NRL Memorandum Report 5400

Electron Energy Loss Rates in N_2, O_2 and Air

A. W. ALI

Plasma Physics Division

August 28, 1984

This report was supported by the Defense Advanced Research Projects Agency (DoD), ARPA Order 4395, Amendment 33, monitored by the Naval Surface Weapons Center under Contract No. N60921-84-WR-W0131.

NAVAL RESEARCH LABORATORY
Washington, D.C.

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY	3 DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b DECLASSIFICATION/DOWNGRADING SCHEDULE	
4 PERFORMING ORGANIZATION REPORT NUMBER(S) NRL Memorandum Report 5400	5 MONITORING ORGANIZATION REPORT NUMBER(S)
6a NAME OF PERFORMING ORGANIZATION Naval Research Laboratory 6b OFFICE SYMBOL (If applicable) Code 4700.1	7a NAME OF MONITORING ORGANIZATION Naval Surface Weapons Center
6c ADDRESS (City, State, and ZIP Code) Washington, DC 20375	7b ADDRESS (City, State, and ZIP Code) White Oak, Silver Spring, MD 20910
8a NAME OF FUNDING/SPONSORING ORGANIZATION DARPA 8b OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c ADDRESS (City, State, and ZIP Code) Arlington, VA 22209	10 SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO: 62707E PROJECT NO: TASK NO: WORK UNIT ACCESSION NO: DN680-415

11 TITLE (Include Security Classification)
Electron Energy Loss Rates in N_2, O_2 and Air

12 PERSONAL AUTHOR(S)
Ali, A. W.

13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
Interim	FROM 1983 TO 1984	1984 August 28	34

16 SUPPLEMENTARY NOTATION This report was supported by the Defense Advanced Research Projects Agency (DoD), ARPA Order No. 4395, Amendment 33, monitored by the Naval Surface Weapons Center under Contract No. N60921-84-WR-W0131.

17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Electron energy loss in N_2; O_2; Air; Vibrational excitation; Dissociation; Ionization

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

The rate of energy loss by low energy electrons in N_2, O_2 and air are calculated for an Electron Maxwellian velocity distribution. For each species the rate coefficients for energy loss to specific inelastic processes are presented. These processes are the vibrational excitation, dissociation, electronic excitations and ionization of the species.

20 DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a NAME OF RESPONSIBLE INDIVIDUAL A. W. Ali	22b TELEPHONE (Include Area Code) (202) 767-3762 22c OFFICE SYMBOL Code 4700.1

DD FORM 1473, 84 MAR 83 APR edition may be used until exhausted
All other editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE

CONTENTS

ELECTRON ENERGY LOSS RATES IN N_2, O_2 AND AIR

I. INTRODUCTION

For discharge modeling in N_2, O_2 and air one needs to know the rates of electron energy loss to various inelastic processes. To obtain these rates one requires a set of established electron-molecule scattering cross sections for the inelastic processes in N_2 and O_2. These cross sections are then utilized with the appropriate electron velocity distribution to generate the collision rate coefficients and the energy loss rate coefficients to each individual inelastic process.

In this report we provide the electron energy loss rate coefficients in N_2, O_2 and air for a Maxwellian electron velocity distribution.

II. ELECTRON ENERGY LOSS RATE COEFFICIENTS IN N_2

A set of cross sections for the electron nitrogen collisions was given recently[1] which was a revision of a previous set[2]. These cross sections have been utilzed[3] to obtain the rate coefficients for the various inelastic processes in N_2 for a Maxwellian electron velocity distribution. Using these data with the appropriate threshold energies[4,5] the rate coefficients of the electron energy loss in N_2, O_2 and air were developed and some results[6] were given in graphical forms in Ref. (4). However, the detailed account of these energy loss processes are provided in this report.

Table I gives the coefficients for the electron energy loss rate to the important triplet states of N_2 i.e. $A^3\pi$, $B^3\pi$, $C^3\pi$, $W^3\Delta$ and $B\ ^3\Sigma$. The coefficients are also shown in Figures 1a and 1b.

Table II gives the electron energy loss rate coefficients to several singlet states ($W^1\Delta$, $a'\ ^1\Sigma$ and $a^1\pi$) whose excitation energies are below 12 eV. These rate coefficients are shown graphically in Figures 2a and 2b. All other singlet states and triplets above 12 eV and a fraction of $a^1\pi$ (18%) are

Manuscript approved June 7, 1984.

assumed to predissociate and are included[7] in the total dissociation rate of N_2.

Table III shows the electron energy loss rate coefficients to the dissociation and ionization of N_2 (Columns 3 and 4, respectively). These rates are also shown in Figure 3.

The rate coefficient for energy loss to eight vibrational levels is given in Table III (Column 5) and is shown graphically in Figure 4.

The total rate coefficient for energy loss in N_2 is given in Table III (Column 6) and is shown in Figure 5 along with the contributions of various processes discussed above.

III. ELECTRON ENERGY LOSS RATE COEFFICIENTS IN O_2

The rate coefficients for the electron energy loss in O_2 are presented in Table IV. Columns 1 and 2 of this table give the coefficients for energy loss to the lowest lying metastable states $a^1\Delta$ and $b^1\Sigma$. Two dissociation channels for O_2 are presented through the $B^3\Sigma$ state and the sum of $A^3\Sigma + C^3\Delta + C^1\Sigma$ states with different dissociation thresholds. The rate coefficients for energy loss to these dissociations are shown in Columns 3 and 4 of Table IV.

The coefficient for energy loss to ionization is given by Column 5 of Table IV while Column 6 presents the coefficient for energy loss to the vibrational levels of O_2. The coefficient for the total energy loss is given in Column 7 of Table IV. All these coefficients which are tabulated in Table IV are shown graphically in Figures 6a and 6b.

