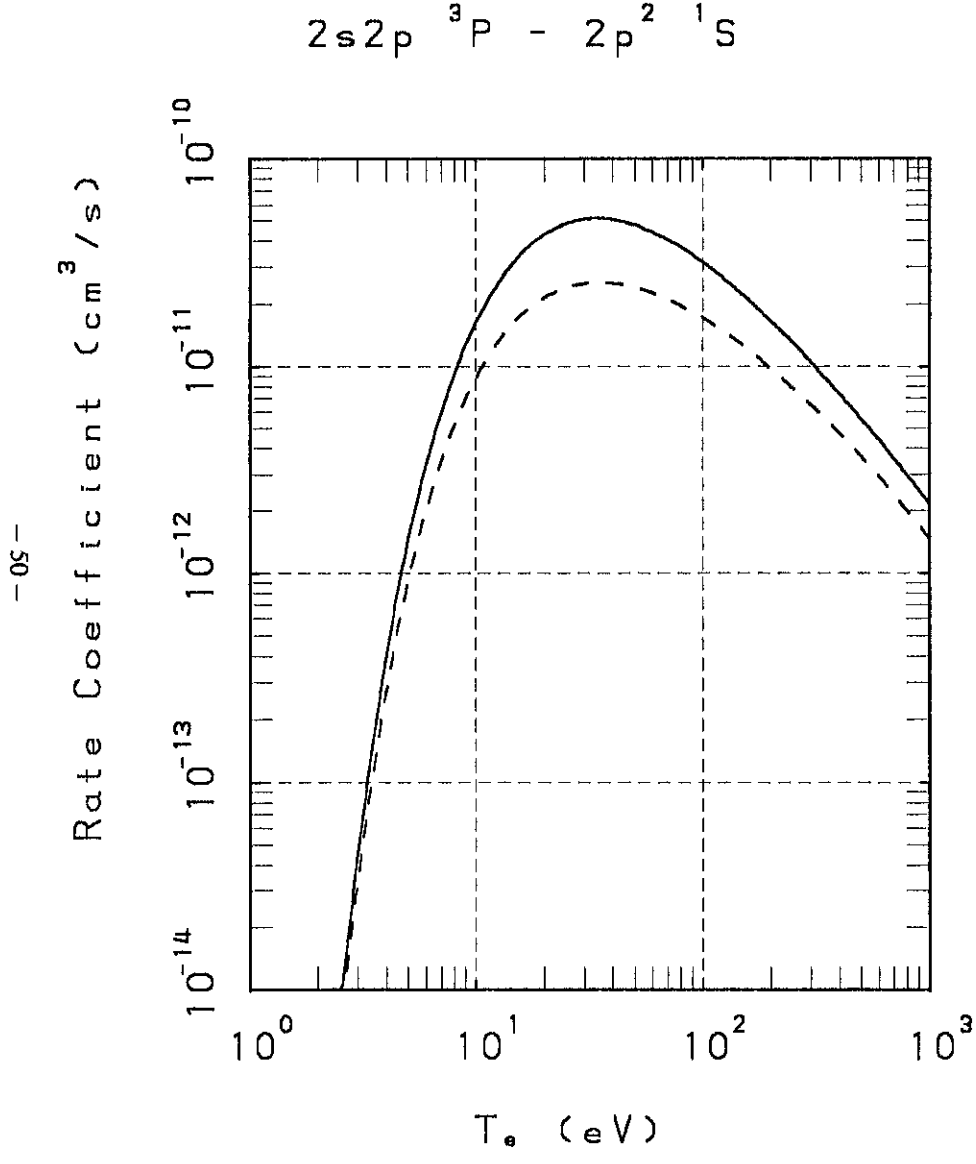

$2s^2\ ^1S - 2s3d\ ^3D$
Rate Coefficient ($cm^3/s$)
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

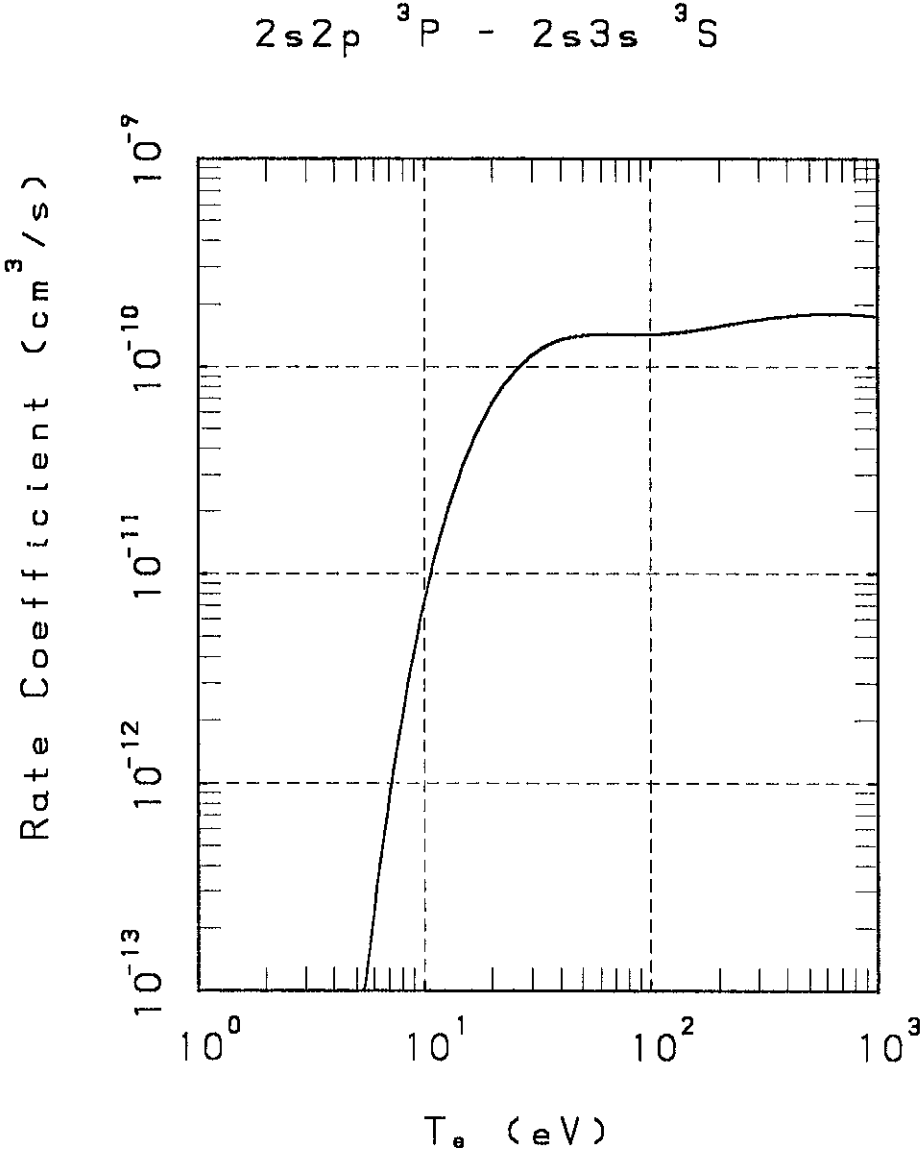

2s2p 3P - 2s2p 1P
Rate Coefficient (cm3/s)
10-8
10-9
10-10
10-11
10-12
Te (eV)
100
101
102
103

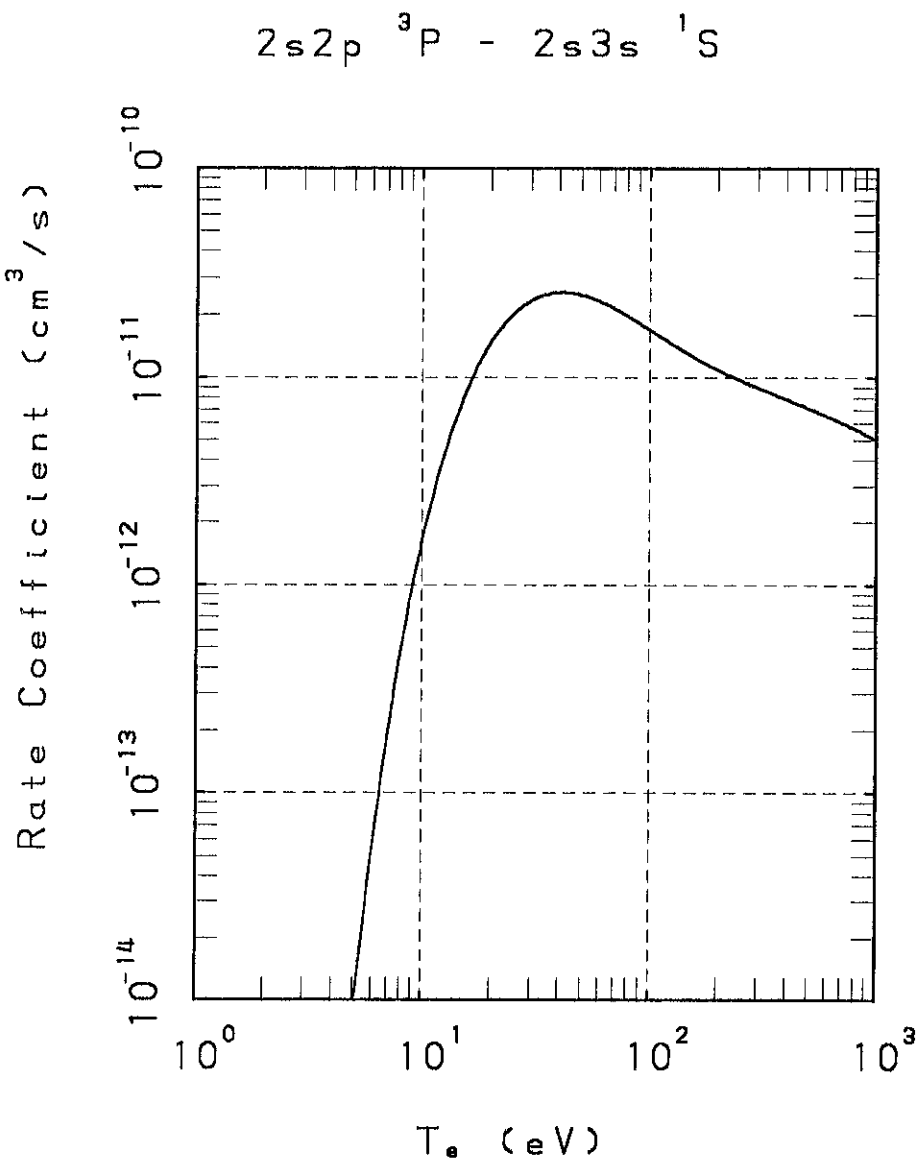

2s2 1S - 2s3d 1D
Rate Coefficient (cm3/s)
10-8
10-9
10-10
10-11
10-12
Te (eV)
100
101
102
103

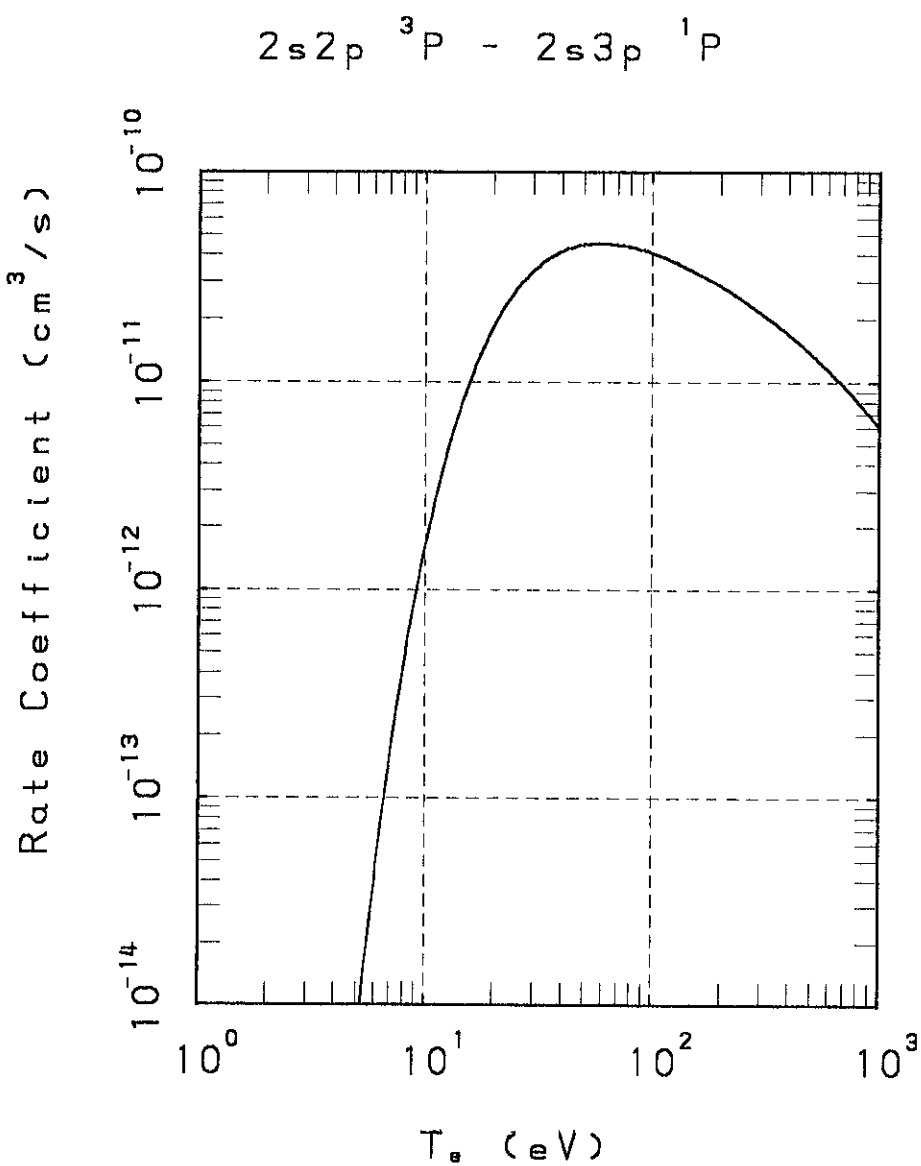

2s2p ³P - 2p² ³P
Rate Coefficient (cm³/s)
10⁻⁷
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁰
10¹
10²
10³
Tₑ (eV)

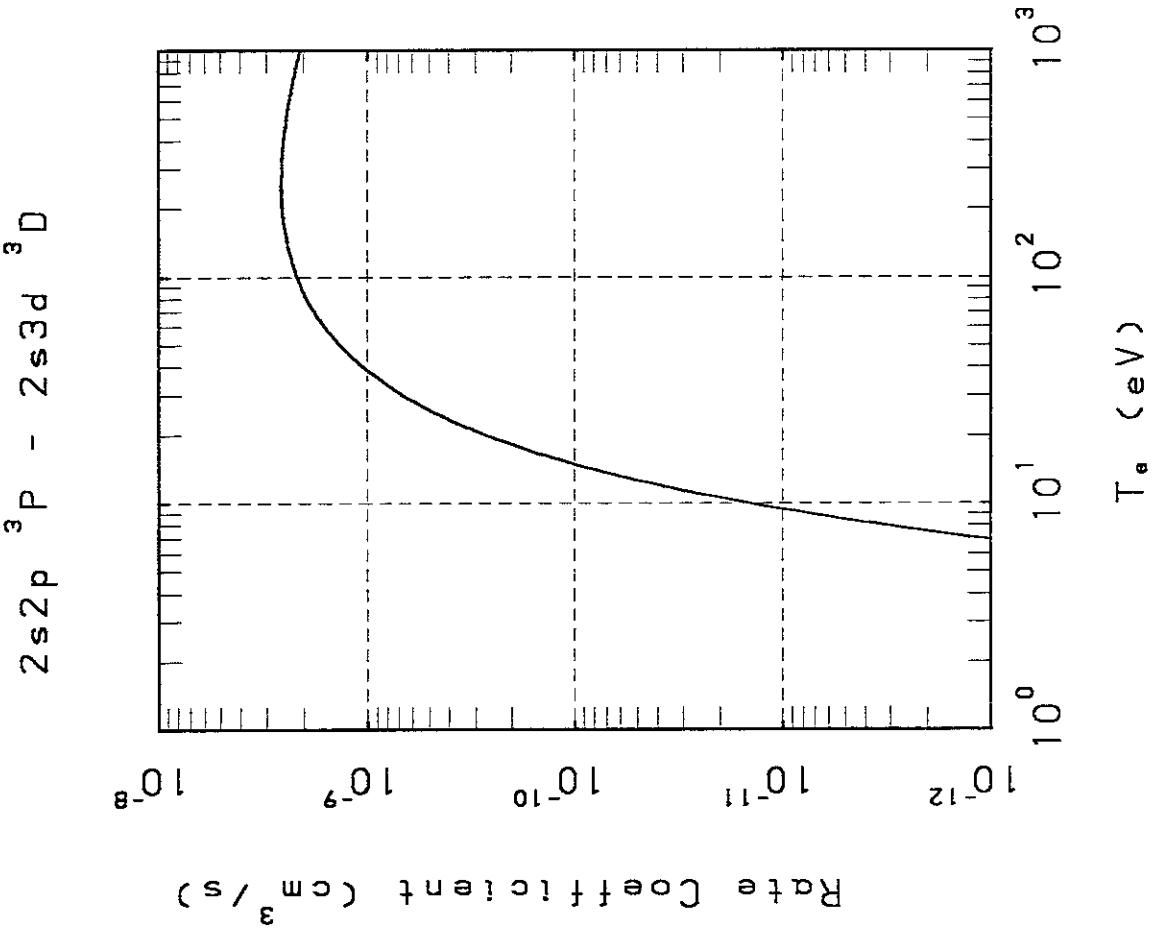

2s2p ³P - 2p² ¹D
Rate Coefficient (cm³/s)
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁻¹³
10⁰
10¹
10²
10³
Tₑ (eV)

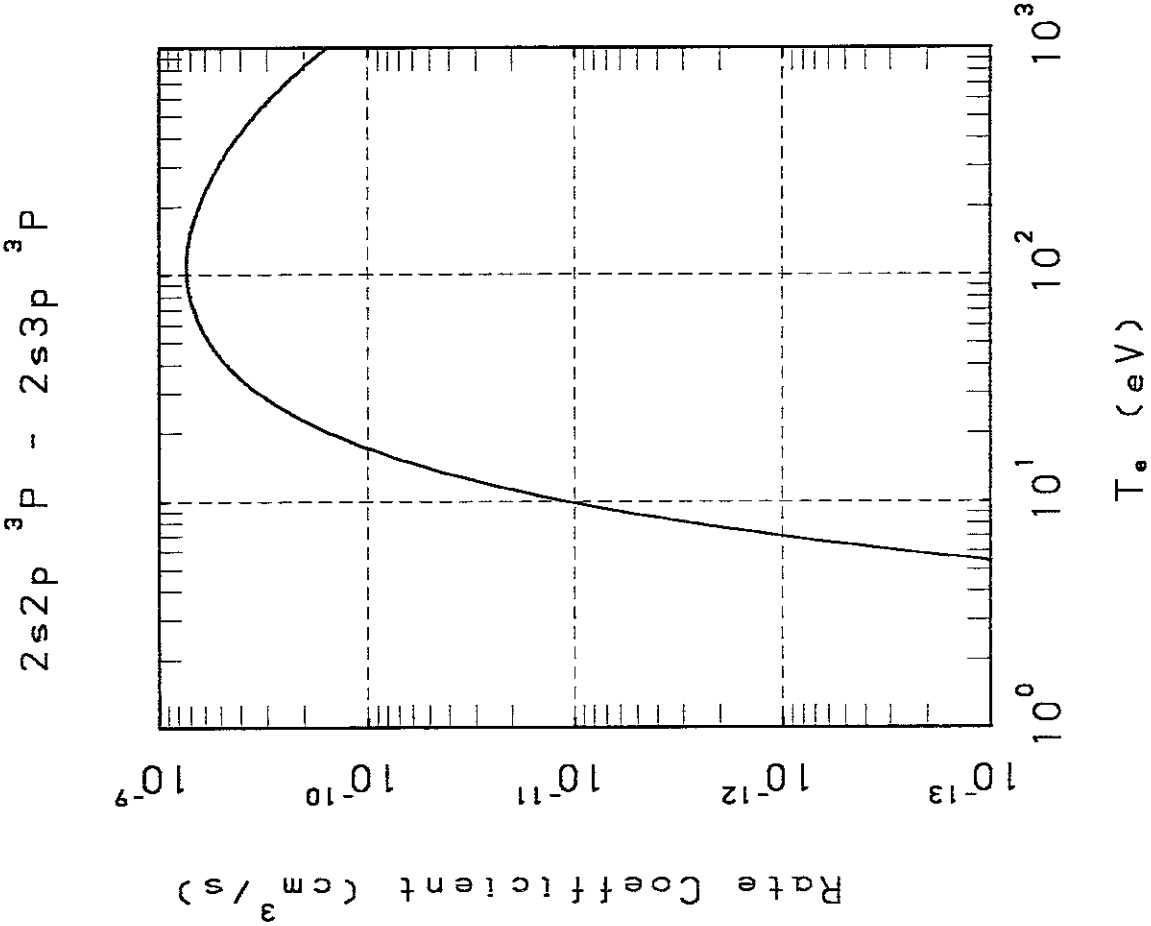

2s2p ³P - 2p² ¹S
Rate Coefficient (cm³/s)
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁻¹³
10⁻¹⁴
10⁰
10¹
10²
10³
Tₑ (eV)

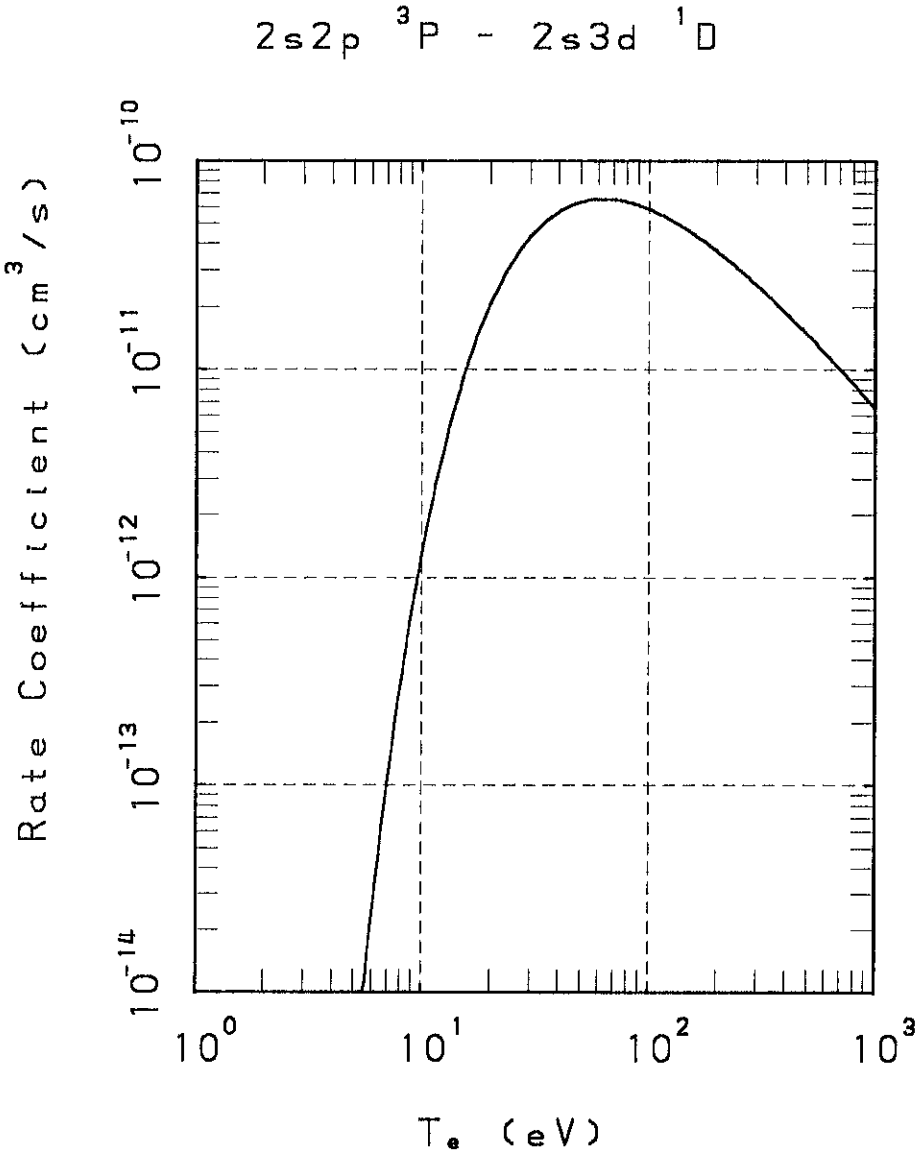

2s2p ³P - 2s3s ³S
Rate Coefficient (cm³/s)
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁻¹³
10⁰
10¹
10²
10³
Tₑ (eV)

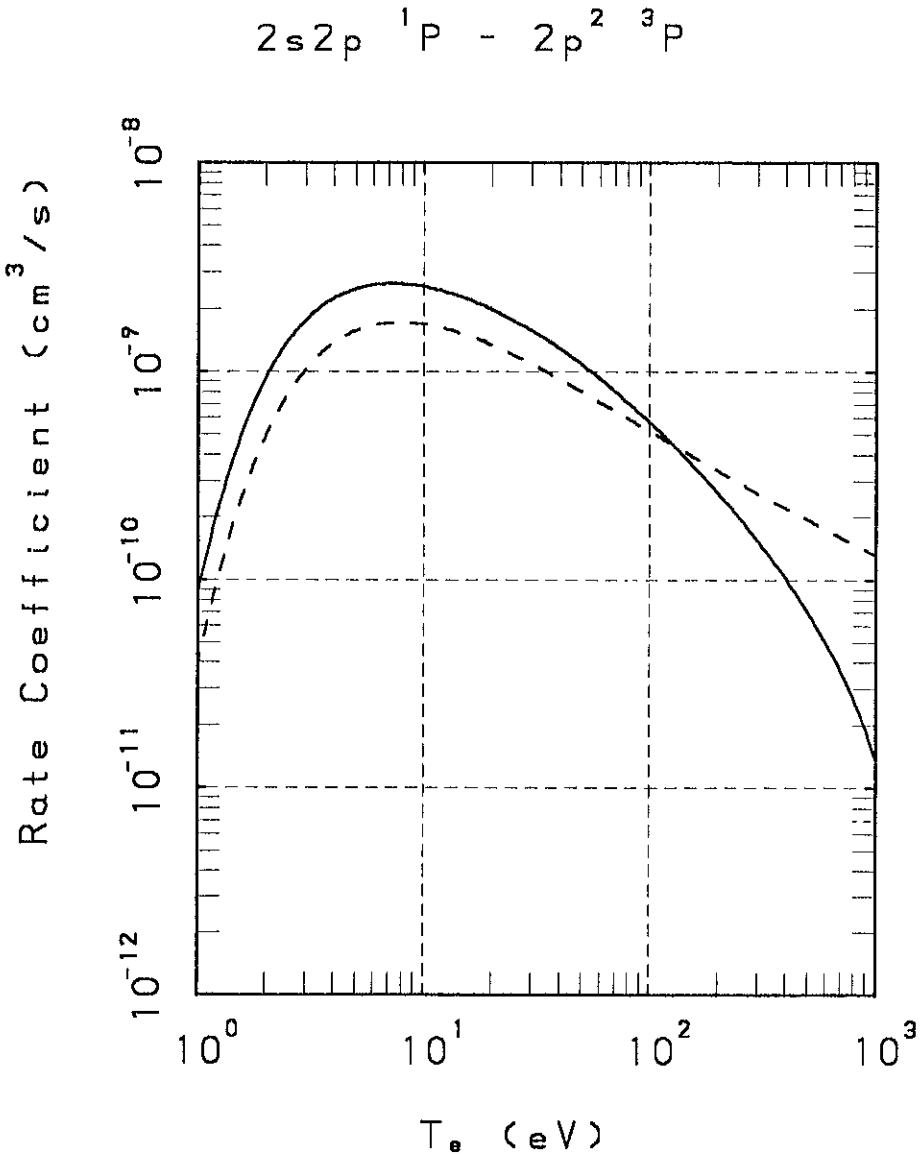

2s2p ³P - 2s3s ¹S
Rate Coefficient (cm³/s)
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁻¹³
10⁻¹⁴
10⁰
10¹
10²
10³
Tₑ (eV)

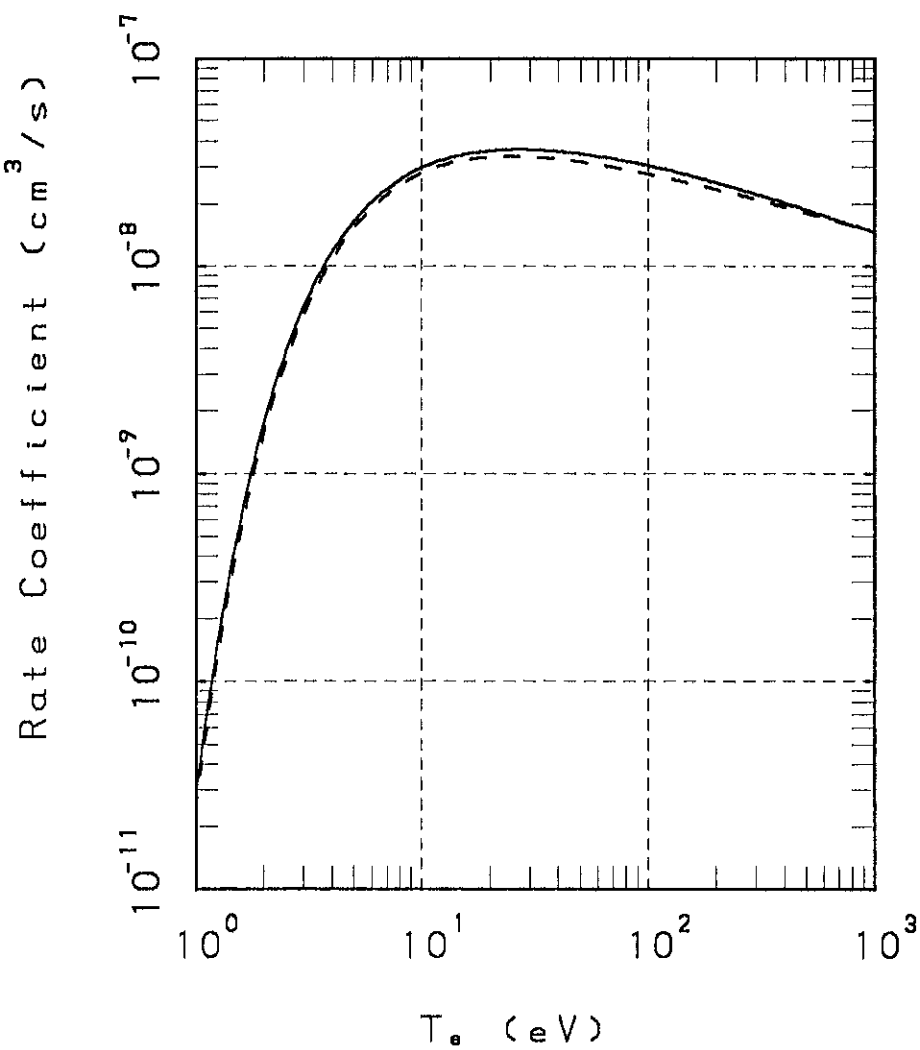

2s2p ³P - 2s3p ¹P
Rate Coefficient (cm³/s)
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁻¹³
10⁻¹⁴
10⁰
10¹
10²
10³
Tₑ (eV)

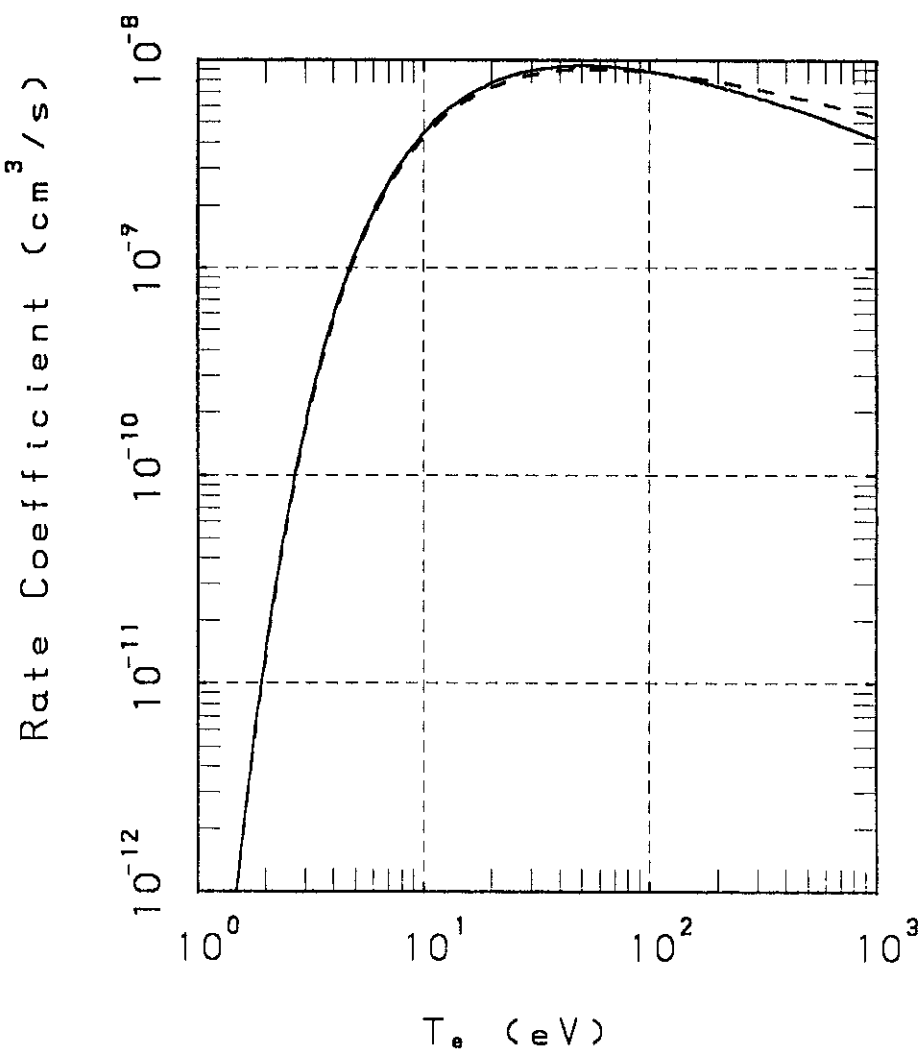

2s2p ³P - 2s3d ³D
Rate Coefficient (cm³/s)
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁰
10¹
10²
10³
Tₑ (eV)

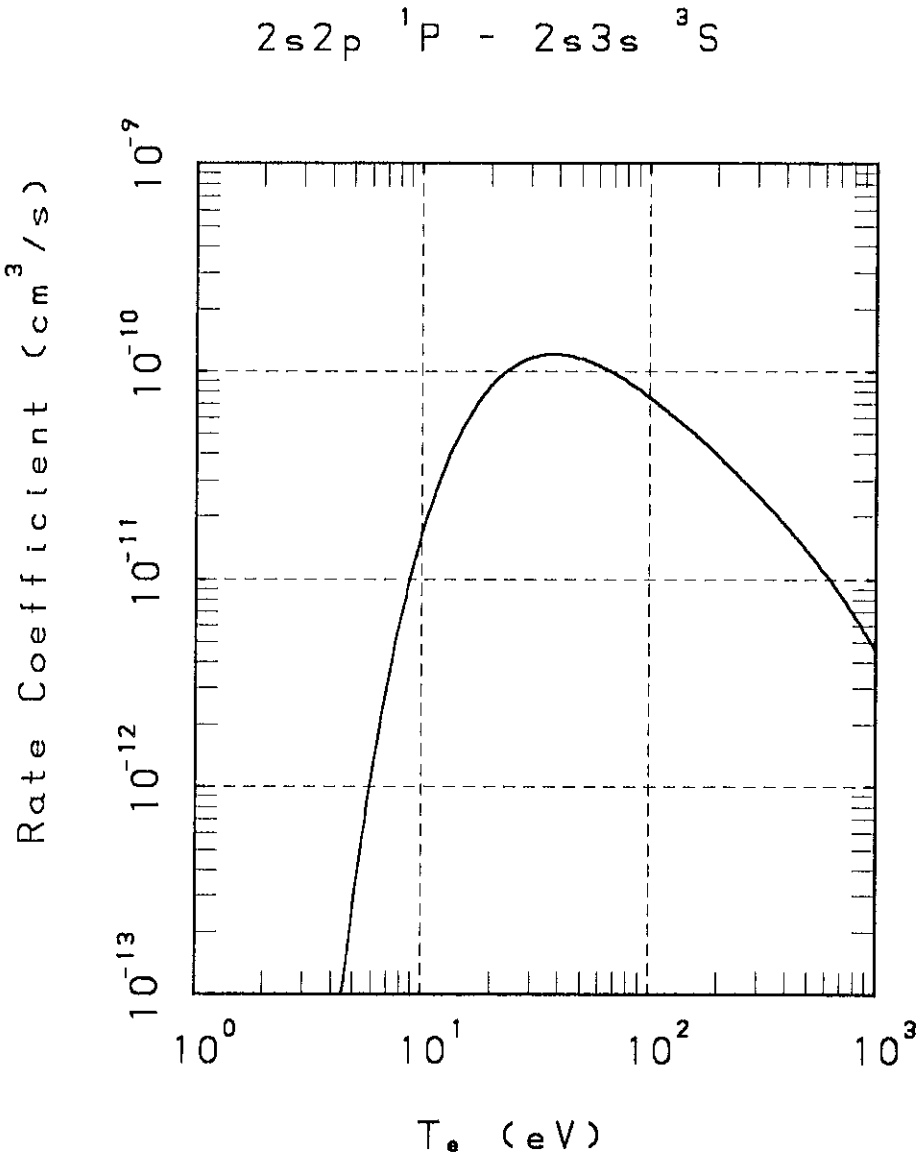

2s2p ³P - 2s3p ³P
Rate Coefficient (cm³/s)
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁻¹³
10⁰
10¹
10²
10³
Tₑ (eV)

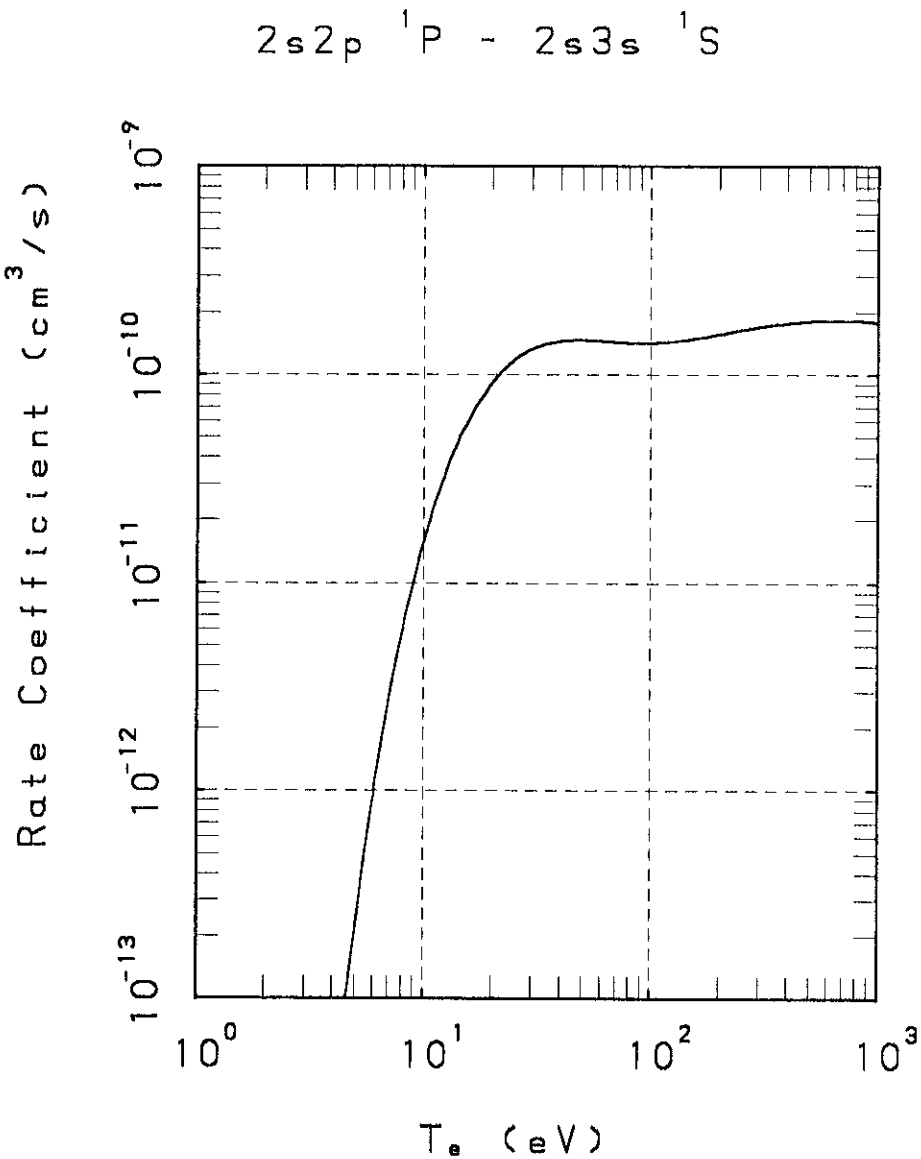

2s2p ³P - 2s3d ¹D
Rate Coefficient (cm³/s)
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁻¹³
10⁻¹⁴
10⁰
10¹
10²
10³
Tₑ (eV)

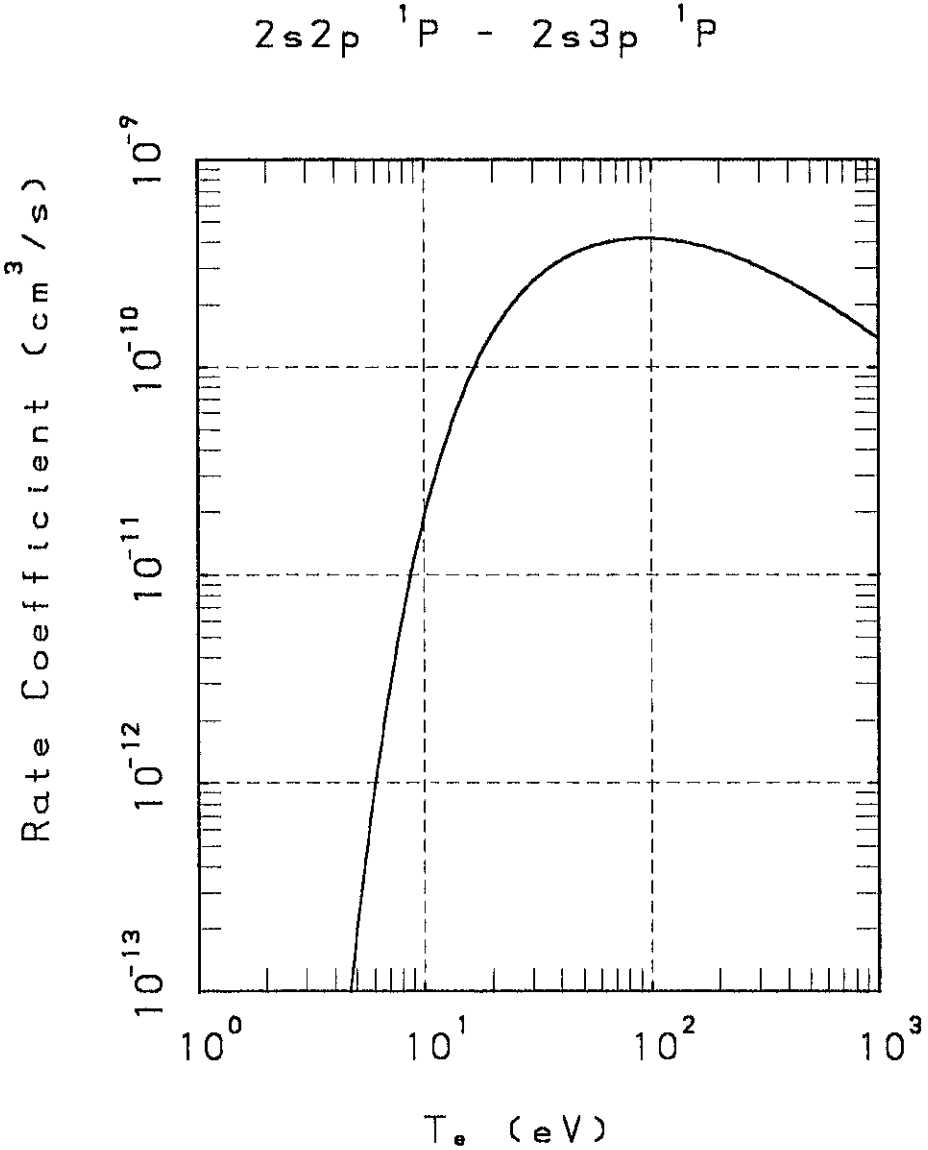

2s2p ¹P - 2p² ³P
Rate Coefficient (cm³/s)
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁰
10¹
10²
10³
Tₑ (eV)

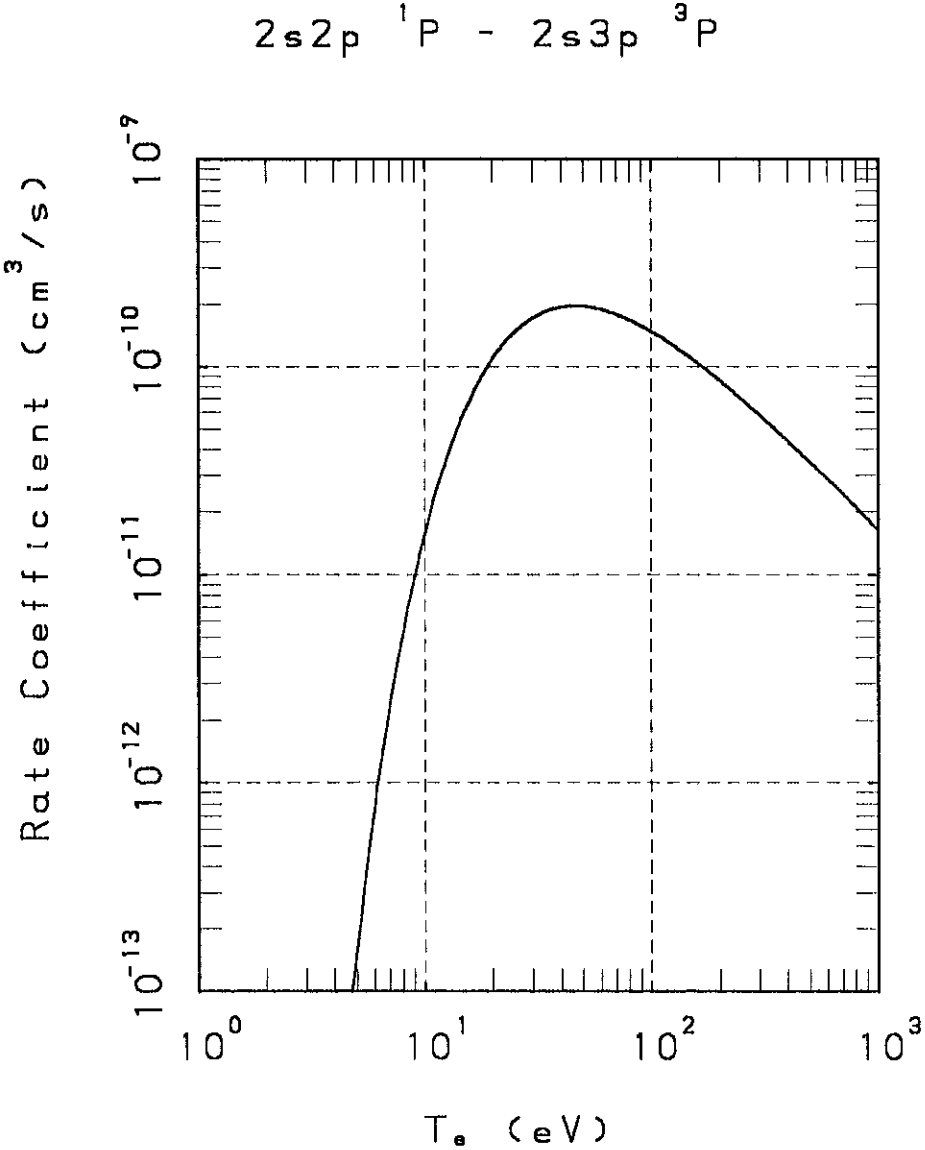

2s2p ¹P - 2p² ¹D
Rate Coefficient (cm³/s)
10⁻⁷
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁰
10¹
10²
10³
Tₑ (eV)