IV. ELECTRON ENERGY LOSS RATE COEFFICIENT IN AIR

The rate coefficients for the energy loss by electrons in N_2 and O_2, given in Tables III and IV, are utilized to obtain the coefficient for energy loss in air by using the following relation

$$R(\text{Air}) \doteq 0.8\ R(N_2) + 0.2\ R(O_2) \qquad (1)$$

Here $R(N_2)$ and $R(O_2)$ are the coefficients for electron energy loss in N_2 and O_2, respectively. The rate coefficients obtained using equation (1) are given in Table V and are shown in Figure 7 along with the total energy loss coefficients in N_2 and O_2. It is obvious from Figure 7 that the energy loss rate in air is slightly lower than the energy loss in N_2.

Table 1 — Rate coefficients for energy loss in N_2(eV-cm^3/sec)

T_e(eV)	$A^3\Sigma$	$B^3\pi$	$W^3\Delta$	$\acute{B}^3\Sigma$	$C^3\pi$
0.2	2.02 (-22)(*)	1.02 (-24)	7.43 (-25)	7.66 (-27)	7.22 (-32)
0.3	6.66 (-18)	3.25 (-19)	2.01 (-19)	7.7 (-21)	8.37 (-24)
0.4	1.28 (-15)	1.93 (-16)	1.11 (-16)	8.2 (-18)	9.40 (-20)
0.5	3.19 (-14)	9.18 (-15)	5.10 (-15)	5.5 (-16)	2.61 (-17)
0.6	2.82 (-13)	1.22 (-13)	6.71 (-14)	9.43 (-15)	1.12 (-15)
0.7	1.38 (-12)	7.86 (-13)	4.30 (-13)	7.26 (-14)	1.67 (-14)
0.8	4.64 (-12)	3.21 (-12)	1.76 (-12)	3.40 (-13)	1.26 (-13)
0.9	1.21 (-11)	9.63 (-12)	5.33 (-12)	1.14 (-12)	6.17 (-13)
1.0	2.60 (-11)	2.4 (-11)	1.3 (-11)	2.9 (-12)	2.0 (-12)
1.2	8.6 (-11)	8.8 (-11)	5.1 (-11)	1.3 (-11)	1.4 (-11)
1.5	2.283(-10)	3.3 (-10)	2.0 (-10)	6.0 (-11)	9.1 (-11)
2.0	8.02 (-10)	1.2 (-9)	8.8 (-10)	2.8 (-10)	5.8 (-10)
2.5	1.66 (-9)	2.7 (-9)	2.1 (-9)	6.9 (-10)	1.8 (-9)
3.0	2.84 (-9)	4.5 (-9)	3.8 (-9)	1.2 (-9)	3.4 (-9)
4.0	5.36 (-9)	8.4 (-9)	8.1 (-9)	2.6 (-9)	7.9 (-9)
5.0	8.02 (-9)	1.2 (-8)	1.2 (-8)	3.8 (-9)	1.2 (-8)

(*) 2.02 (-22) implies 2.02×10^{-22}

Table 1 (Cont'd) — Rate coefficients for energy loss in N_2($eV\text{-}cm^3/sec$)

T_e(eV)	$A^3\Sigma$	$B^3\pi$	$W^3\Delta$	$\acute{B}^3\Sigma$	$C^3\pi$
6.0	9.87 (-9)	1.5 (-8)	1.5 (-8)	5.0 (-9)	1.7 (-8)
7.0	1.17 (-8)	1.7 (-8)	1.7 (-8)	5.8 (-9)	2.0 (-8)
8.0	1.29 (-8)	1.8 (-8)	2.0 (-8)	6.5 (-9)	2.2 (-8)
9.0	1.38 (-8)	1.9 (-8)	2.1 (-8)	7.0 (-9)	2.3 (-8)
10	1.48 (-8)	2.0 (-8)	2.2 (-8)	7.4 (-9)	2.5 (-8)
11	1.51 (-8)	2.0 (-8)	2.3 (-8)	7.7 (-9)	2.5 (-8)
12	1.54 (-8)	2.0 (-8)	2.4 (-8)	7.9 (-9)	2.6 (-8)
13	1.60 (-8)	2.0 (-8)	2.4 (-8)	8.0 (-9)	2.6 (-8)
14	1.60 (-8)	2.0 (-8)	2.4 (-8)	8.2 (-9)	2.6 (-8)
15	1.60 (-8)	2.0 (-8)	2.4 (-8)	8.2 (-9)	2.6 (-8)
16	1.60 (-8)	2.0 (-8)	2.4 (-8)	8.2 (-9)	2.6 (-8)
17	1.66 (-8)	2.0 (-8)	2.3 (-8)	8.2 (-9)	2.6 (-8)
18	1.66 (-8)	2.0 (-8)	2.3 (-8)	8.2 (-9)	2.6 (-8)
19	1.66 (-8)	2.0 (-8)	2.2 (-8)	8.2 (-9)	2.5 (-8)
20	1.66 (-8)	2.0 (-8)	2.2 (-8)	8.1 (-9)	2.5 (-8)

Table II — Rate coefficients for energy loss to N_2 singlets (eV-cm^3/sec)

T_e(eV)	$a'\,{}^1\Sigma^-$	$a\,{}^1\pi$	$w\,{}^1\Delta$
0.2	2.15 (-27)	2.69 (-27)	2.98 (-28)
0.3	3.18 (-21)	5.10 (-21)	1.13 (-21)
0.4	4.11 (-18)	7.39 (-18)	2.38 (-18)
0.5	3.13 (-16)	6.02 (-16)	2.41 (-16)
0.6	5.76 (-15)	1.16 (-14)	5.37 (-15)
0.7	4.70 (-14)	9.73 (-14)	5.00 (-14)
0.8	2.29 (-13)	4.86 (-13)	2.69 (-13)
0.9	8.00 (-13)	1.72 (-12)	1.00 (-12)
1.0	2.2 (-12)	4.5 (-12)	2.5 (-12)
1.2	1.0 (-11)	2.2 (-11)	1.4 (-11)
1.5	4.7 (-11)	1.1 (-10)	6.2 (-11)
2.0	2.2 (-10)	5.4 (-10)	3.0 (-10)
2.5	2.6 (-10)	1.5 (-9)	7.6 (-10)
3	1.0 (-9)	2.9 (-9)	1.3 (-9)
4	2.1 (-9)	6.7 (-9)	2.8 (-9)
5	3.1 (-9)	1.1 (-8)	4.0 (-9)

Table II (Cont'd) — Rate coefficients for energy loss to N_2 singlets (eV-cm^3/sec)

T_e(eV)	$a' \, ^1\Sigma^-$	$a \, ^1\pi$	$w \, ^1\Delta$
6	3.9 (-9)	1.5 (-8)	5.0 (-9)
7	4.7 (-9)	1.9 (-8)	5.8 (-9)
8	5.2 (-9)	2.2 (-8)	6.3 (-9)
9	5.6 (-9)	2.6 (-8)	6.7 (-9)
10	5.9 (-9)	2.8 (-8)	6.9 (-9)
11	6.1 (-9)	3.0 (-8)	7.0 (-9)
12	6.3 (-9)	3.2 (-8)	7.1 (-9)
13	6.5 (-9)	3.3 (-8)	7.1 (-9)
14	6.6 (-9)	3.4 (-8)	7.2 (-9)
15	6.6 (-9)	3.5 (-8)	7.0 (-9)
16	6.7 (-9)	3.6 (-8)	7.0 (-9)
17	6.8 (-9)	3.7 (-8)	6.8 (-9)
18	6.8 (-9)	3.7 (-8)	6.7 (-9)
19	6.9 (-9)	3.8 (-8)	6.6 (-9)
20	6.9 (-9)	3.8 (-8)	6.4 (-9)

Table III — Rate of energy loss in N_2($eV\text{-}cm^3/sec$)

T_e(eV)	TRIPLETS	SINGLETS	DISS.	ION.	VIB.	TOTAL
0.2	2.02 (-22)	4.65 (-27)	8.51 (-30)		8.0 (-12)	8.0 (-12)
0.3	7.1 (-18)	8.5 (-21)	1.01 (-22)		9.2 (-11)	9.2 (-11)
0.4	1.48 (-15)	1.25 (-17)	3.66 (-19)	6.60 (-25)	7.7 (-10)	7.7 (-10)
0.5	4.7 (-14)	1.0 (-15)	5.1 (-17)	1.82 (-21)	1.7 (-9)	1.7 (-9)
0.6	4.8 (-13)	2.06 (-15)	1.4 (-15)	3.66 (-19)	2.7 (-9)	2.7 (-9)
0.7	2.7 (-12)	1.76 (-13)	1.6 (-14)	1.65 (-17)	4.1 (-9)	4.1 (-9)
0.8	1.01 (-11)	6.54 (-13)	9.96 (-14)	2.91 (-16)	5.2 (-9)	5.2 (-9)
0.9	2.91 (-11)	3.2 (-12)	4.3 (-13)	2.7 (-15)	6.1 (-9)	6.1 (-9)
1.0	6.2 (-11)	8.39 (-12)	1.44 (-12)	1.67 (-14)	6.8 (-9)	6.85 (-9)
1.5	9.1 (-10)	2.03 (-11)	6.46 (-11)	4.11 (-12)	8.6 (-9)	9.59 (-9)
2.0	3.7 (-9)	9.99 (-10)	5.01 (-10)	7.01 (-11)	8.8 (-9)	1.41 (-8)
2.5	8.95 (-9)	2.68 (-9)	1.82 (-9)	4.05 (-10)	8.0 (-9)	1.74 (-8)
3	1.57 (-8)	5.0 (-9)	4.47 (-9)	1.34 (-9)	7.2 (-9)	3.37 (-8)
4	3.2 (-8)	1.14 (-8)	1.44 (-8)	6.42 (-9)	6.0 (-9)	7.02 (-8)
5	4.78 (-8)	1.78 (-8)	3.02 (-8)	1.71 (-8)	5.0 (-9)	1.18 (-7)

Table III (Cont'd) — Rate of energy loss in N_2($eV \cdot cm^3/sec$)

T_e(ev)	TRIPLETS	SINGLETS	DISS.	ION.	VIB.	TOTAL
6	6.2 (-8)	2.38 (-8)	5.04 (-8)	3.4 (-8)		1.70 (-9)
7	7.15 (-8)	2.95 (-8)	7.35 (-8)	5.7 (-8)		2.31 (-7)
8	7.94 (-8)	3.37 (-8)	9.8 (-8)	8.6 (-8)		2.97 (-7)
9	8.38 (-8)	3.83 (-8)	1.24 (-7)	1.2 (-7)		3.66 (-7)
10	8.9 (-8)	4.11 (-8)	1.51 (-7)	1.6 (-7)		4.4· (-7)
11	9.08 (-8)	4.33 (-8)	1.76 (-7)	1.9 (-7)		5.0 (-7)
12	9.33 (-8)	4.56 (-8)	2.01 (-7)	2.3 (-7)		5.69 (-7)
13	9.4 (-8)	4.68 (-8)	2.25 (-7)	2.8 (-7)		6.46 (-7)
14	9.4 (-8)	4.82 (-8)	2.49 (-7)	3.3 (-7)		7.2 (-7)
15	9.42 (-8)	4.9 (-8)	2.72 (-7)	3.8 (-7)		7.95 (-7)
16	9.42 (-8)	5.01 (-8)	2.94 (-7)	4.2 (-7)		8.58 (-7)
17	9.38 (-8)	5.09 (-8)	3.15 (-7)	4.7 (-7)		9.28 (-7)
18	9.38 (-8)	5.09 (-8)	3.36 (-7)	5.1 (-7)		9.89 (-7)
19	9.18 (-8)	5.18 (-8)	3.55 (-7)	5.6 (-7)		10.58 (-7)
20	9.17 (-8)	5.16 (-8)	3.74 (-7)	6.1 (-7)		11.27 (-7)