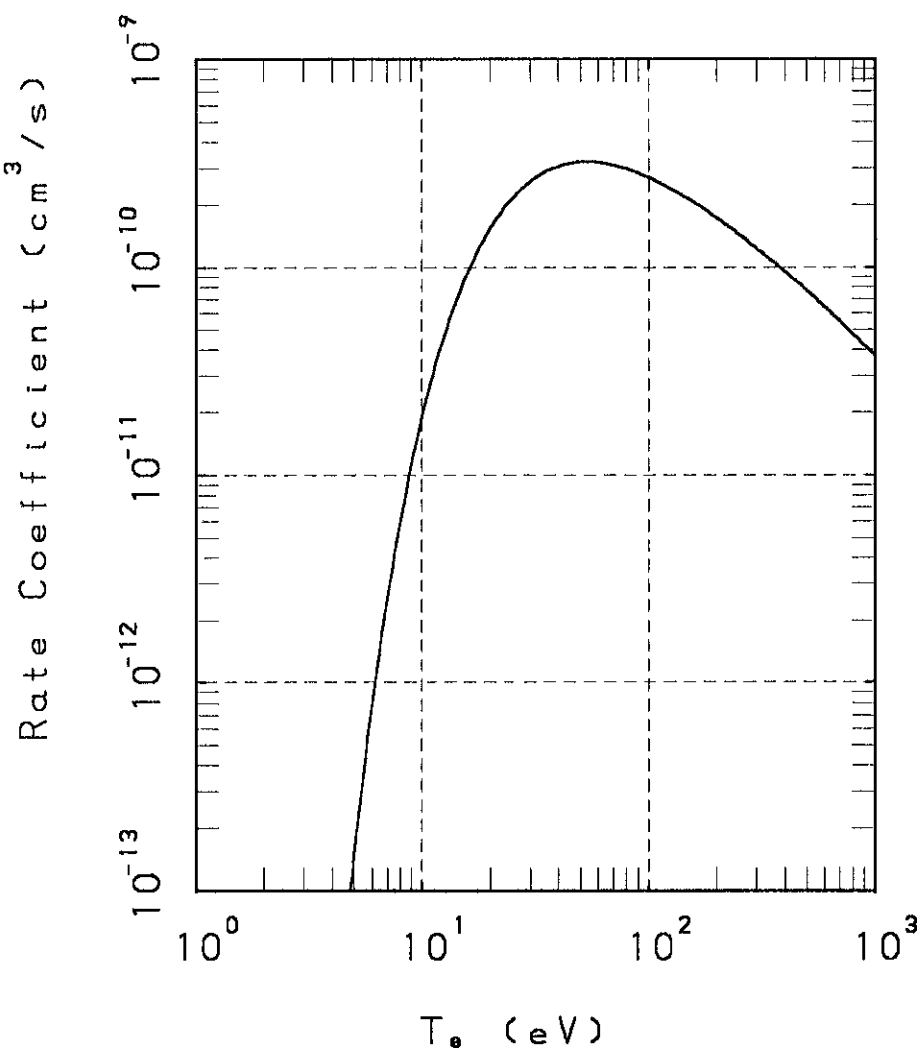

2s2p ¹P - 2p² ¹S
Rate Coefficient (cm³/s)
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁰
10¹
10²
10³
Tₑ (eV)

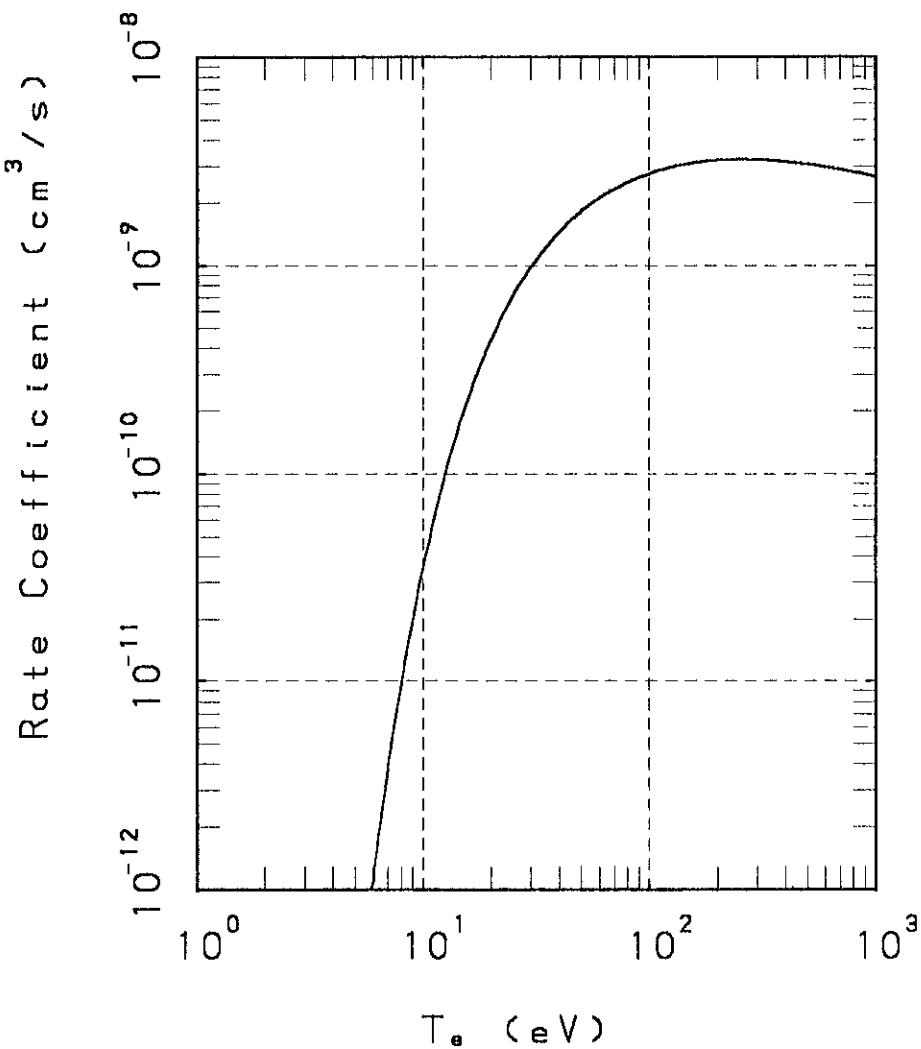

2s2p ¹P - 2s3s ³S
Rate Coefficient (cm³/s)
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁻¹³
10⁰
10¹
10²
10³
Tₑ (eV)

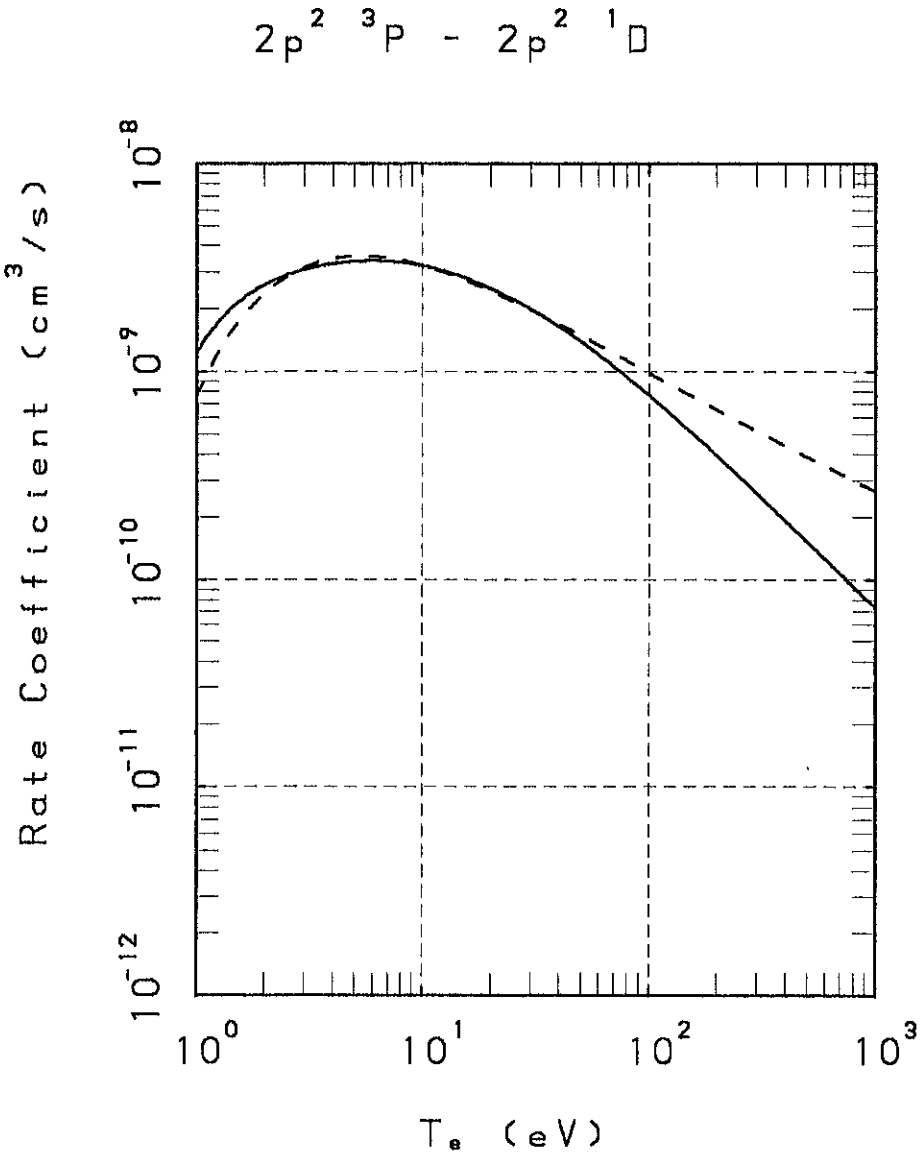

2s2p ¹P - 2s3s ¹S
Rate Coefficient (cm³/s)
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁻¹³
10⁰
10¹
10²
10³
Tₑ (eV)

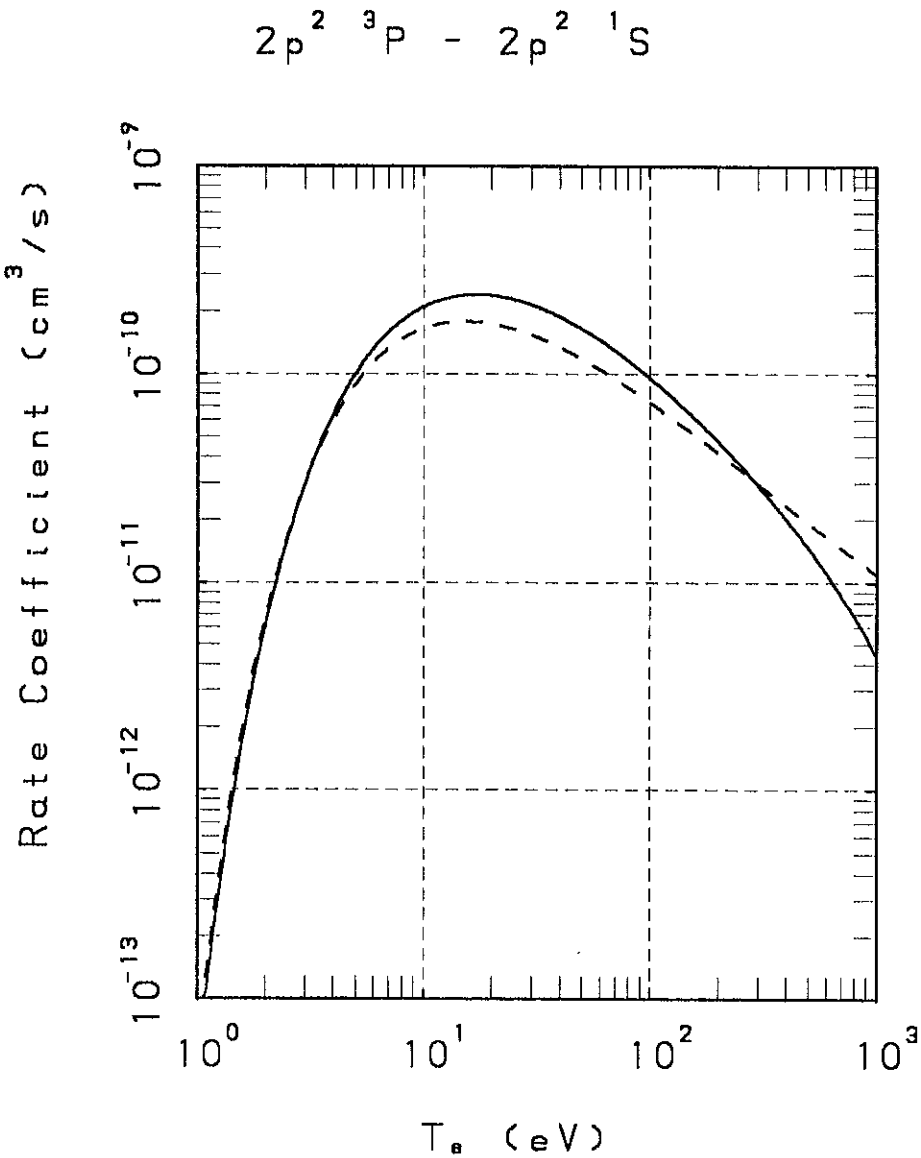

2s2p ¹P - 2s3p ¹P
Rate Coefficient (cm³/s)
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁻¹³
10⁰
10¹
10²
10³
Tₑ (eV)

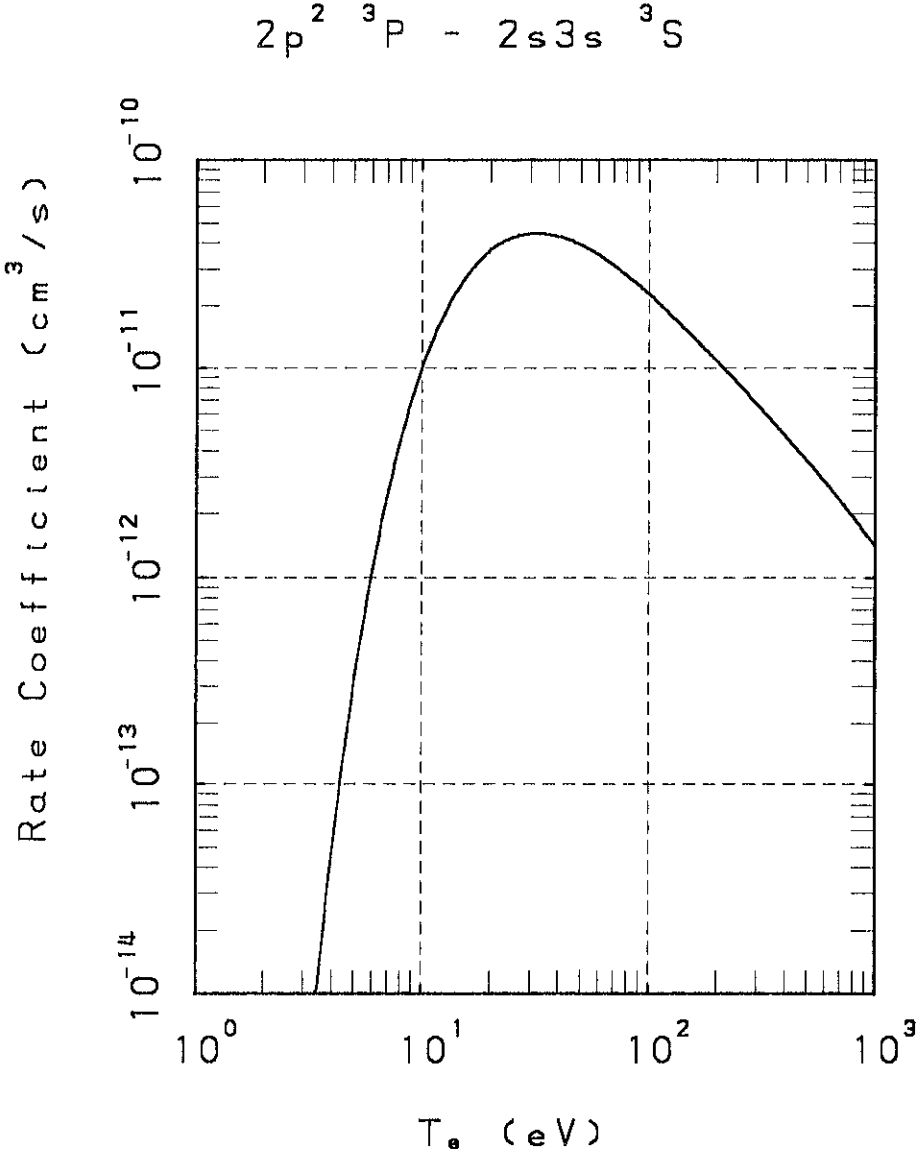

2s2p ¹P - 2s3p ³P
Rate Coefficient (cm³/s)
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁻¹³
10⁰
10¹
10²
10³
Tₑ (eV)

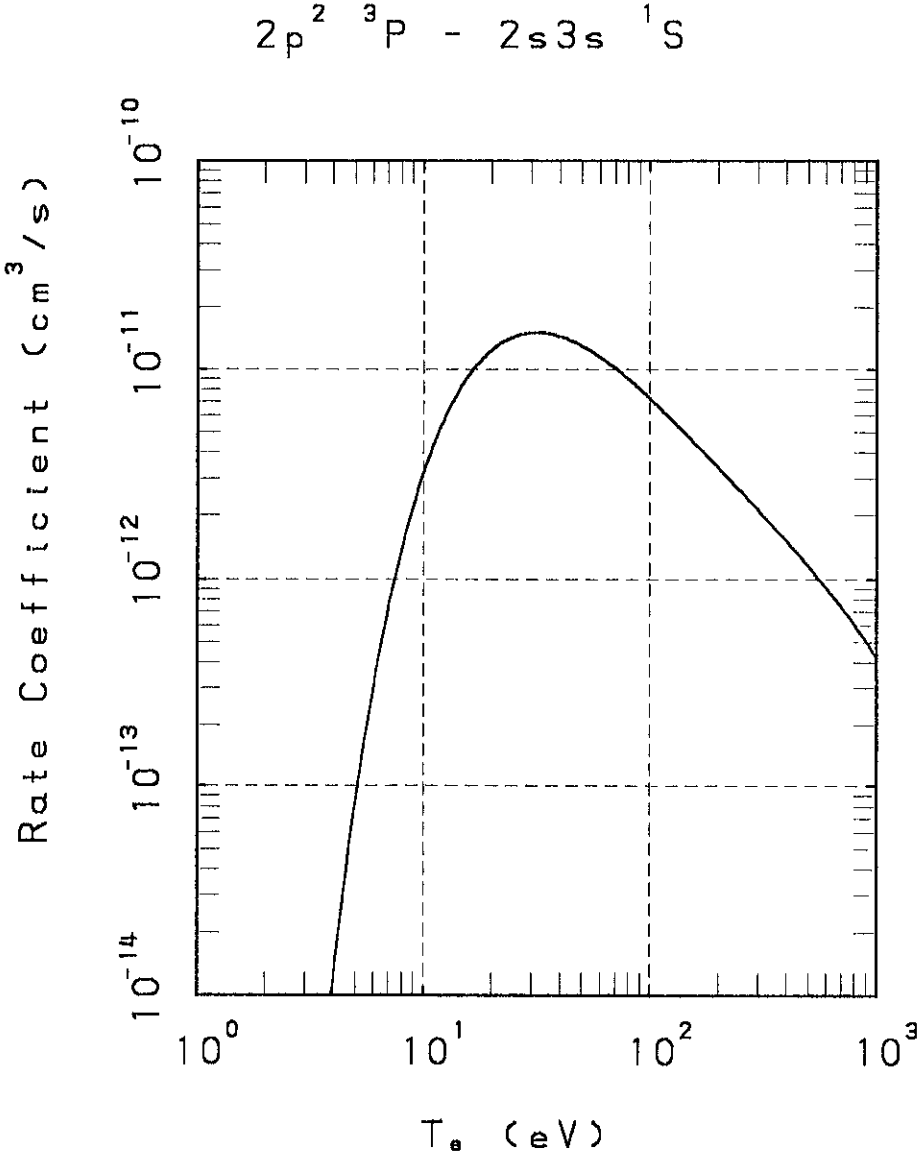

2s2p ¹P - 2s3d ³D
Rate Coefficient (cm³/s)
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁻¹³
10⁰
10¹
10²
10³
Tₑ (eV)

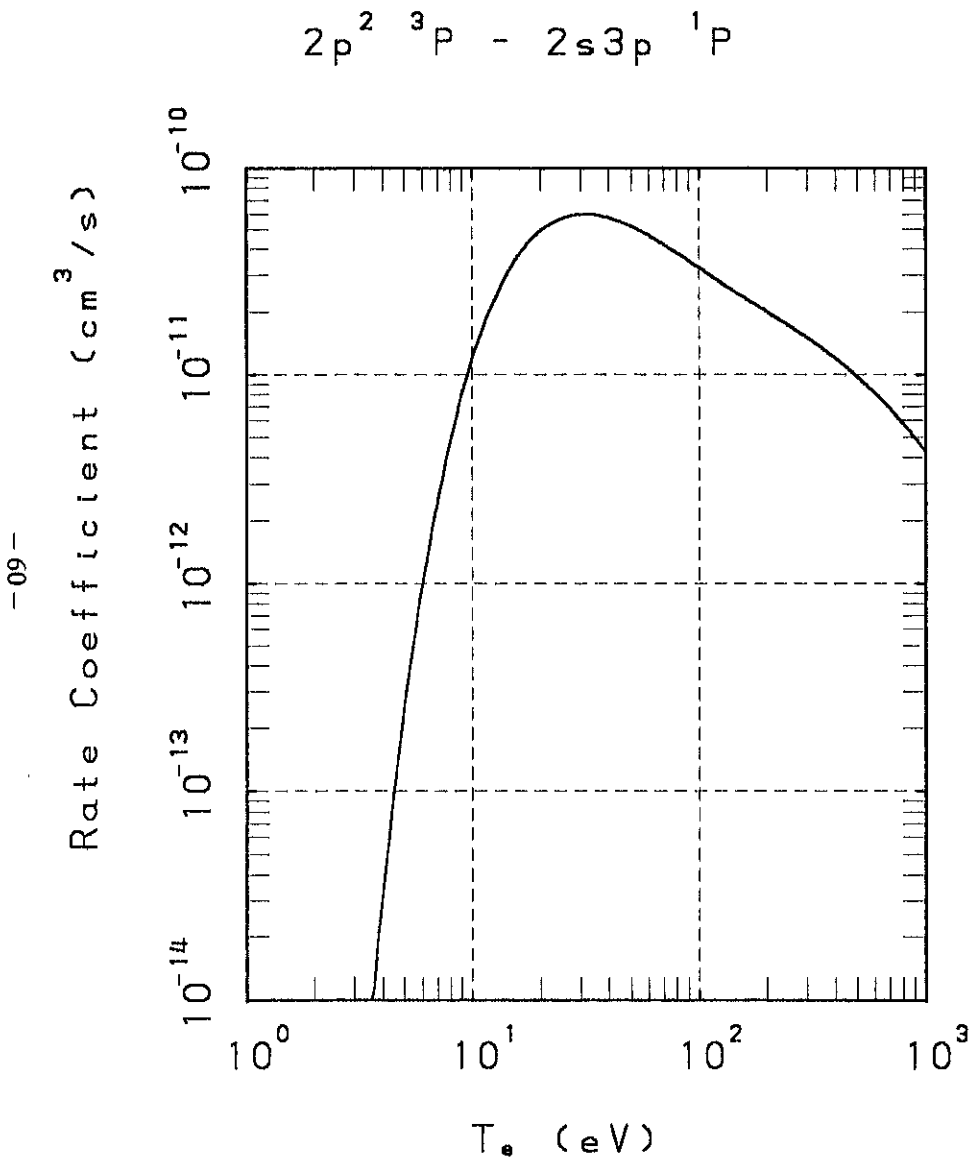

2s2p ¹P - 2s3d ¹D
Rate Coefficient (cm³/s)
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁰
10¹
10²
10³
Tₑ (eV)

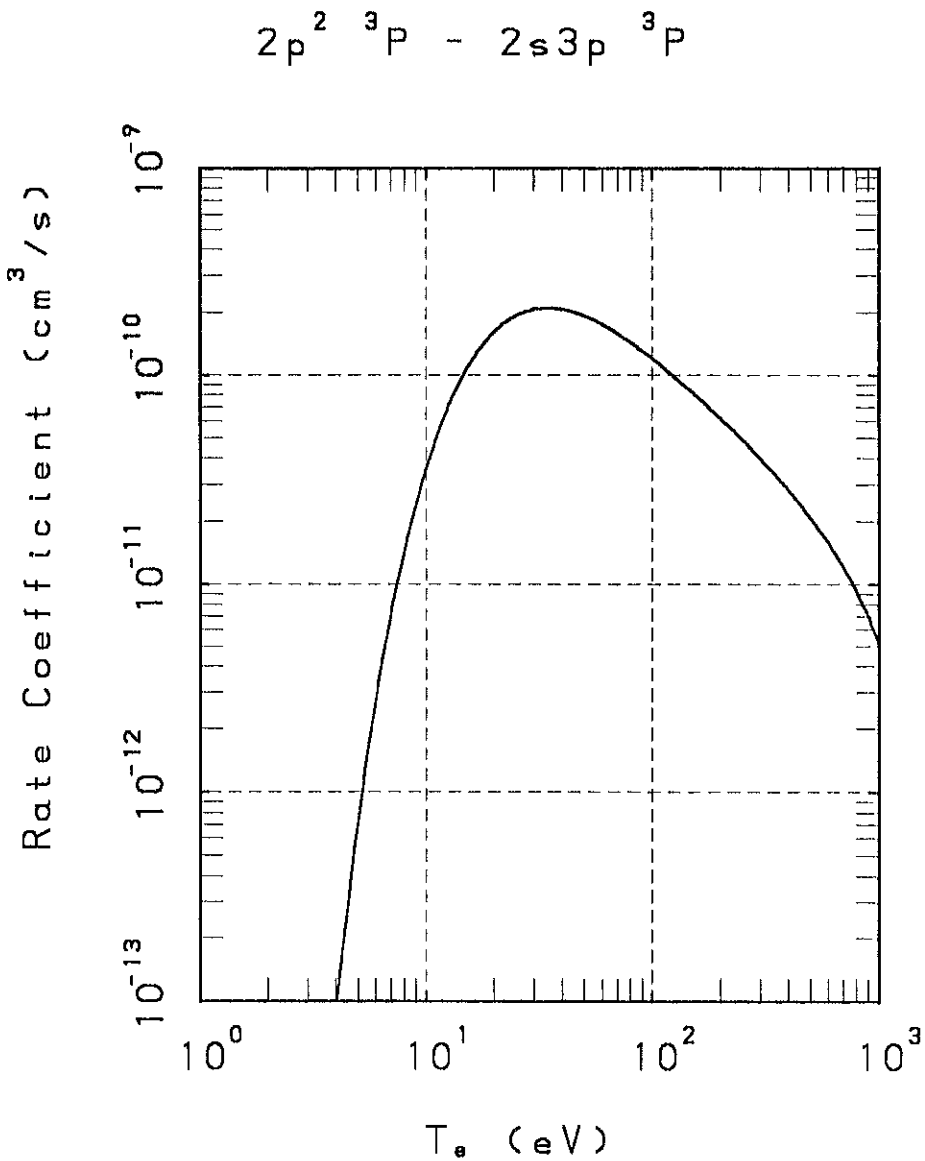

$2p^2\ ^3P - 2p^2\ ^1D$
Rate Coefficient ($cm^3/s$)
$10^{-8}$
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

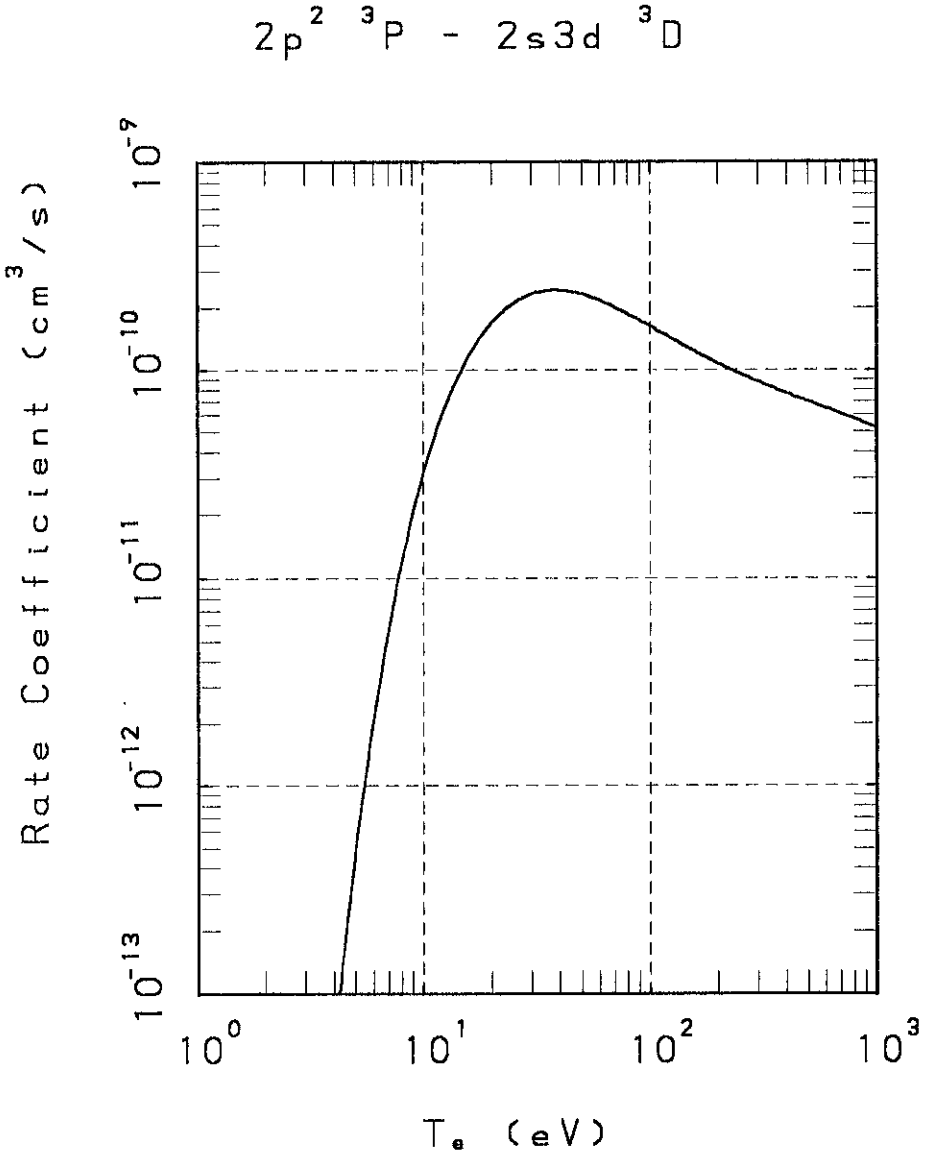

$2p^2\ ^3P - 2p^2\ ^1S$
Rate Coefficient ($cm^3/s$)
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

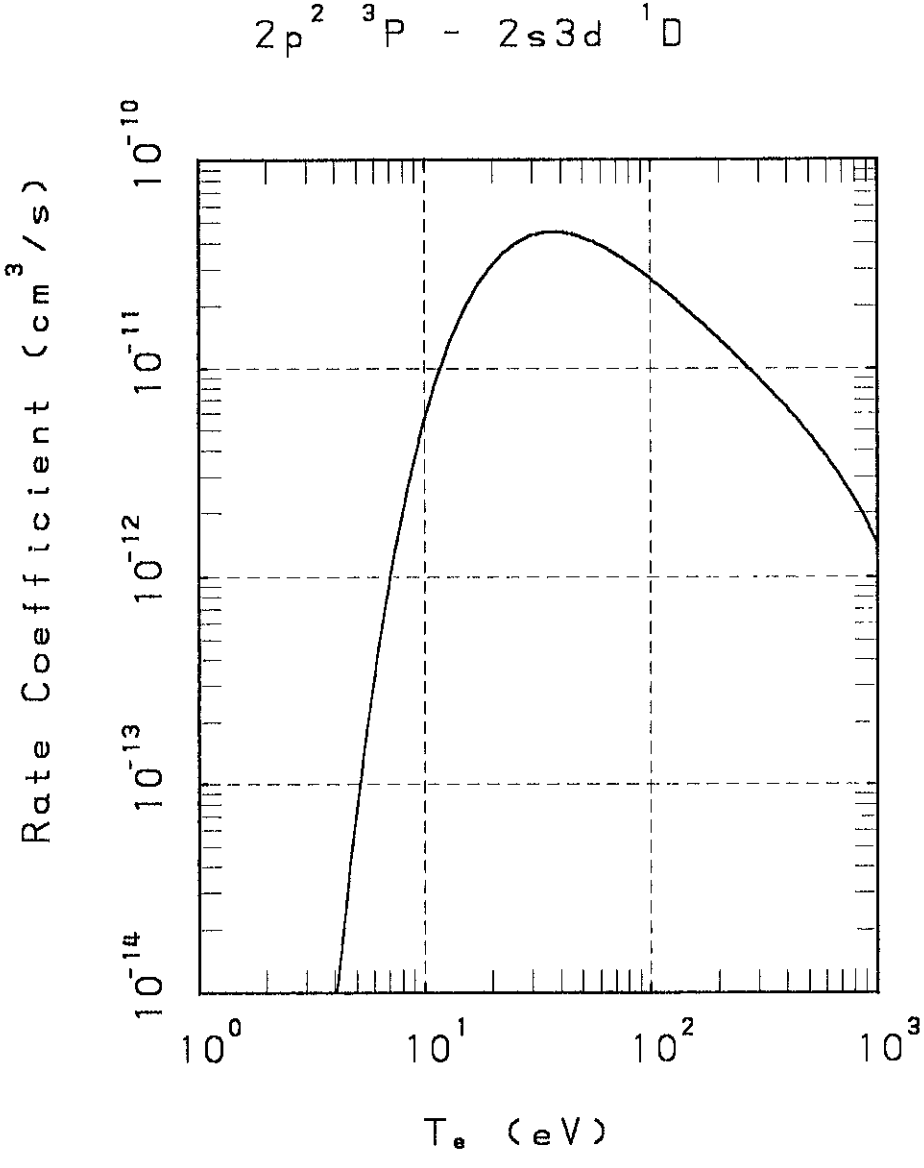

2p² ³P - 2s3s ³S
Rate Coefficient (cm³/s)
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁻¹³
10⁻¹⁴
10⁰
10¹
10²
10³
Tₑ (eV)


2p² ³P - 2s3s ¹S
Rate Coefficient (cm³/s)
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁻¹³
10⁻¹⁴
10⁰
10¹
10²
10³
Tₑ (eV)


$2p^2\ ^3P - 2s3p\ ^1P$
Rate Coefficient ($cm^3/s$)
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^{-14}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

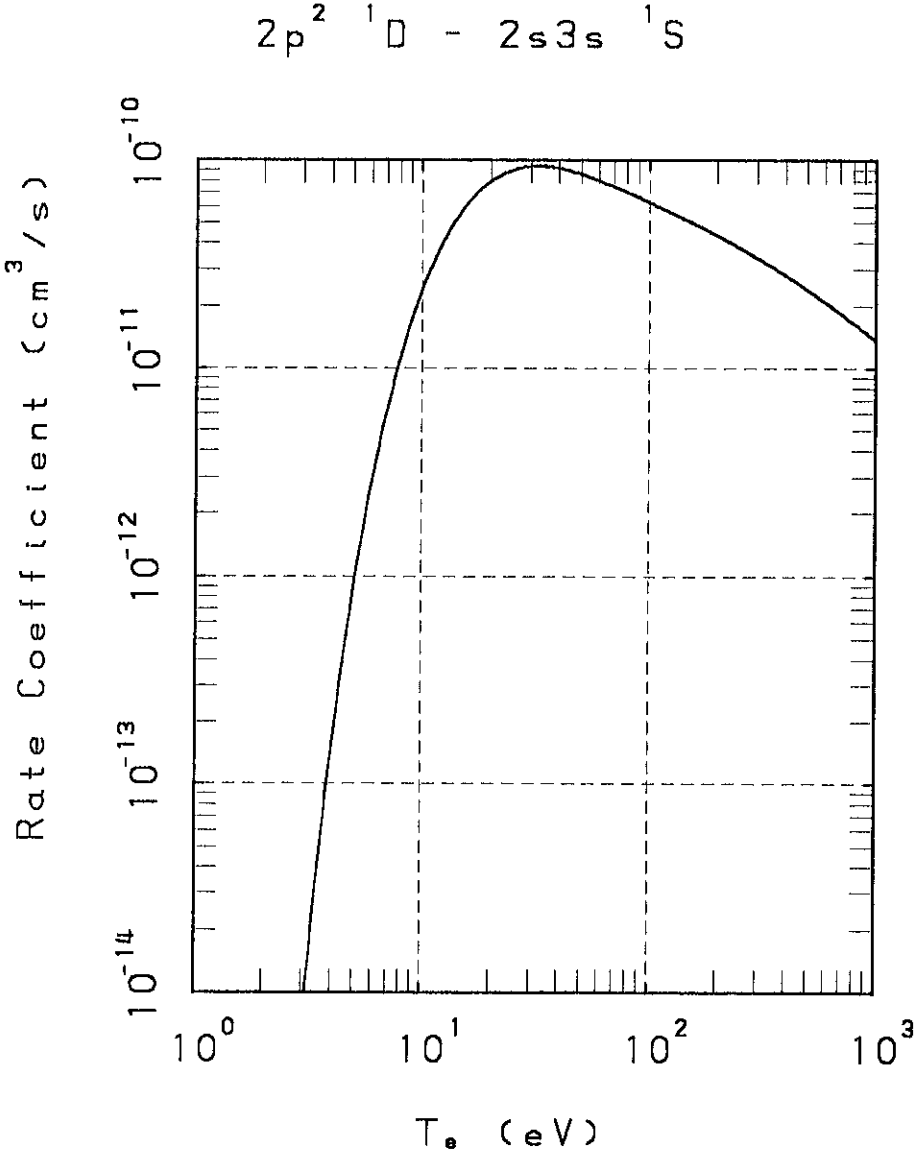

$2p^2\ ^3P - 2s3p\ ^3P$
Rate Coefficient ($cm^3/s$)
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

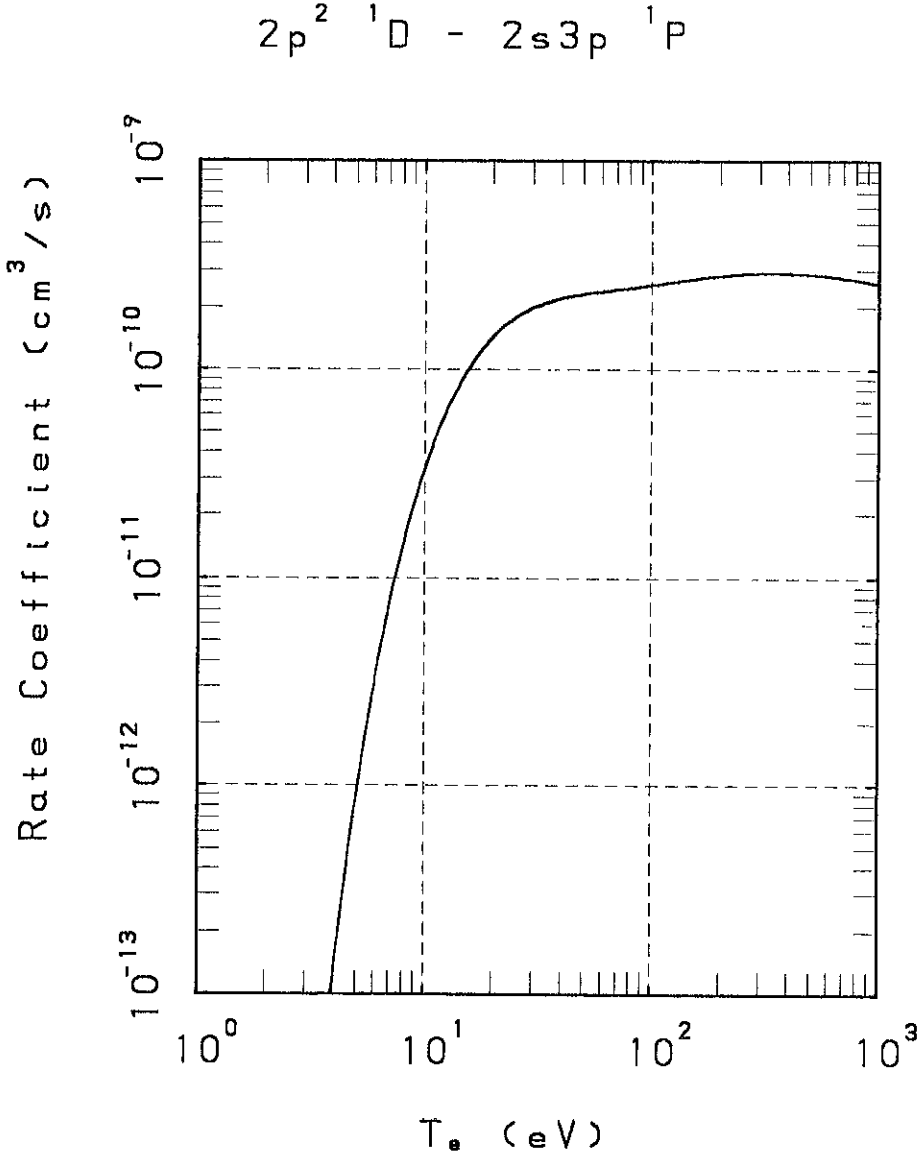

$2p^2\ ^3P - 2s3d\ ^3D$
Rate Coefficient ($cm^3/s$)
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

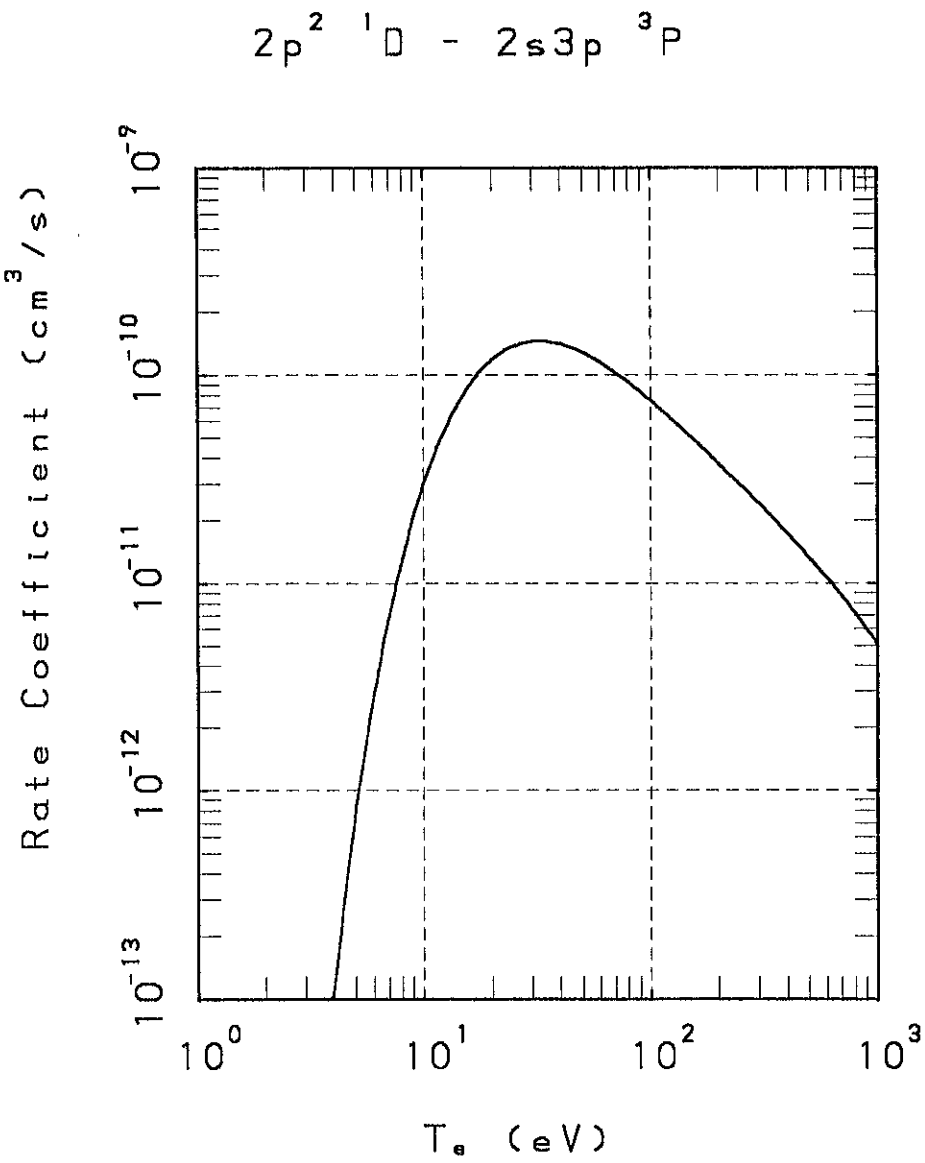

$2p^2\ ^3P - 2s3d\ ^1D$
Rate Coefficient ($cm^3/s$)
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^{-14}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

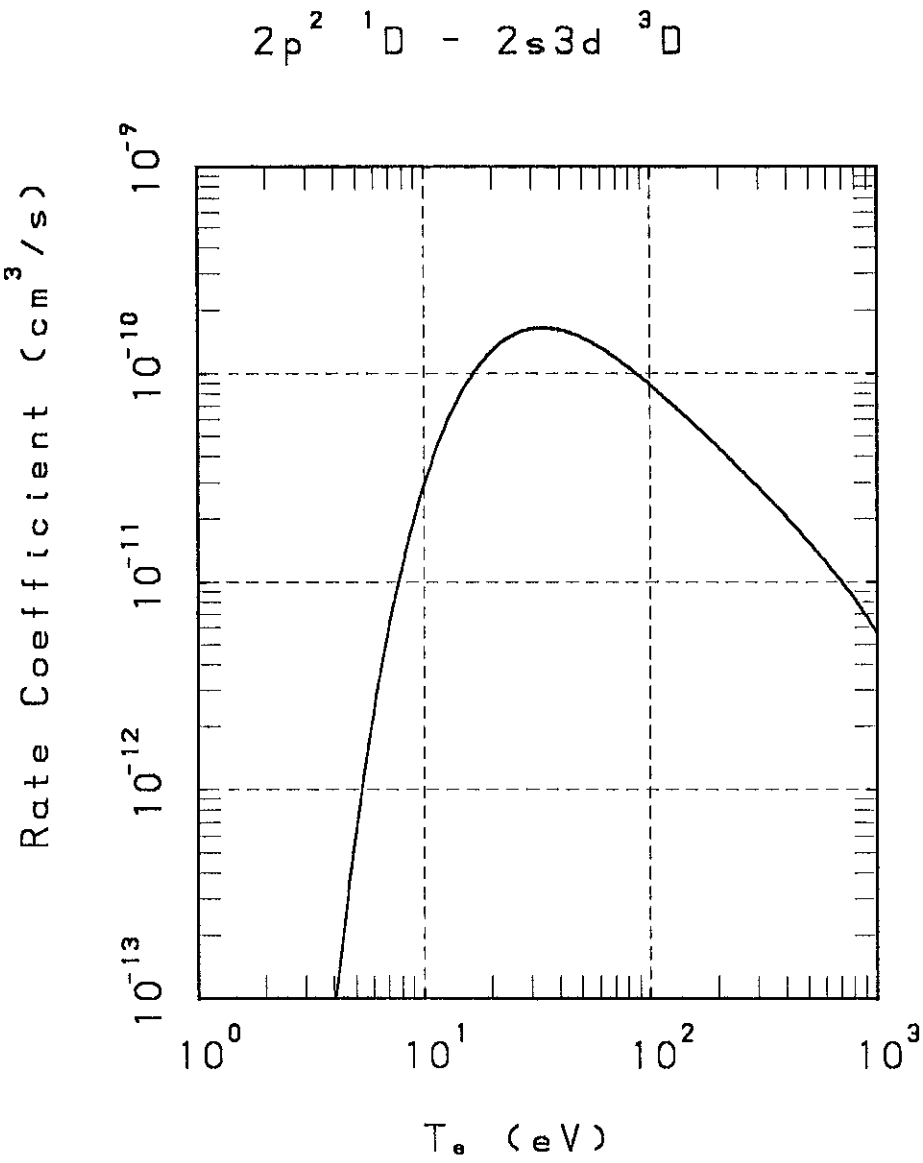
$2p^2\ ^1D - 2s3s\ ^3S$
Rate Coefficient ($cm^3/s$)
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

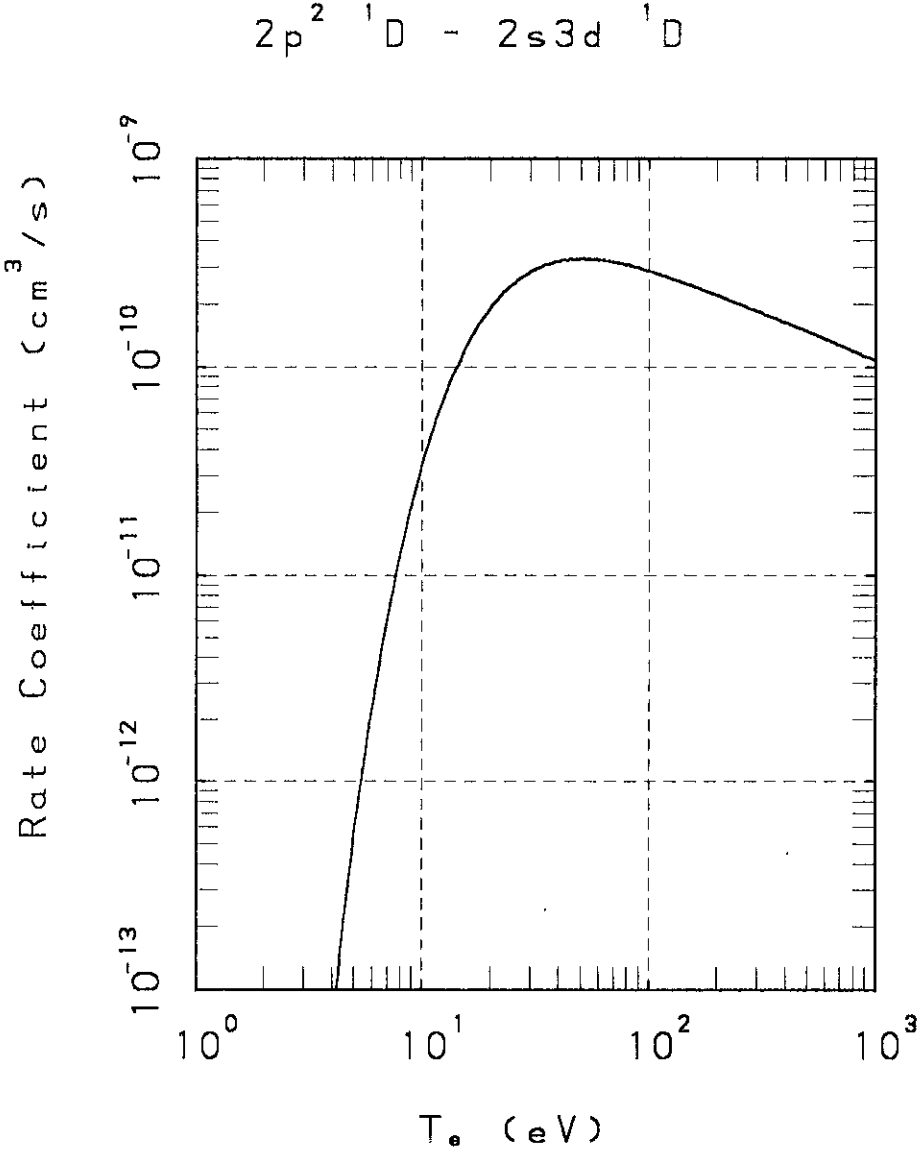

$2p^2\ ^1D - 2p^2\ ^1S$
Rate Coefficient ($cm^3/s$)
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

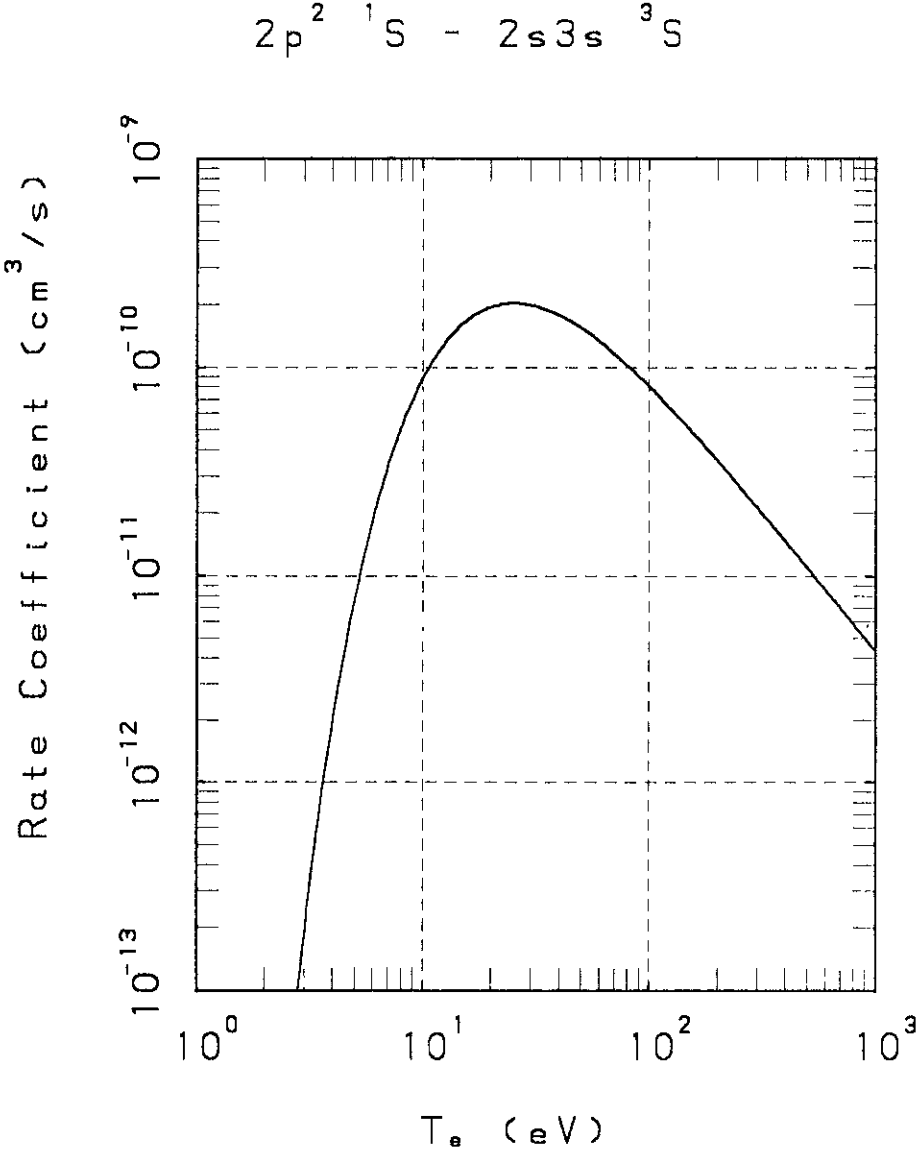

2p² ¹D - 2s3s ¹S
Rate Coefficient (cm³/s)
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁻¹³
10⁻¹⁴
10⁰
10¹
10²
10³
Tₑ (eV)

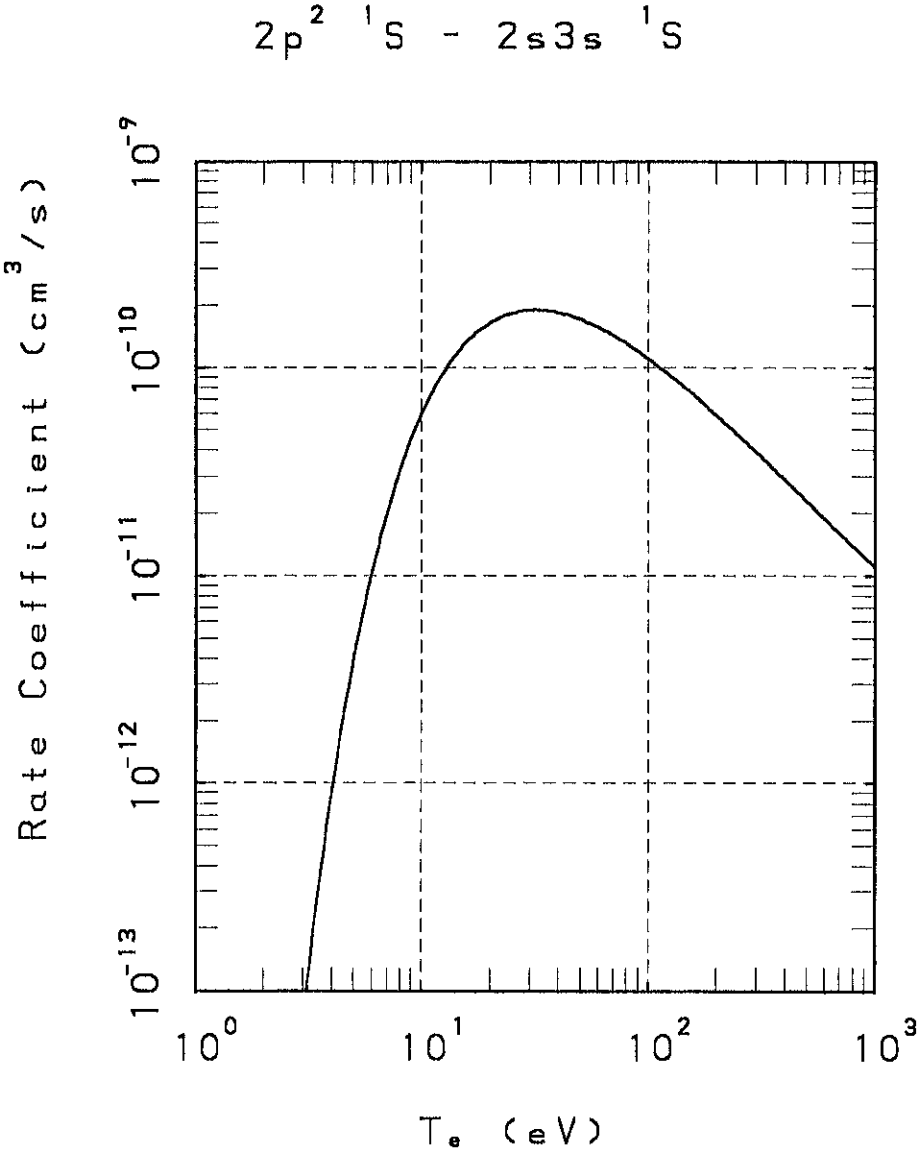

2p² ¹D - 2s3p ¹P
Rate Coefficient (cm³/s)
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁻¹³
10⁰
10¹
10²
10³
Tₑ (eV)

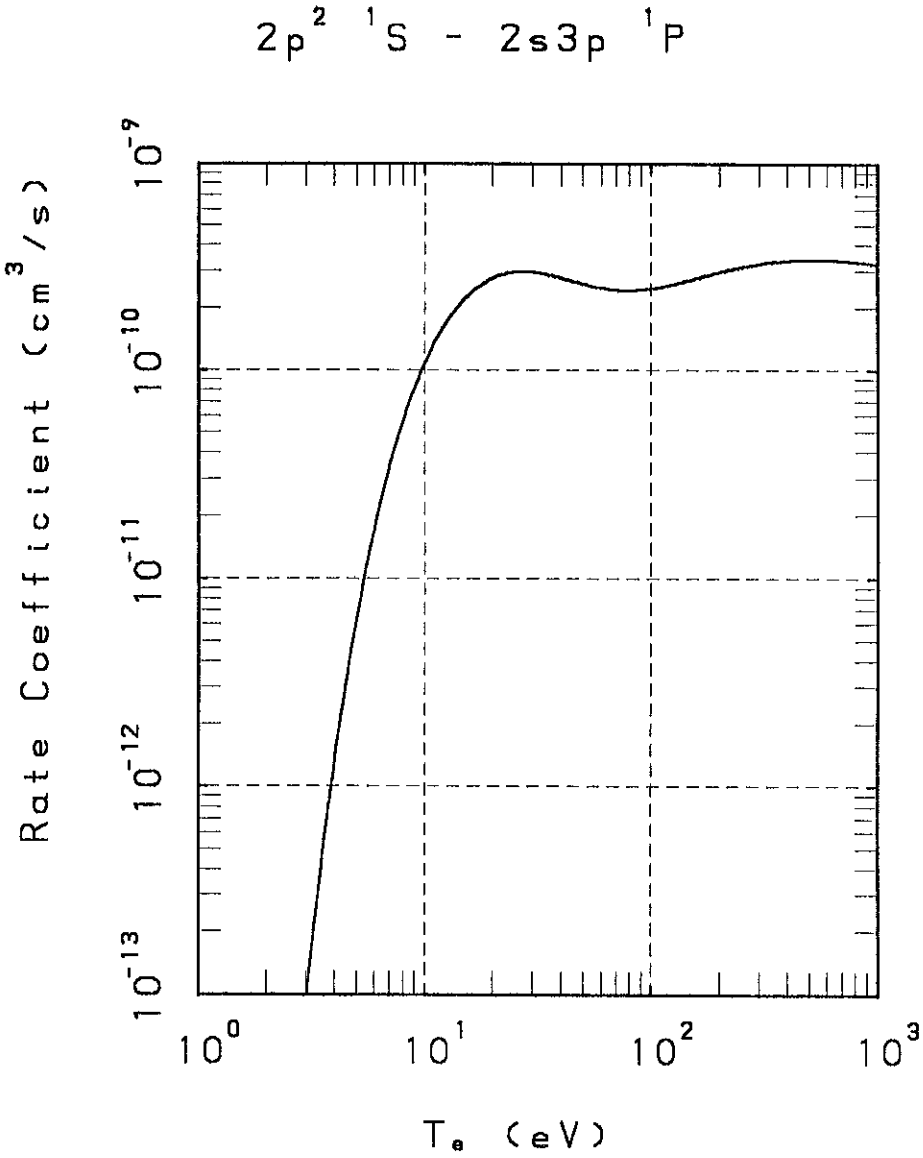

$2p^2\ ^1D - 2s3p\ ^3P$
Rate Coefficient ($cm^3/s$)
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

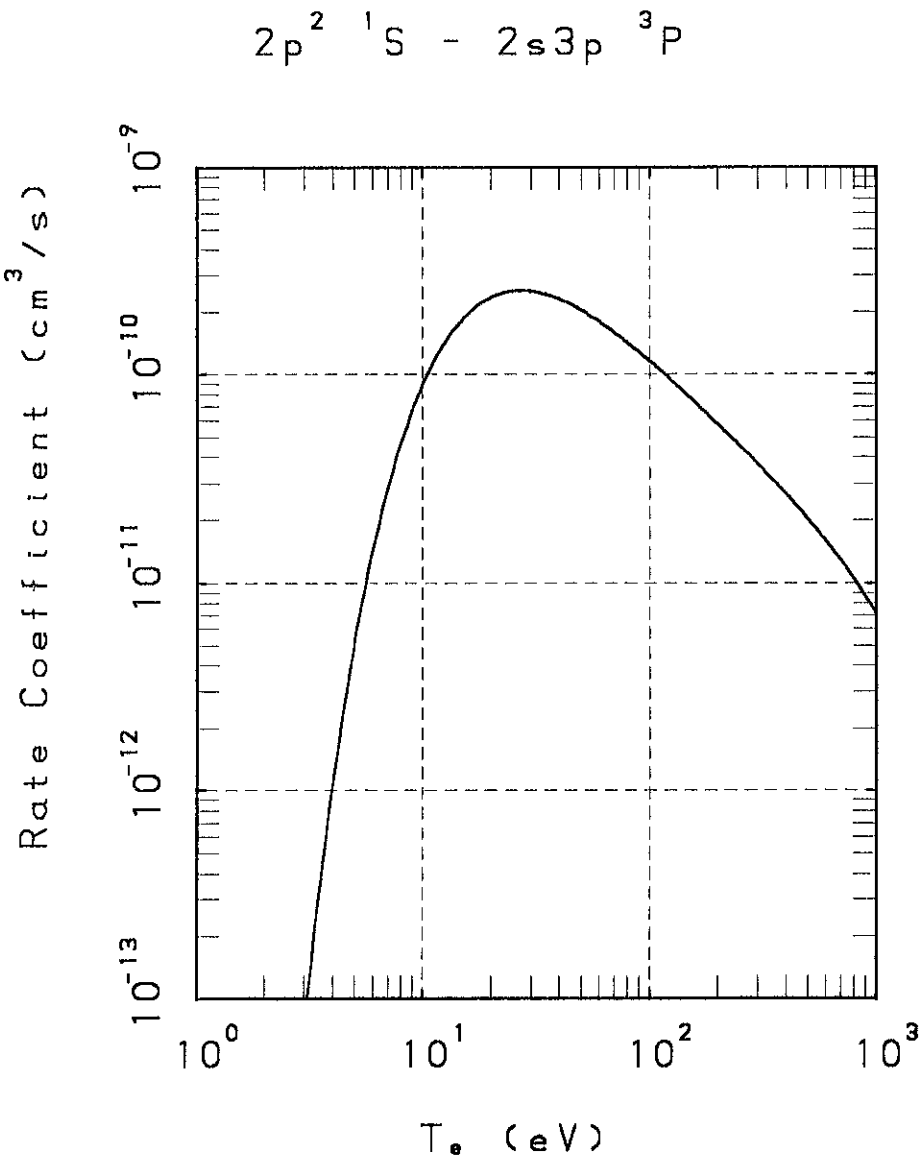

$2p^2\ ^1D - 2s3d\ ^3D$
Rate Coefficient ($cm^3/s$)
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

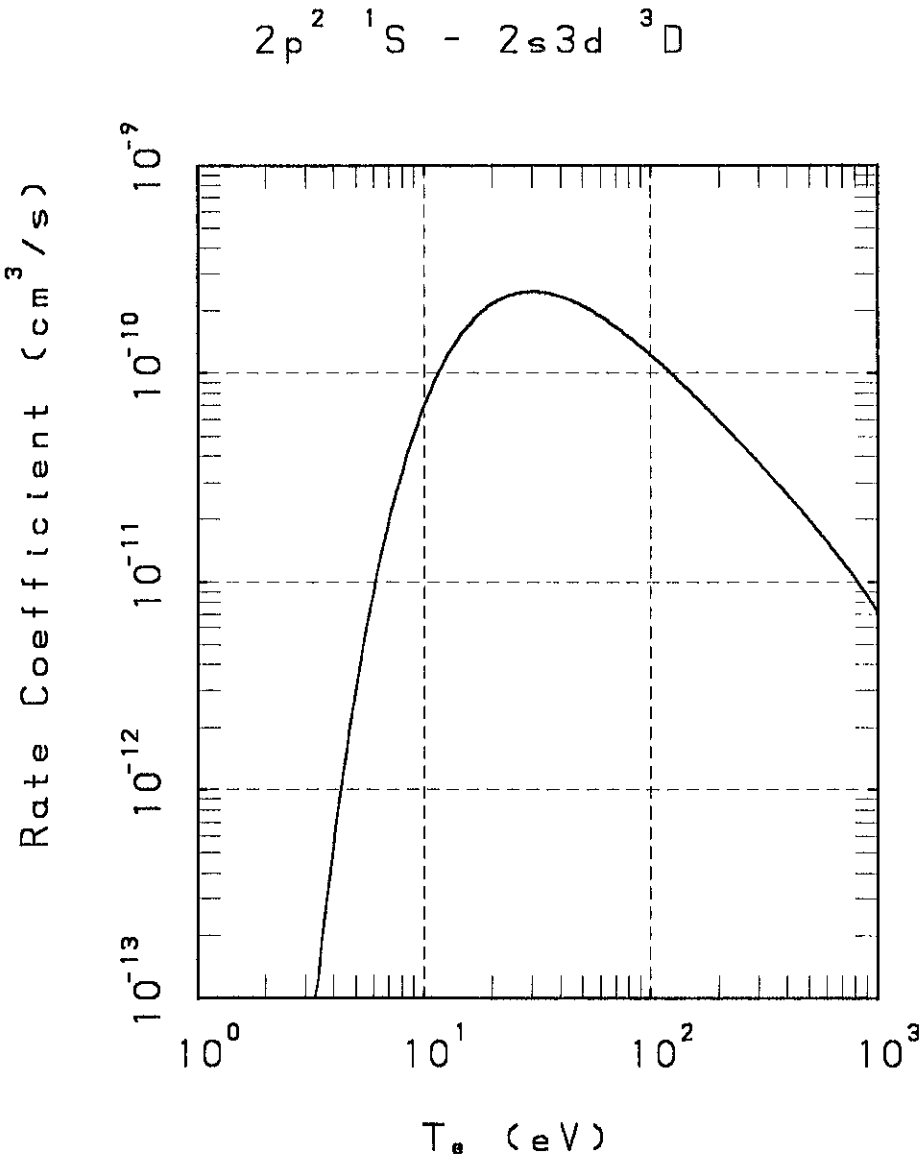

2p² ¹D - 2s3d ¹D
Rate Coefficient (cm³/s)
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁻¹³
10⁰
10¹
10²
10³
Tₑ (eV)

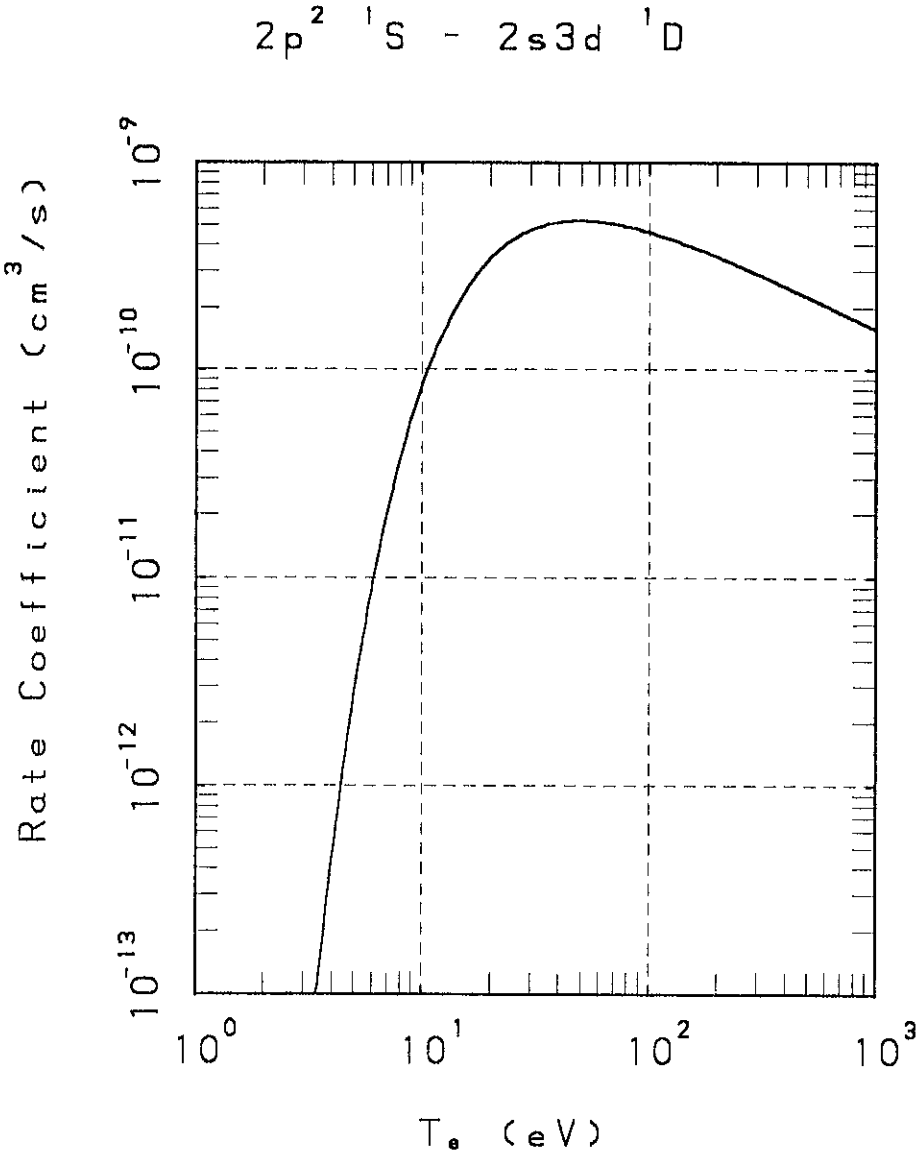

2p² ¹S - 2s3s ³S
Rate Coefficient (cm³/s)
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁻¹³
10⁰
10¹
10²
10³
Tₑ (eV)

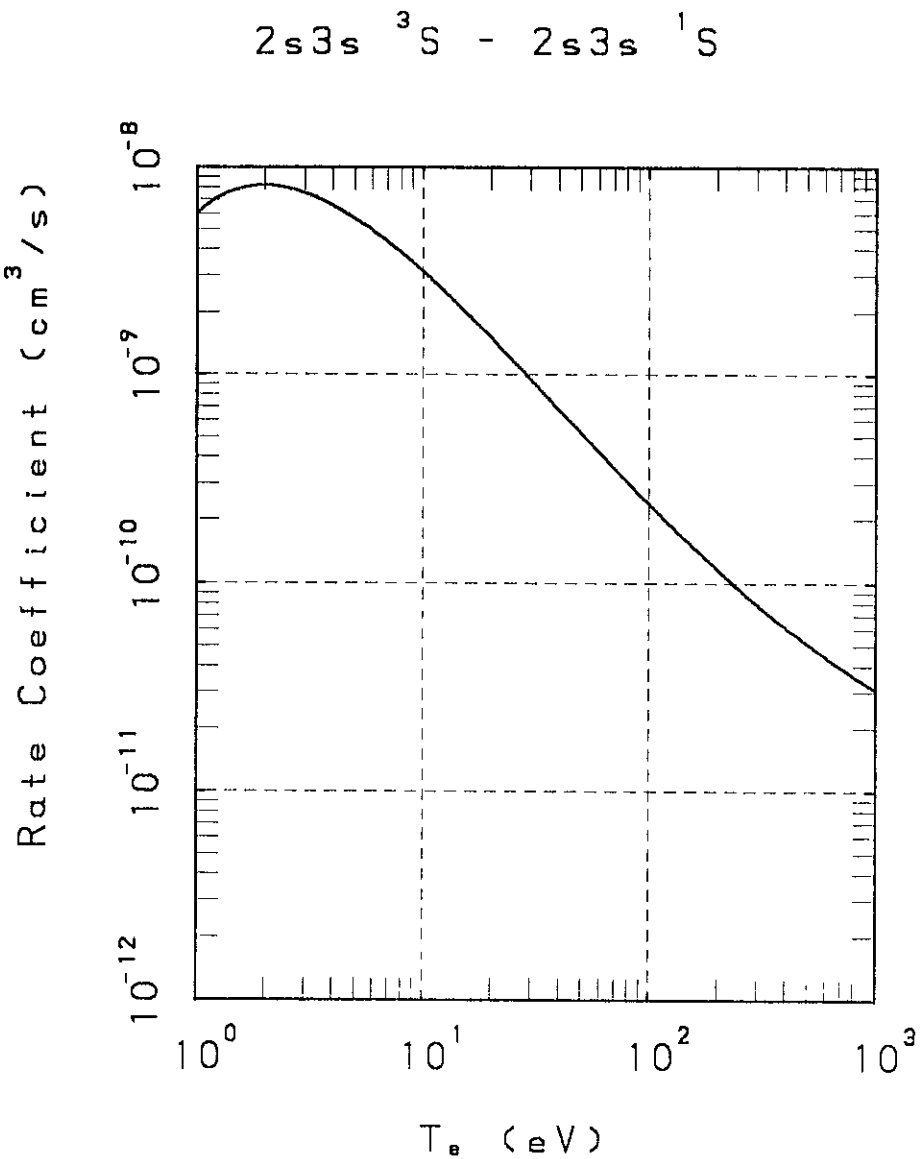

2p² ¹S - 2s3s ¹S
Rate Coefficient (cm³/s)
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁻¹³
10⁰
10¹
10²
10³
Tₑ (eV)

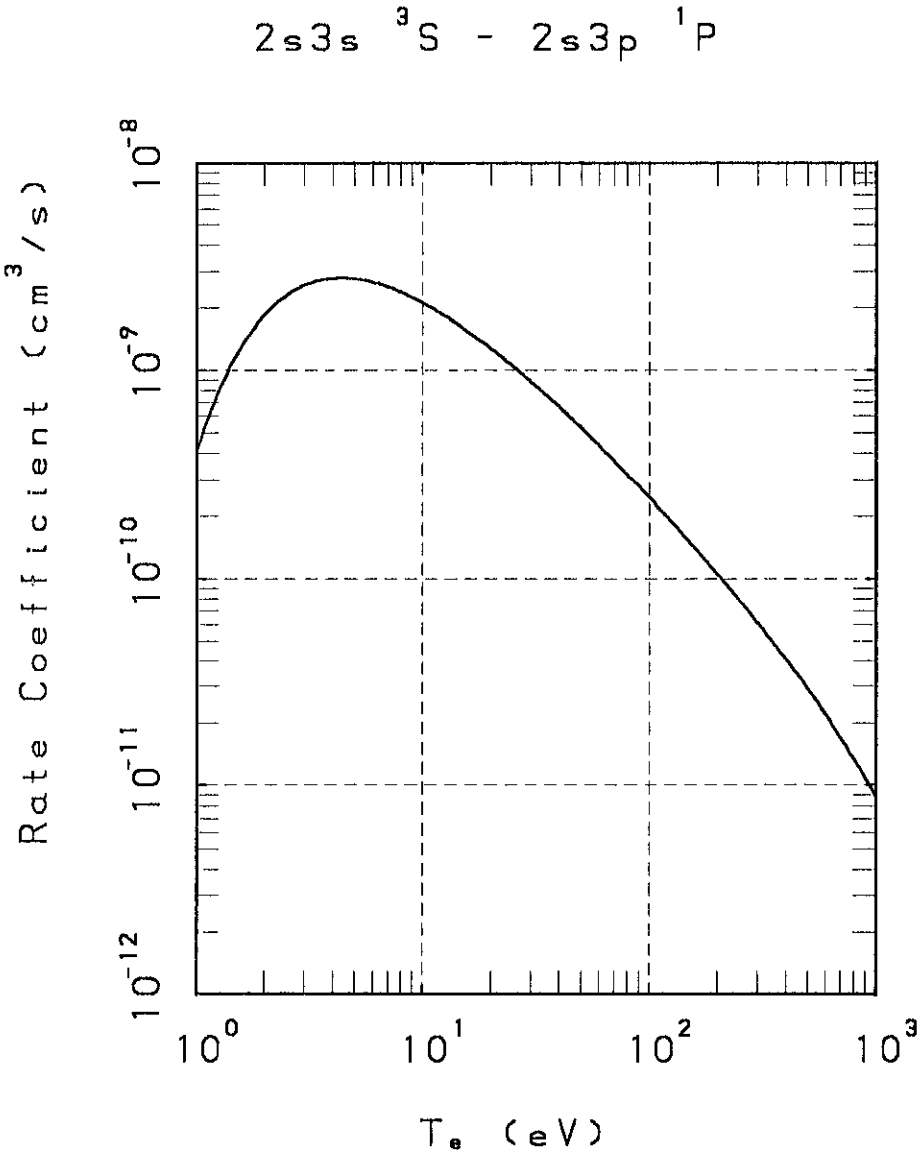

2p² ¹S - 2s3p ¹P
Rate Coefficient (cm³/s)
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁻¹³
10⁰
10¹
10²
10³
Tₑ (eV)

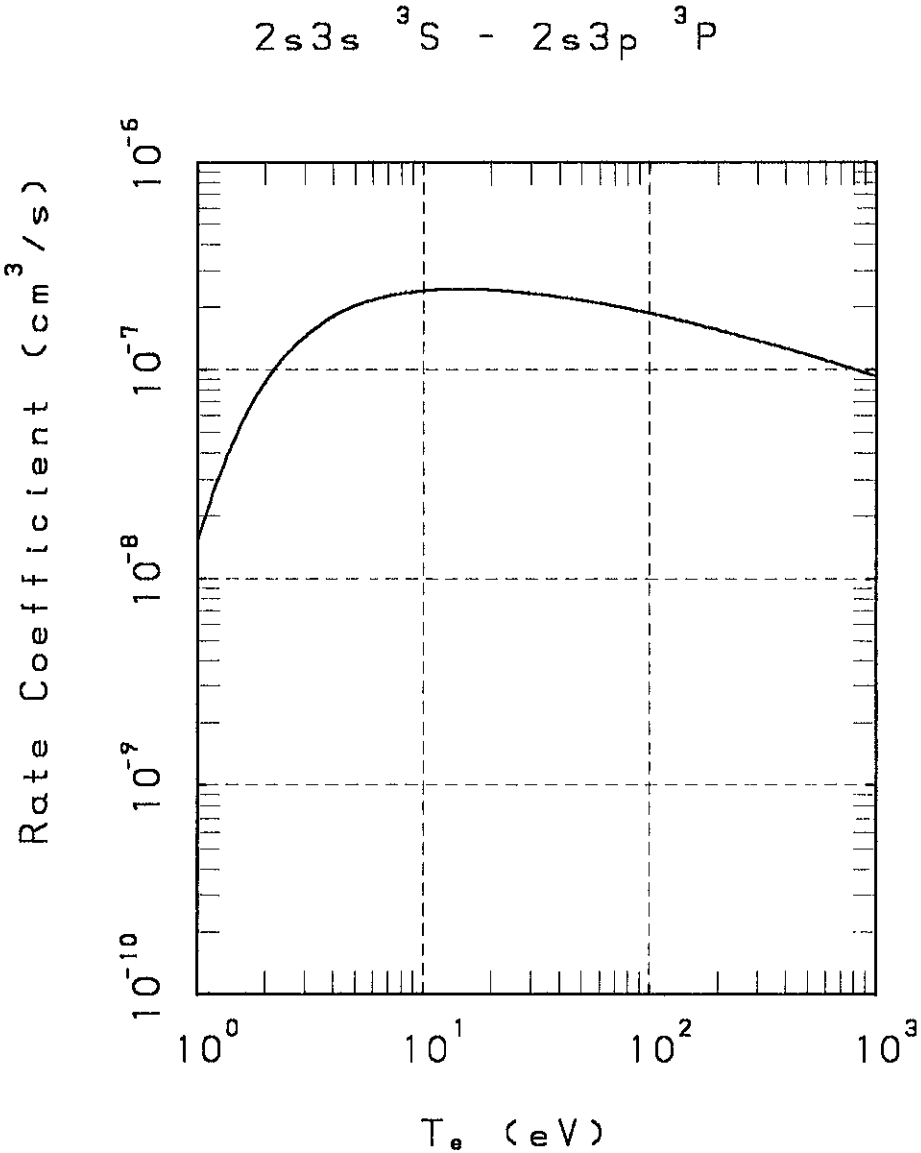

$2p^2\ ^1S - 2s3p\ ^3P$
Rate Coefficient ($cm^3/s$)
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

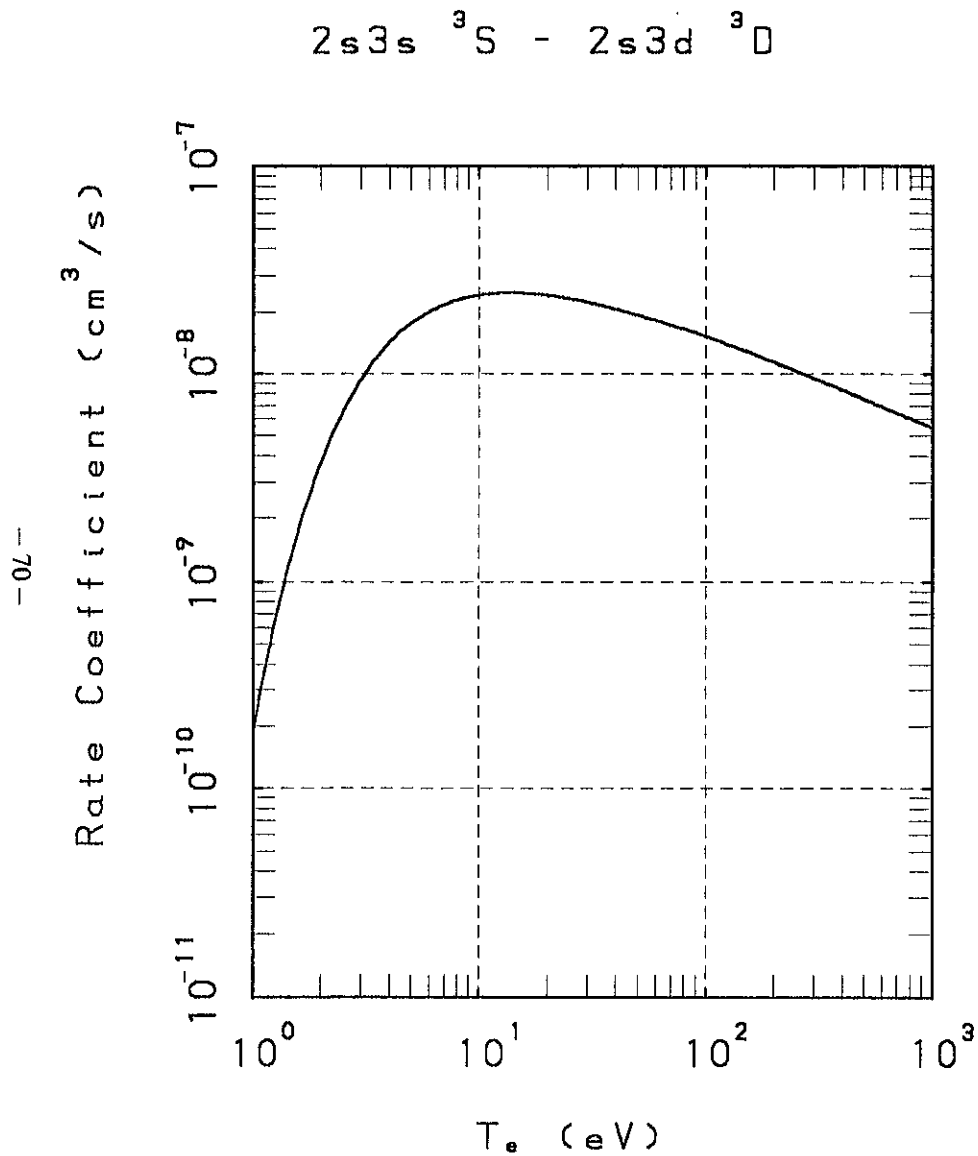

$2p^2\ ^1S - 2s3d\ ^3D$
Rate Coefficient ($cm^3/s$)
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

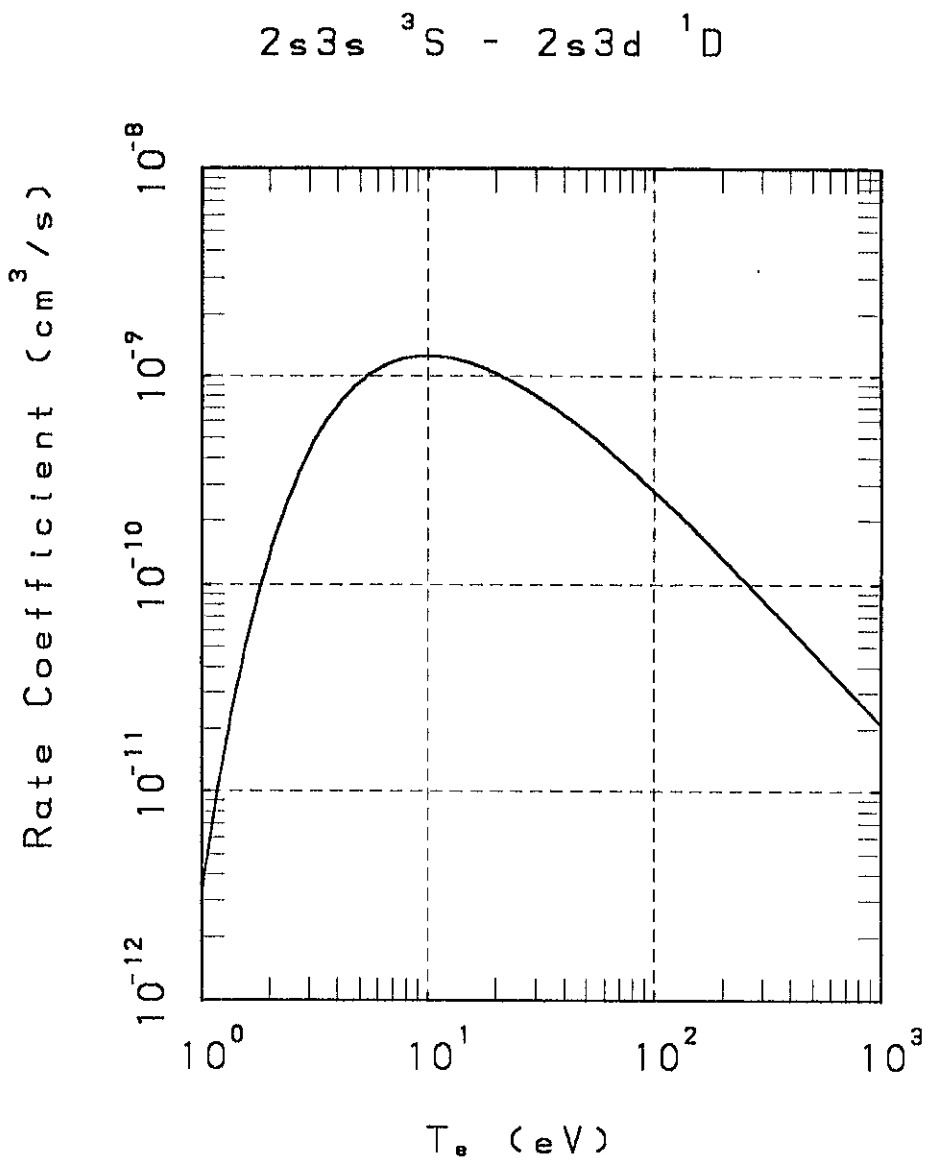

2p² ¹S - 2s3d ¹D
Rate Coefficient (cm³/s)
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁻¹³
10⁰
10¹
10²
10³
Tₑ (eV)

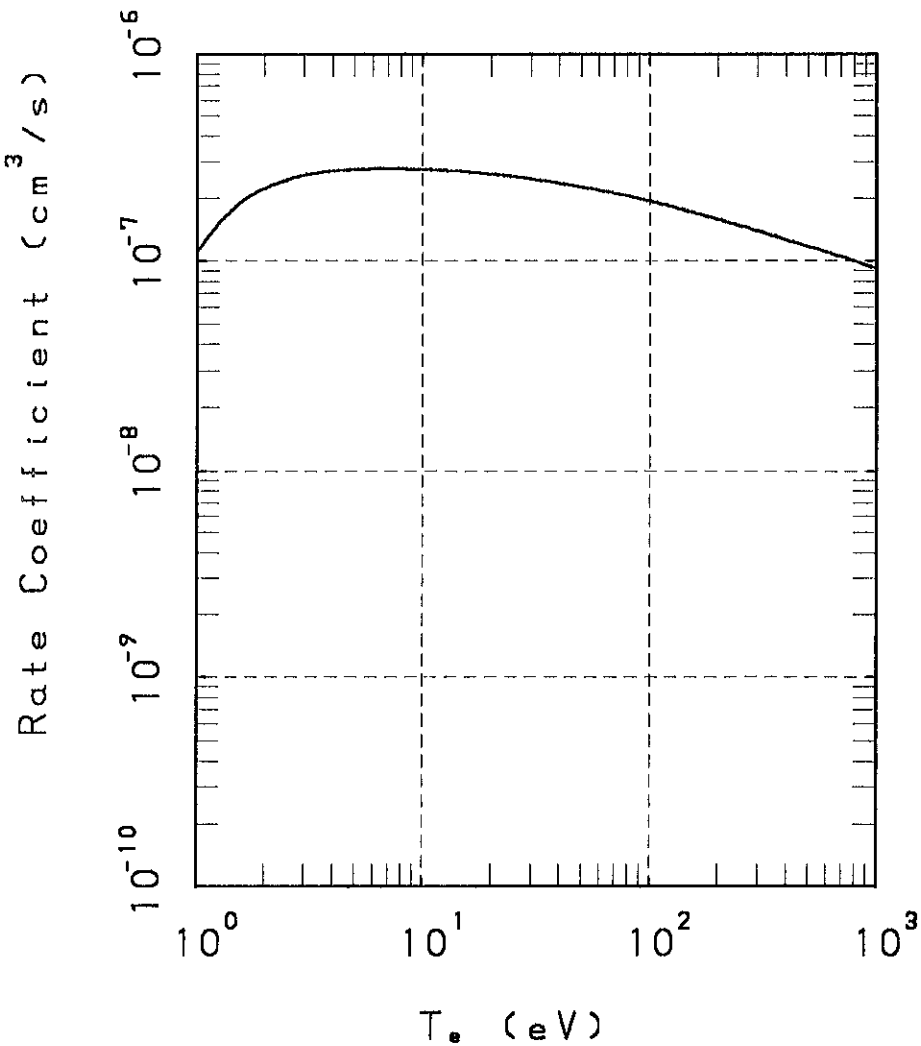

2s3s ³S - 2s3s ¹S
Rate Coefficient (cm³/s)
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁰
10¹
10²
10³
Tₑ (eV)

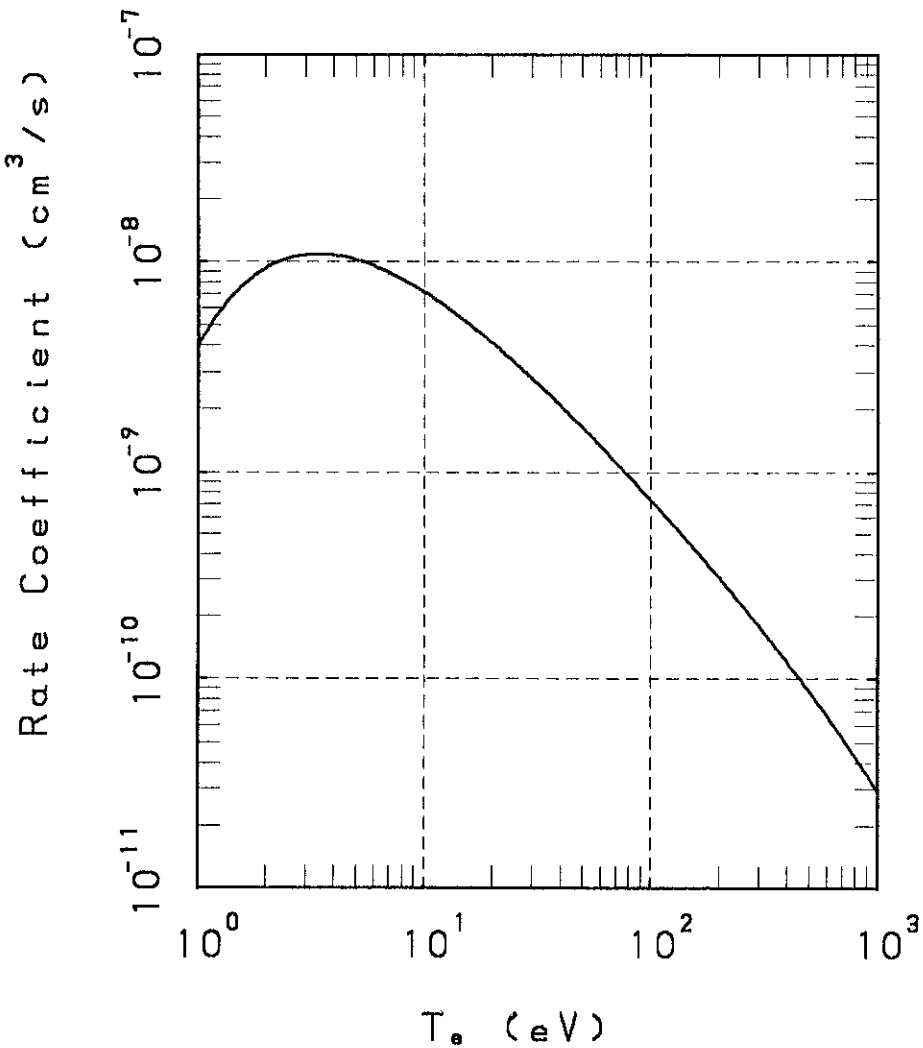

2s3s ³S - 2s3p ¹P
Rate Coefficient (cm³/s)
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁰
10¹
10²
10³
Tₑ (eV)

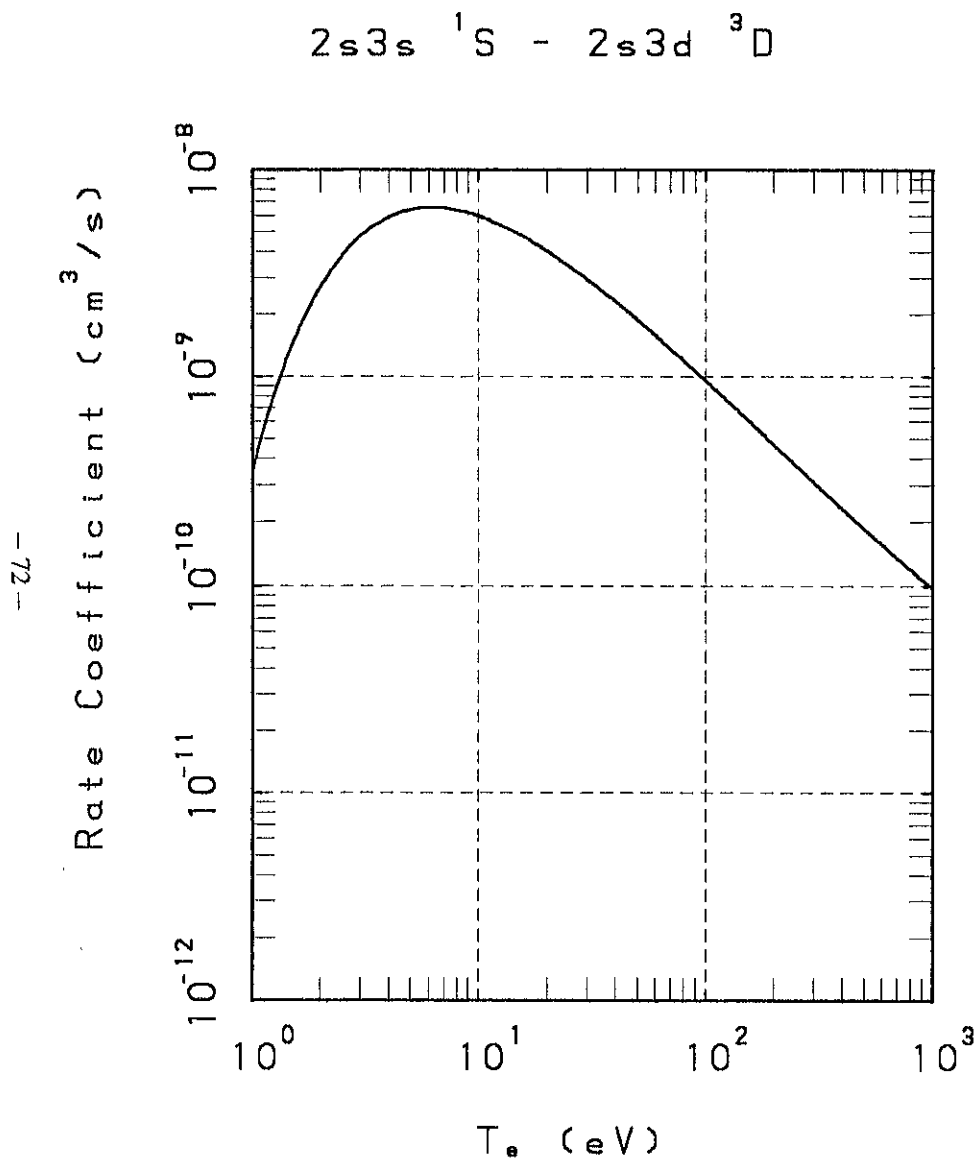

2s3s ³S - 2s3p ³P
Rate Coefficient (cm³/s)
10⁻⁶
10⁻⁷
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁰
10¹
10²
10³
Tₑ (eV)