Table IV — Rate coefficients for energy loss in O_2(eV-cm^3/sec)

T_e(eV)	$a^1\Delta$	$b^1\Sigma$	$B^3\Sigma$	$A^3\Sigma + \cdots$	ION.	VIB.	TOTAL
0.2	2.18 (-13)	2.81 (-14)	2.56 (-23)	2.75 (-19)	8.45 (-35)	2.26 (-11)	2.28 (-11)
0.4	7.87 (-12)	2.10 (-12)	1.07 (-16)	1.97 (-14)	1.53 (-21)	3.89 (-11)	4.88 (-11)
0.6	3.3 (-11)	1.10 (-11)	6.88 (-14)	9.33 (-13)	4.47 (-17)	3.95 (-11)	8.35 (-11)
0.8	7.36 (-11)	8.71 (-11)	2.66 (-12)	6.92 (-12)	8.12 (-15)	3.58 (-11)	1.46 (-10)
1.0	1.24 (-10)	4.82 (-11)	2.54 (-11)	2.41 (-11)	1.92 (-13)	3.14 (-11)	2.53 (-10)
1.5	2.7 (-10)	1.08 (-10)	5.37 (-10)	1.41 (-10)	1.45 (-11)	2.27 (-11)	9.65 (-10)
2.0	4.13 (-10)	1.64 (-10)	2.51 (-9)	3.69 (-10)	1.42 (-10)	9.99 (-12)	3.61 (-9)
2.5	5.35 (-10)	2.11 (-10)	6.41 (-9)	6.88 (-10)	5.94 (-10)	7.14 (-12)	8.44 (-9)
3	6.35 (-10)	2.47 (-10)	1.20 (-8)	1.06 (-9)	1.63 (-9)	6.5 (-12)	1.55 (-8)
4	7.77 (-10)	3.01 (-10)	2.64 (-8)	1.90 (-9)	6.21 (-9)	5.8 (-12)	3.55 (-8)
5	8.65 (-10)	3.37 (-10)	4.25 (-8)	2.71 (-9)	1.48 (-8)	5.74 (-12)	6.12 (-8)
6	9.1 (-10)	3.63 (-10)	5.85 (-8)	3.44 (-9)	2.77 (-8)		8.96 (-8)
7	9.5 (-10)	3.83 (-10)	7.33 (-8)	4.09 (-9)	4.46 (-8)		12.3 (-8)

Table IV (Cont'd) — Rate coefficients for energy loss in O_2(eV-cm^3/sec)

T_e(eV)	$a^1\Delta$	$b^1\Sigma$	$B^3\Sigma$	$A^3\Sigma+\cdots$	ION.	VIB.	TOTAL
8	9.68 (-10)	3.97 (-10)	8.67 (-8)	4.60 (-9)	6.50 (-8)		15.76 (-8)
9	9.77 (-10)	4.10 (-10)	9.94 (-8)	5.03 (-9)	8.83 (-8)		19.4 (-8)
10	9.79 (-10)	4.18 (-10)	1.09 (-7)	5.37 (-9)	1.13 (-7)		2.27 (-7)
11	9.77 (-10)	4.25 (-10)	1.19 (-7)	5.67 (-9)	1.41 (-7)		2.65 (-7)
12	9.72 (-10)	4.3 (-10)	1.28 (-7)	5.89 (-9)	1.71 (-7)		3.05 (-7)
13	9.64 (-10)	4.33 (-10)	1.36 (-7)	6.06 (-9)	2.01 (-7)		3.43 (-7)
14	9.54 (-10)	4.35 (-10)	1.43 (-7)	6.19 (-9)	2.31 (-7)		3.81 (-7)
15	9.43 (-10)	4.35 (-10)	1.49 (-7)	6.27 (-9)	2.64 (-7)		4.19 (-7)
16	9.3 (-10)	4.35 (-10)	1.54 (-7)	6.36 (-9)	2.95 (-7)		4.55 (-7)
17	9.18 (-10)	4.32 (-10)	1.59 (-7)	6.41 (-9)	3.28 (-7)		4.93 (-7)
18	9.07 (-10)	4.30 (-10)	1.64 (-7)	6.45 (-9)	3.60 (-7)		5.3 (-7)
19	8.91 (-10)	4.27 (-10)	1.69 (-7)	6.45 (-9)	3.9 (-7)		5.65 (-7)
20	8.76 (-10)	4.24 (-10)	1.72 (-7)	6.45 (-9)	4.2 (-7)		5.98 (-7)

Table V — Rate coefficients for energy loss in air(eV-cm^3/sec)

T_e(eV)	0.8R(N_2)	0.2R(O_2)	R(AIR)
0.2	6.4 (-12)	4.55 (-12)	1.09 (-11)
0.4	6.16 (-10)	9.76 (-12)	6.26 (-10)
0.6	2.16 (-9)	1.67 (-11)	2.17 (-9)
0.8	4.16 (-9)	2.92 (-11)	4.18 (-9)
1.0	5.48 (-9)	5.06 (-11)	5.53 (-9)
1.5	7.67 (-9)	1.93 (-10)	7.86 (-9)
2.0	1.13 (-8)	7.22 (-10)	1.20 (-8)
2.5	1.39 (-8)	1.68 (-9)	1.56 (-8)
3	2.69 (-8)	3.10 (-9)	3.00 (-8)
4	5.6 (-8)	7.10 (-9)	6.31 (-8)
5	9.44 (-8)	1.22 (-8)	10.66 (-8)
6	1.36 (-7)	1.79 (-8)	1.54 (-7)
7	1.85 (-7)	2.46 (-8)	2.09 (-7)
8	2.37 (-7)	3.15 (-8)	2.68 (-7)
9	2.93 (-7)	3.88 (-8)	3.32 (-7)
10	3.52 (-7)	4.54 (-8)	3.97 (-7)

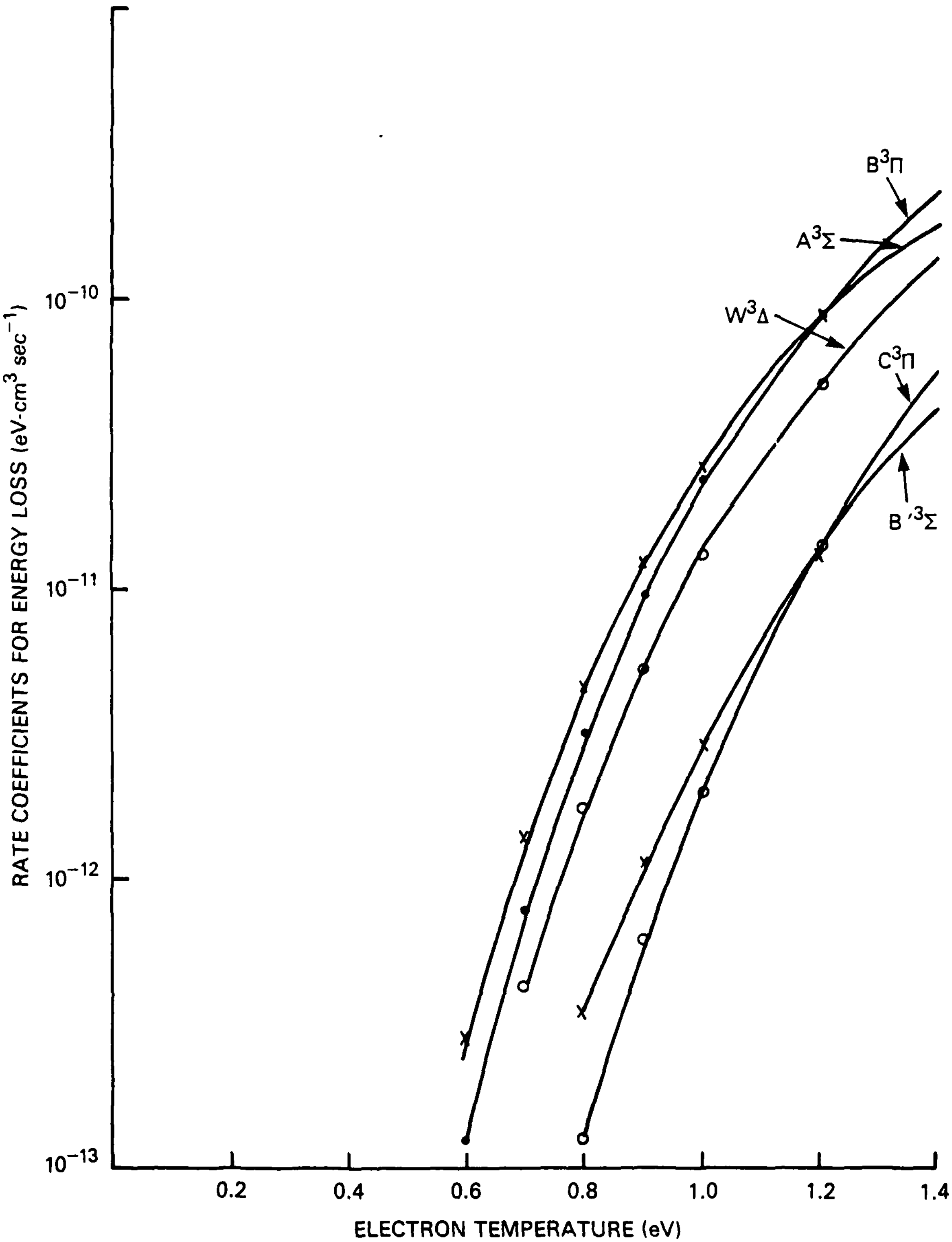

Figure 1a Electron energy loss rate coefficients to triplet states in nitrogen

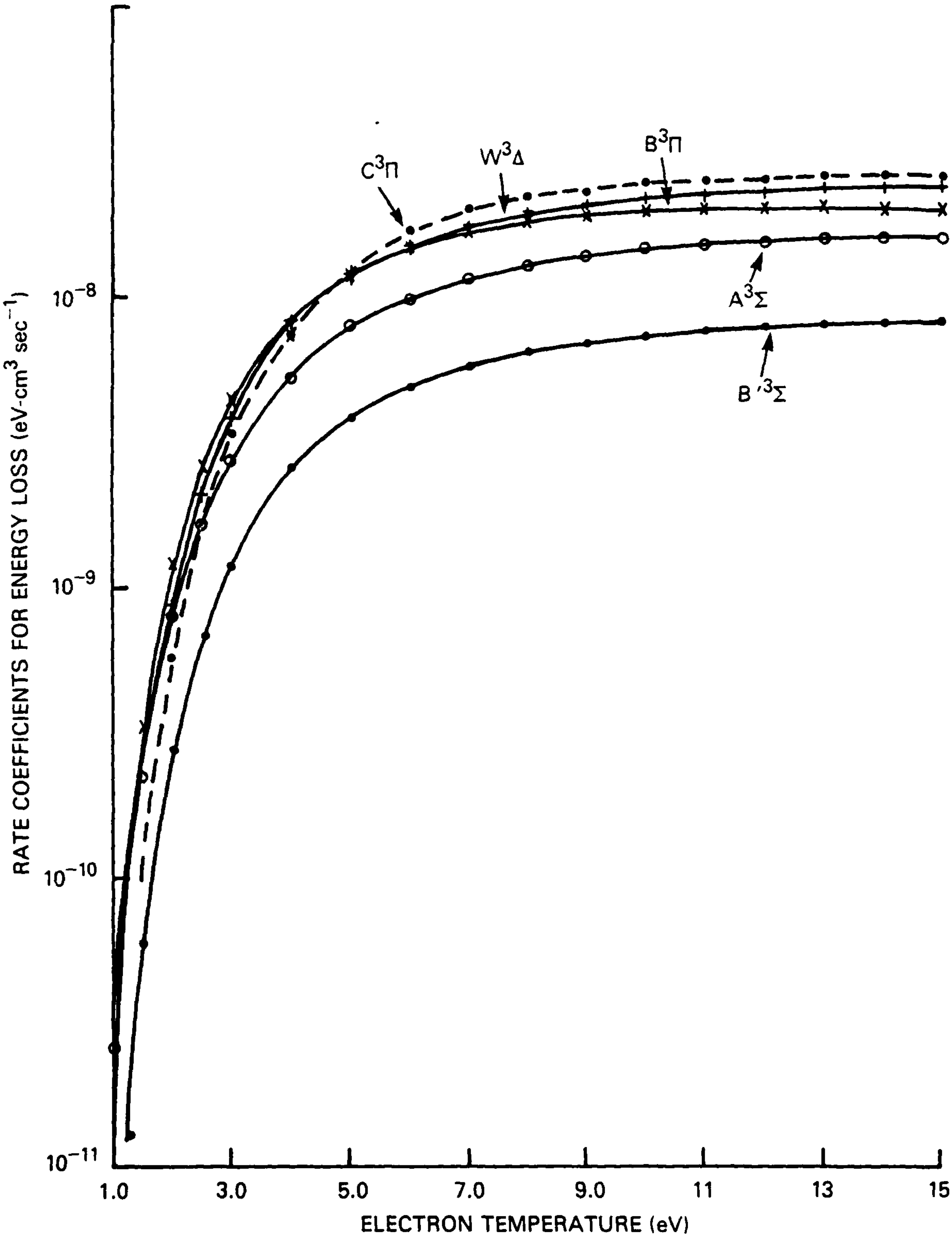