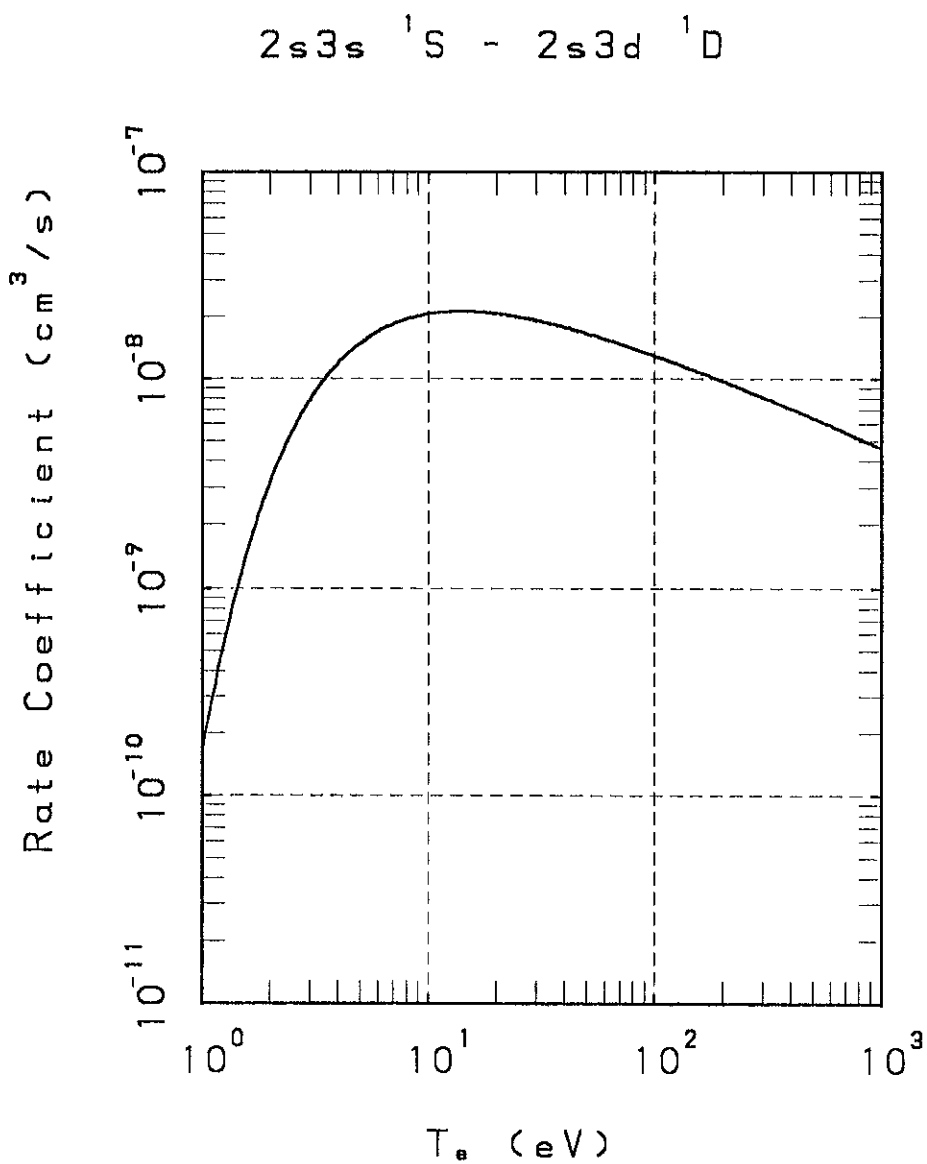

2s3s ³S - 2s3d ³D
Rate Coefficient (cm³/s)
10⁻⁷
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁰
10¹
10²
10³
Tₑ (eV)

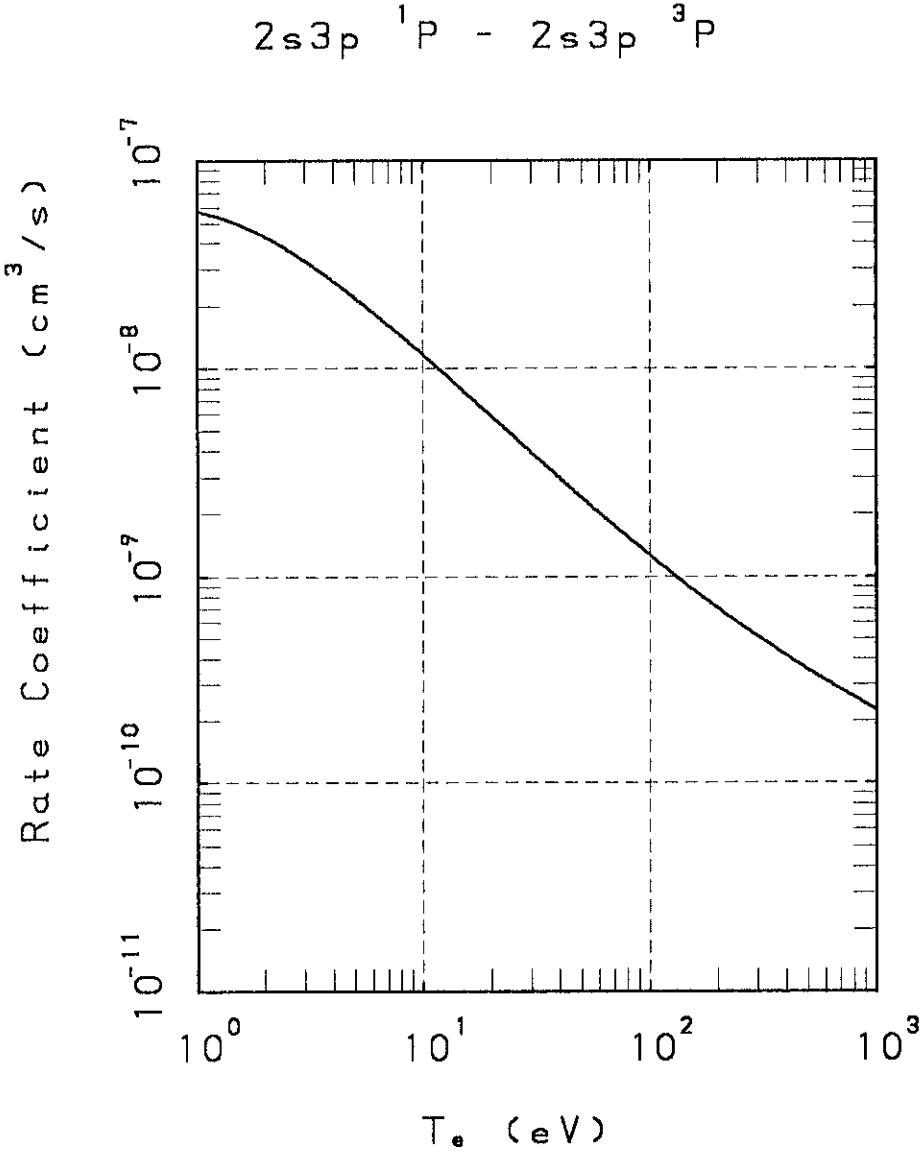

2s3s ³S - 2s3d ¹D
Rate Coefficient (cm³/s)
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁰
10¹
10²
10³
Tₑ (eV)


2s3s ¹S - 2s3p ¹P
Rate Coefficient (cm³/s)
10⁻⁶
10⁻⁷
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁰
10¹
10²
10³
Tₑ (eV)


2s3s ¹S - 2s3p ³P
Rate Coefficient (cm³/s)
10⁻⁷
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁰
10¹
10²
10³
Tₑ (eV)


2s3s ¹S - 2s3d ³D
Rate Coefficient (cm³/s)
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁰
10¹
10²
10³
Tₑ (eV)


2s3s ¹S - 2s3d ¹D
Rate Coefficient (cm³/s)
10⁻⁷
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁰
10¹
10²
10³
Tₑ (eV)


2s3p ¹P - 2s3p ³P
Rate Coefficient (cm³/s)
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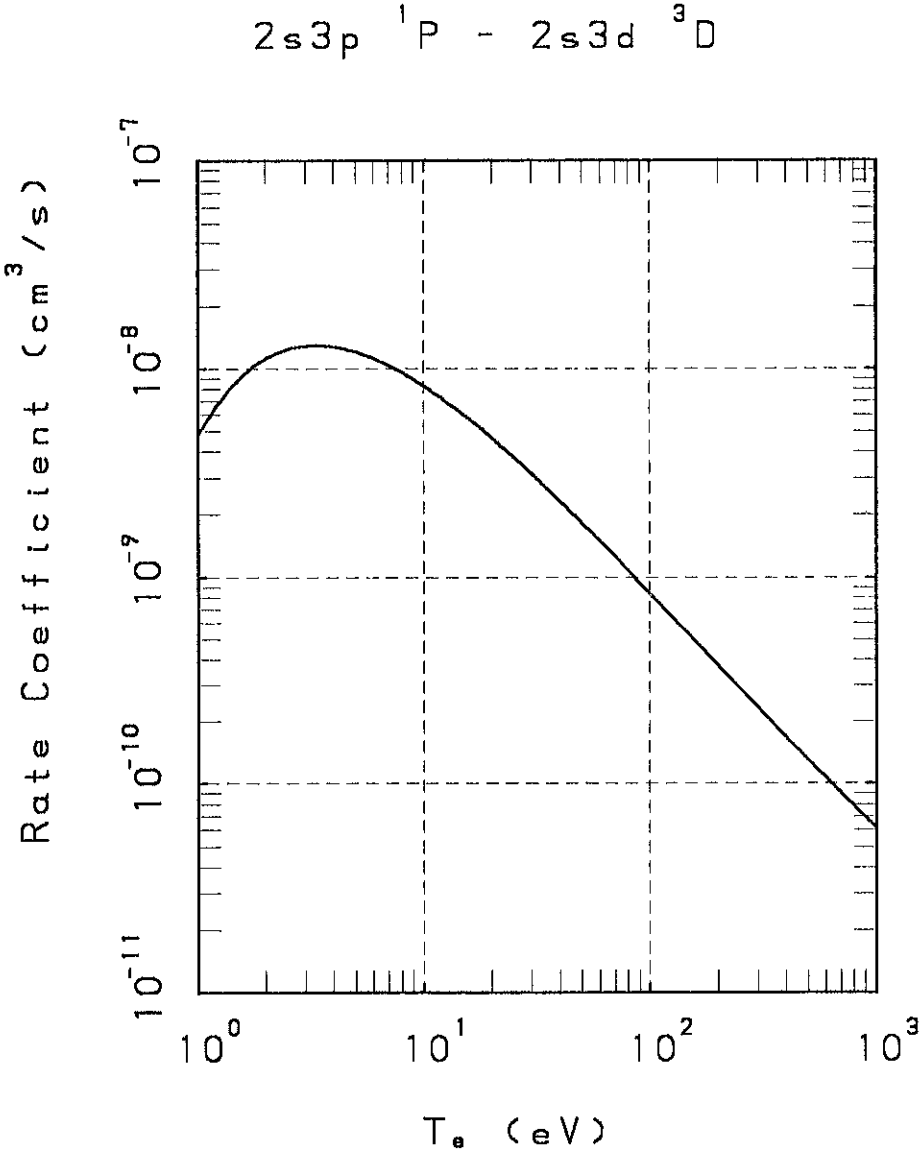
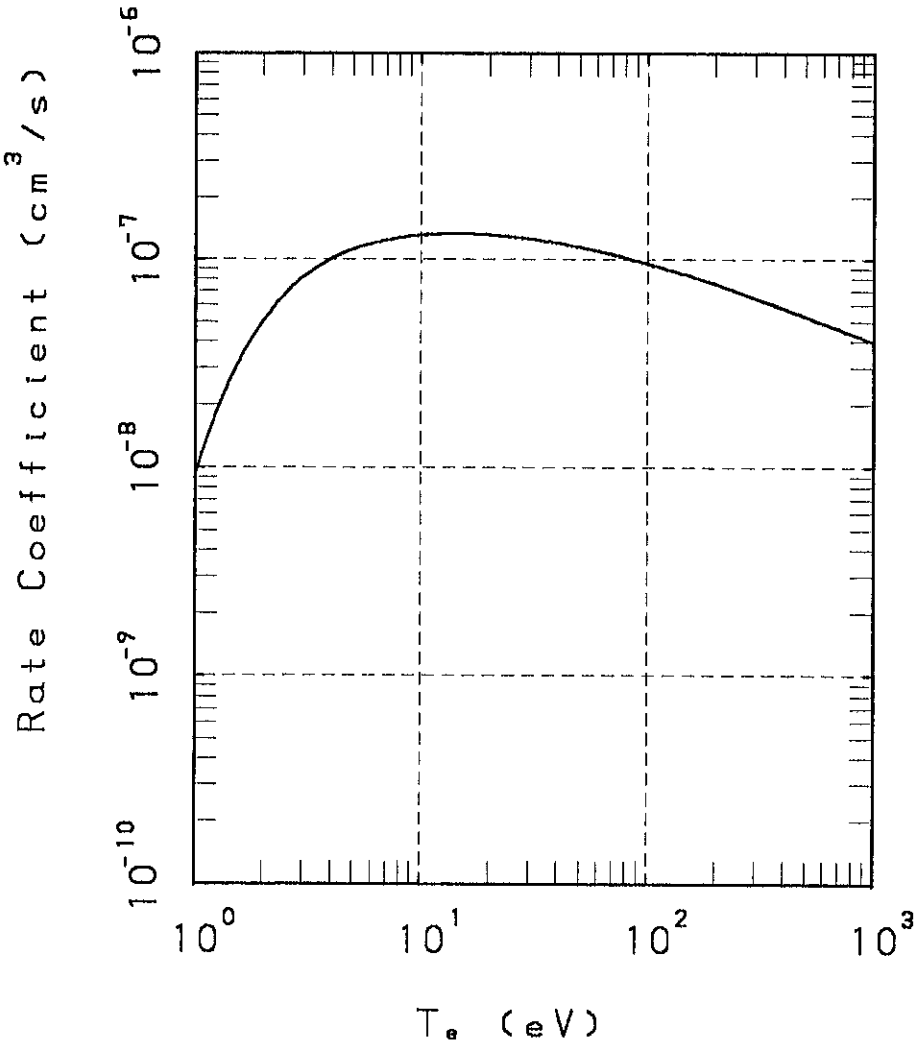
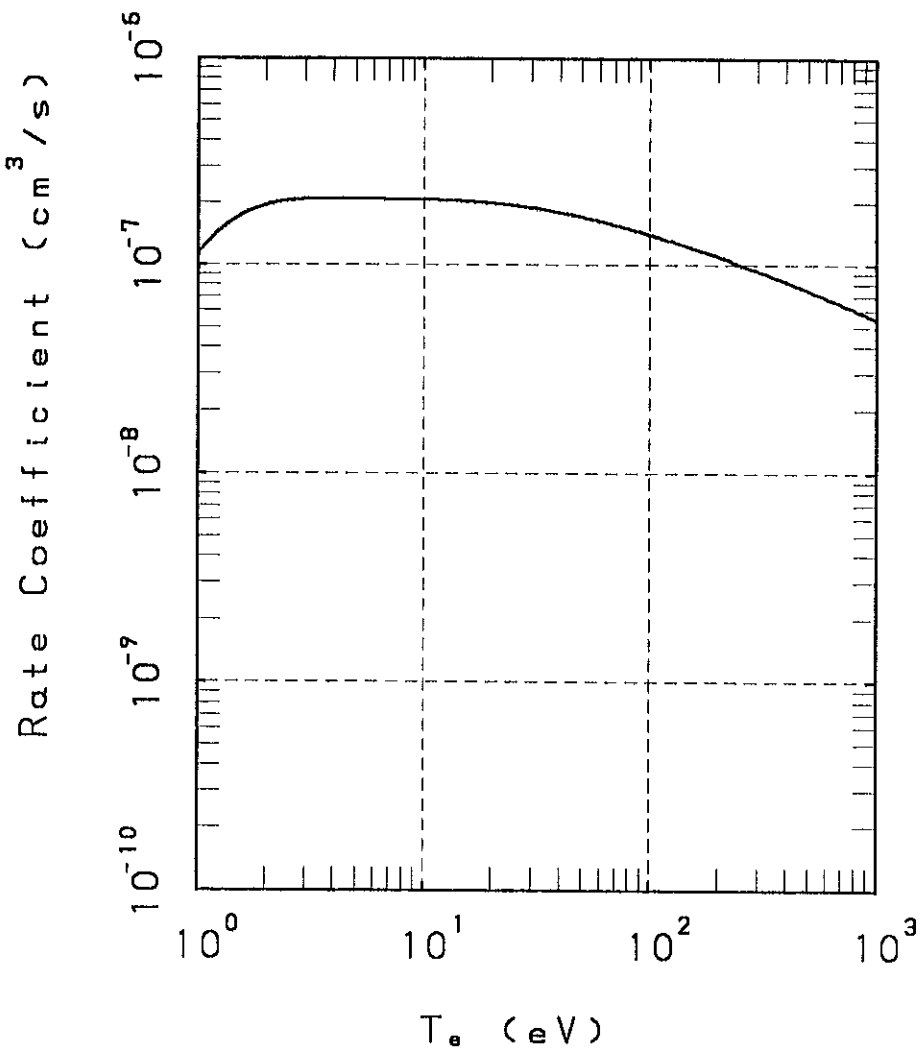
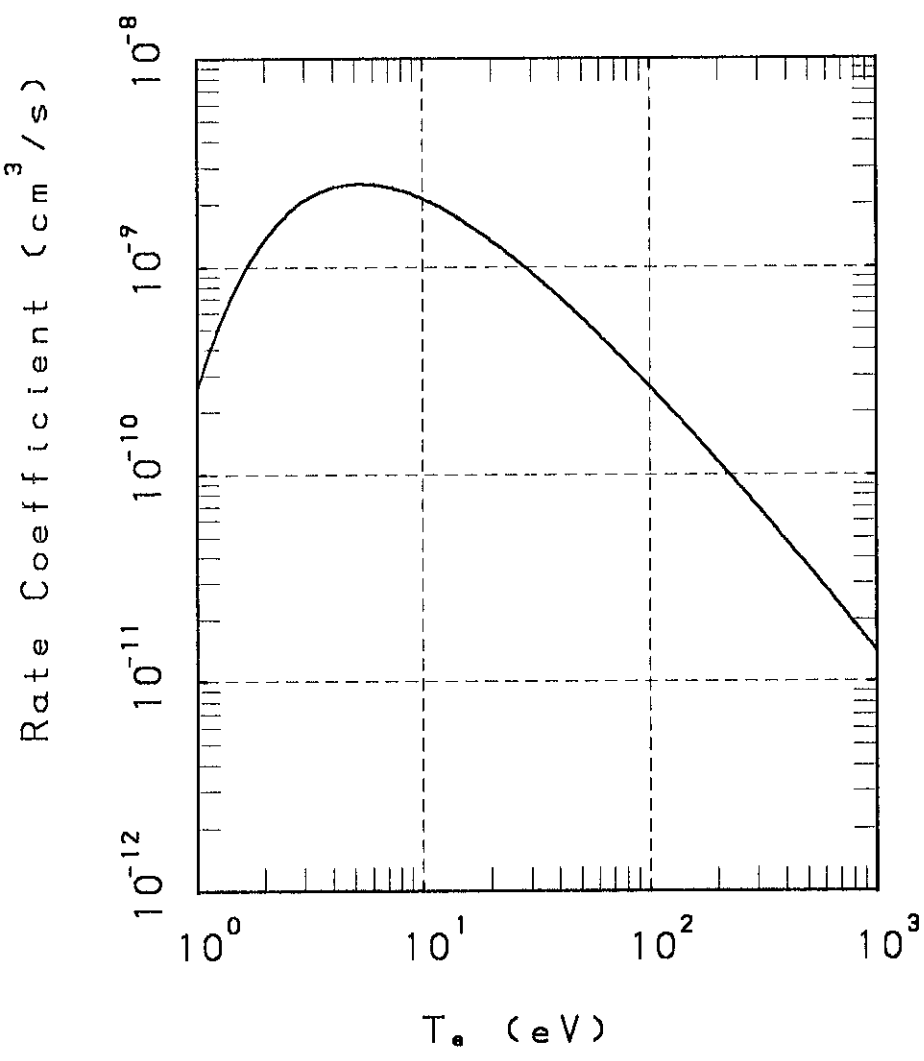
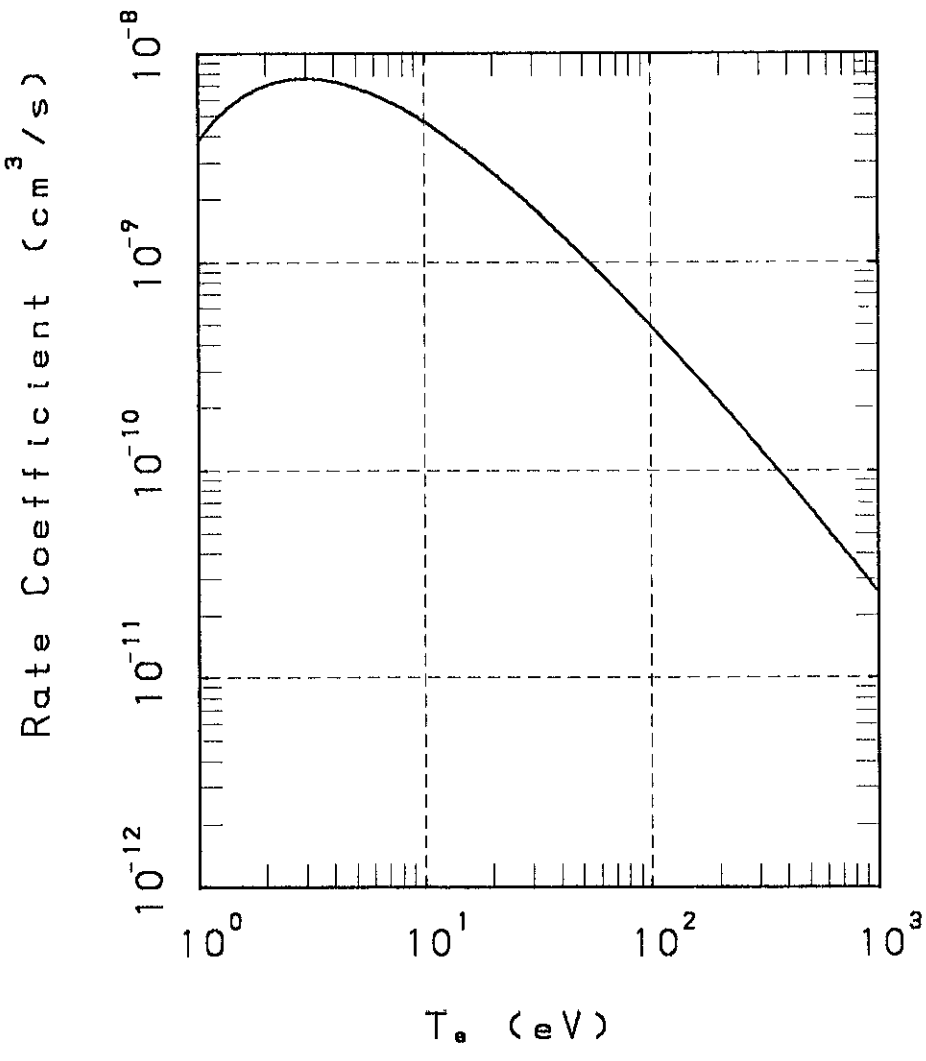
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁰
10¹
10²
10³
Tₑ (eV)

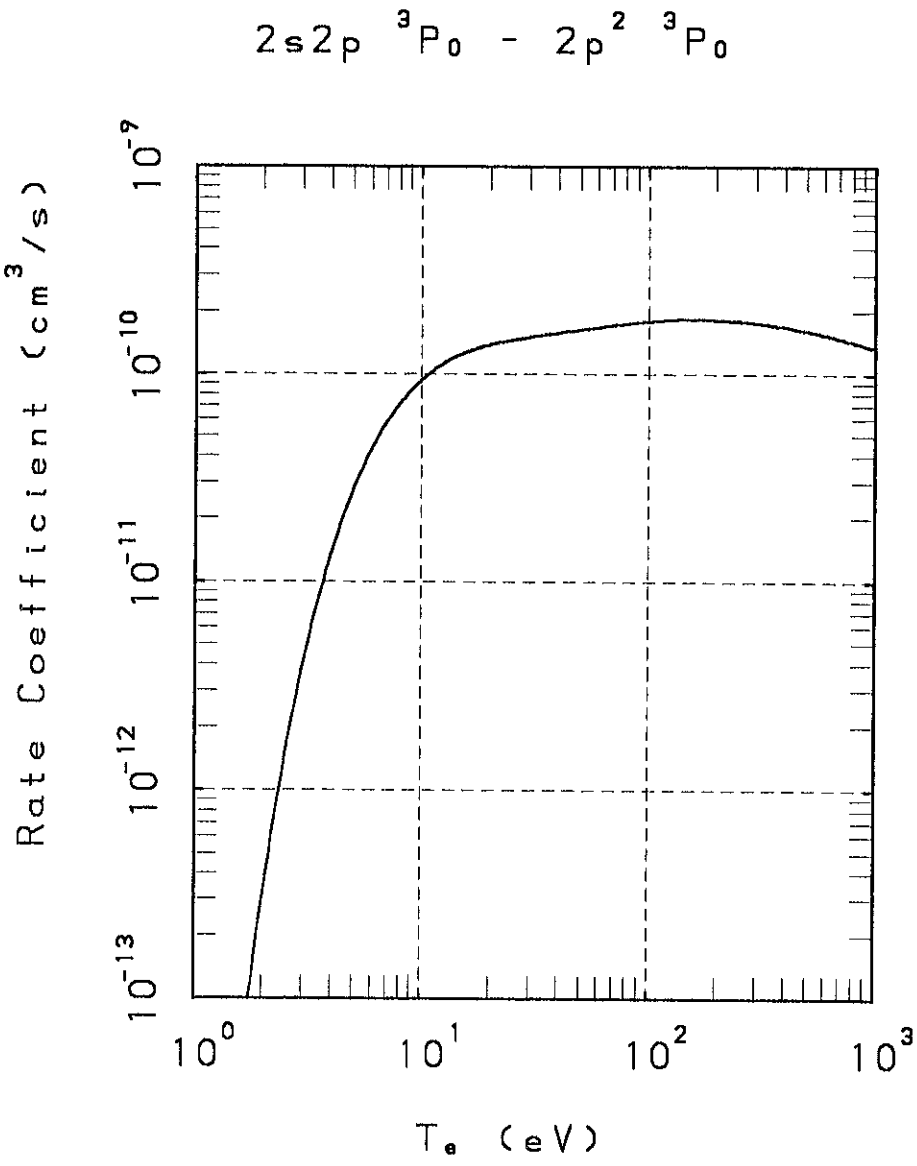

2s3p ¹P - 2s3d ³D
Rate Coefficient (cm³/s)
10⁻⁷
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁰
10¹
10²
10³
Tₑ (eV)

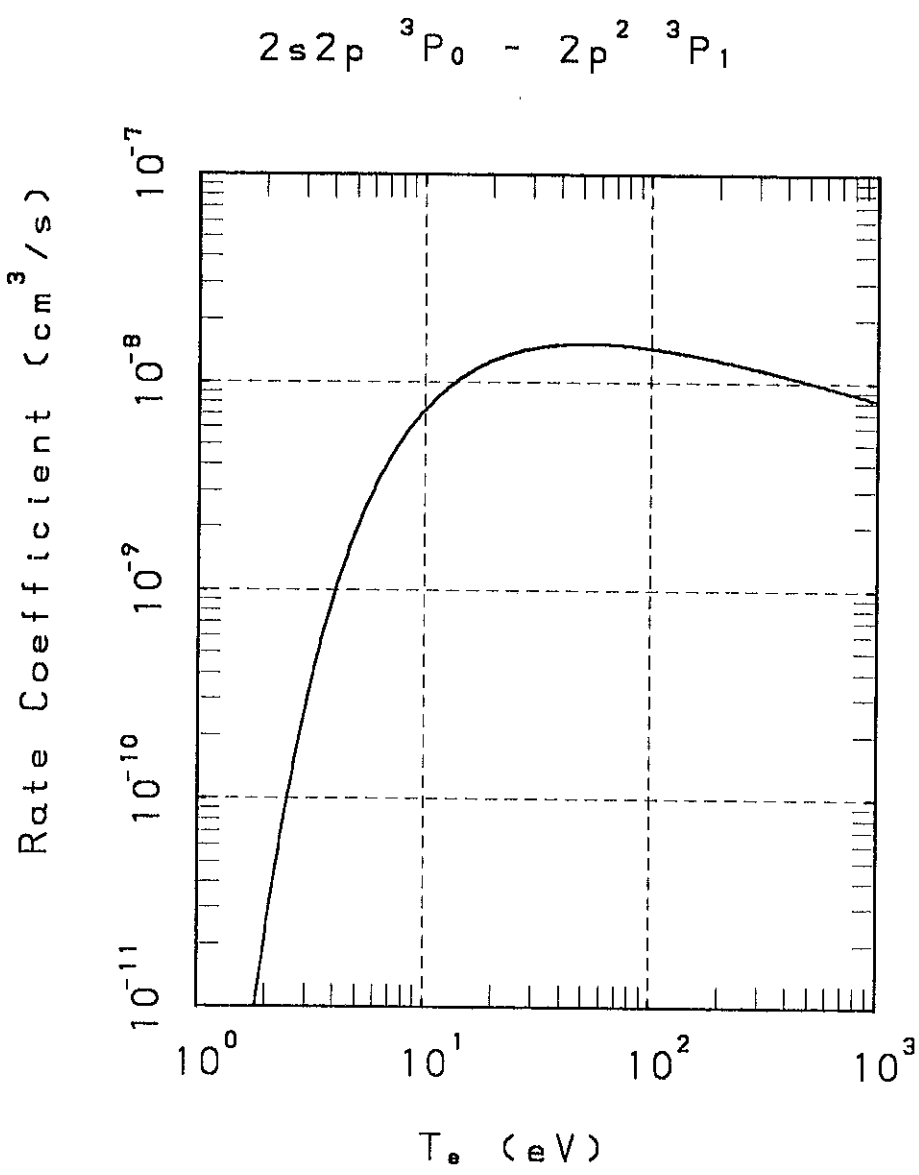

2s3p $^1$P - 2s3d $^1$D
Rate Coefficient (cm$^3$/s)
$10^{-6}$
$10^{-7}$
$10^{-8}$
$10^{-9}$
$10^{-10}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

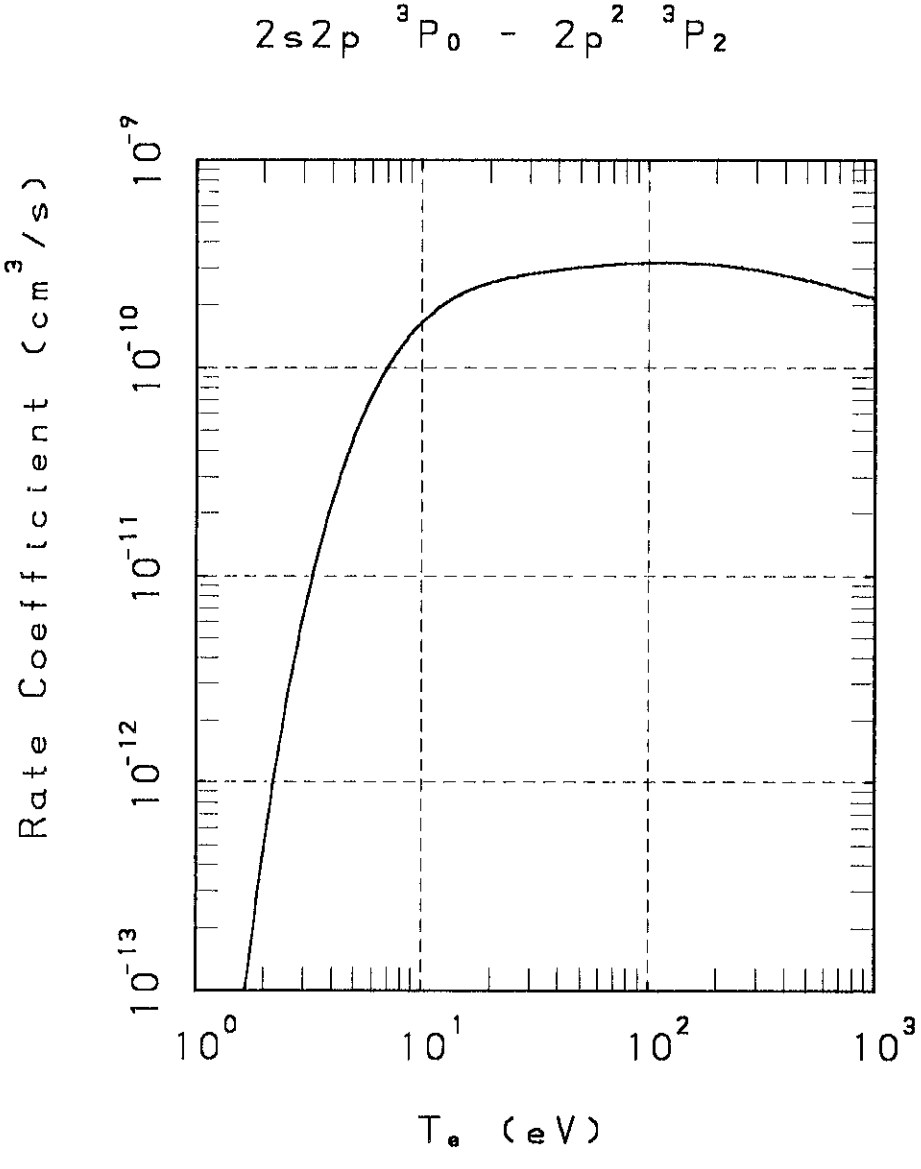

2s3p $^3$P - 2s3d $^3$D
Rate Coefficient (cm$^3$/s)
$10^{-6}$
$10^{-7}$
$10^{-8}$
$10^{-9}$
$10^{-10}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

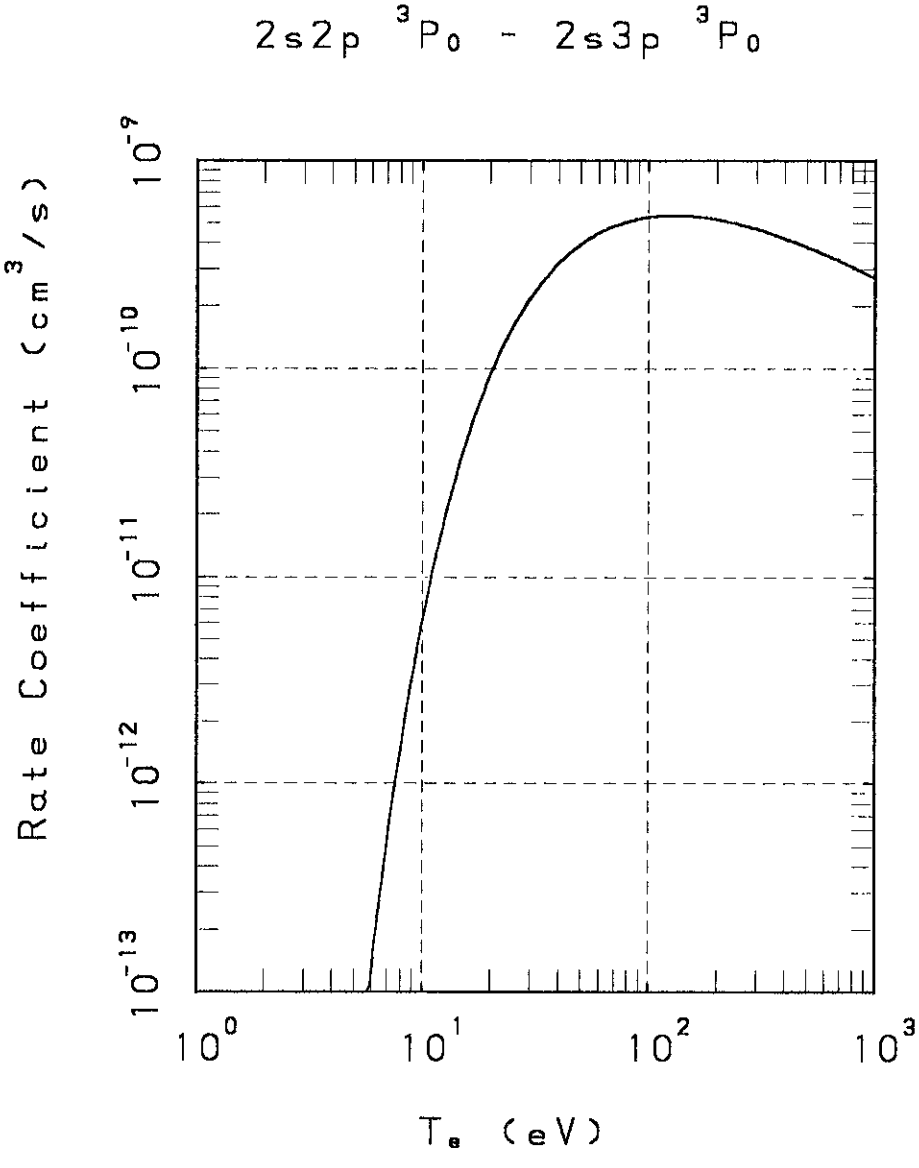

2s3p ³P - 2s3d ¹D
Rate Coefficient (cm³/s)
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁰
10¹
10²
10³
Tₑ (eV)

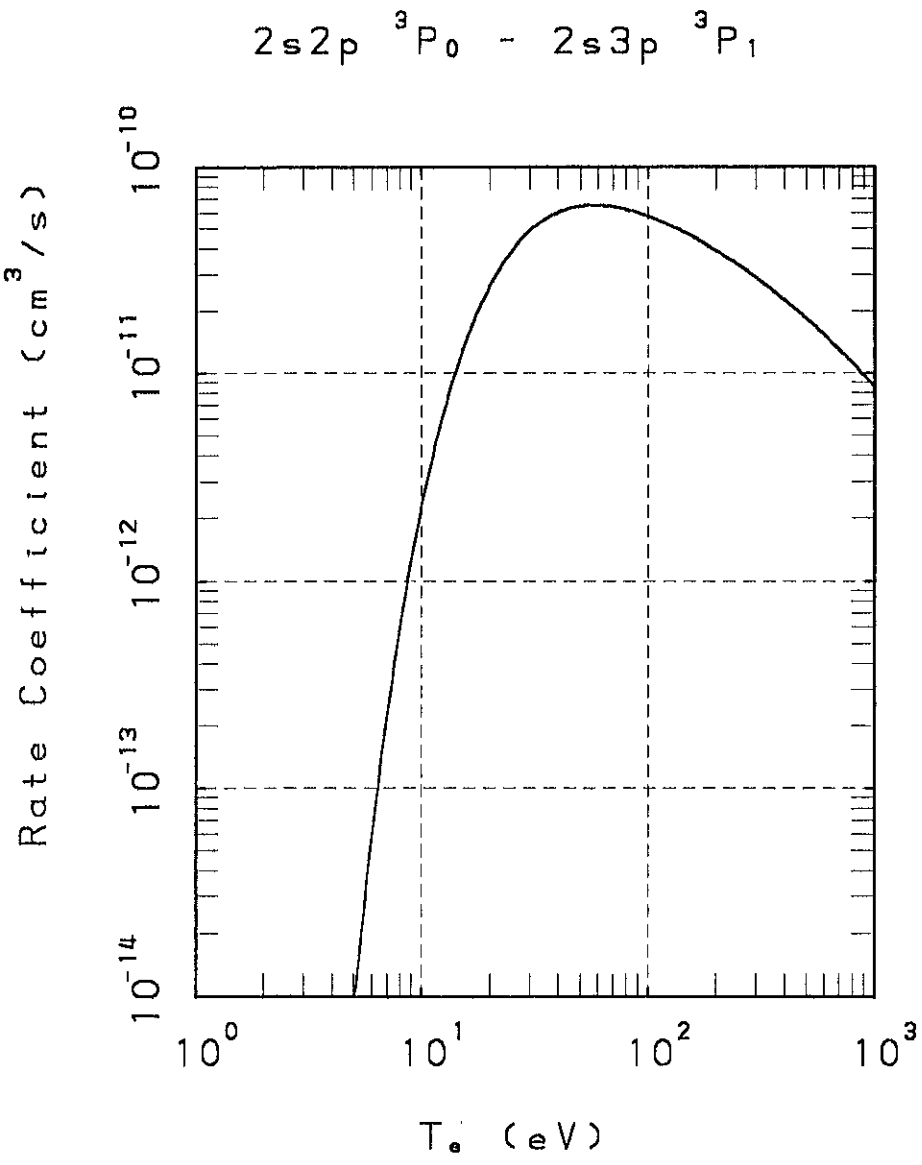

2s3d ³D - 2s3d ¹D
Rate Coefficient (cm³/s)
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁰
10¹
10²
10³
Tₑ (eV)

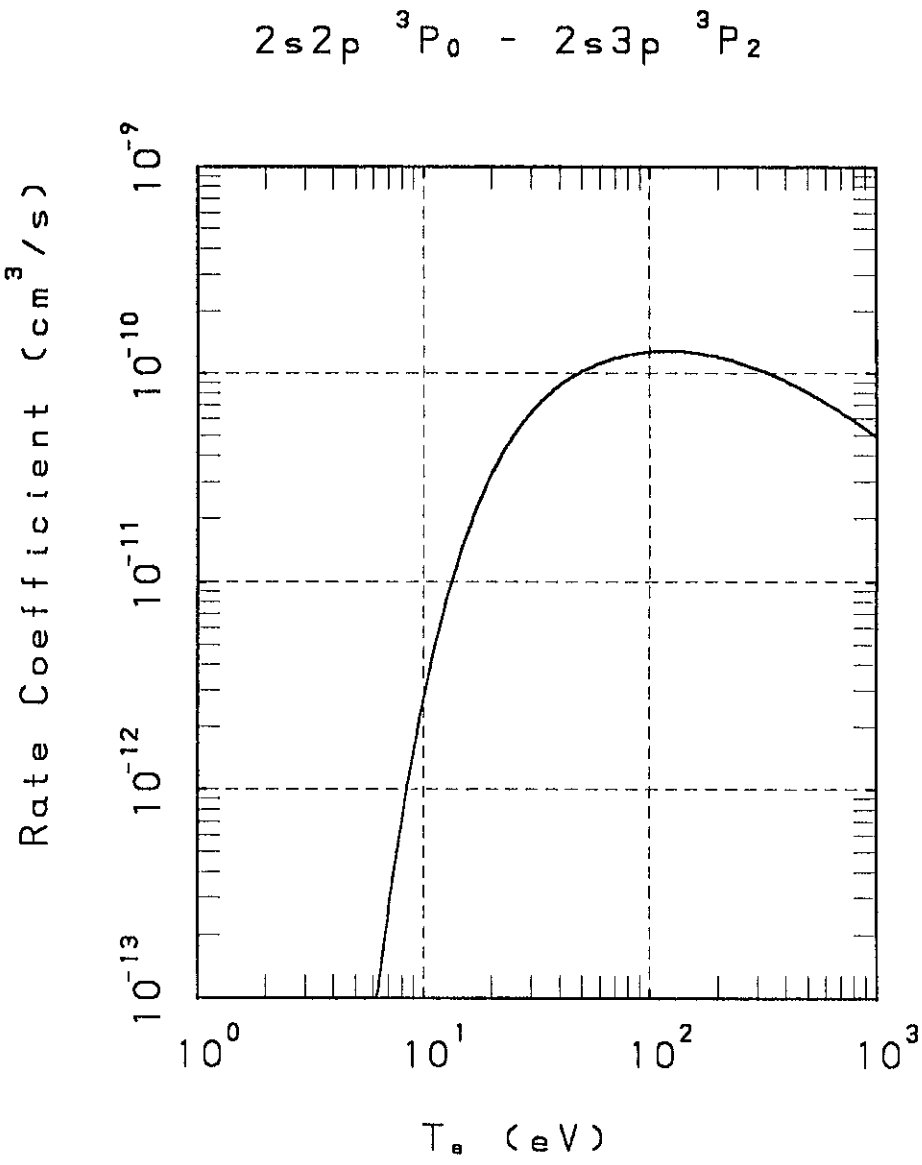

2s2p $^3P_0$ - 2p$^2$ $^3P_0$
Rate Coefficient (cm$^3$/s)
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

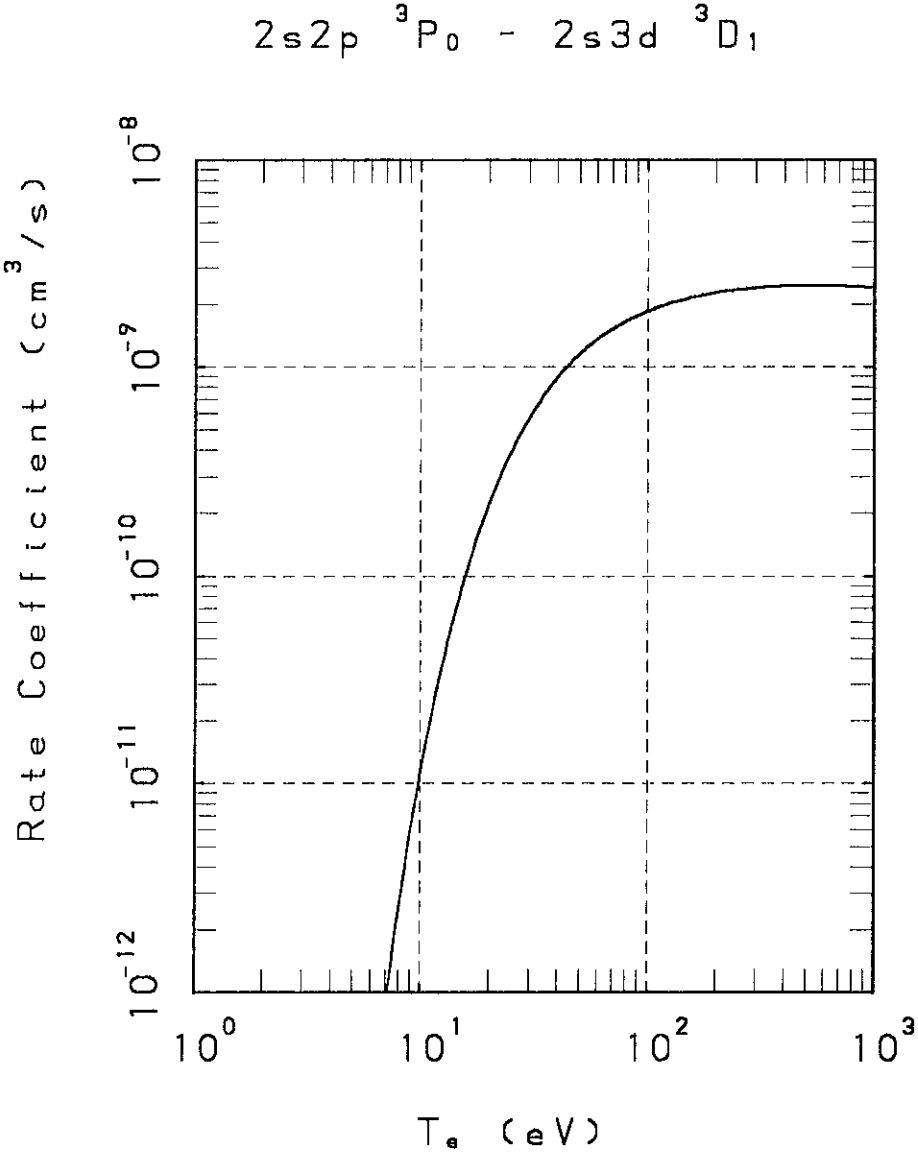

2s2p $^3P_0$ - 2p$^2$ $^3P_1$
Rate Coefficient (cm$^3$/s)
$10^{-7}$
$10^{-8}$
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

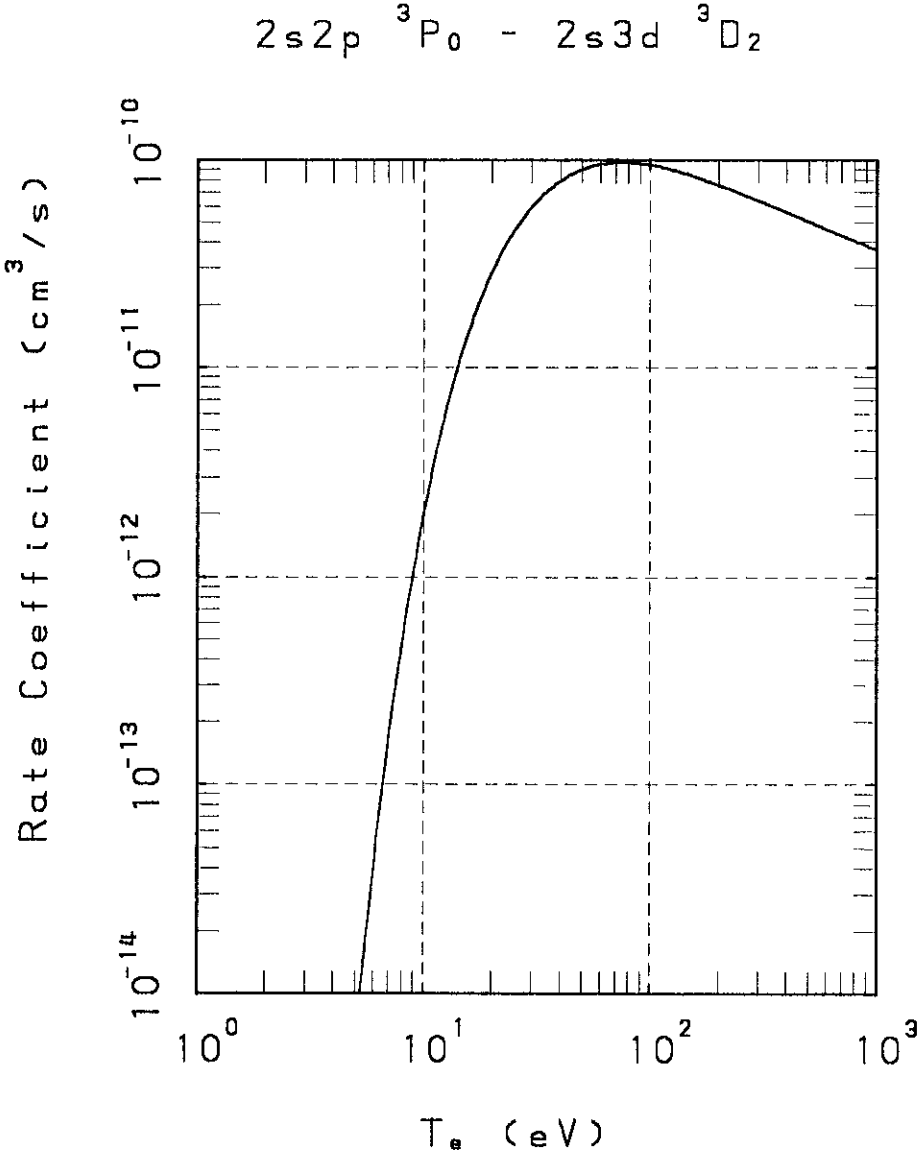

2s2p $^3P_0$ - $2p^2$ $^3P_2$
Rate Coefficient ($cm^3/s$)
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

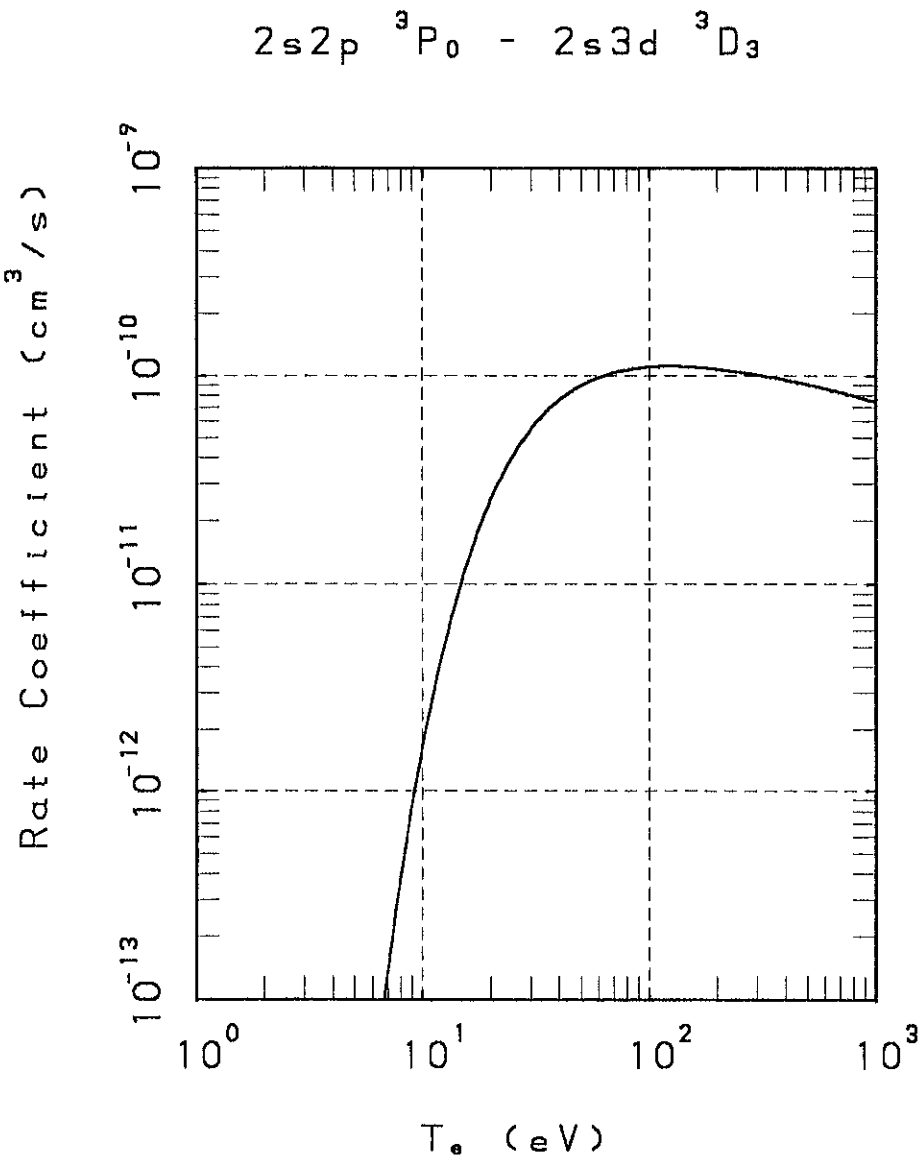

2s2p $^3P_0$ - 2s3p $^3P_0$
Rate Coefficient ($cm^3/s$)
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

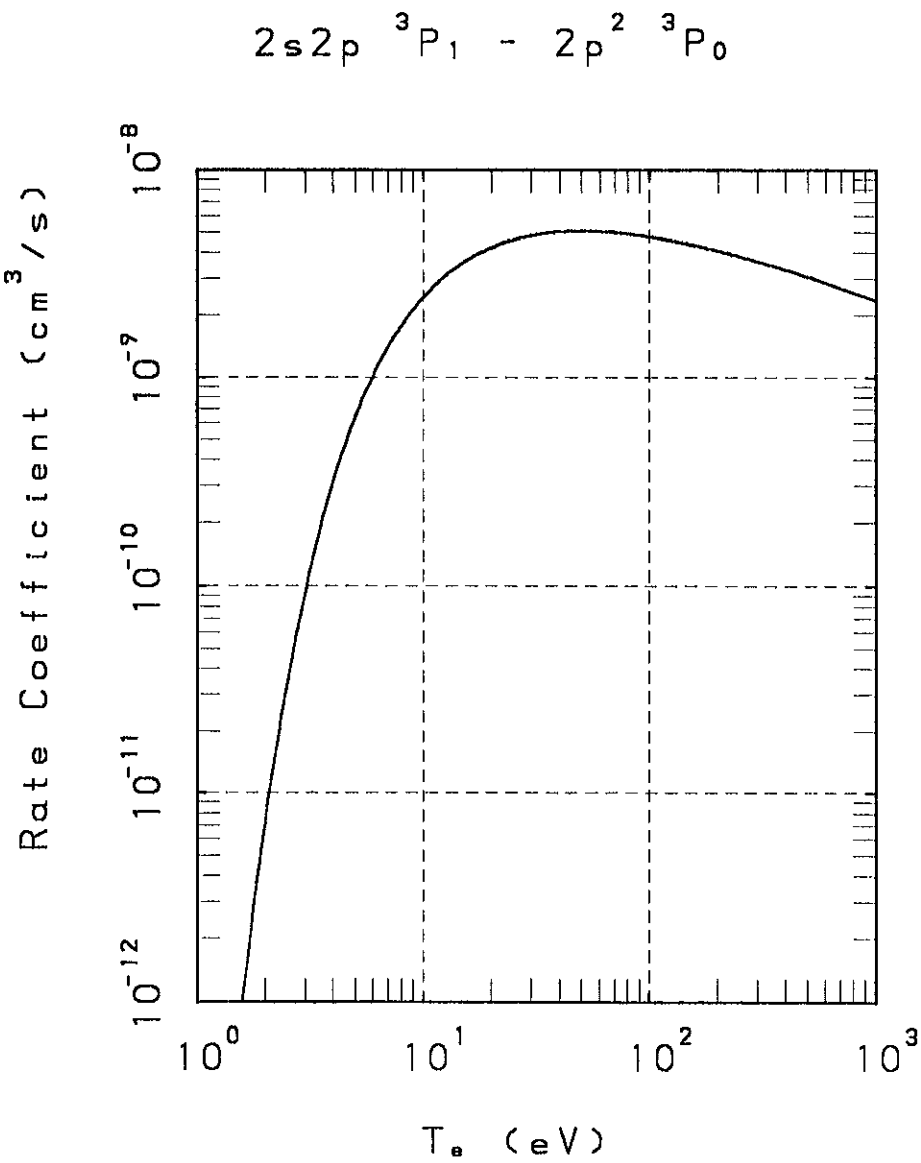

2s2p $^3P_0$ - 2s3p $^3P_1$
Rate Coefficient (cm$^3$/s)
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^{-14}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

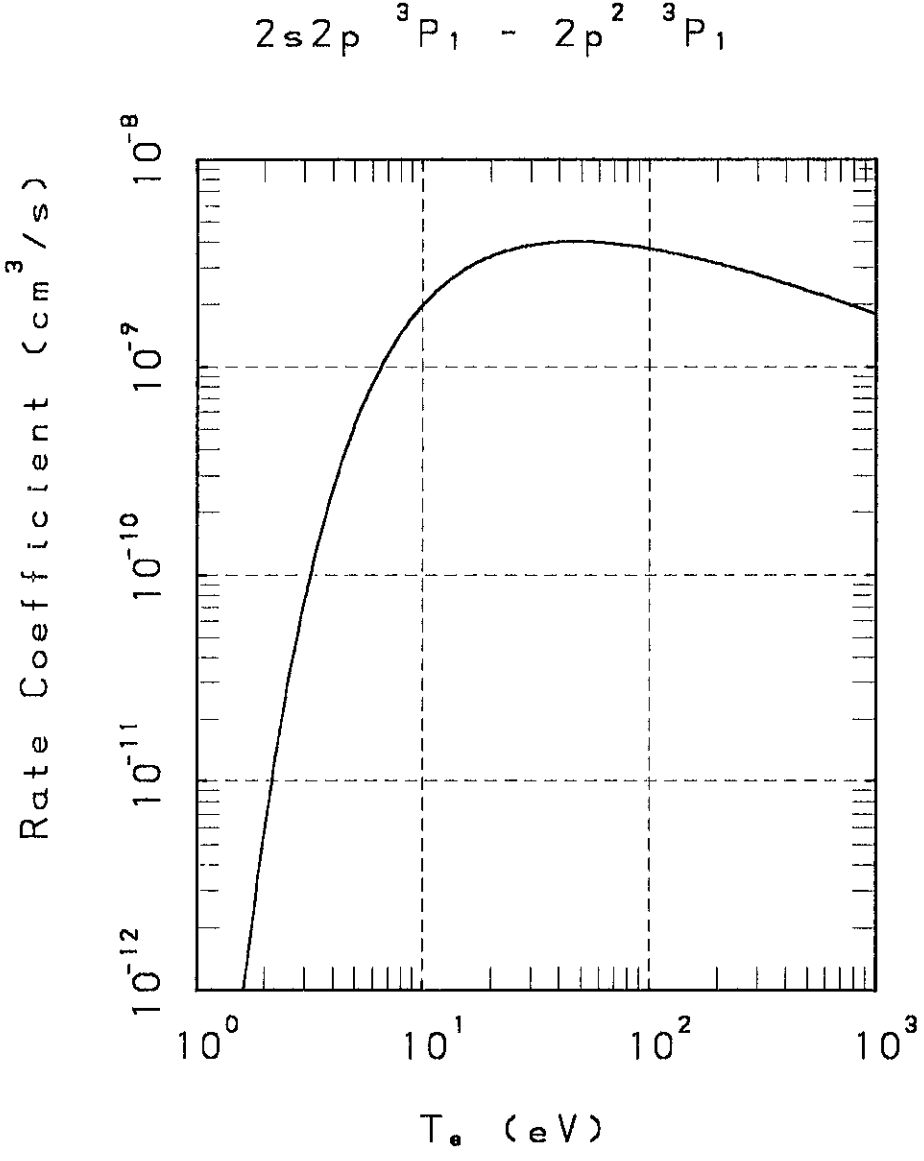

2s2p $^3P_0$ - 2s3p $^3P_2$
Rate Coefficient (cm$^3$/s)
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

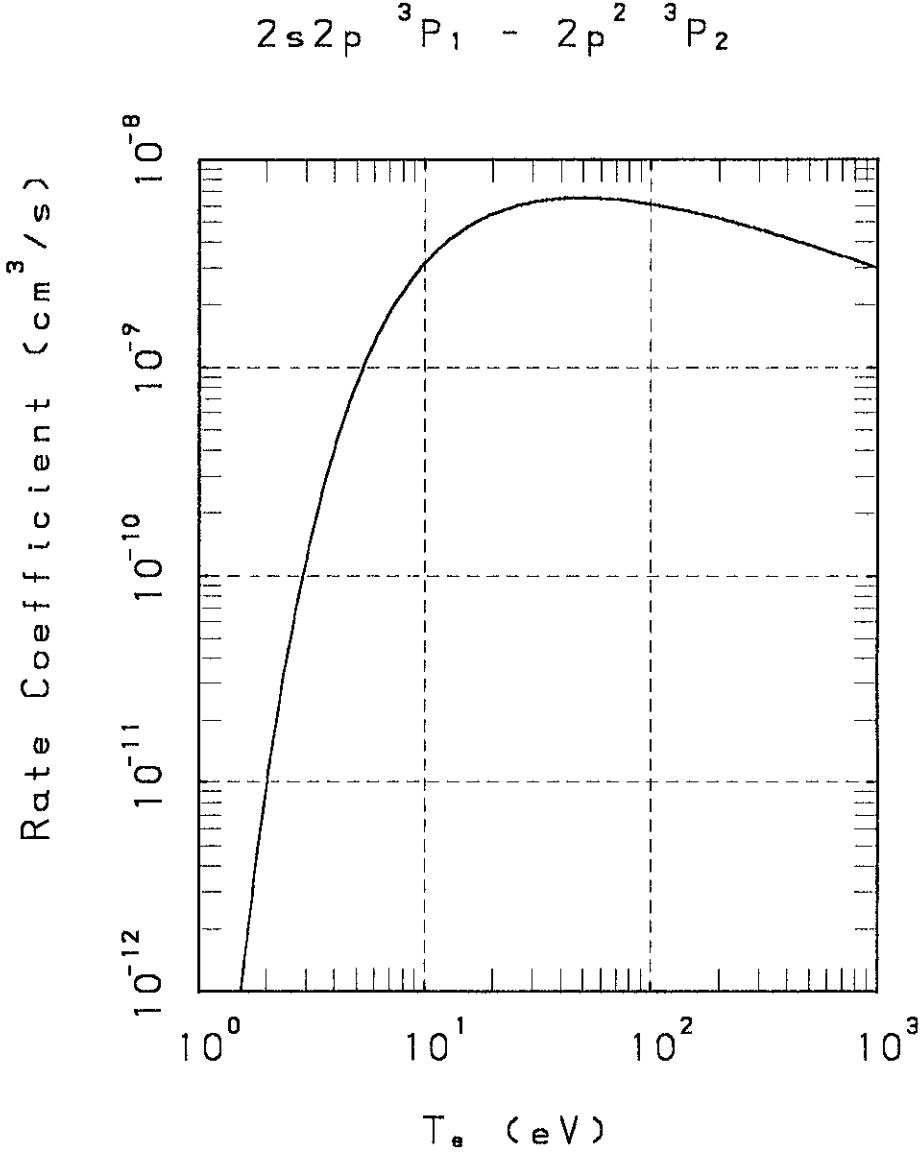

2s2p $^3P_0$ - 2s3d $^3D_1$
Rate Coefficient ($cm^3/s$)
$10^{-8}$
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

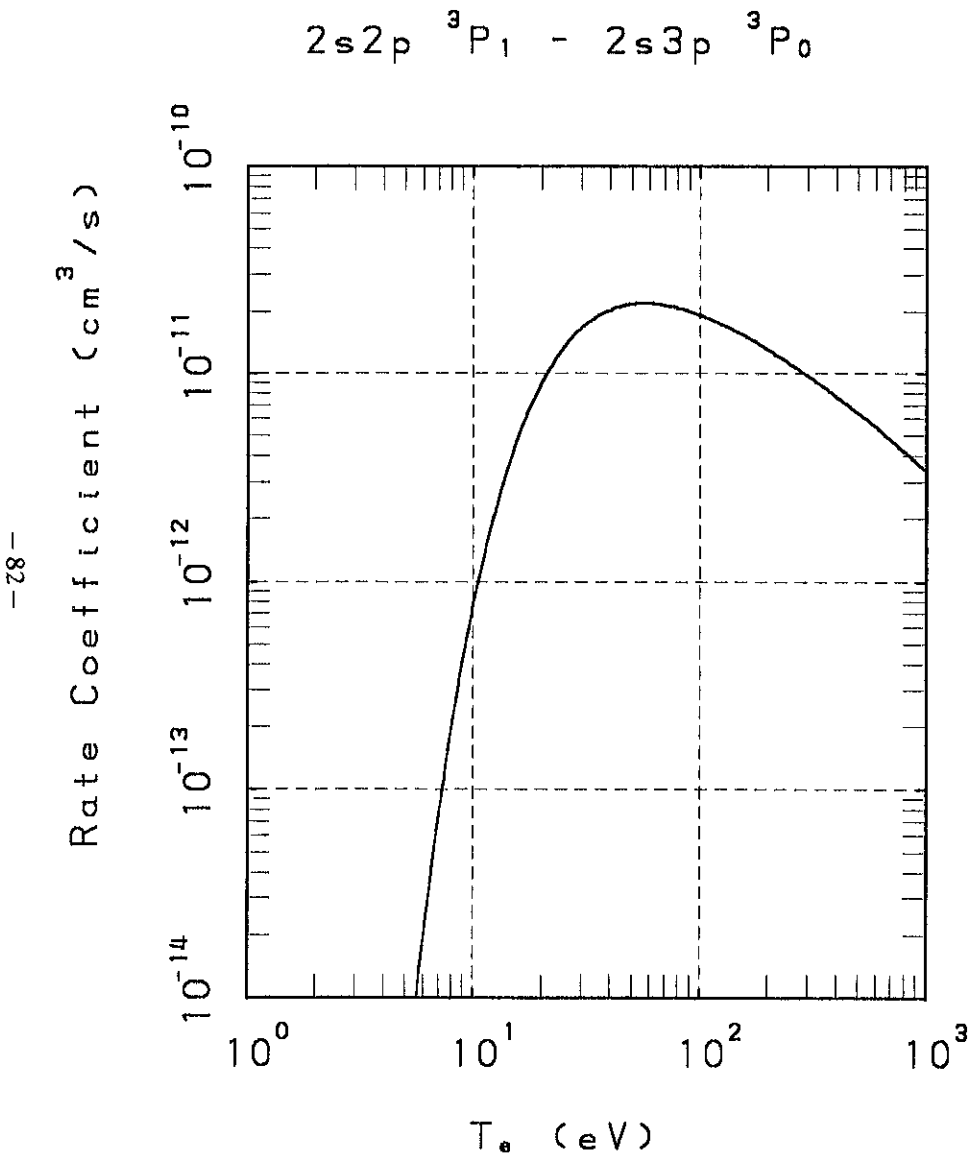

2s2p $^3P_0$ - 2s3d $^3D_2$
Rate Coefficient ($cm^3/s$)
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^{-14}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

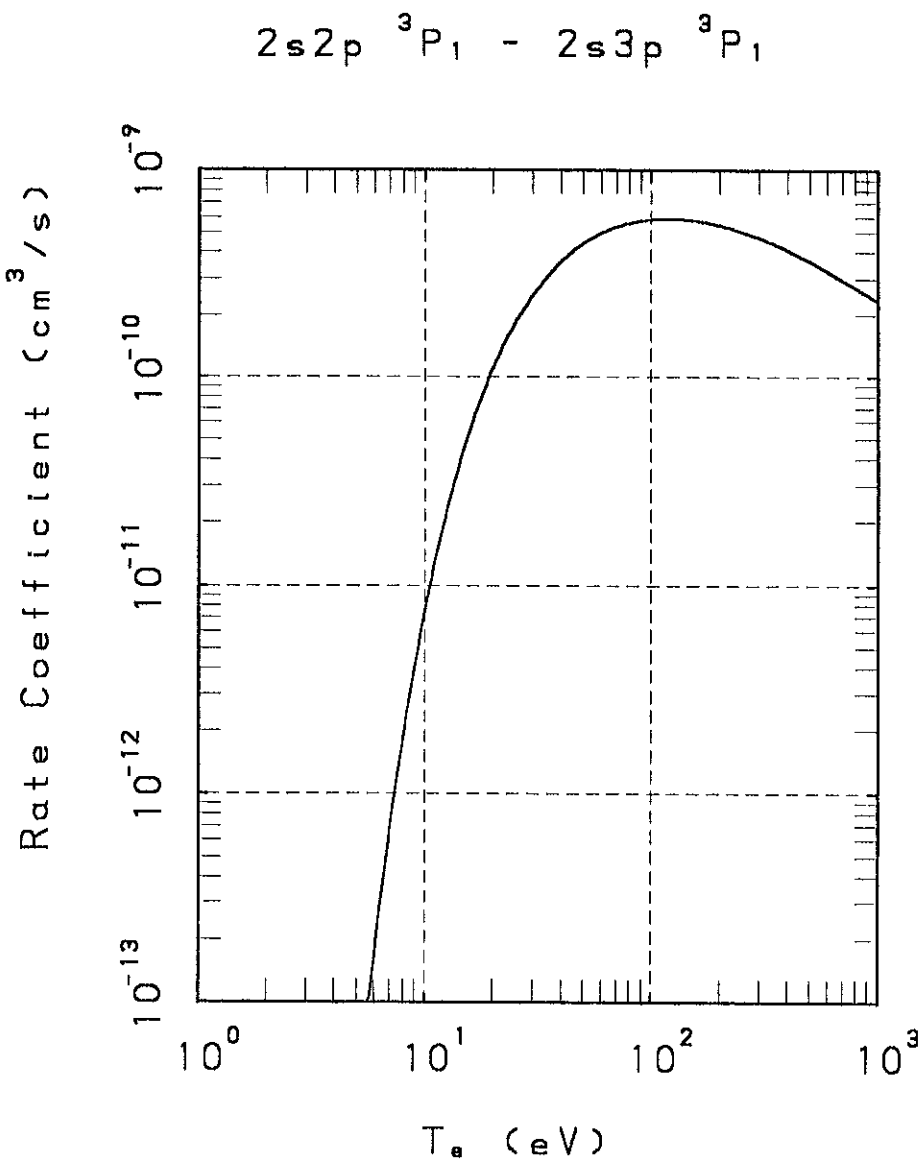

2s2p ³P₀ - 2s3d ³D₃
Rate Coefficient (cm³/s)
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁻¹³
10⁰
10¹
10²
10³
Tₑ (eV)

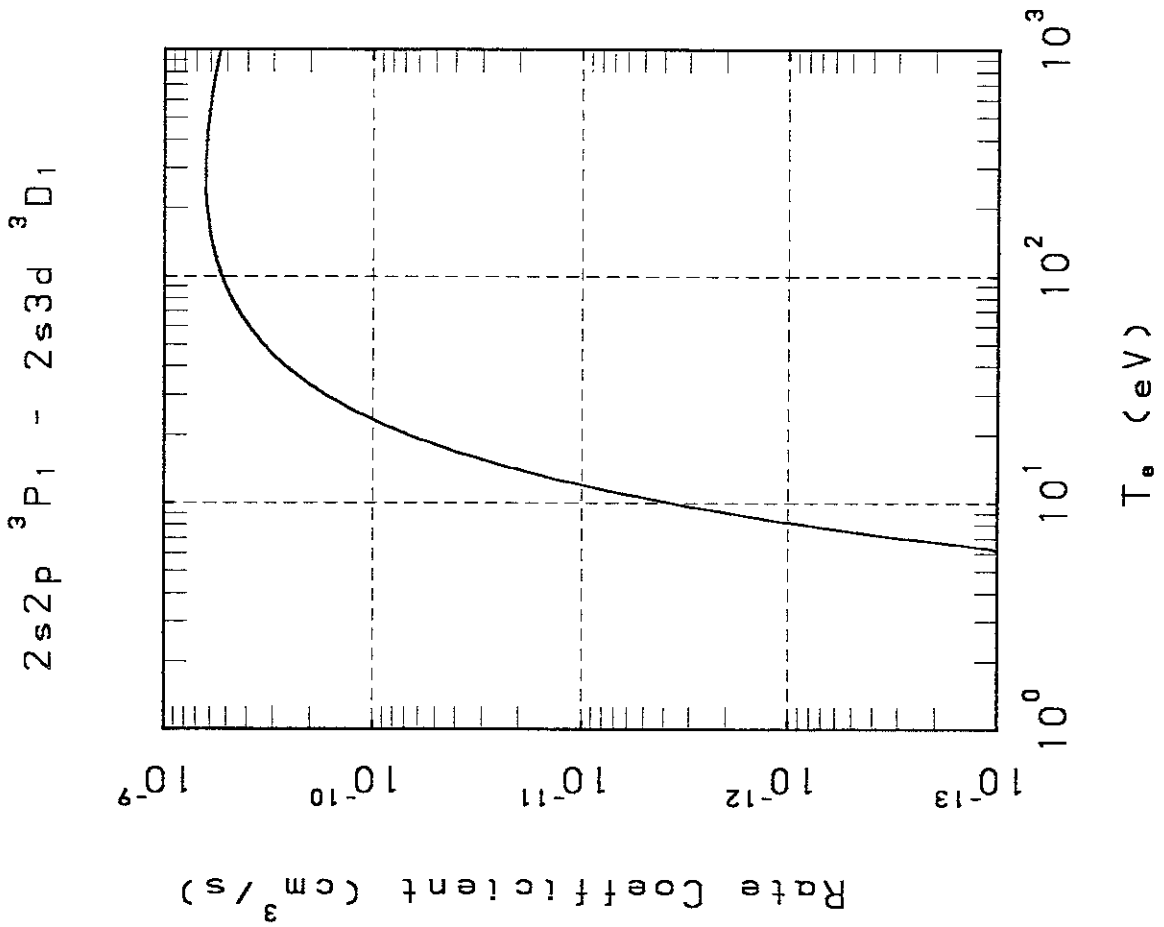

2s2p ³P₁ - 2p² ³P₀
Rate Coefficient (cm³/s)
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁰
10¹
10²
10³
Tₑ (eV)

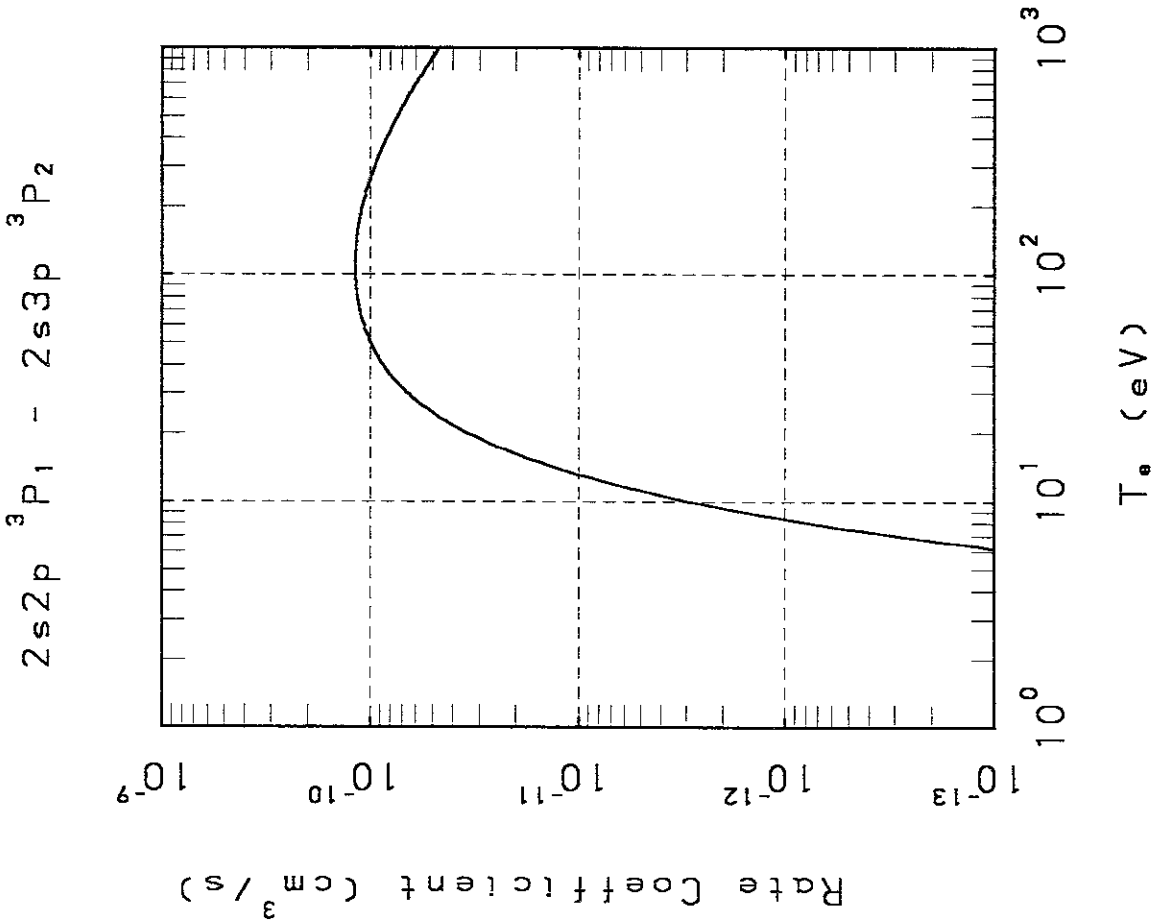

2s2p $^3P_1$ - $2p^2$ $^3P_1$
Rate Coefficient (cm$^3$/s)
$10^{-8}$
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

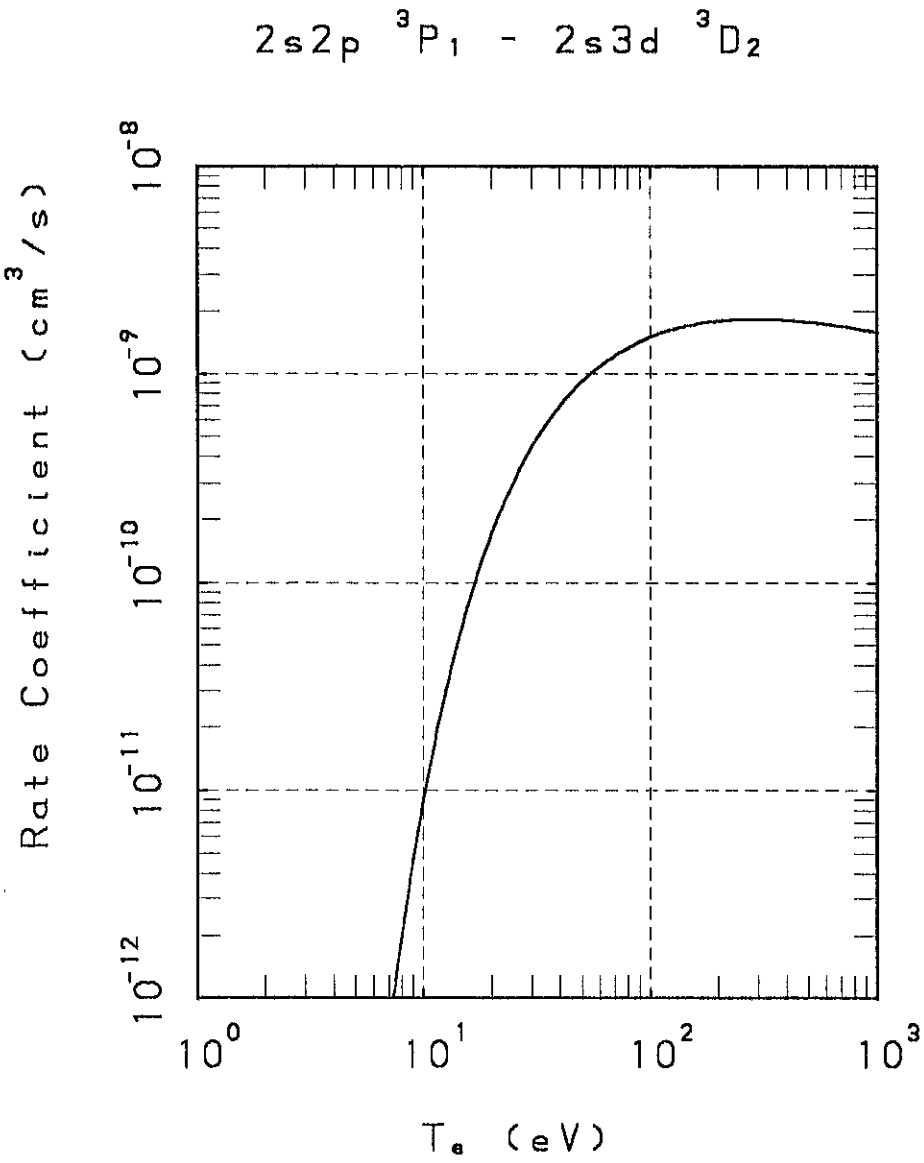

2s2p $^3P_1$ - $2p^2$ $^3P_2$
Rate Coefficient (cm$^3$/s)
$10^{-8}$
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

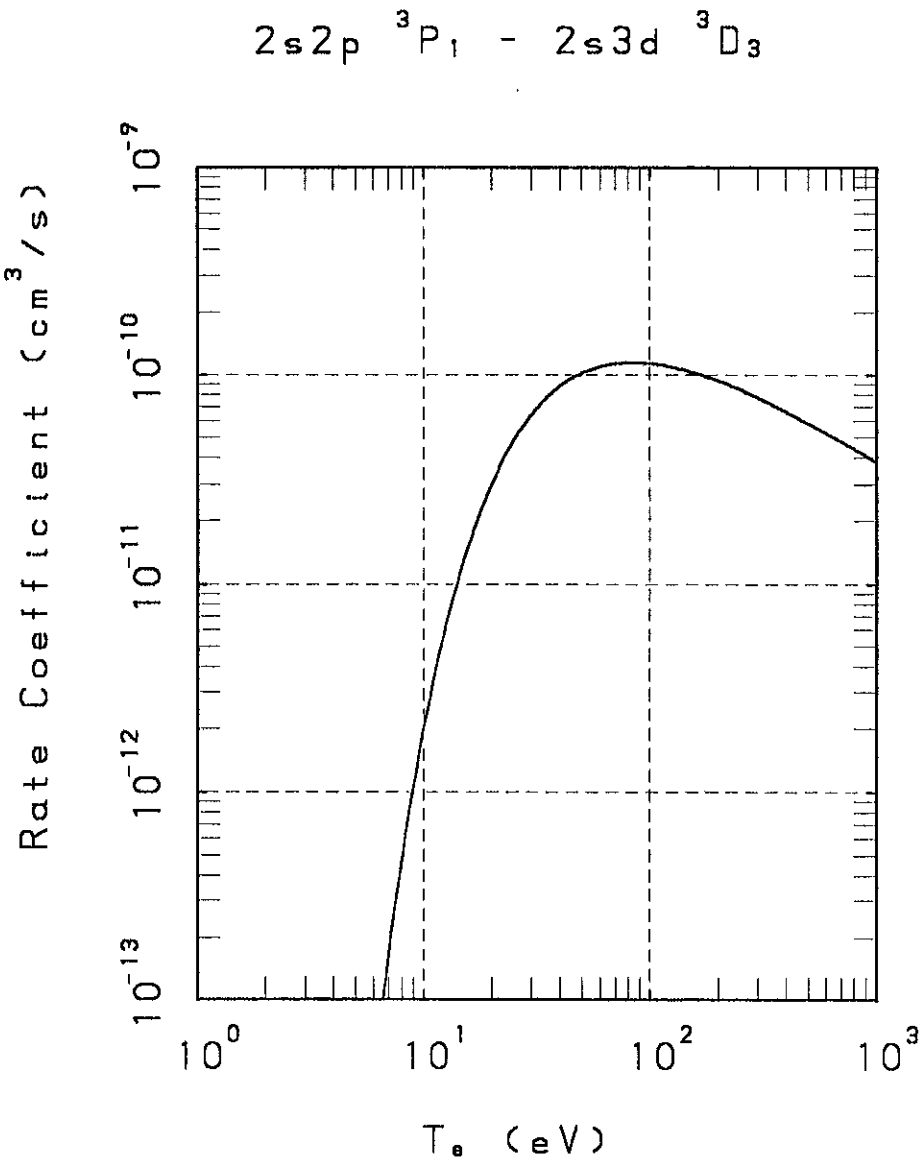

2s2p $^3P_1$ - 2s3p $^3P_0$
Rate Coefficient (cm$^3$/s)
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^{-14}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

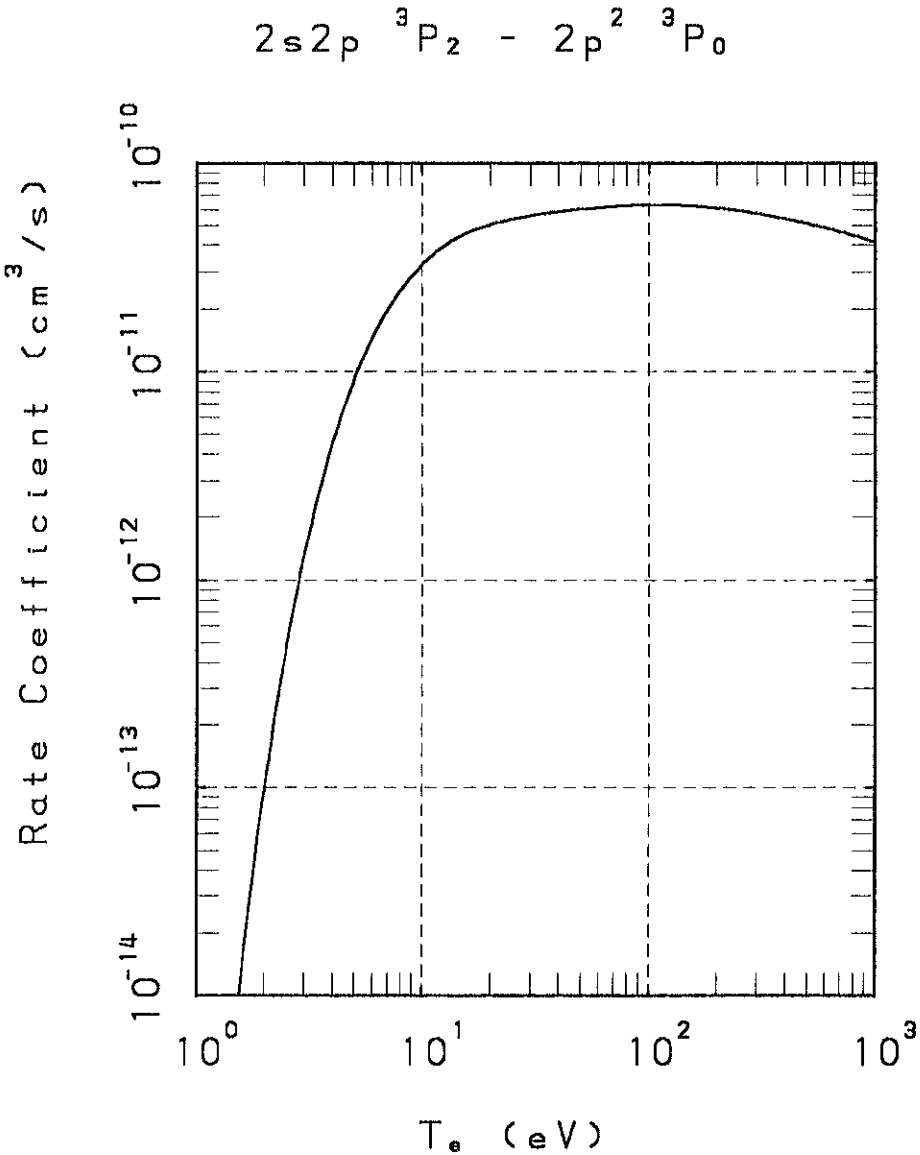

2s2p $^3P_1$ - 2s3p $^3P_1$
Rate Coefficient (cm$^3$/s)
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

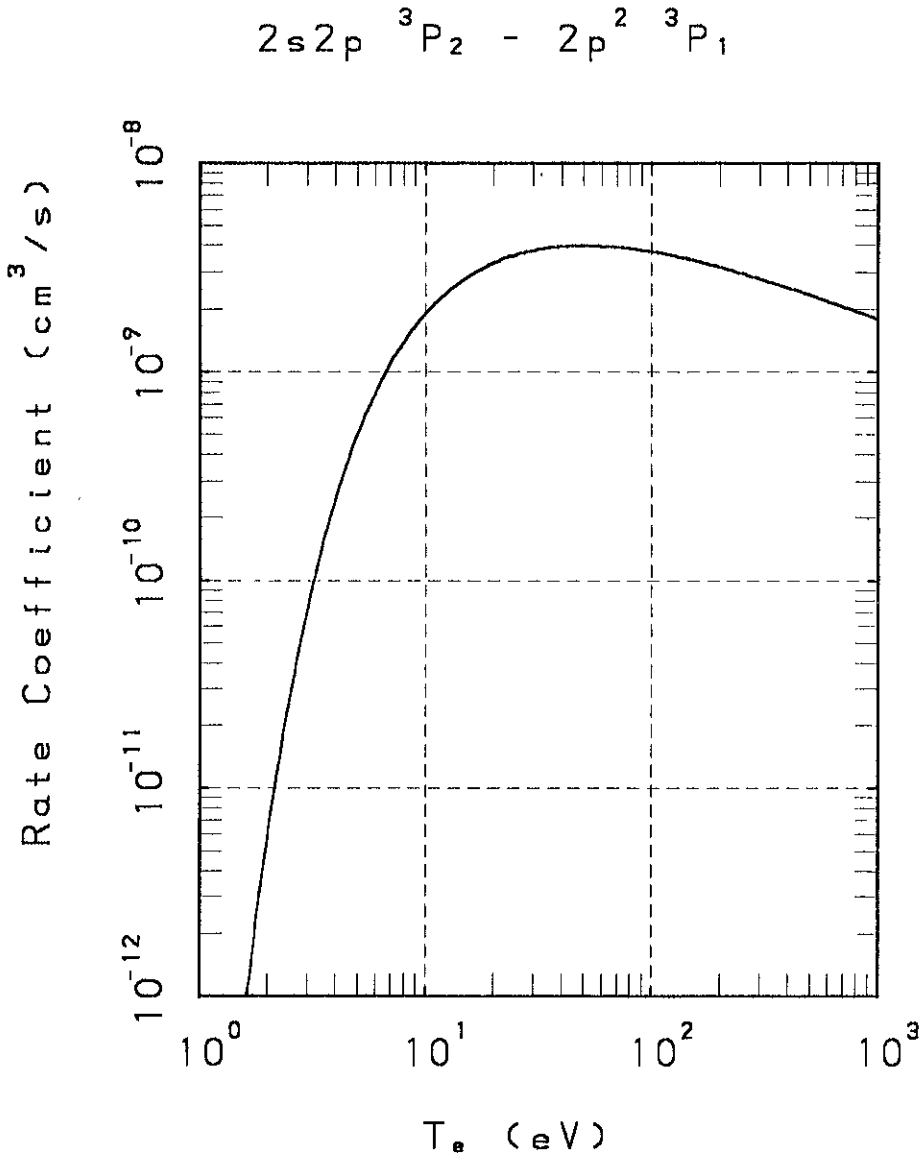

2s2p $^3P_1$ - 2s3d $^3D_1$
Rate Coefficient ($cm^3/s$)
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

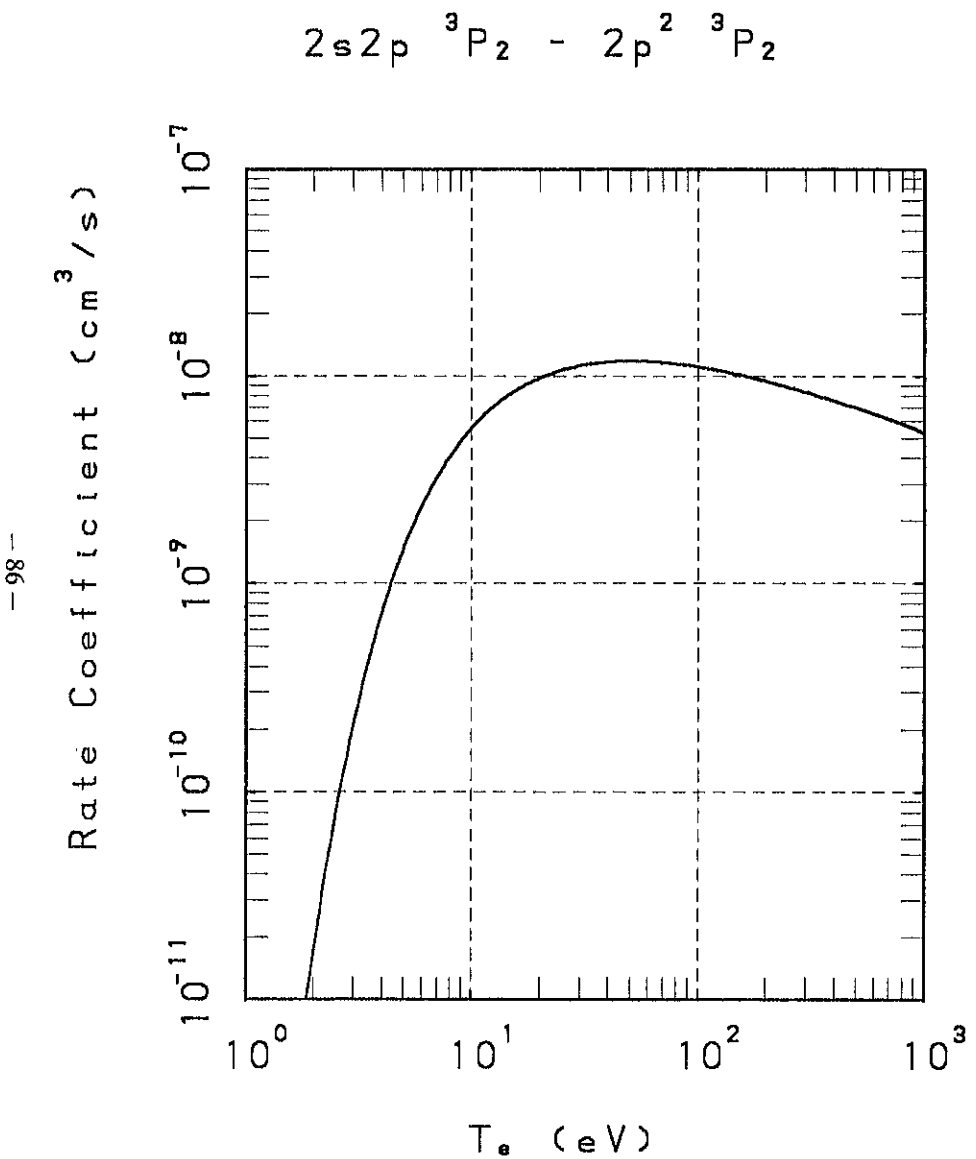

2s2p $^3P_1$ - 2s3p $^3P_2$
Rate Coefficient ($cm^3/s$)
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