Figure 1b Electron energy loss rate coefficients to triplet states in nitrogen

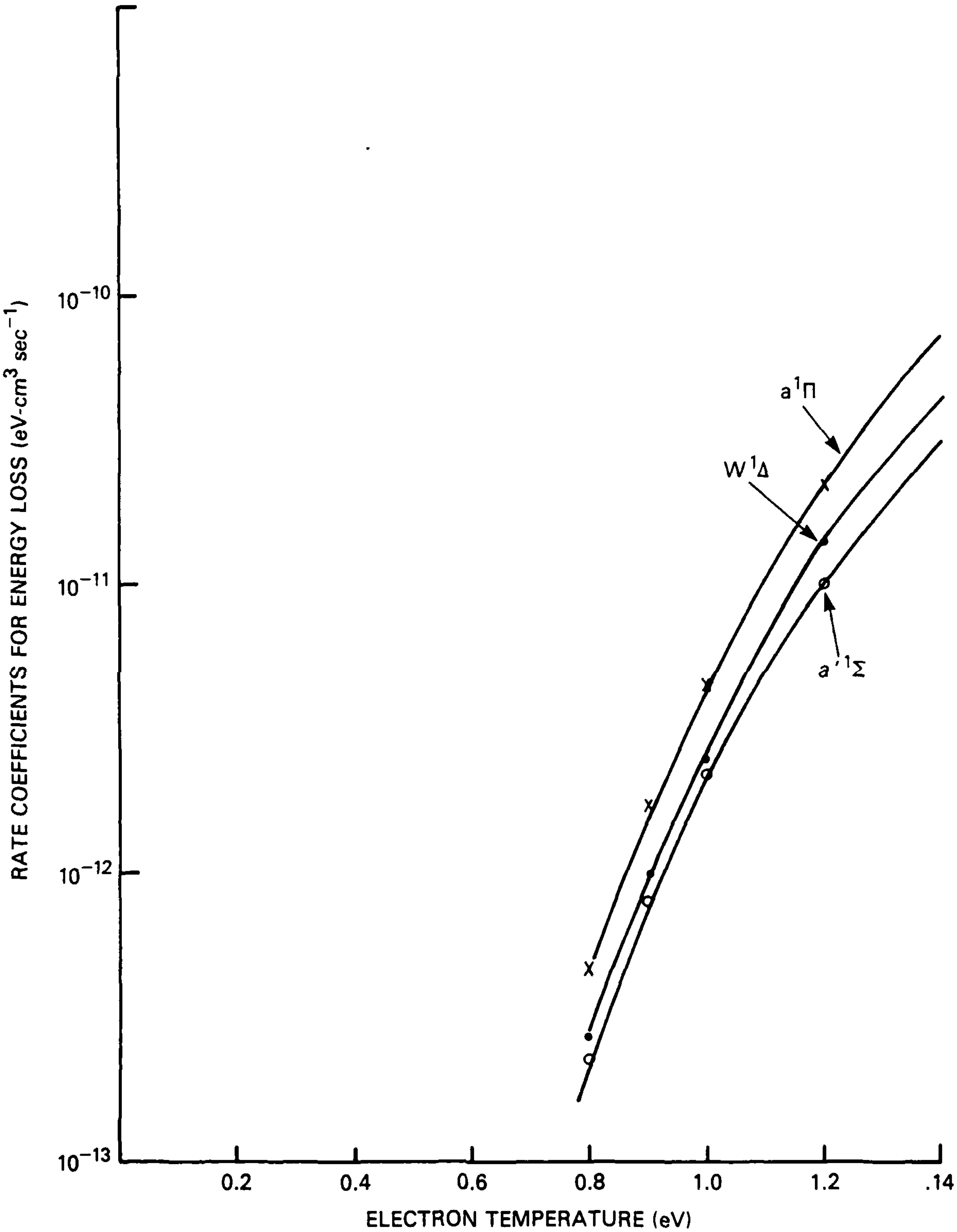

Figure 2a Electron energy loss rate coefficients to singlet states in nitrogen