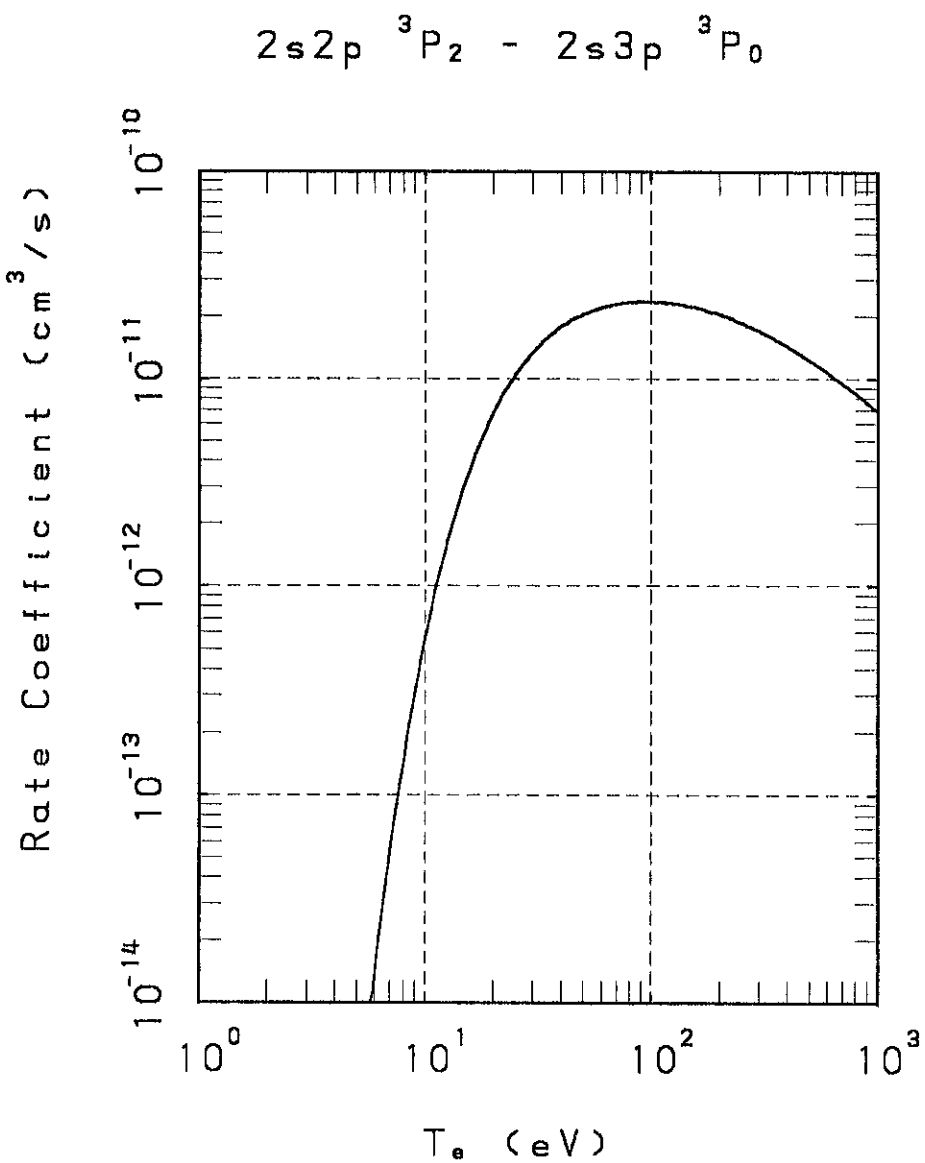

2s2p $^3P_1$ - 2s3d $^3D_2$
Rate Coefficient (cm$^3$/s)
$10^{-8}$
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

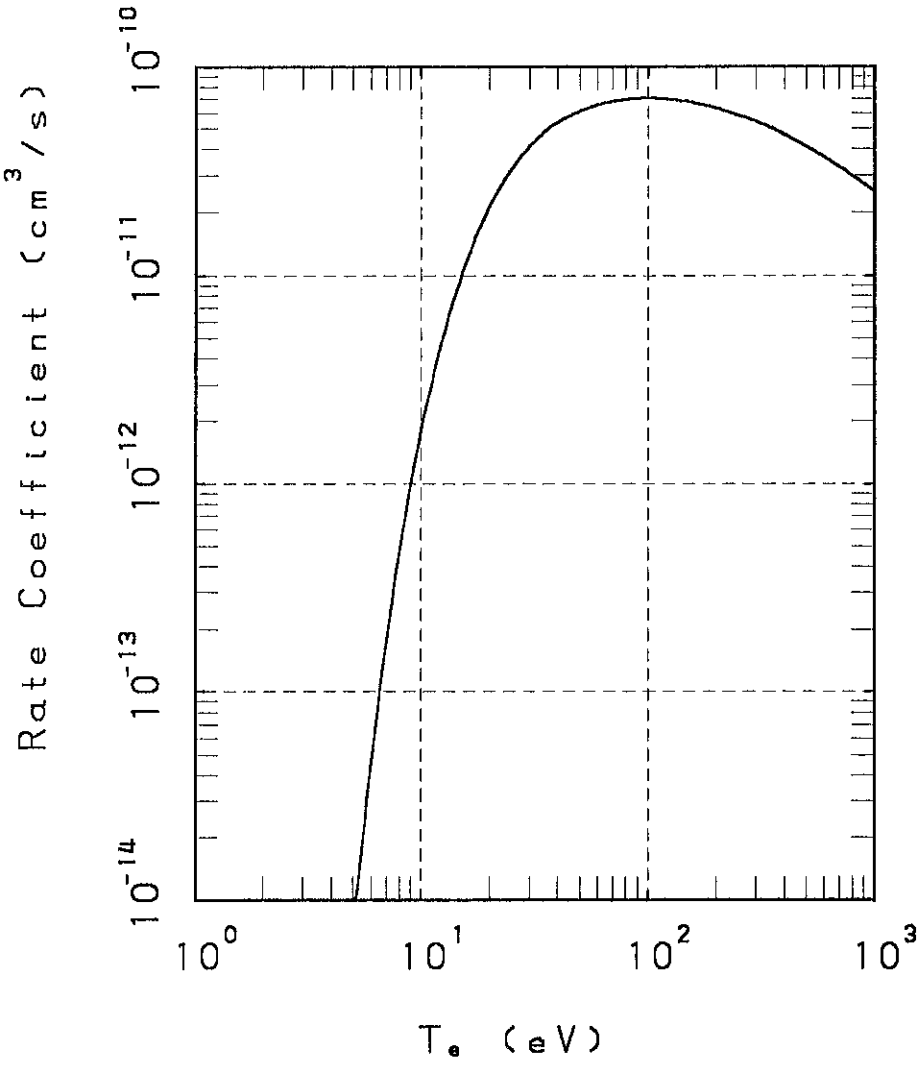

2s2p $^3P_1$ - 2s3d $^3D_3$
Rate Coefficient (cm$^3$/s)
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

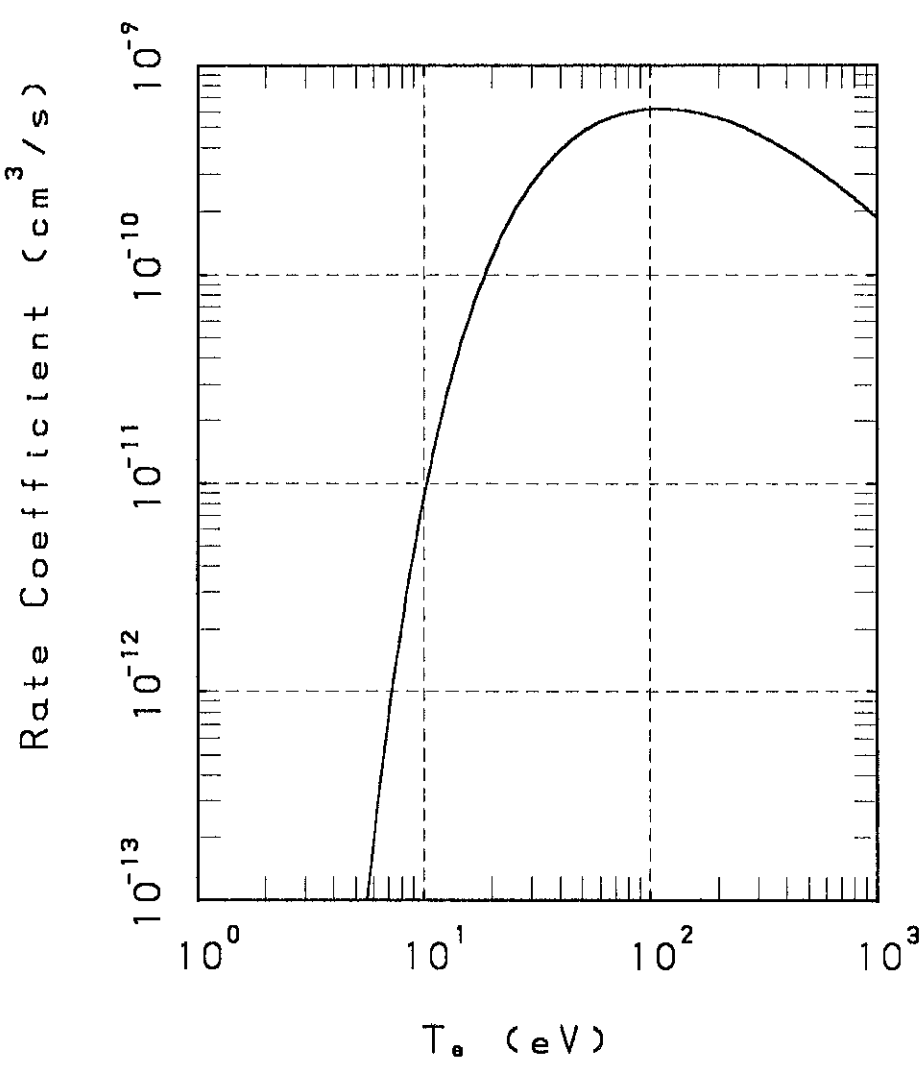

2s2p $^3P_2$ - $2p^2$ $^3P_0$
Rate Coefficient (cm$^3$/s)
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^{-14}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

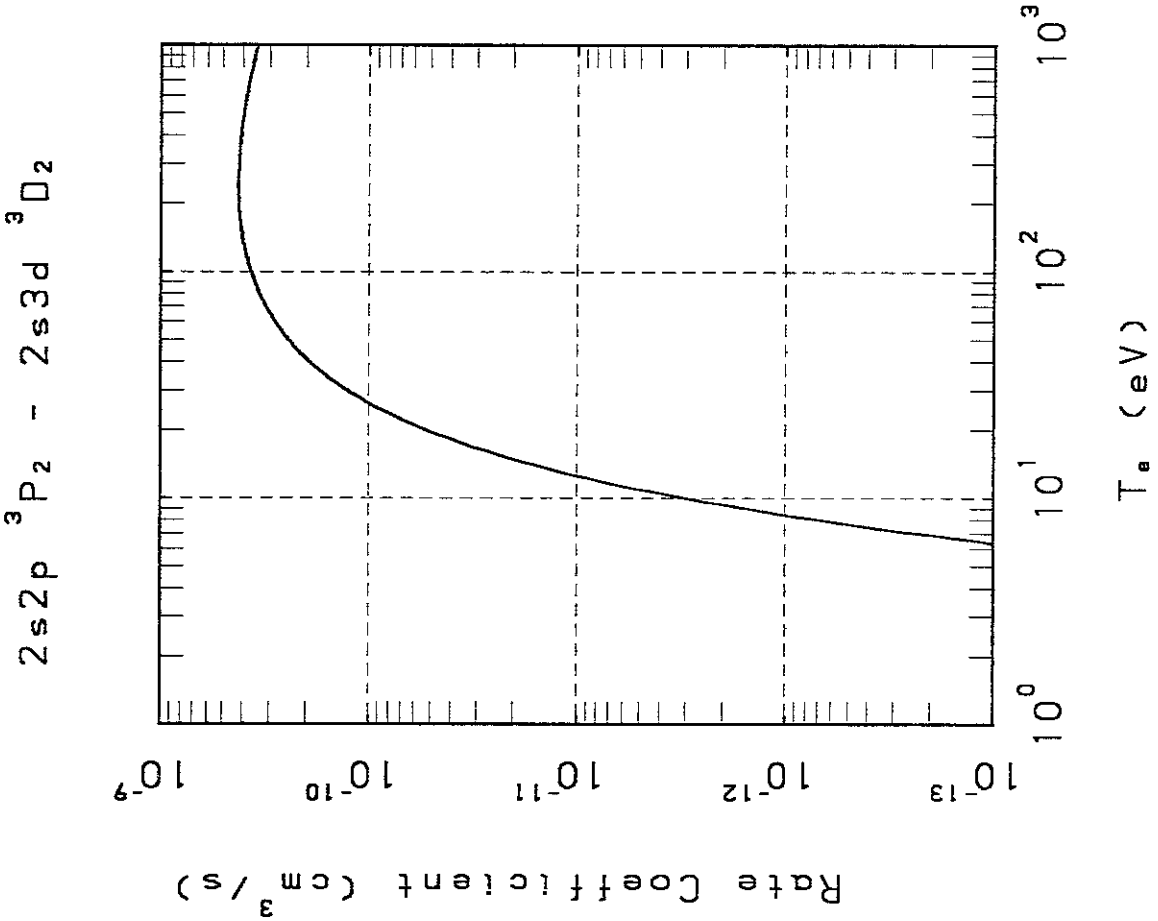

2s2p $^3P_2$ - $2p^2$ $^3P_1$
Rate Coefficient (cm$^3$/s)
$10^{-8}$
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

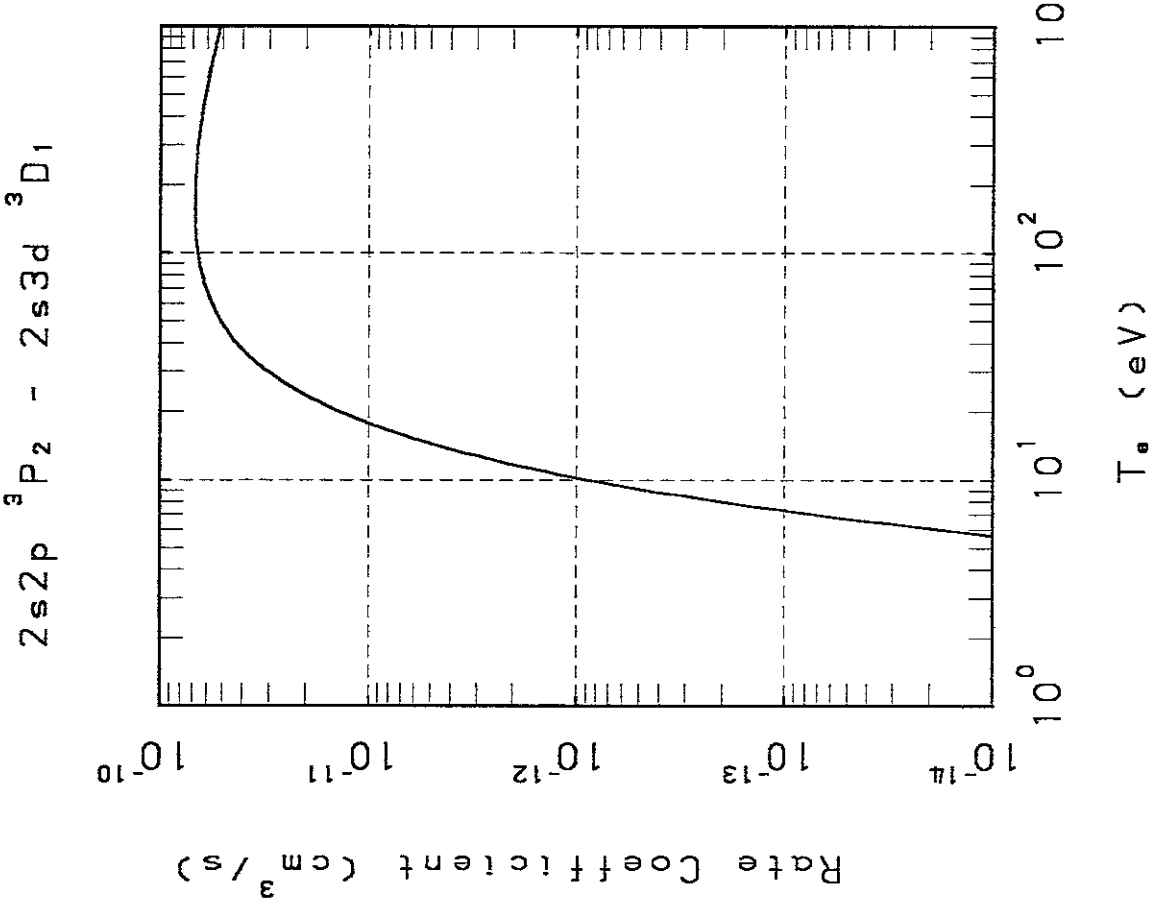

2s2p ³P₂ - 2p² ³P₂
Rate Coefficient (cm³/s)
10⁻⁷
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁰
10¹
10²
10³
Tₑ (eV)

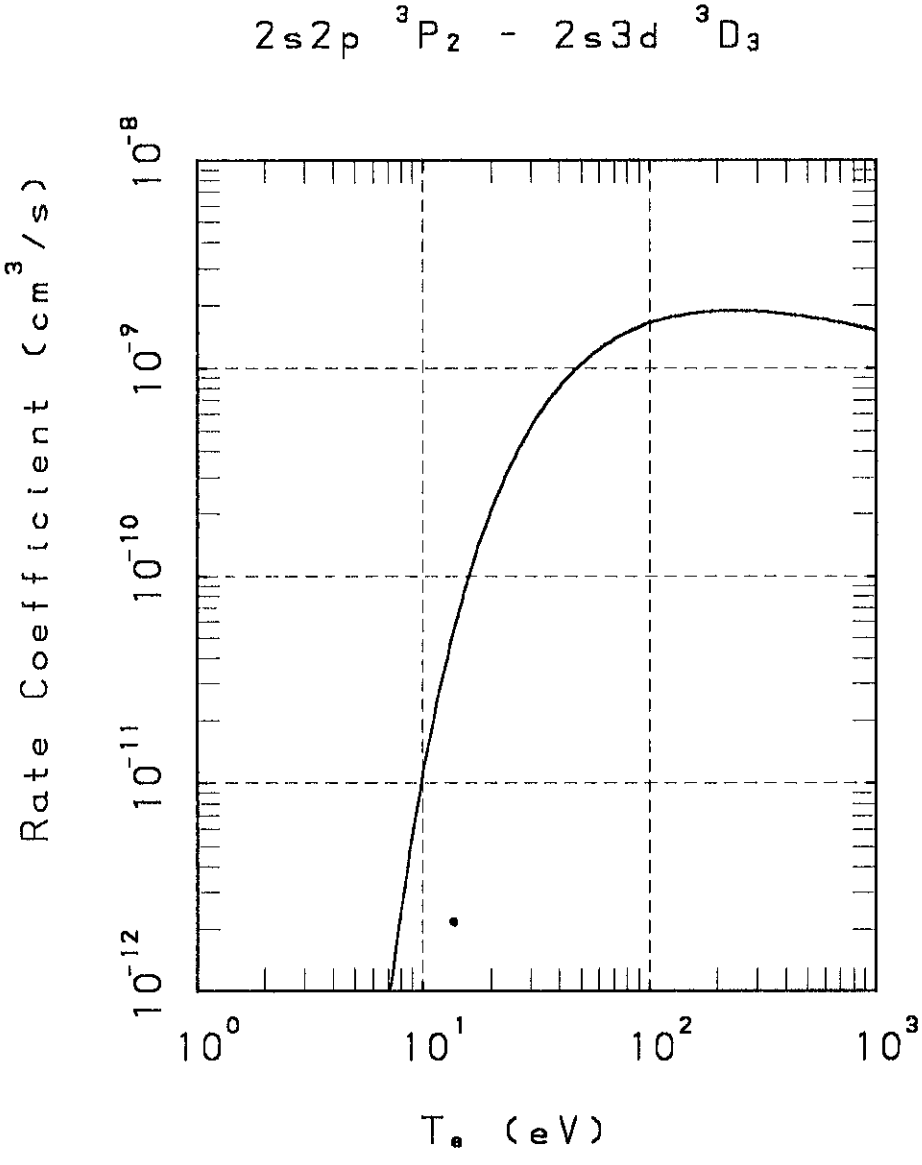

2s2p ³P₂ - 2s3p ³P₀
Rate Coefficient (cm³/s)
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁻¹³
10⁻¹⁴
10⁰
10¹
10²
10³
Tₑ (eV)

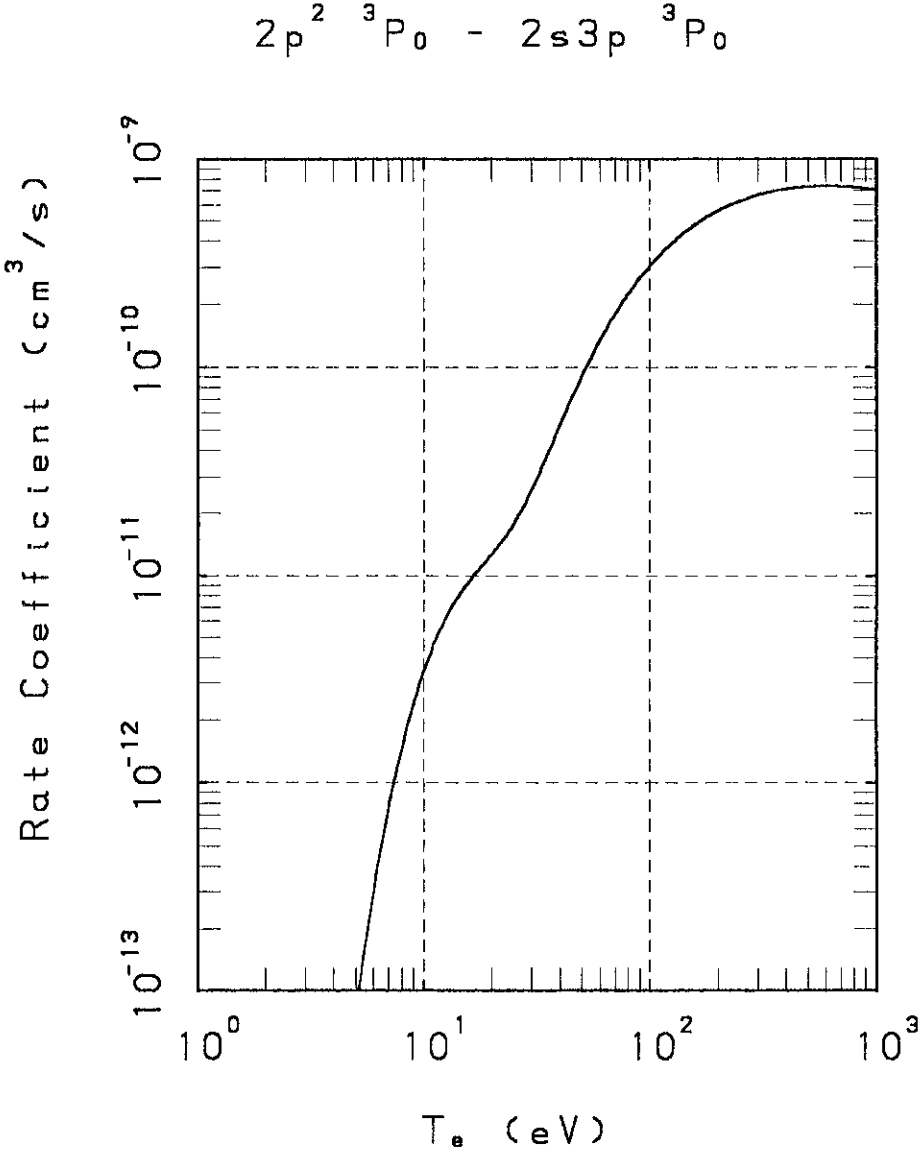

2s2p $^3P_2$ - 2s3p $^3P_1$
Rate Coefficient (cm$^3$/s)
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^{-14}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

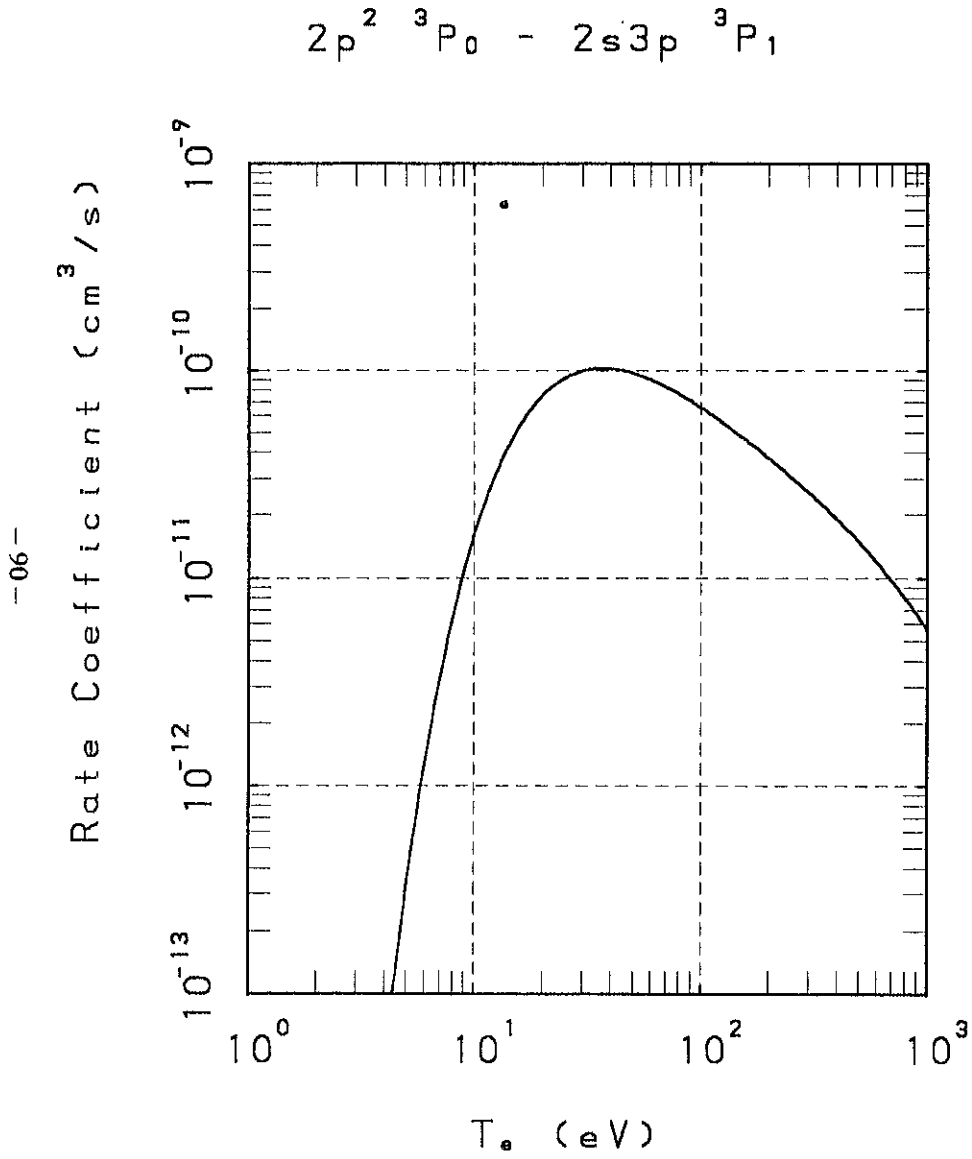

2s2p $^3P_2$ - 2s3p $^3P_2$
Rate Coefficient (cm$^3$/s)
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

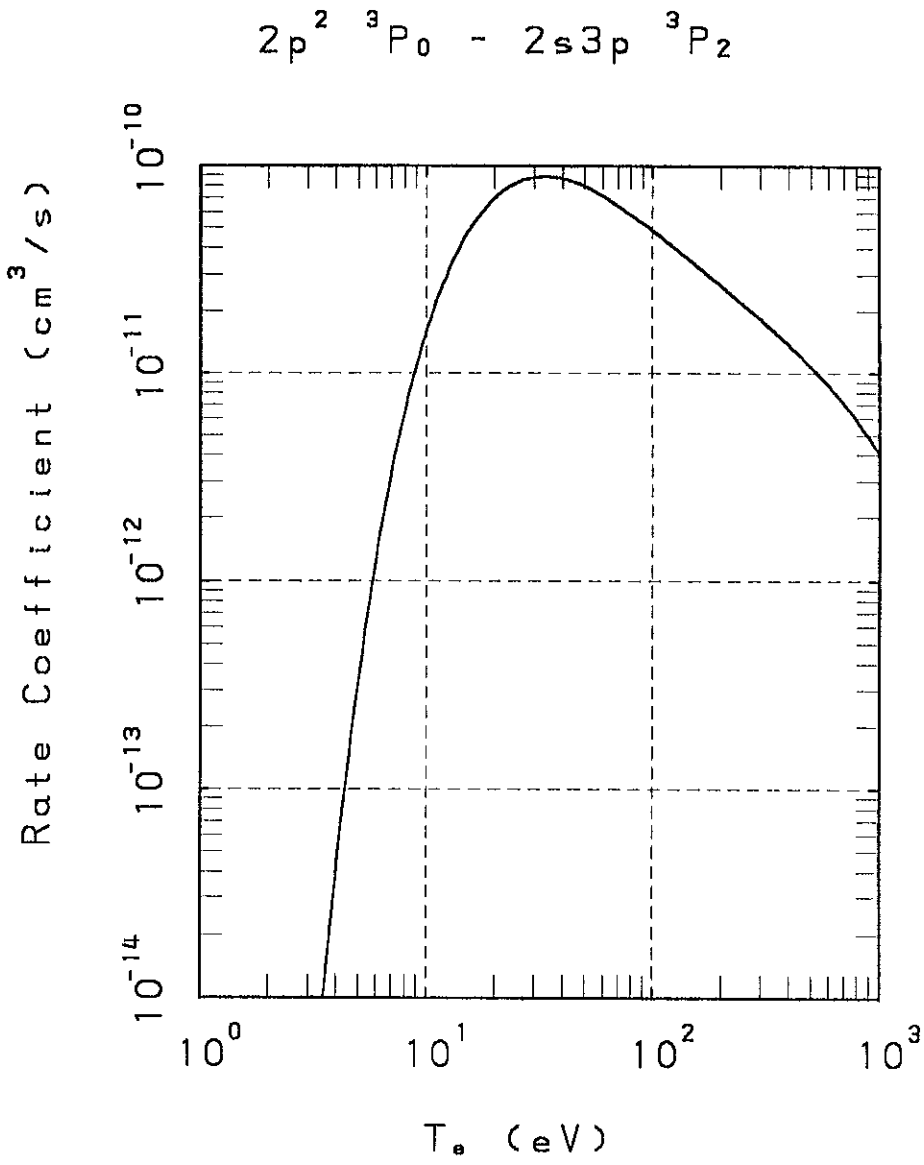

2s2p $^3P_2$ - 2s3d $^3D_2$
Rate Coefficient ($cm^3/s$)
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

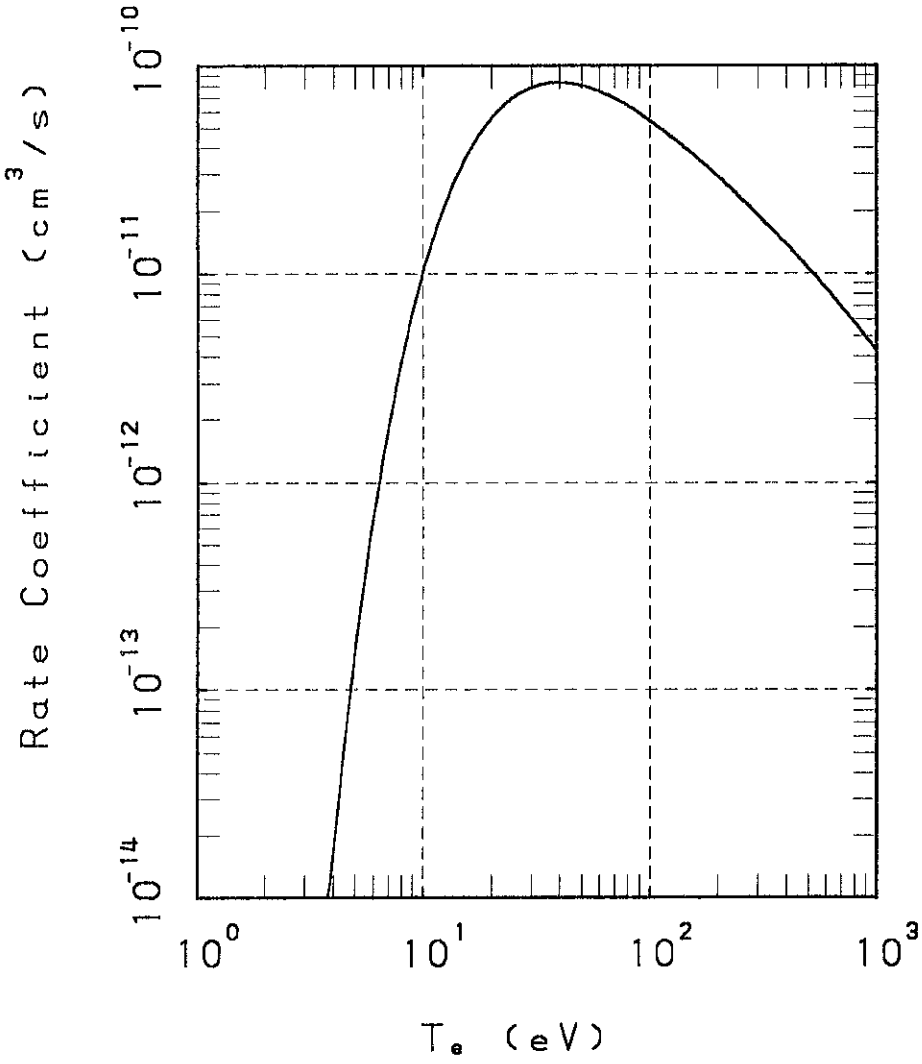

2s2p $^3P_2$ - 2s3d $^3D_1$
Rate Coefficient ($cm^3/s$)
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^{-14}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

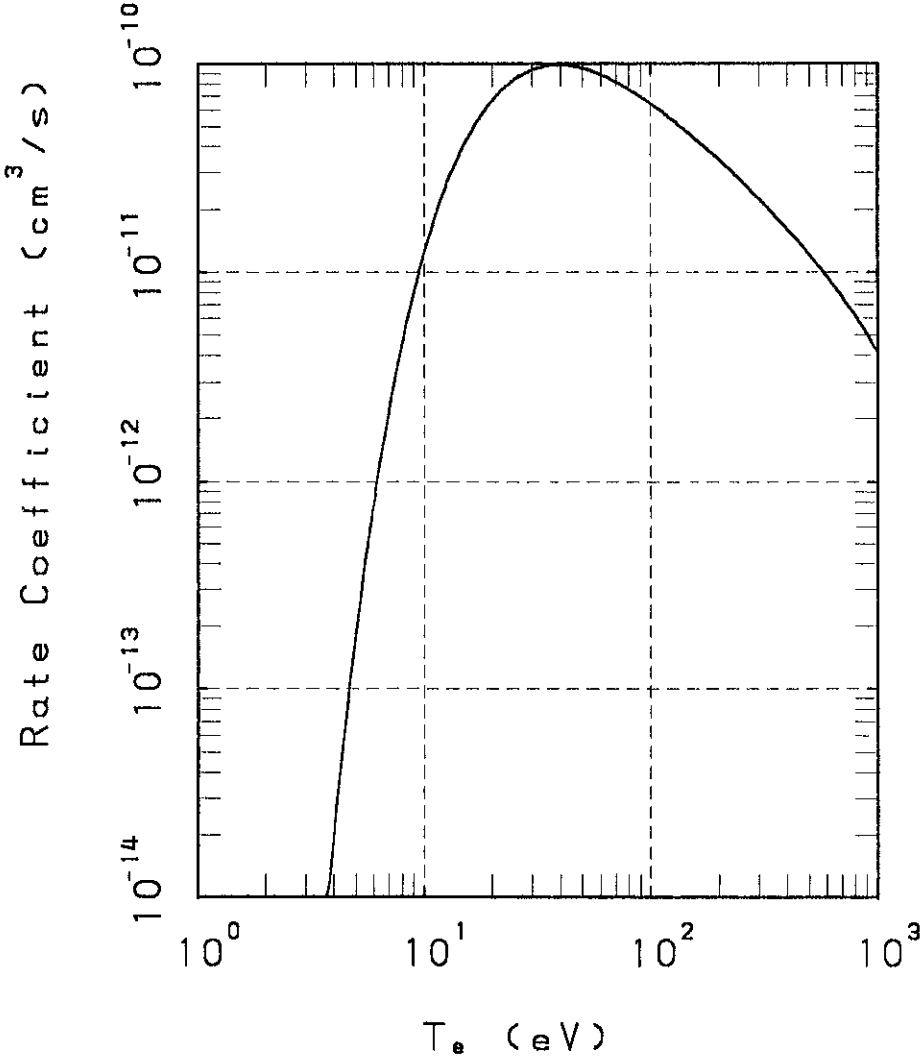

2s2p ³P₂ - 2s3d ³D₃
Rate Coefficient (cm³/s)
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁰
10¹
10²
10³
Tₑ (eV)

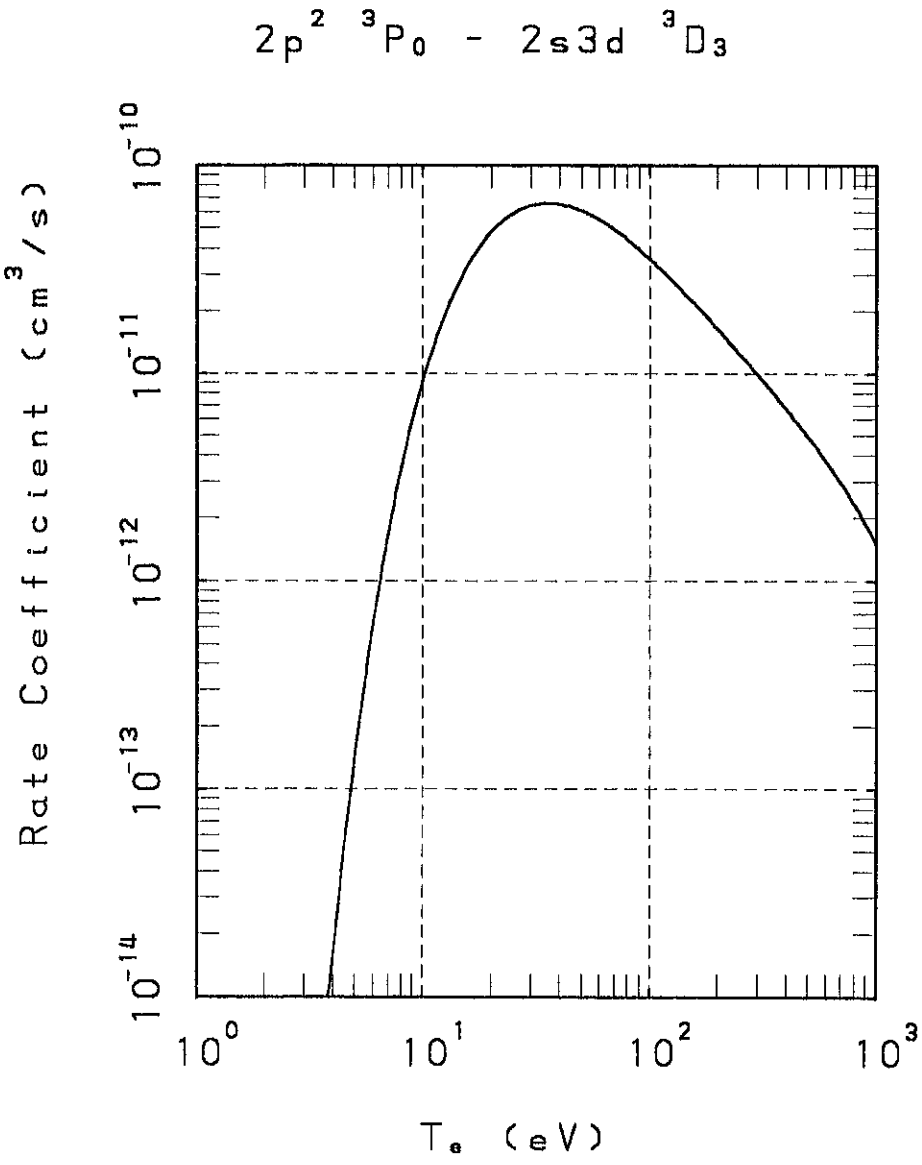

2p² ³P₀ - 2s3p ³P₀
Rate Coefficient (cm³/s)
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁻¹³
10⁰
10¹
10²
10³
Tₑ (eV)

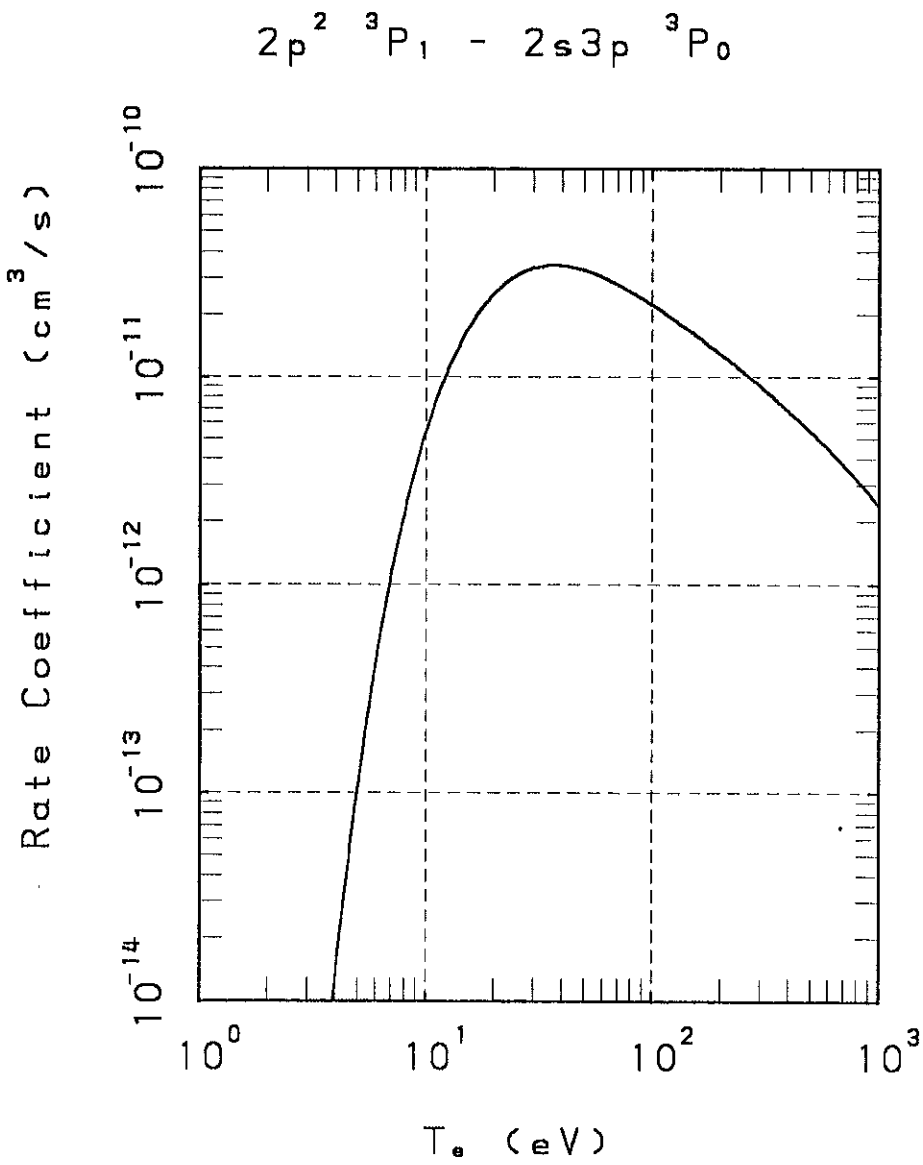

$2p^2\ ^3P_0 - 2s3p\ ^3P_1$
Rate Coefficient ($cm^3/s$)
$10^{-7}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

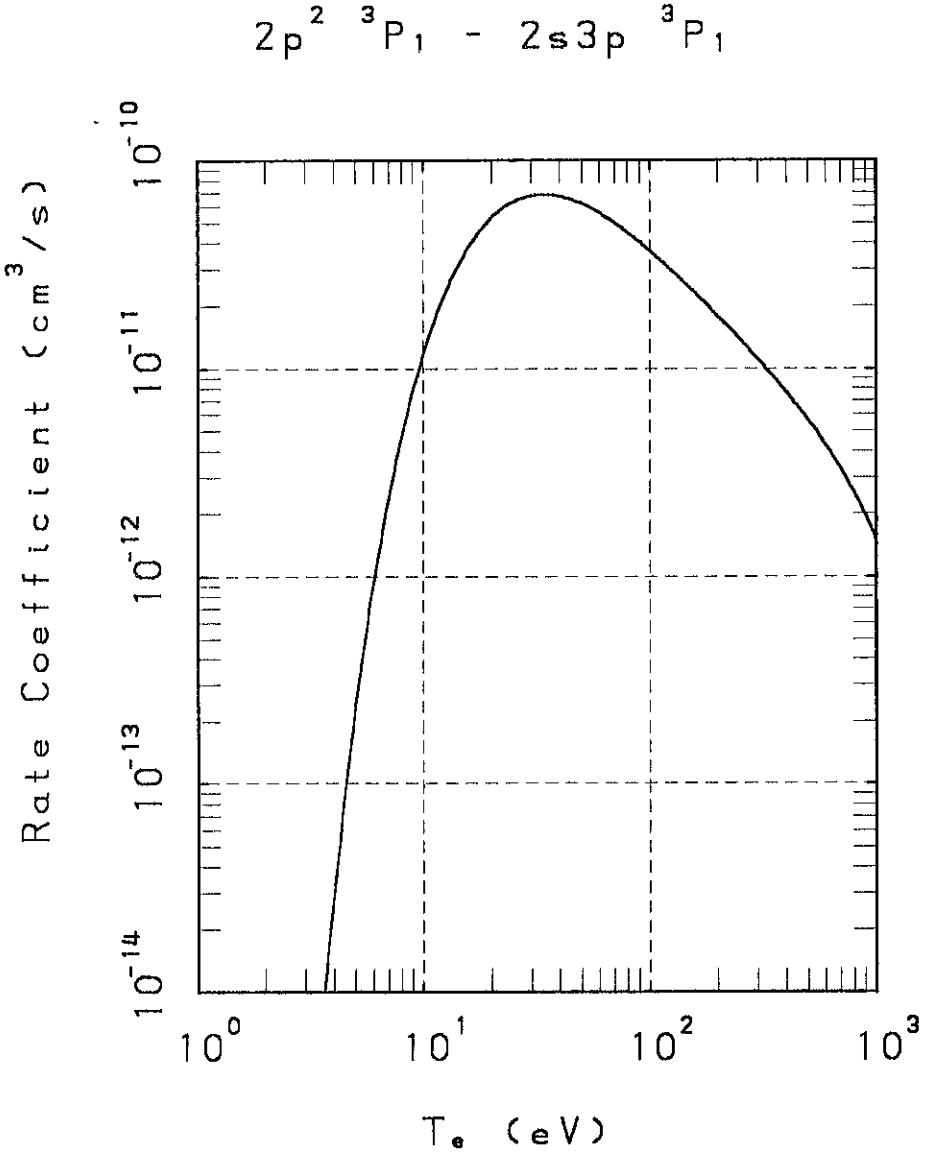

$2p^2\ ^3P_0 - 2s3p\ ^3P_2$
Rate Coefficient ($cm^3/s$)
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^{-14}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

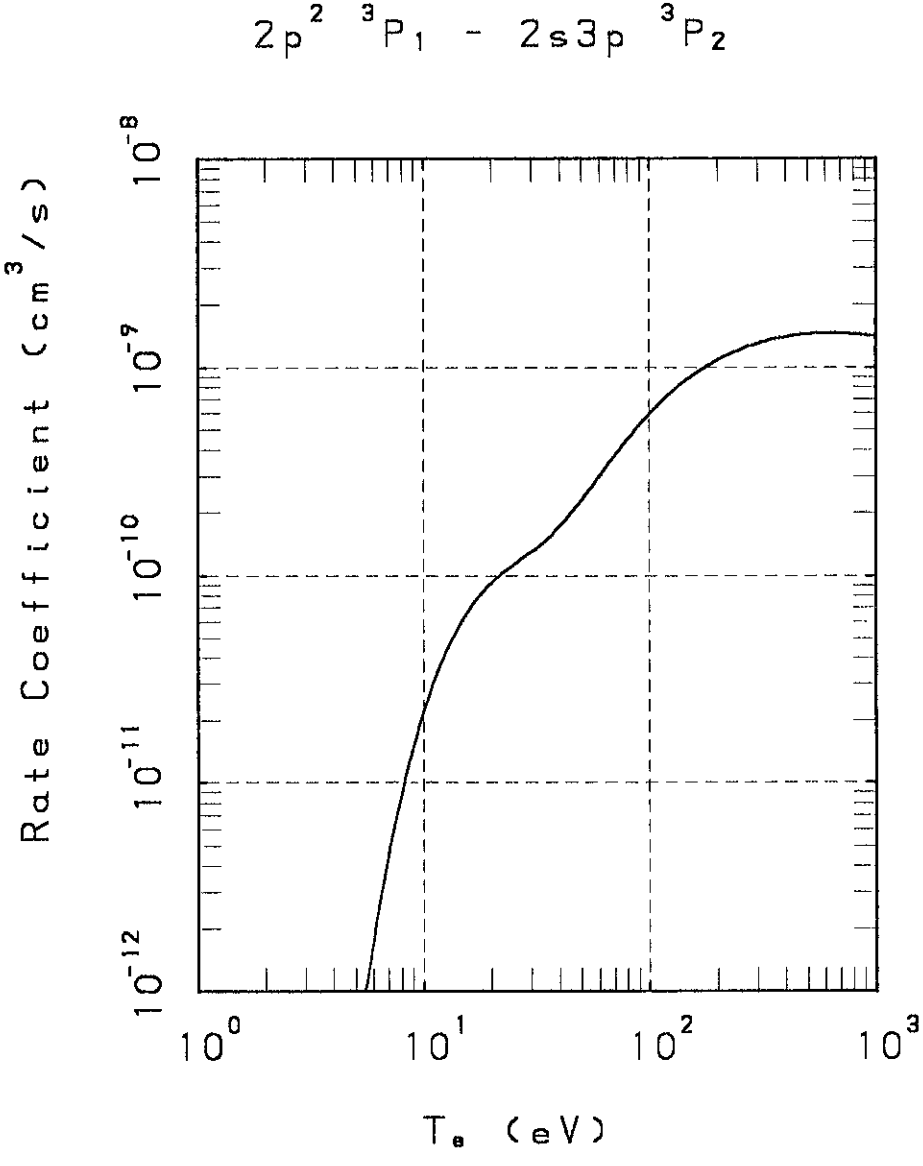

2p² ³P₀ - 2s3d ³D₁
Rate Coefficient (cm³/s)
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁻¹³
10⁻¹⁴
10⁰
10¹
10²
10³
Tₑ (eV)

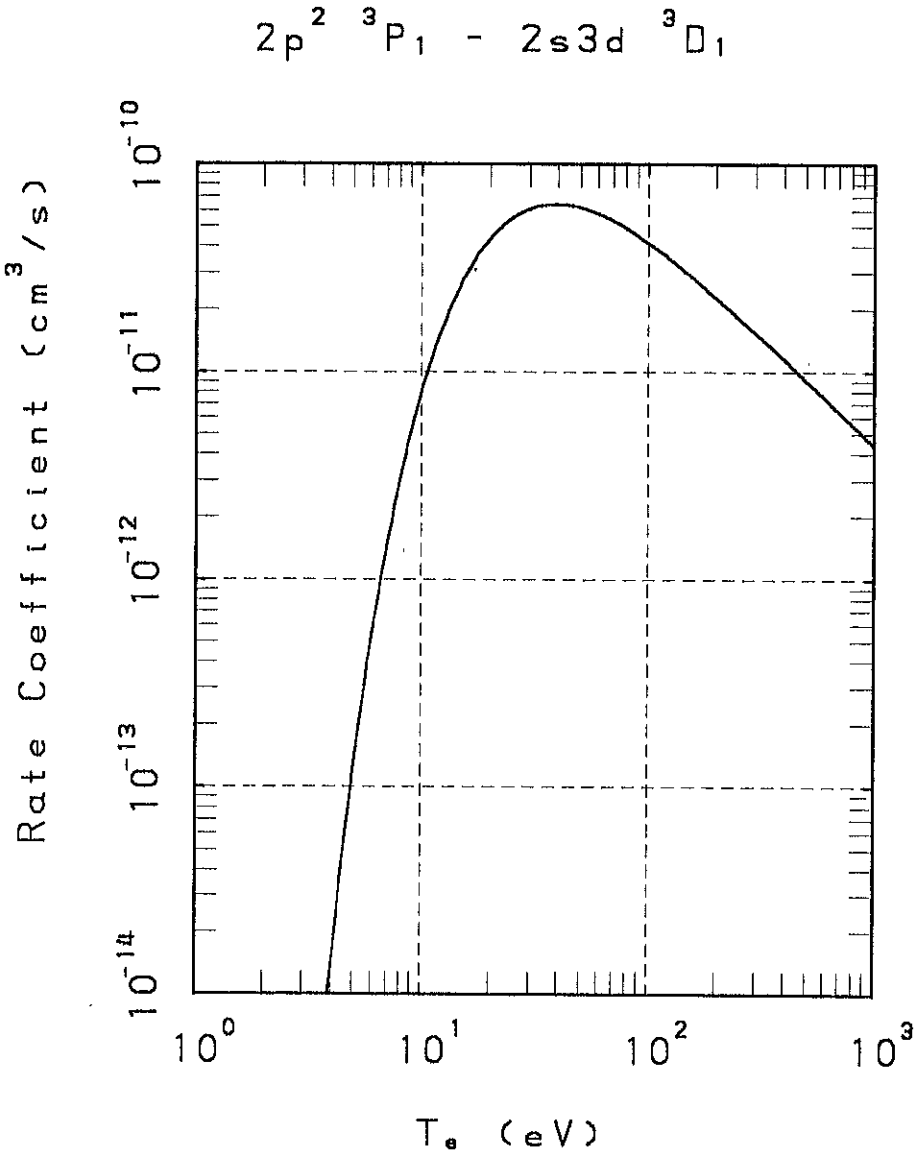

2p² ³P₀ - 2s3d ³D₂
Rate Coefficient (cm³/s)
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁻¹³
10⁻¹⁴
10⁰
10¹
10²
10³
Tₑ (eV)

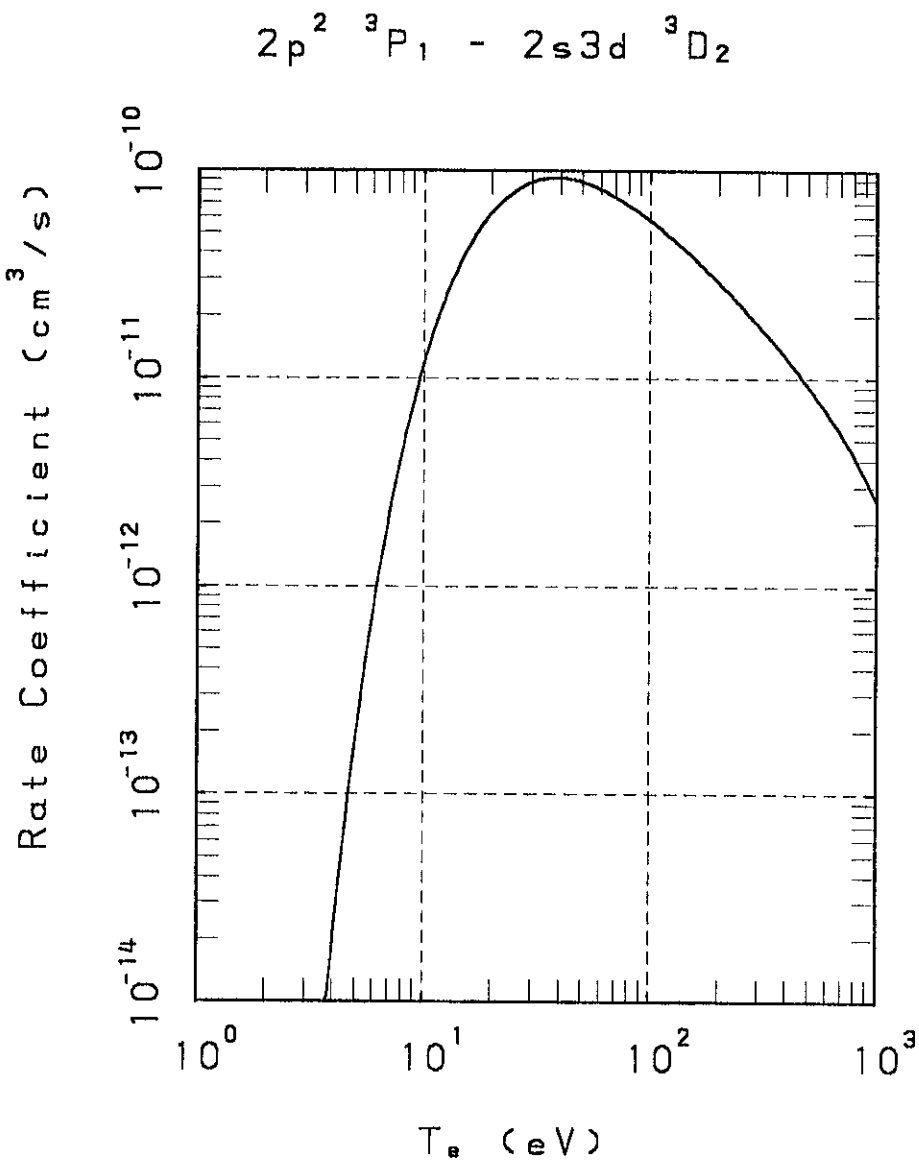

$2p^2\ ^3P_0 - 2s3d\ ^3D_3$
Rate Coefficient (cm$^3$/s)
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^{-14}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

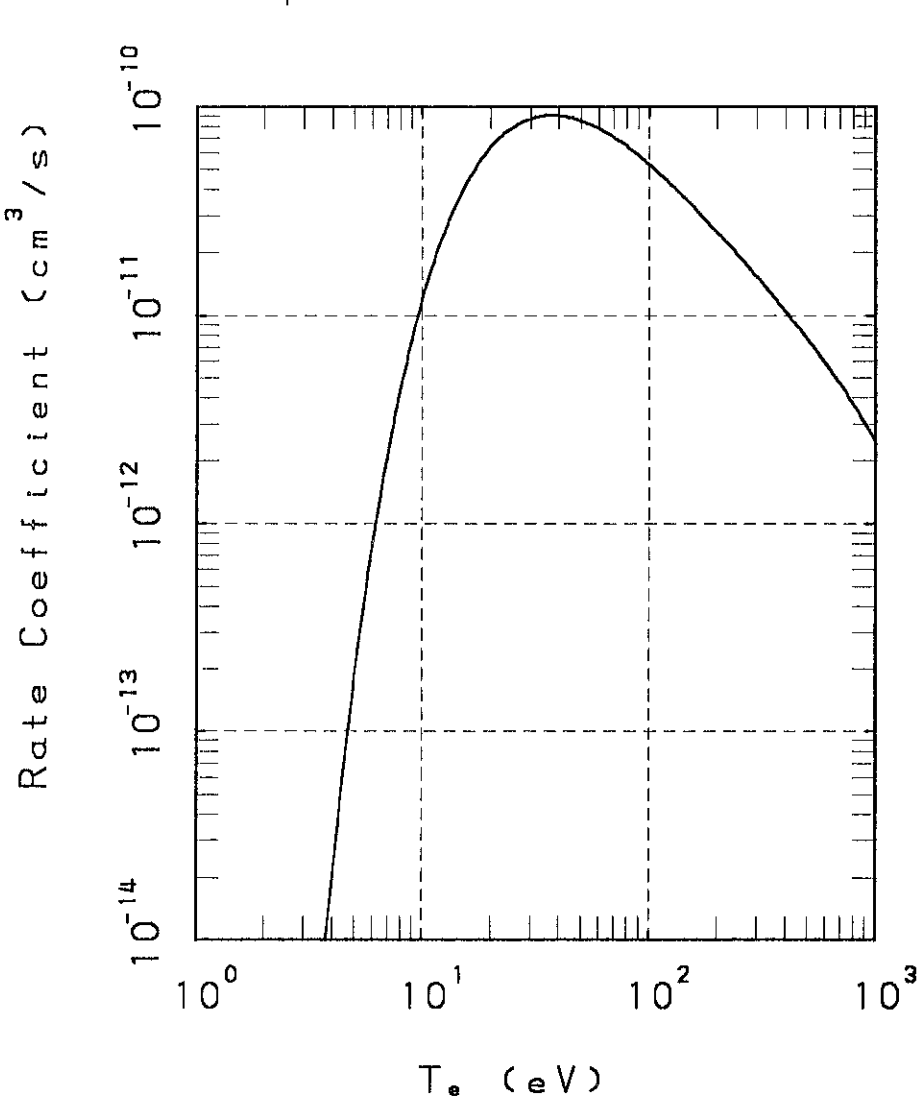

$2p^2\ ^3P_1 - 2s3p\ ^3P_0$
Rate Coefficient (cm$^3$/s)
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^{-14}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

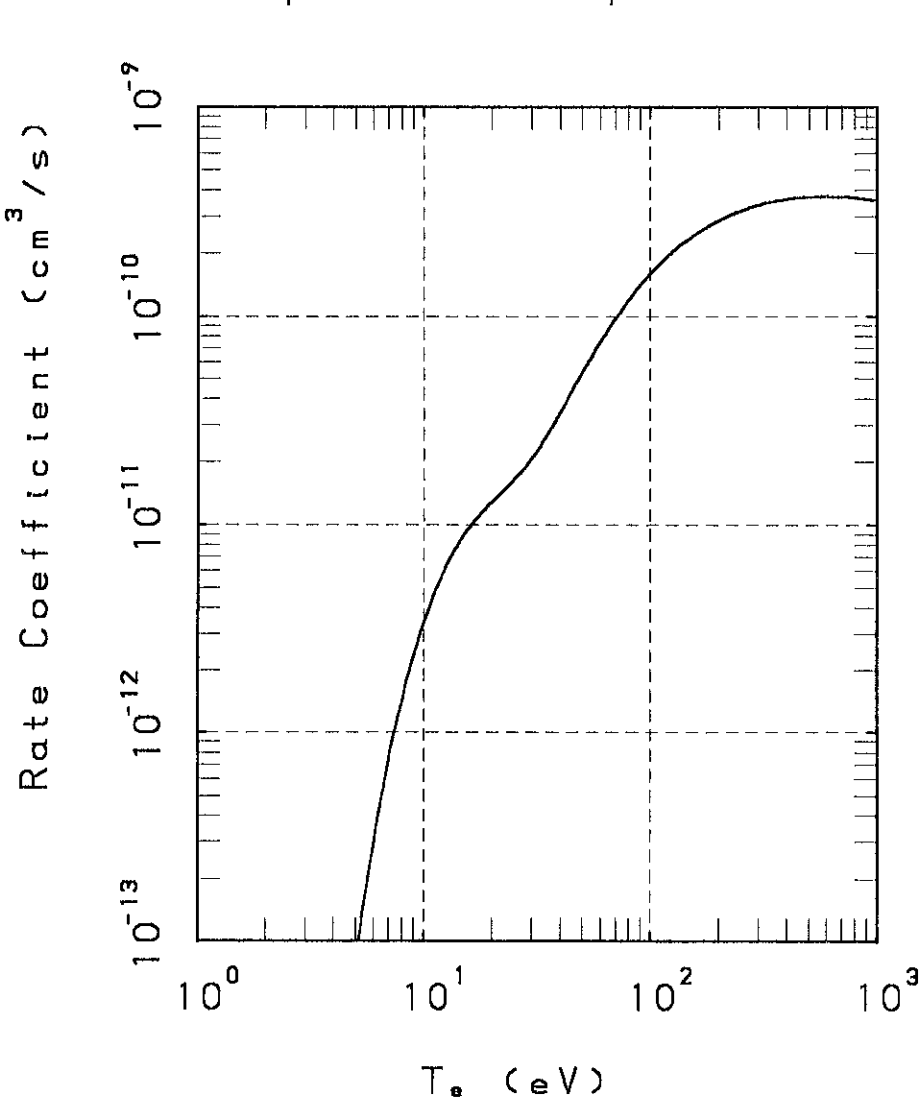

$2p^2\ ^3P_1 - 2s3p\ ^3P_1$
Rate Coefficient ($cm^3/s$)
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^{-14}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

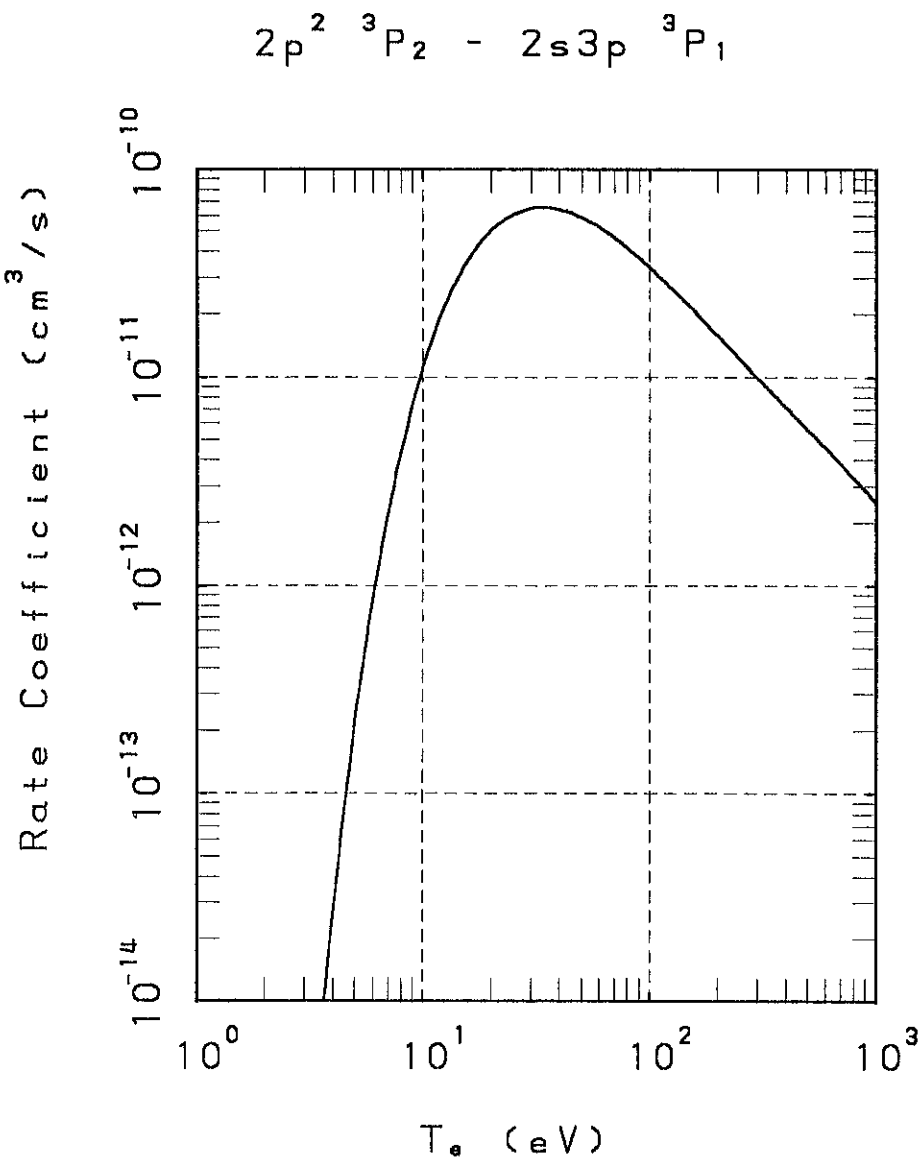

$2p^2\ ^3P_1 - 2s3p\ ^3P_2$
Rate Coefficient ($cm^3/s$)
$10^{-8}$
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

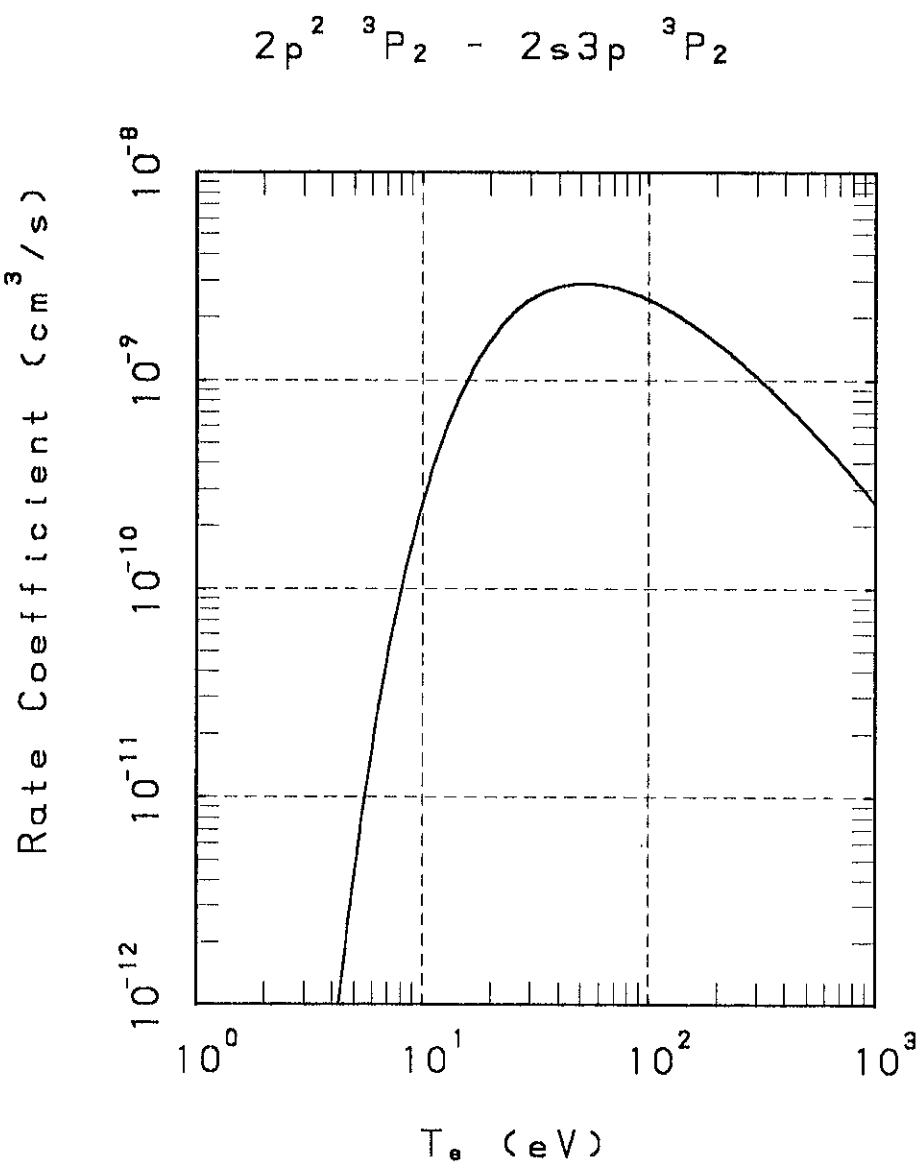

2p² ³P₁ - 2s3d ³D₁
Rate Coefficient (cm³/s)
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁻¹³
10⁻¹⁴
10⁰
10¹
10²
10³
Tₑ (eV)

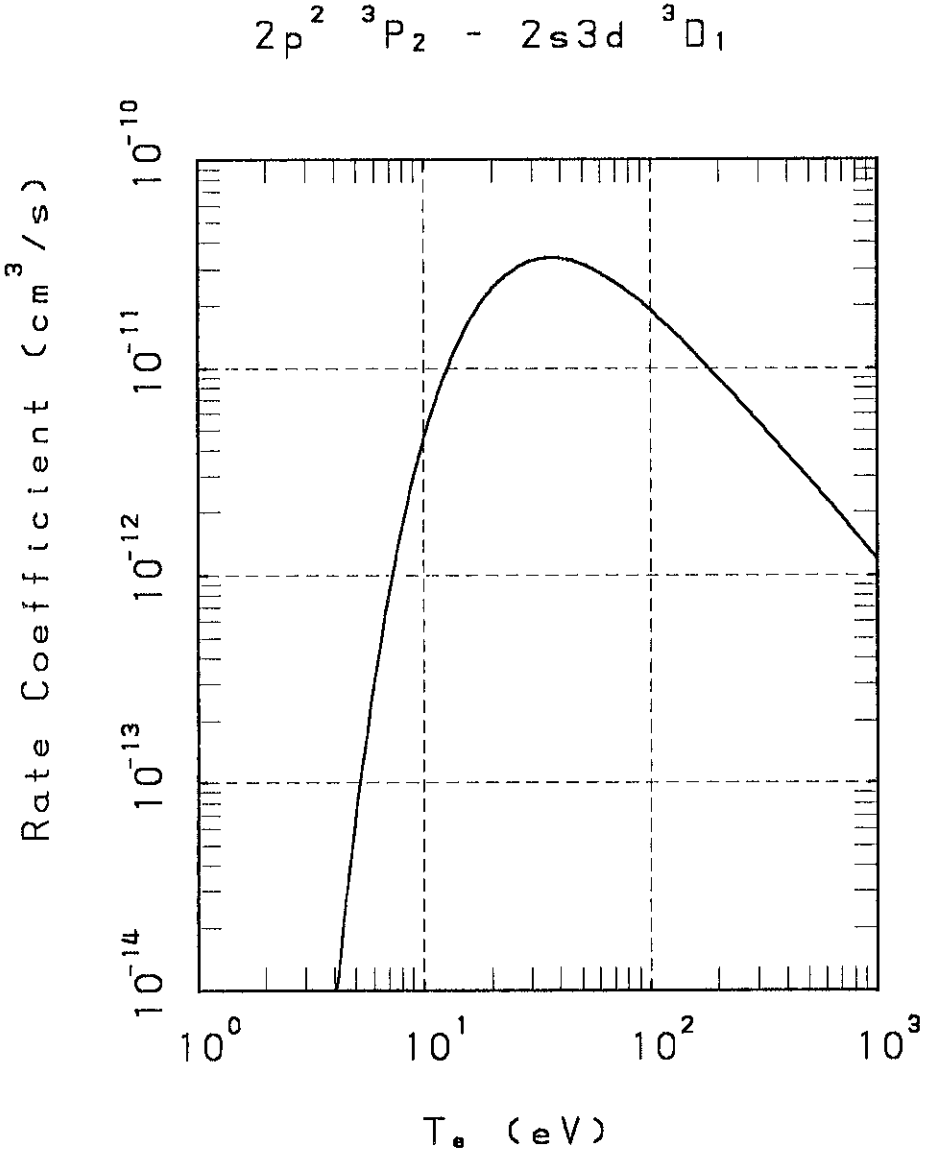

2p² ³P₁ - 2s3d ³D₂
Rate Coefficient (cm³/s)
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁻¹³
10⁻¹⁴
10⁰
10¹
10²
10³
Tₑ (eV)

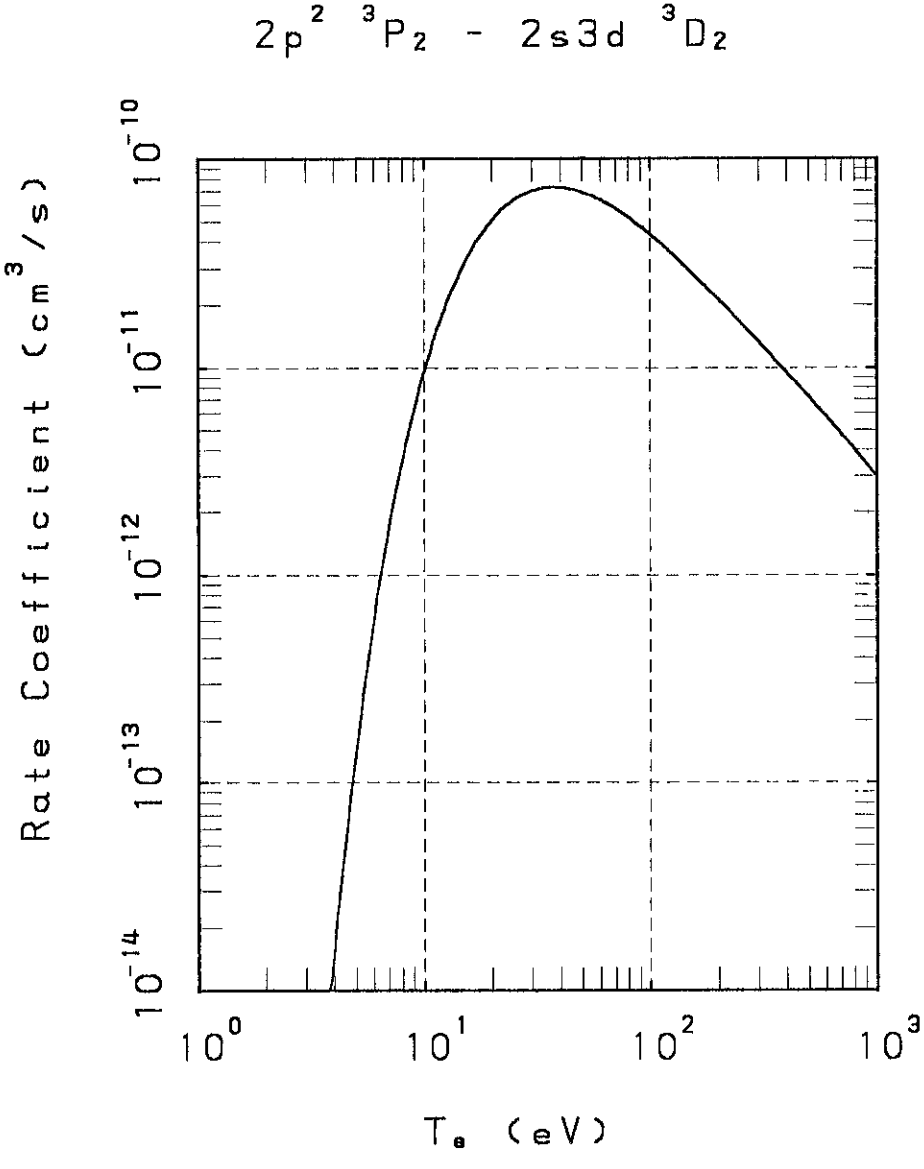

2p² ³P₁ - 2s3d ³D₃
Rate Coefficient (cm³/s)
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁻¹³
10⁻¹⁴
10⁰
10¹
10²
10³
Tₑ (eV)

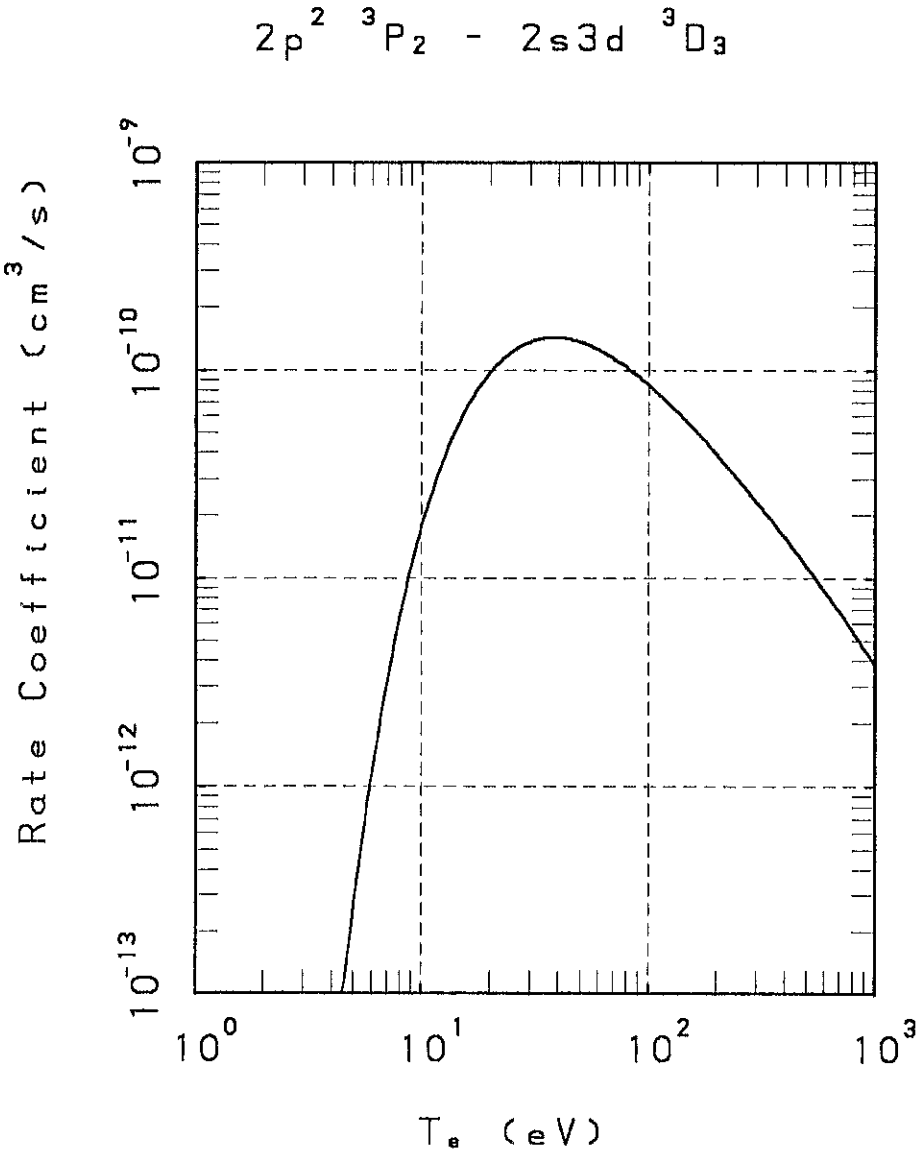

2p² ³P₂ - 2s3p ³P₀
Rate Coefficient (cm³/s)
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁻¹³
10⁰
10¹
10²
10³
Tₑ (eV)

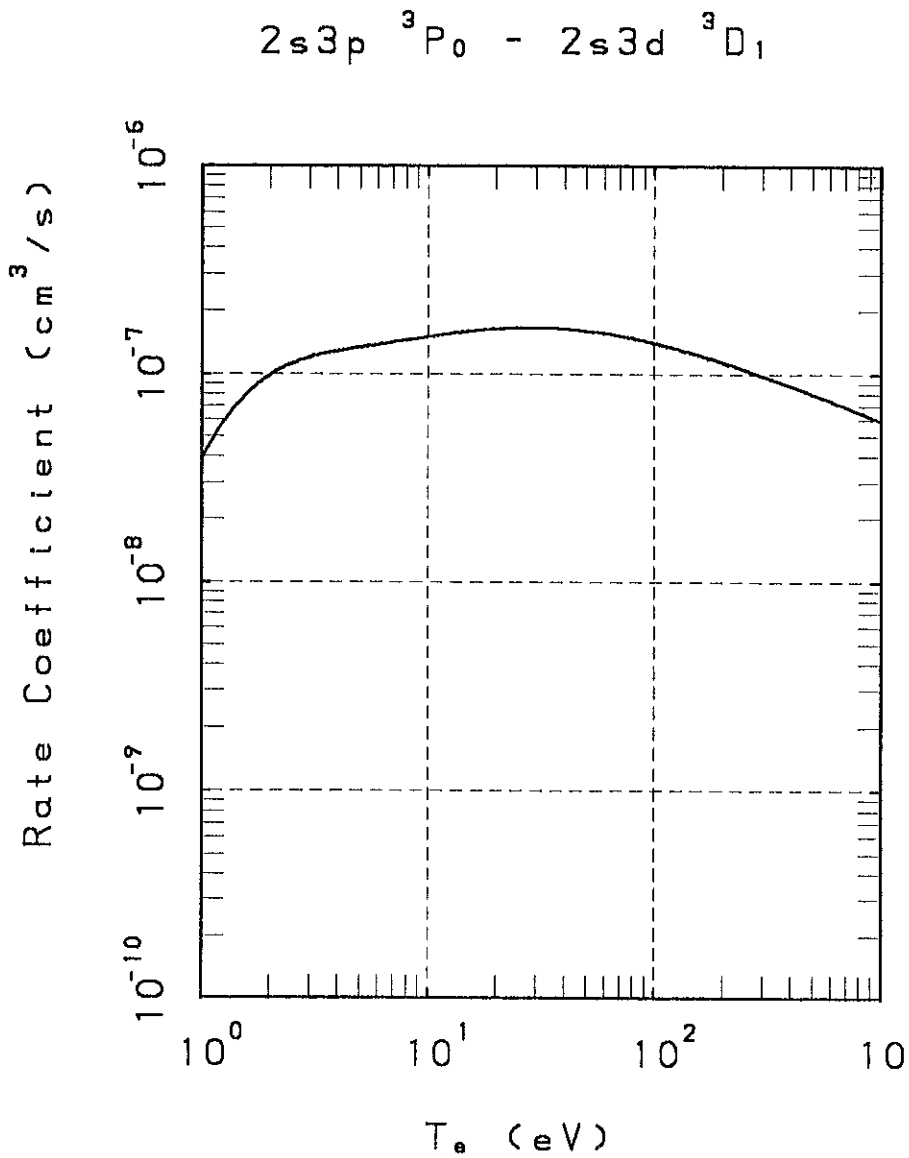

$2p^2\ ^3P_2 - 2s3p\ ^3P_1$
Rate Coefficient ($cm^3/s$)
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^{-14}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

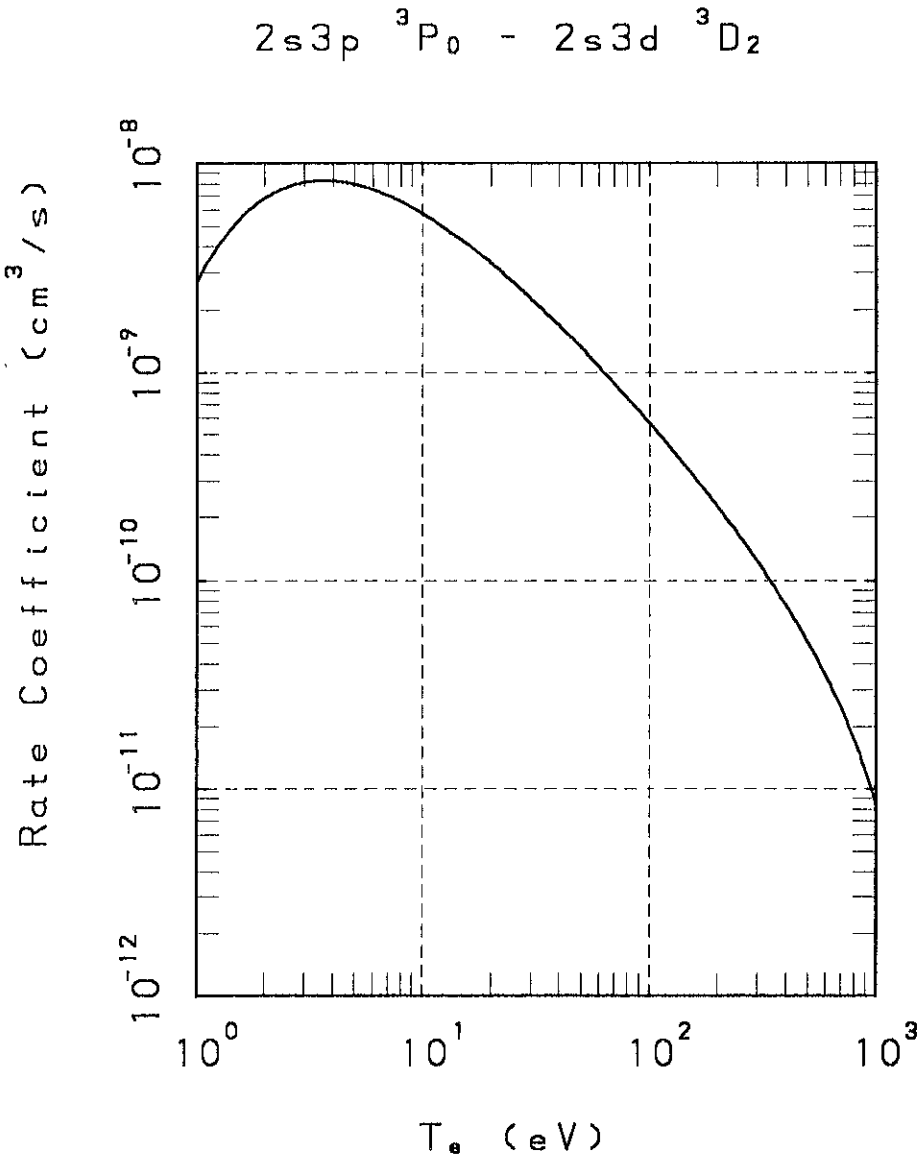

$2p^2\ ^3P_2 - 2s3p\ ^3P_2$
Rate Coefficient ($cm^3/s$)
$10^{-8}$
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

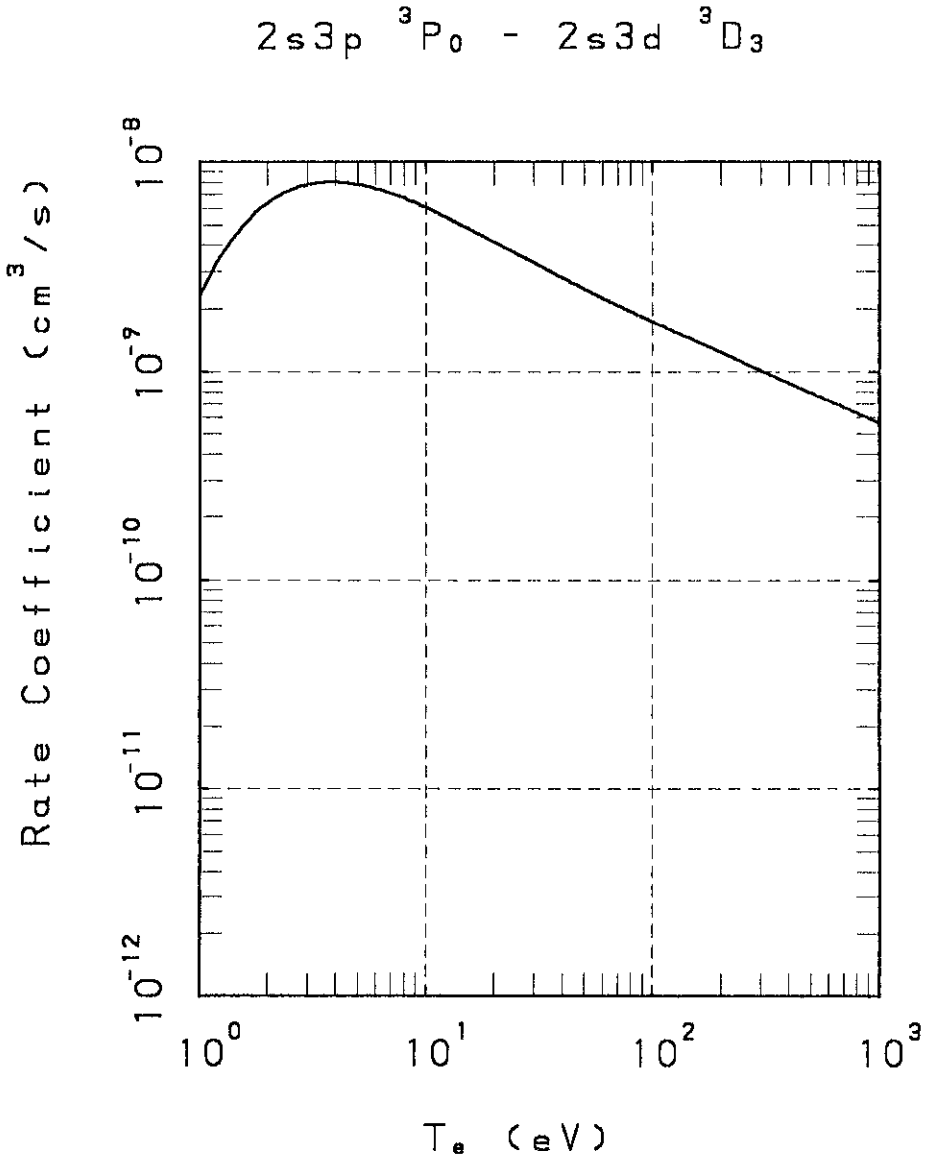

$2p^2\ ^3P_2 - 2s3d\ ^3D_1$
Rate Coefficient ($cm^3/s$)
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^{-14}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

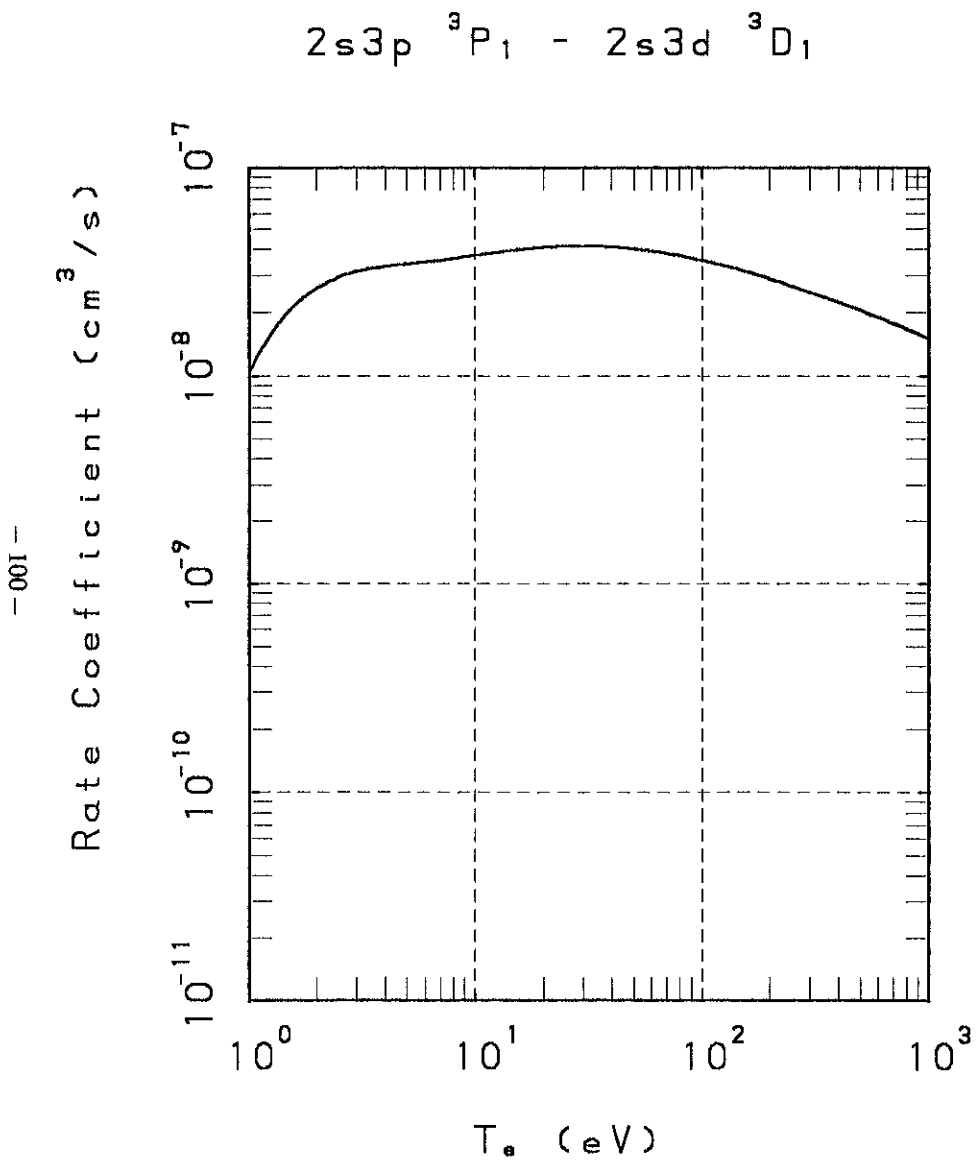

$2p^2\ ^3P_2 - 2s3d\ ^3D_2$
Rate Coefficient ($cm^3/s$)
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^{-14}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

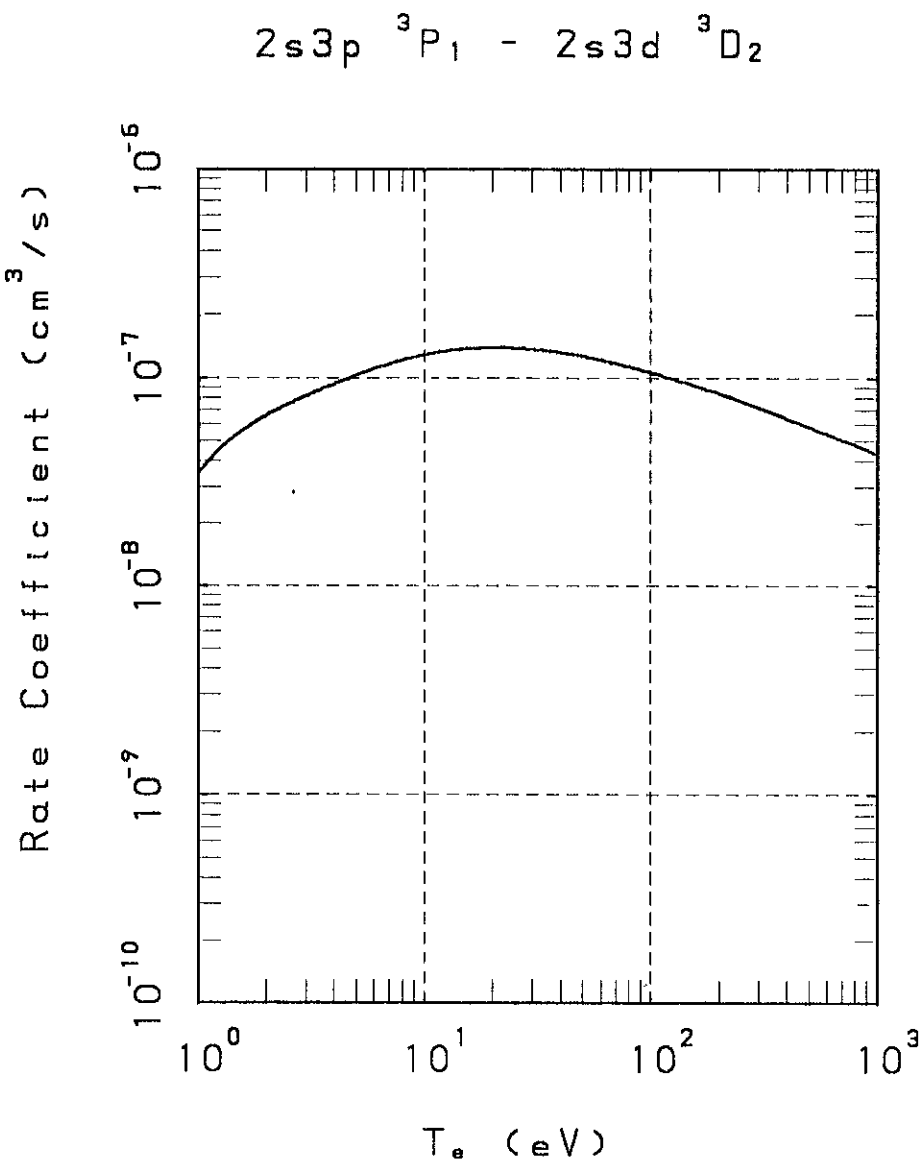

$2p^2\ ^3P_2 - 2s3d\ ^3D_3$
Rate Coefficient ($cm^3/s$)
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