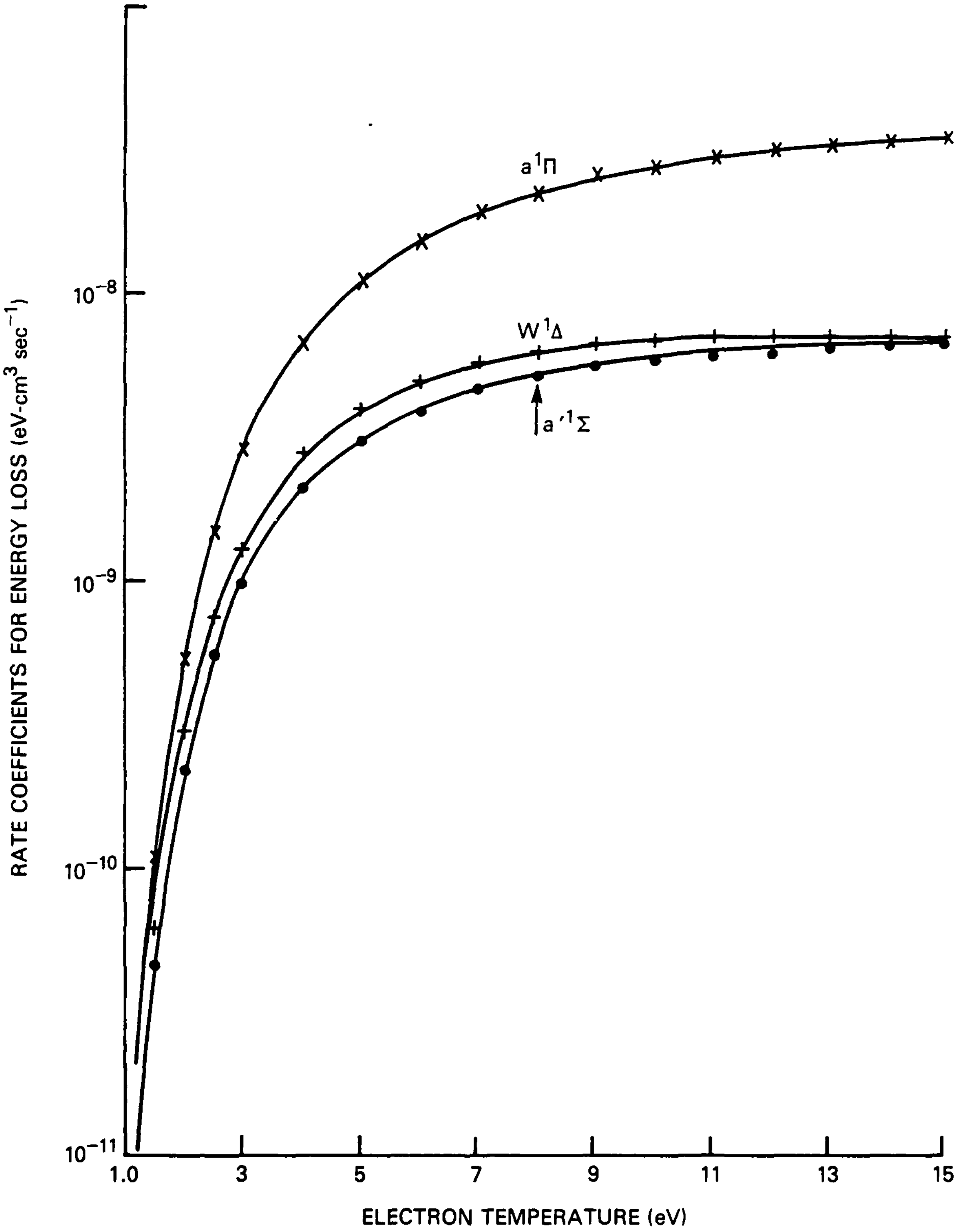

Figure 2b Electron energy loss rate coefficients to singlet states in nitrogen

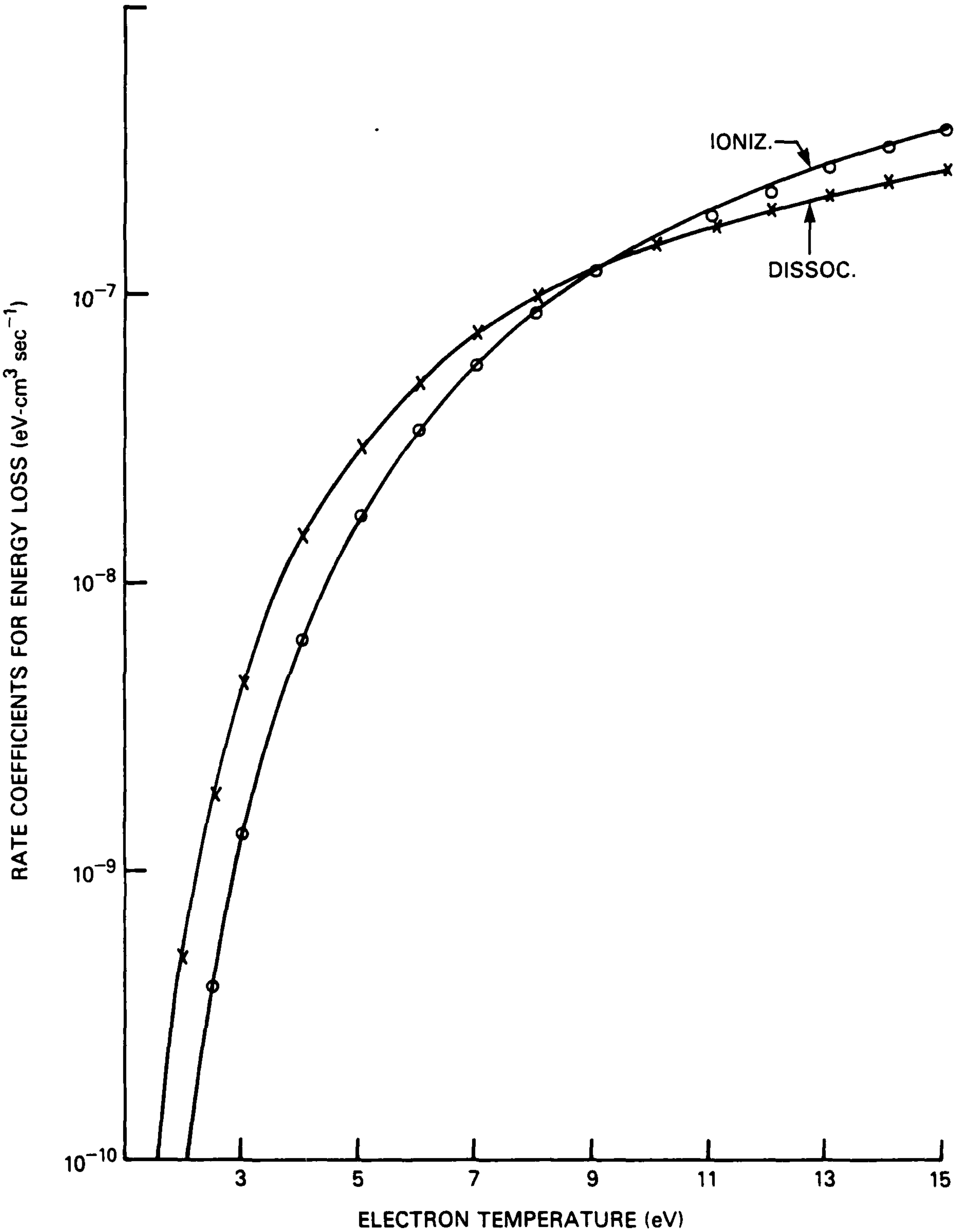

Figure 3 Electron energy loss rate