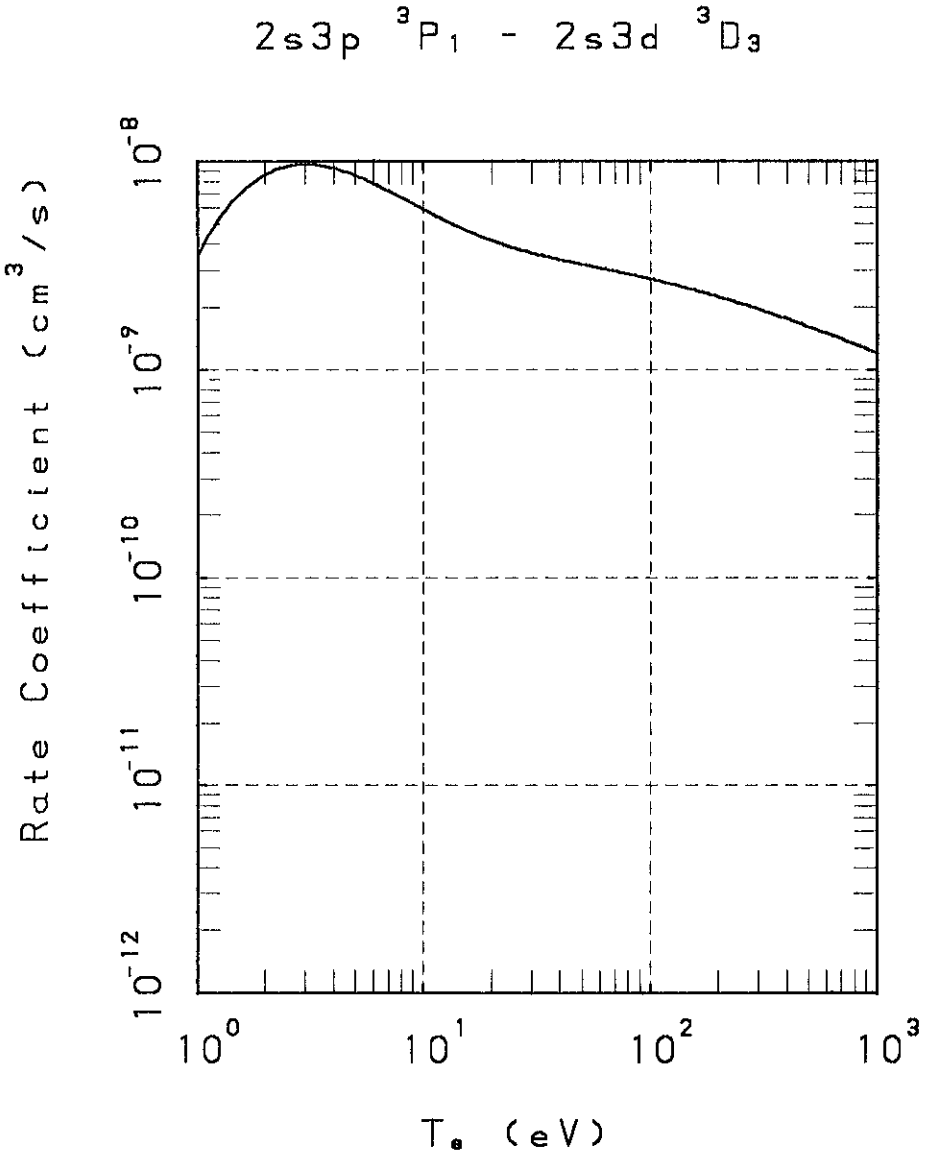

$2s3p\ ^3P_0 - 2s3d\ ^3D_1$
Rate Coefficient ($cm^3/s$)
$10^{-6}$
$10^{-7}$
$10^{-8}$
$10^{-9}$
$10^{-10}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

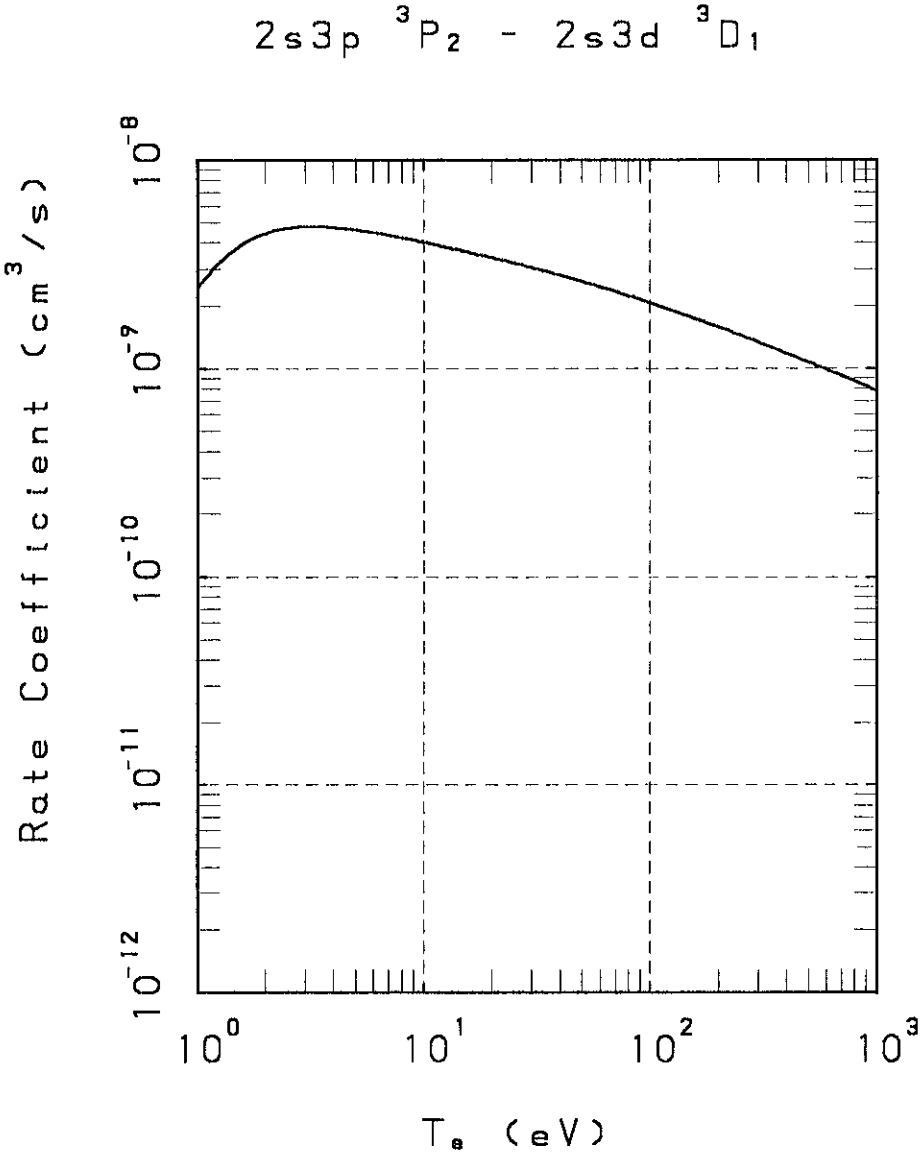

2s3p ³P₀ - 2s3d ³D₂
Rate Coefficient (cm³/s)
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁰
10¹
10²
10³
Tₑ (eV)

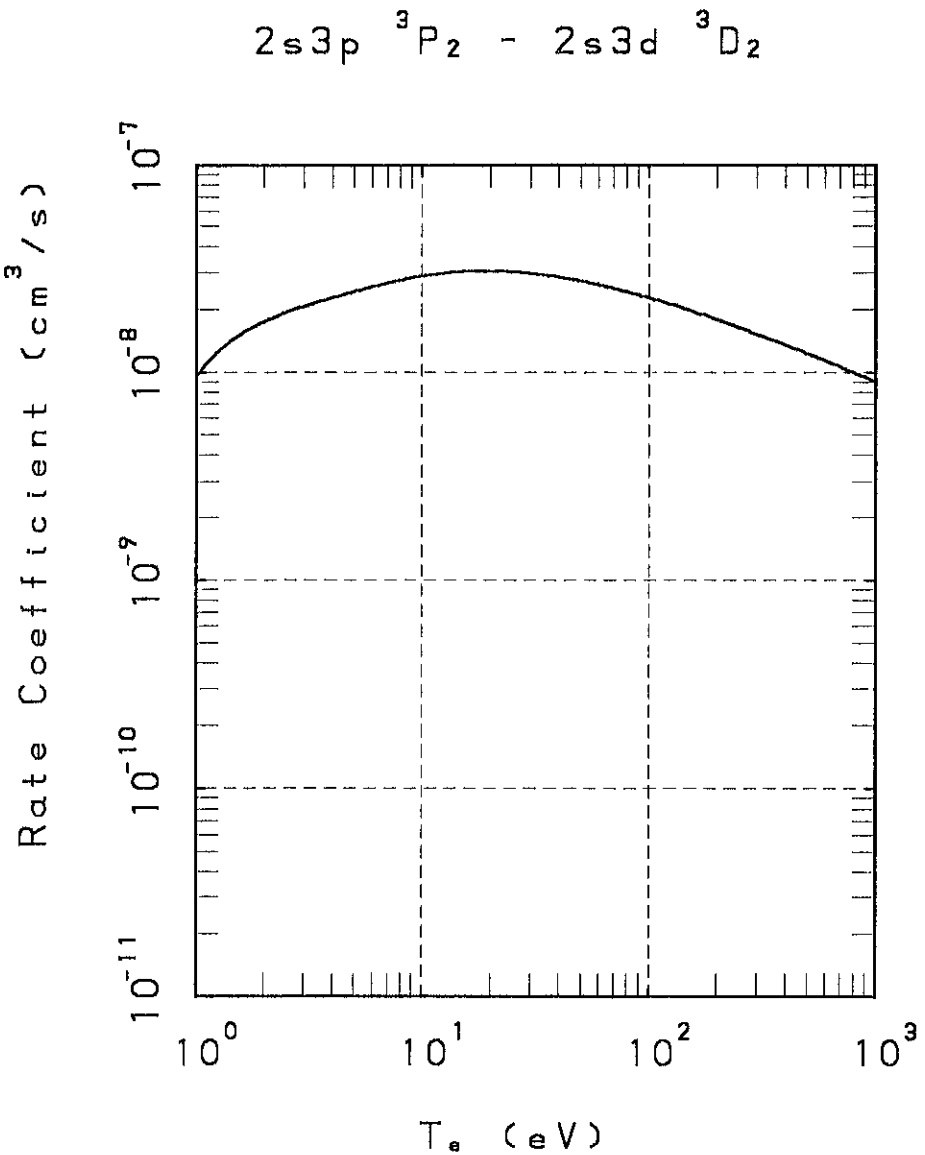

2s3p ³P₀ - 2s3d ³D₃
Rate Coefficient (cm³/s)
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁰
10¹
10²
10³
Tₑ (eV)

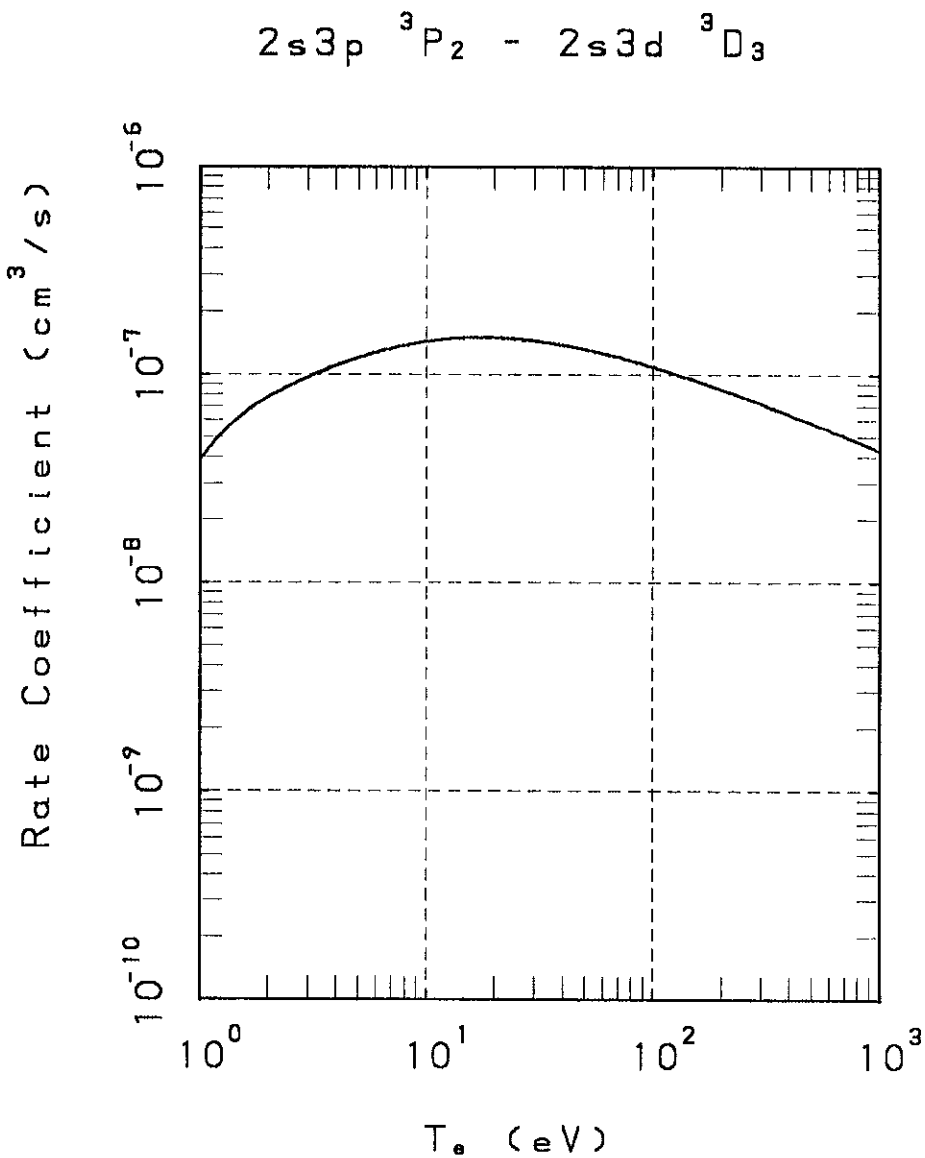

2s3p $^3P_1$ - 2s3d $^3D_1$
Rate Coefficient (cm$^3$/s)
$10^{-7}$
$10^{-8}$
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

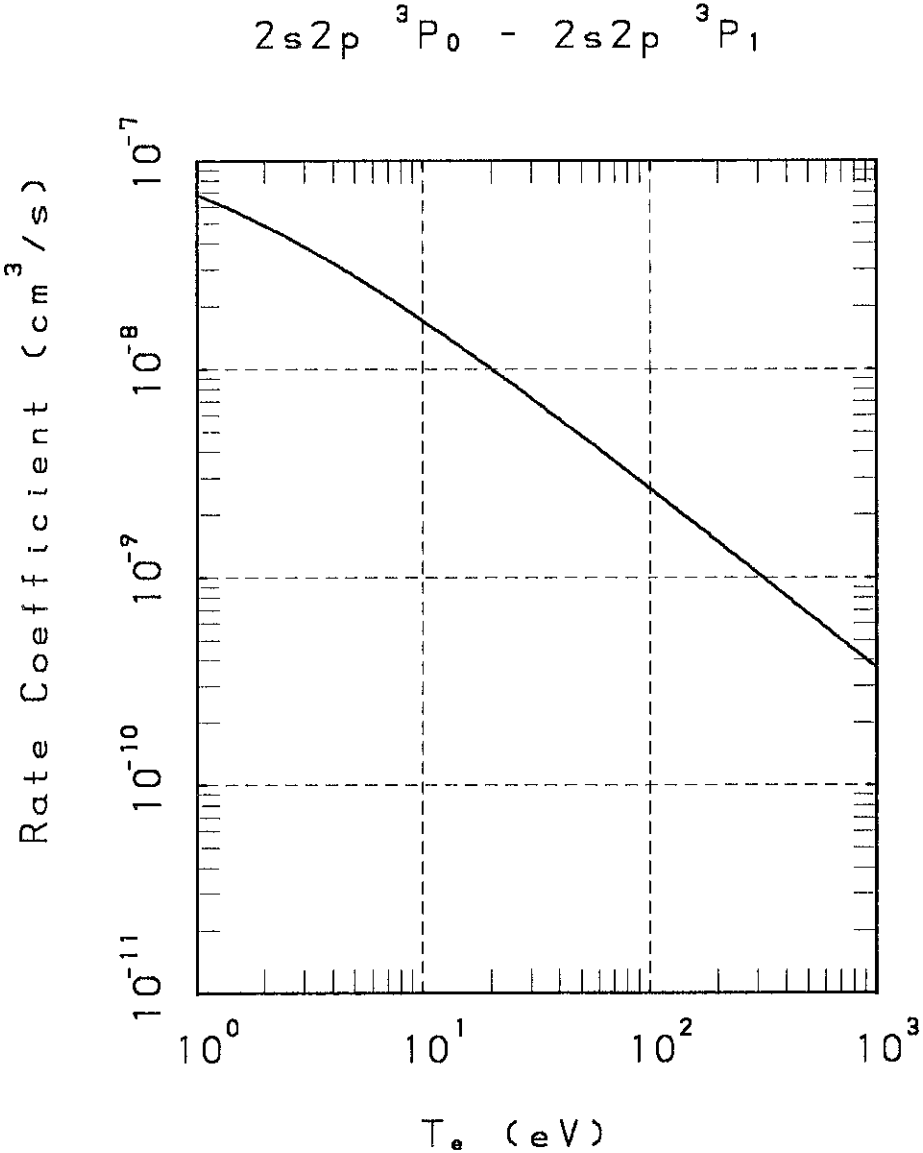

2s3p $^3P_1$ - 2s3d $^3D_2$
Rate Coefficient (cm$^3$/s)
$10^{-5}$
$10^{-7}$
$10^{-8}$
$10^{-9}$
$10^{-10}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

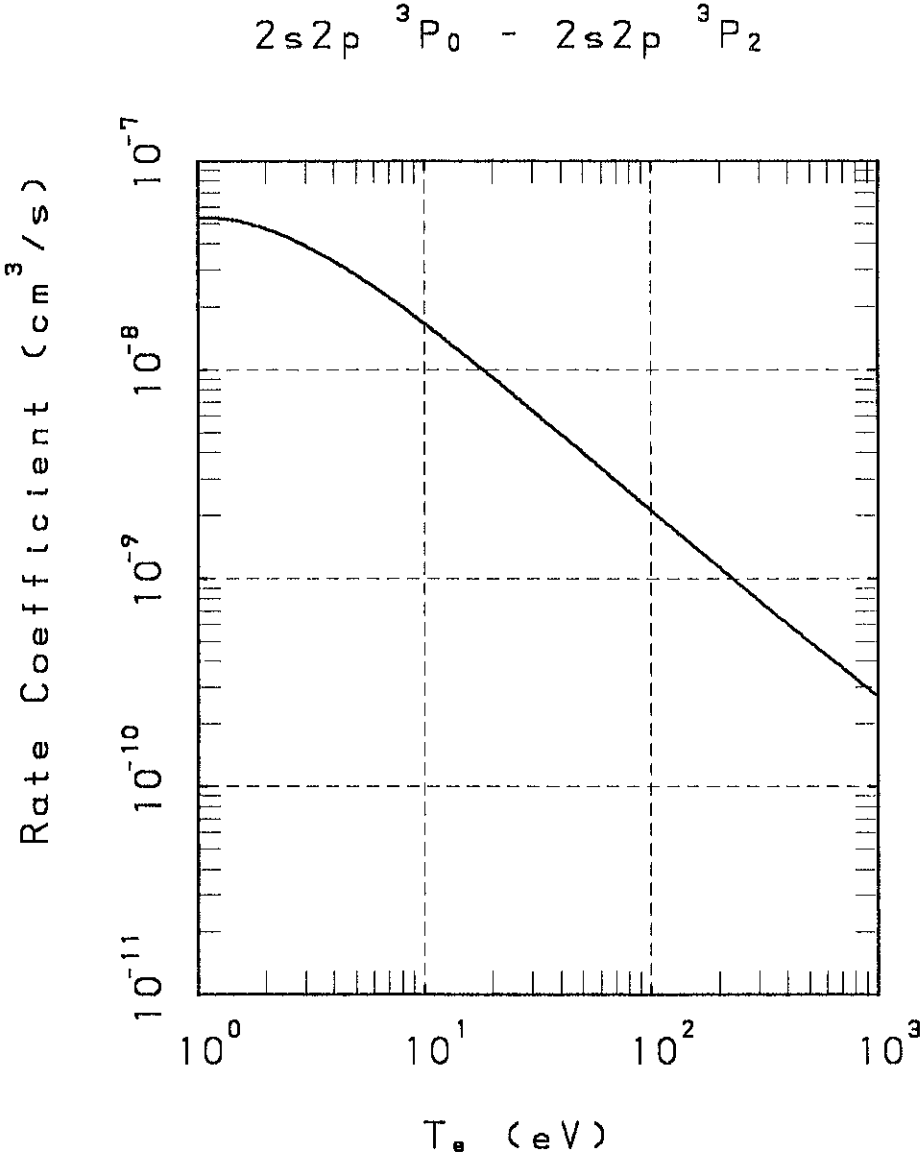

2s3p ³P₁ - 2s3d ³D₃
Rate Coefficient (cm³/s)
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁰
10¹
10²
10³
Tₑ (eV)


2s3p ³P₂ - 2s3d ³D₁
Rate Coefficient (cm³/s)
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁰
10¹
10²
10³
Tₑ (eV)


2s3p $^3P_2$ - 2s3d $^3D_2$
Rate Coefficient (cm$^3$/s)
$10^{-7}$
$10^{-8}$
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

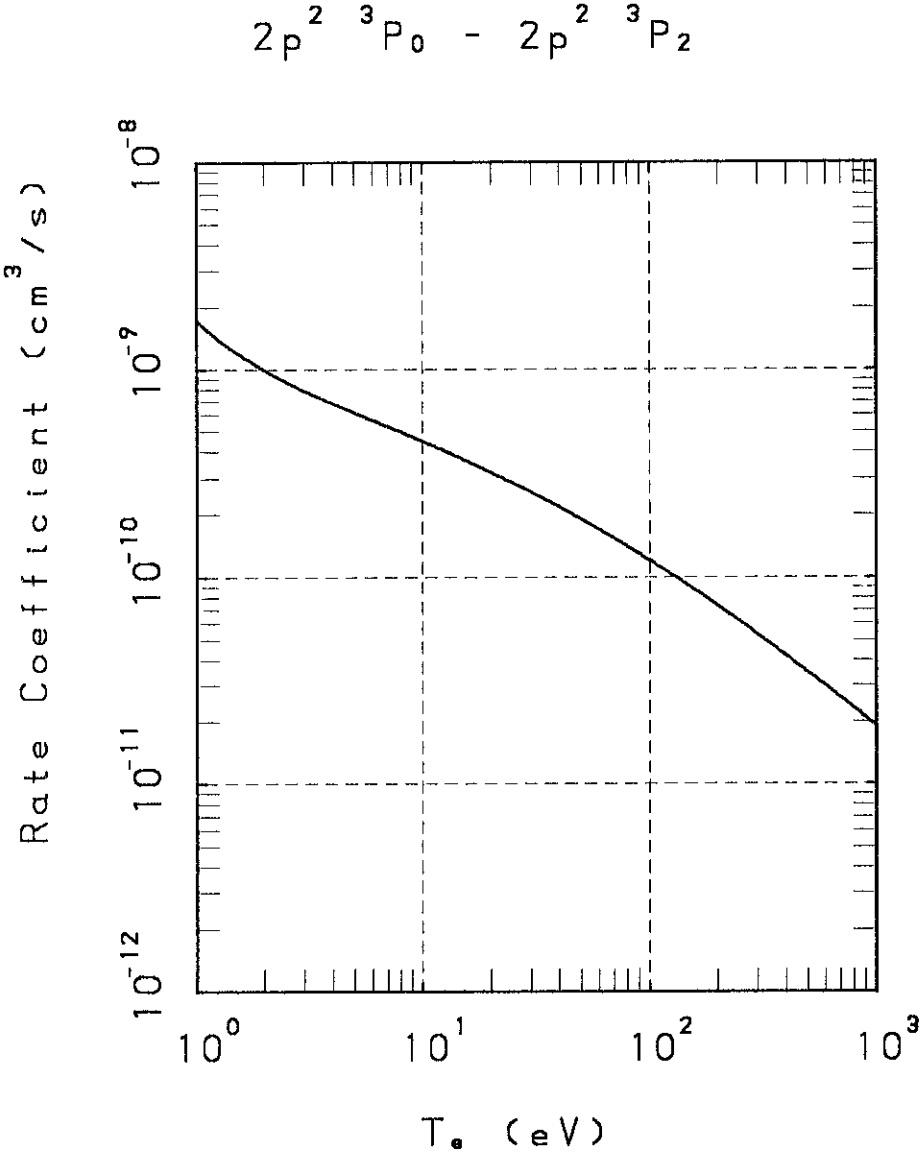

2s3p $^3P_2$ - 2s3d $^3D_3$
Rate Coefficient (cm$^3$/s)
$10^{-6}$
$10^{-7}$
$10^{-8}$
$10^{-9}$
$10^{-10}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

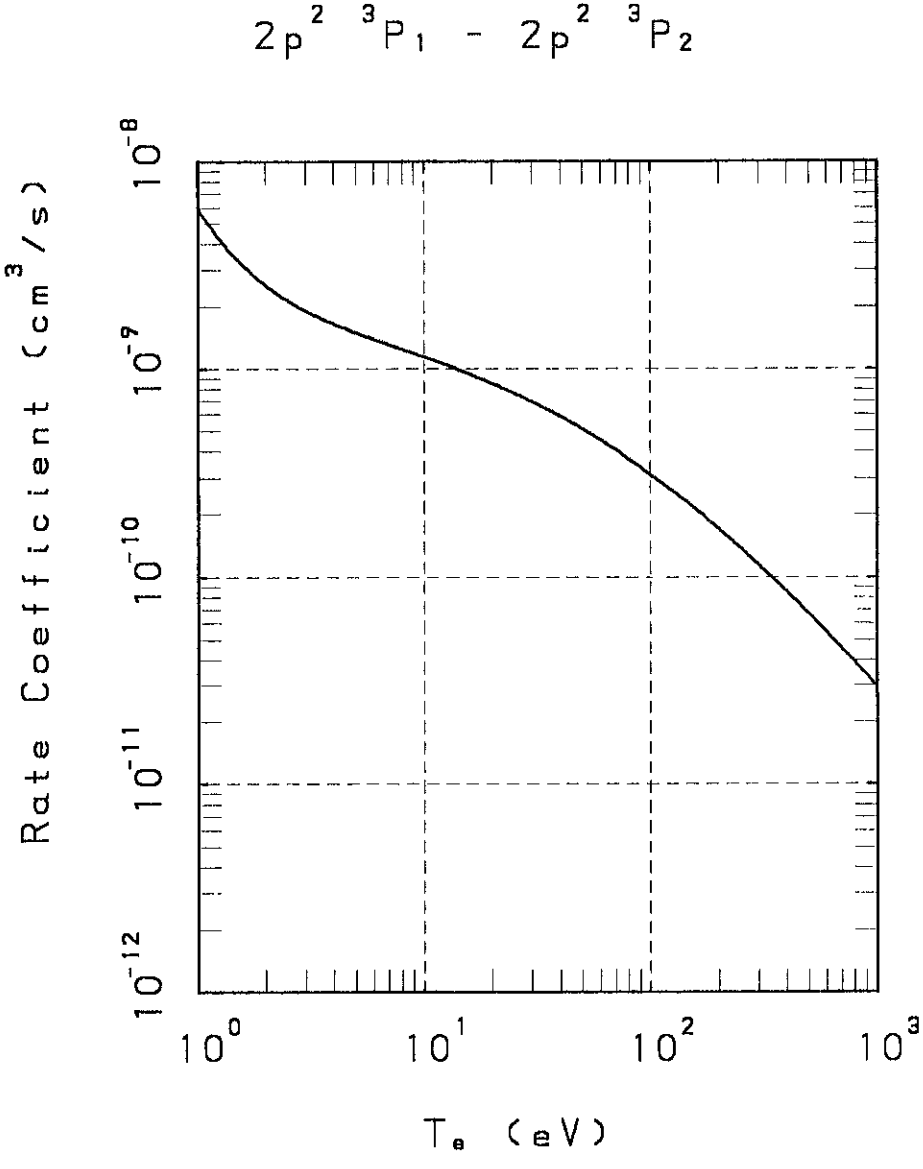

2s2p ³P₀ - 2s2p ³P₁
Rate Coefficient (cm³/s)
10⁻⁷
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁰
10¹
10²
10³
Tₑ (eV)

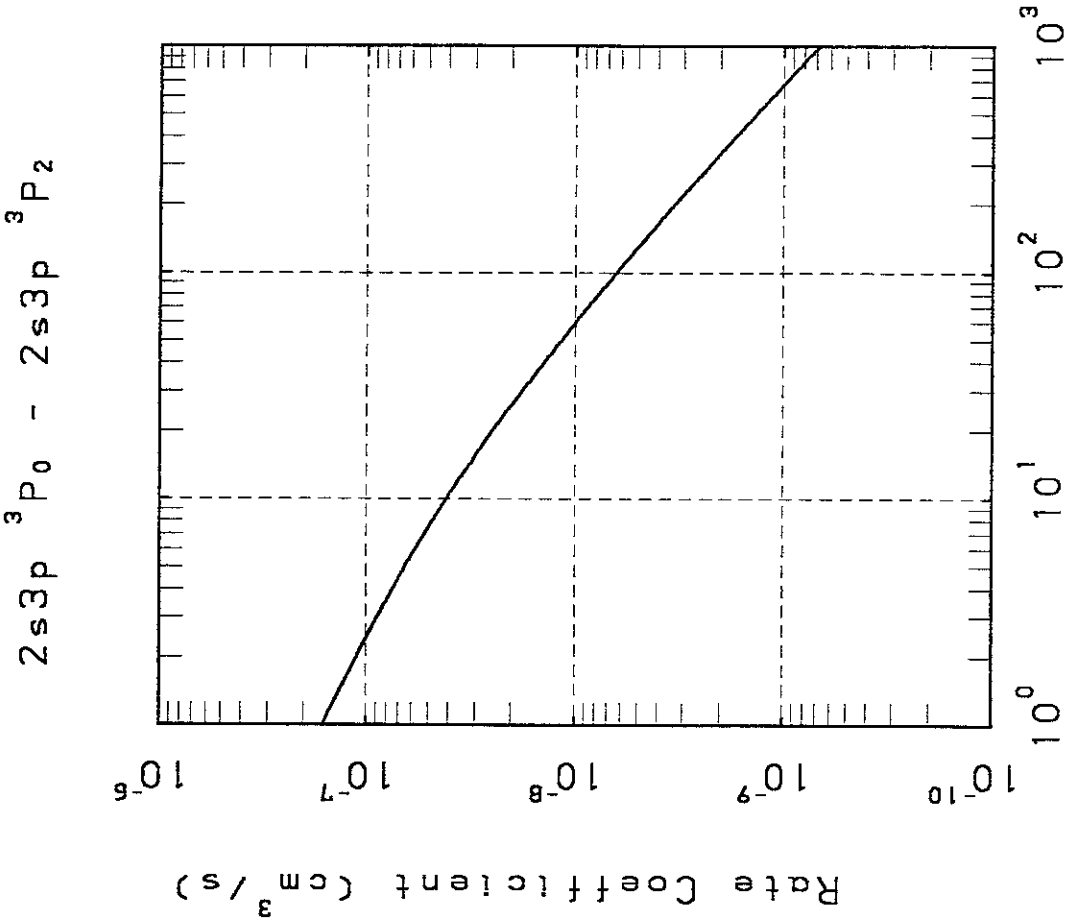

2s2p ³P₀ - 2s2p ³P₂
Rate Coefficient (cm³/s)
10⁻⁷
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁰
10¹
10²
10³
Tₑ (eV)

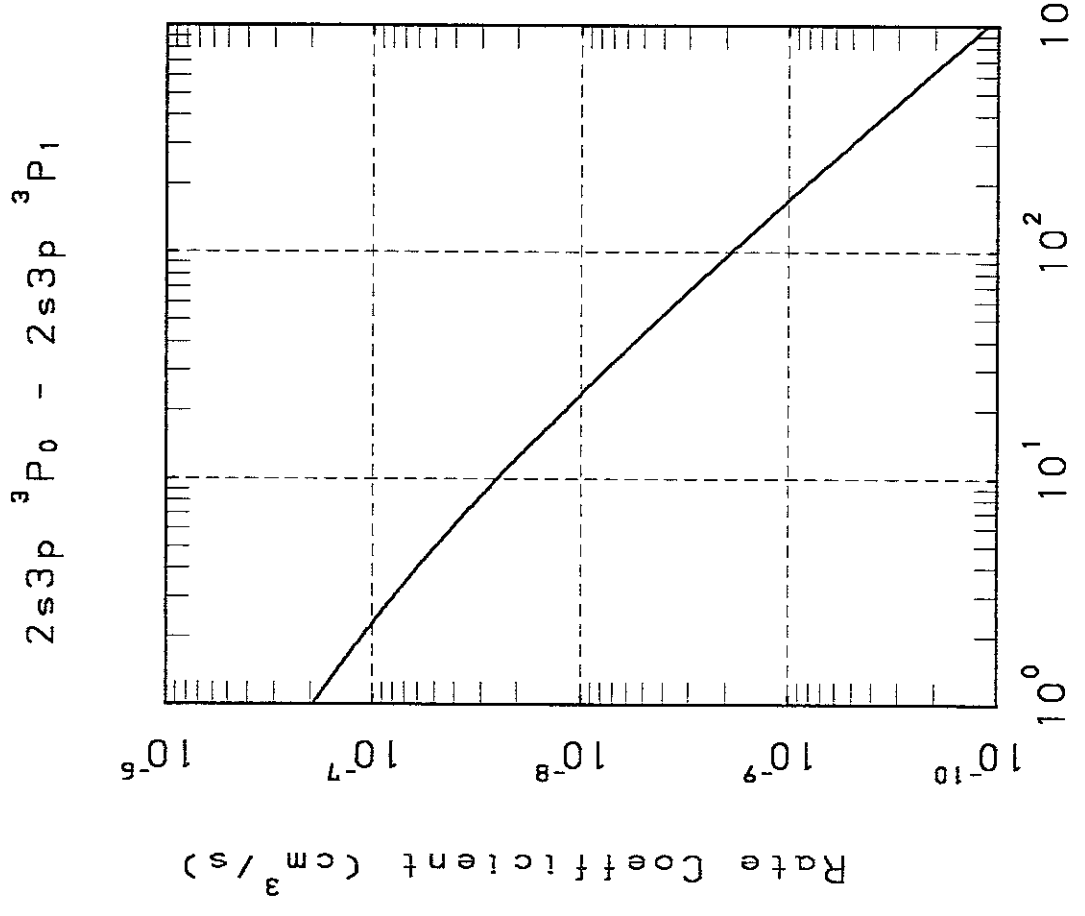
$2p^2\ ^3P_0 - 2p^2\ ^3P_1$
Rate Coefficient ($cm^3/s$)
$10^{-8}$
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

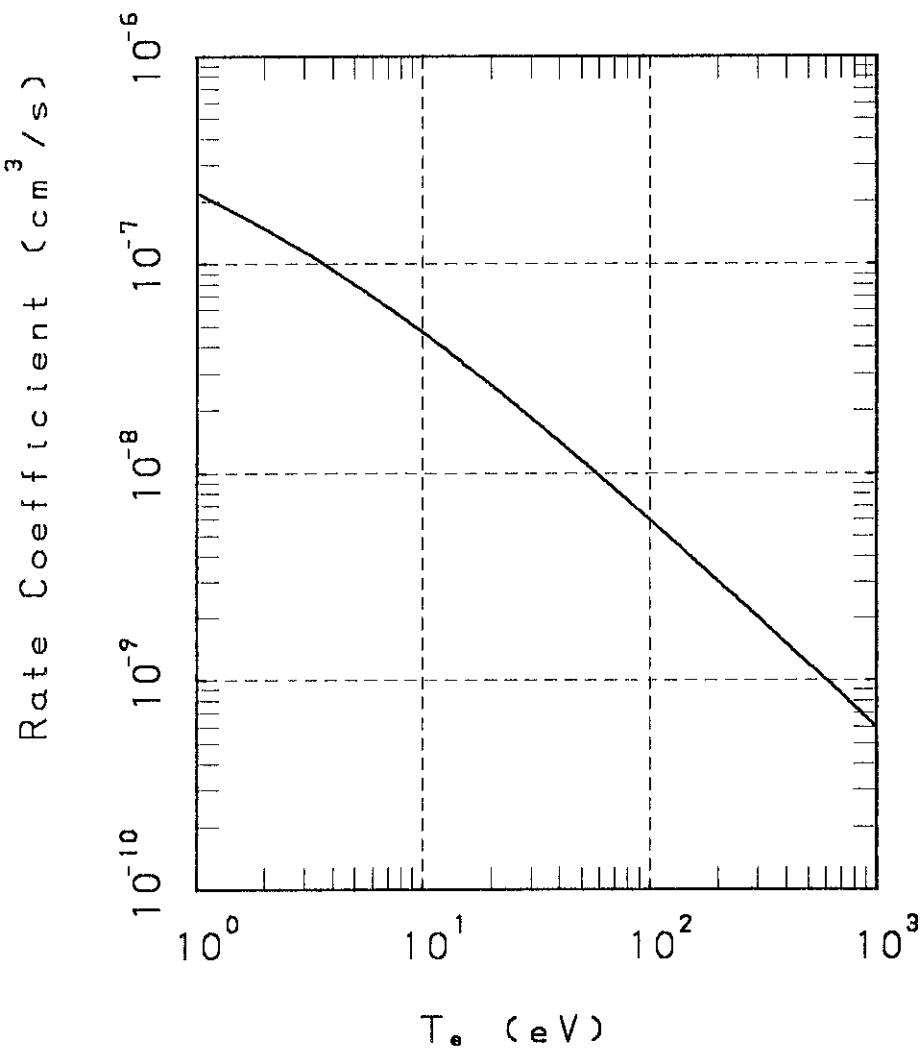

$2s2p\ ^3P_1 - 2s2p\ ^3P_2$
Rate Coefficient ($cm^3/s$)
$10^{-7}$
$10^{-8}$
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

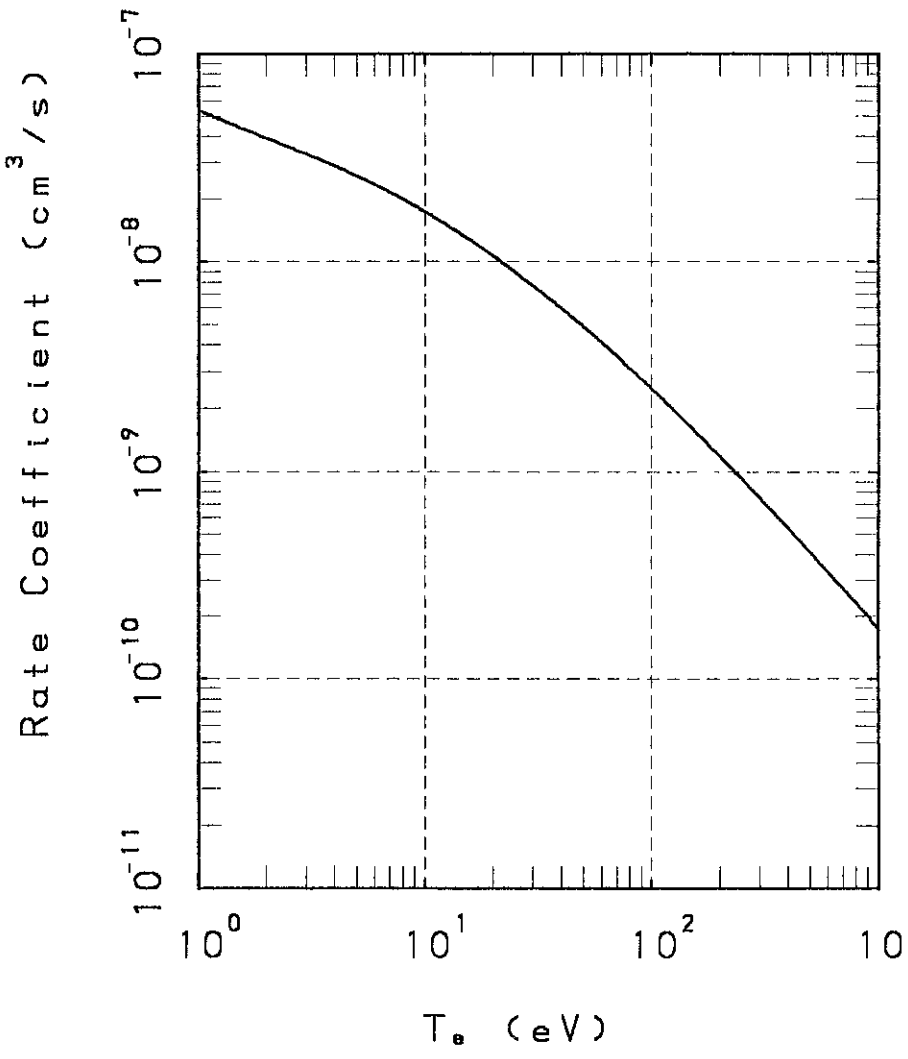

$2p^2\ ^3P_0 - 2p^2\ ^3P_2$
Rate Coefficient ($cm^3/s$)
$10^{-8}$
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

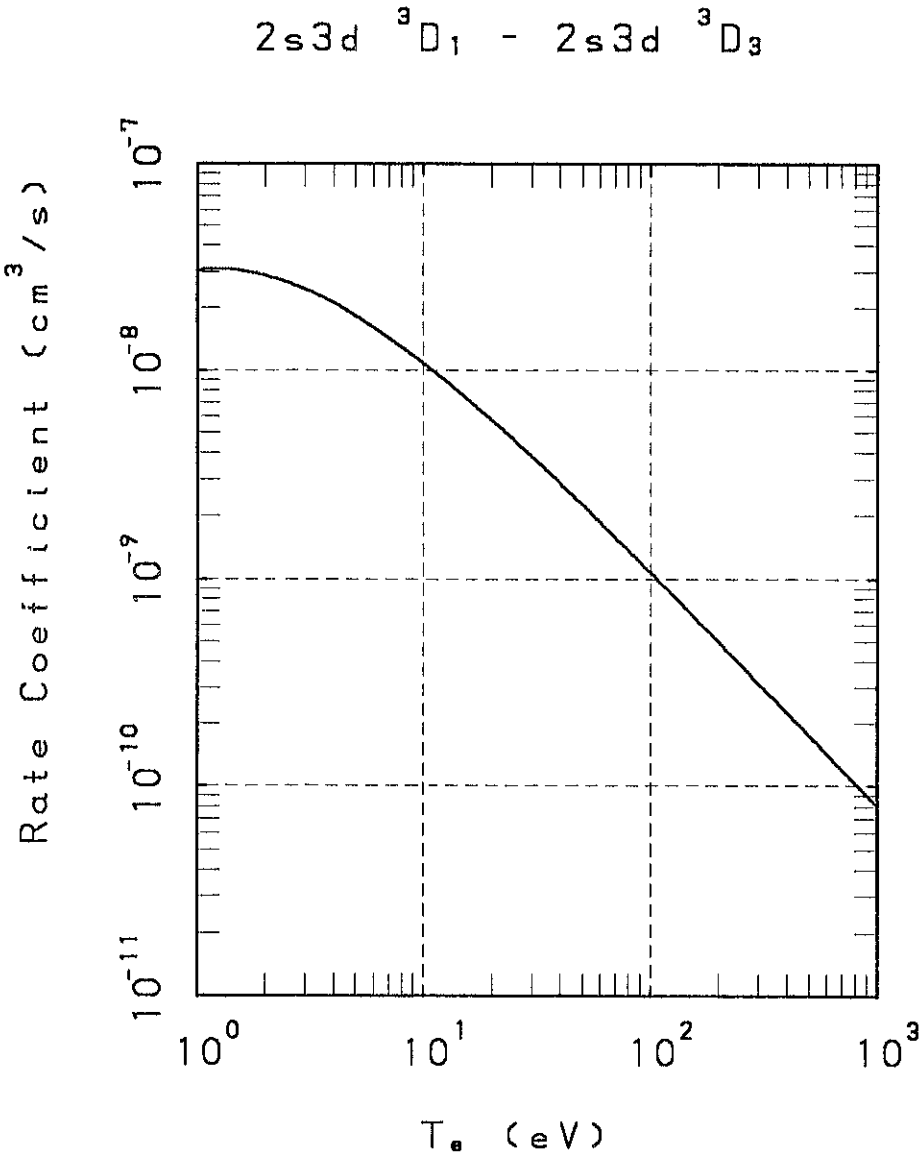

$2p^2\ ^3P_1 - 2p^2\ ^3P_2$
Rate Coefficient ($cm^3/s$)
$10^{-8}$
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)

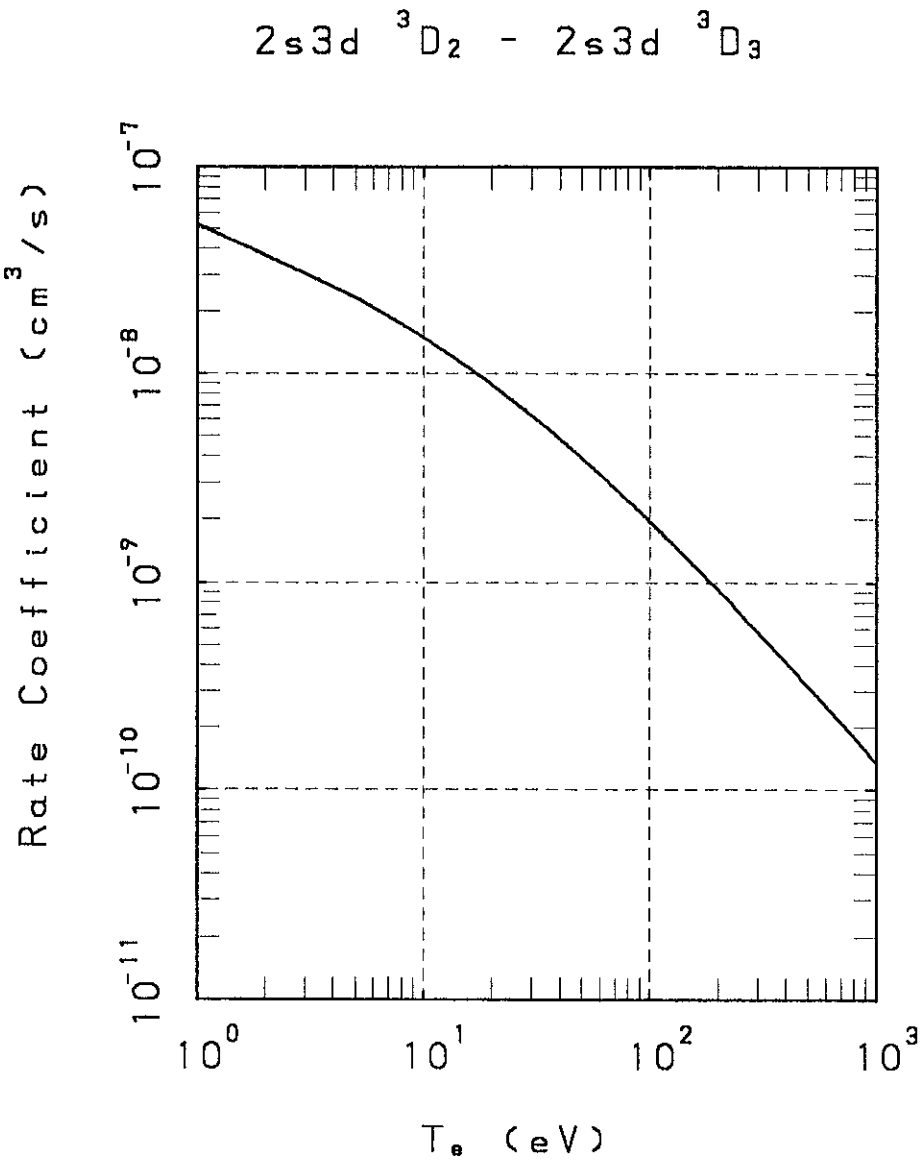

2s3p ³P₀ - 2s3p ³P₂
Rate Coefficient (cm³/s)
10⁻⁶
10⁻⁷
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁰
10¹
10²
10³
Tₑ (eV)


2s3p ³P₀ - 2s3p ³P₁
Rate Coefficient (cm³/s)
10⁻⁶
10⁻⁷
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁰
10¹
10²
10³
Tₑ (eV)


2s3p $^3P_1$ - 2s3p $^3P_2$
Rate Coefficient (cm$^3$/s)
$10^{-6}$
$10^{-7}$
$10^{-8}$
$10^{-9}$
$10^{-10}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)


2s3d $^3D_1$ - 2s3d $^3D_2$
Rate Coefficient (cm$^3$/s)
$10^{-7}$
$10^{-8}$
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)


2s3d $^3D_1$ - 2s3d $^3D_3$
Rate Coefficient (cm$^3$/s)
$10^{-7}$
$10^{-8}$
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)


2s3d $^3D_2$ - 2s3d $^3D_3$
Rate Coefficient (cm$^3$/s)
$10^{-7}$
$10^{-8}$
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^0$
$10^1$
$10^2$
$10^3$
$T_e$ (eV)