coefficients to ionization and dissociation in nitrogen

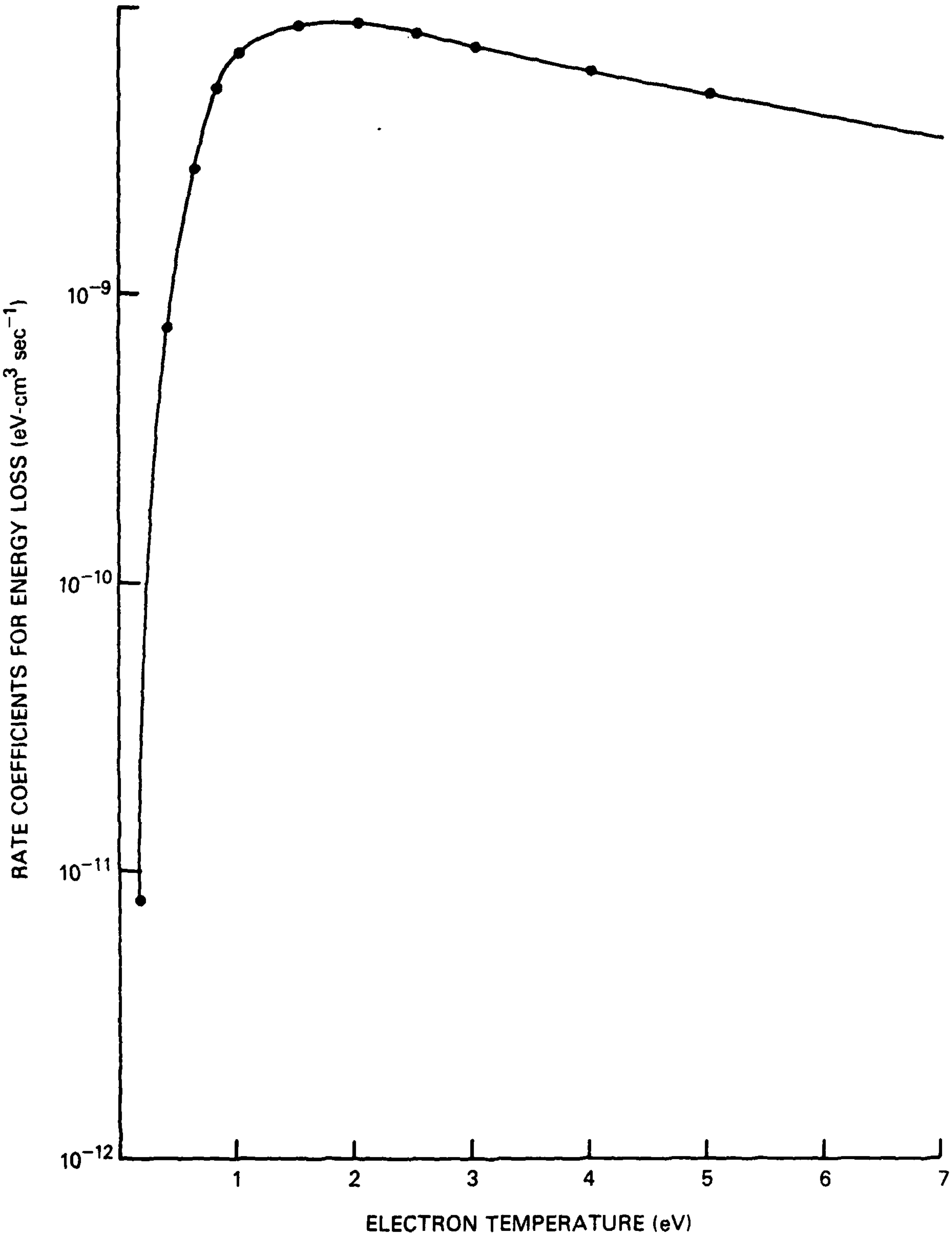

Figure 4 Electron energy loss rate coefficients for the vibrational excitation of nitrogen

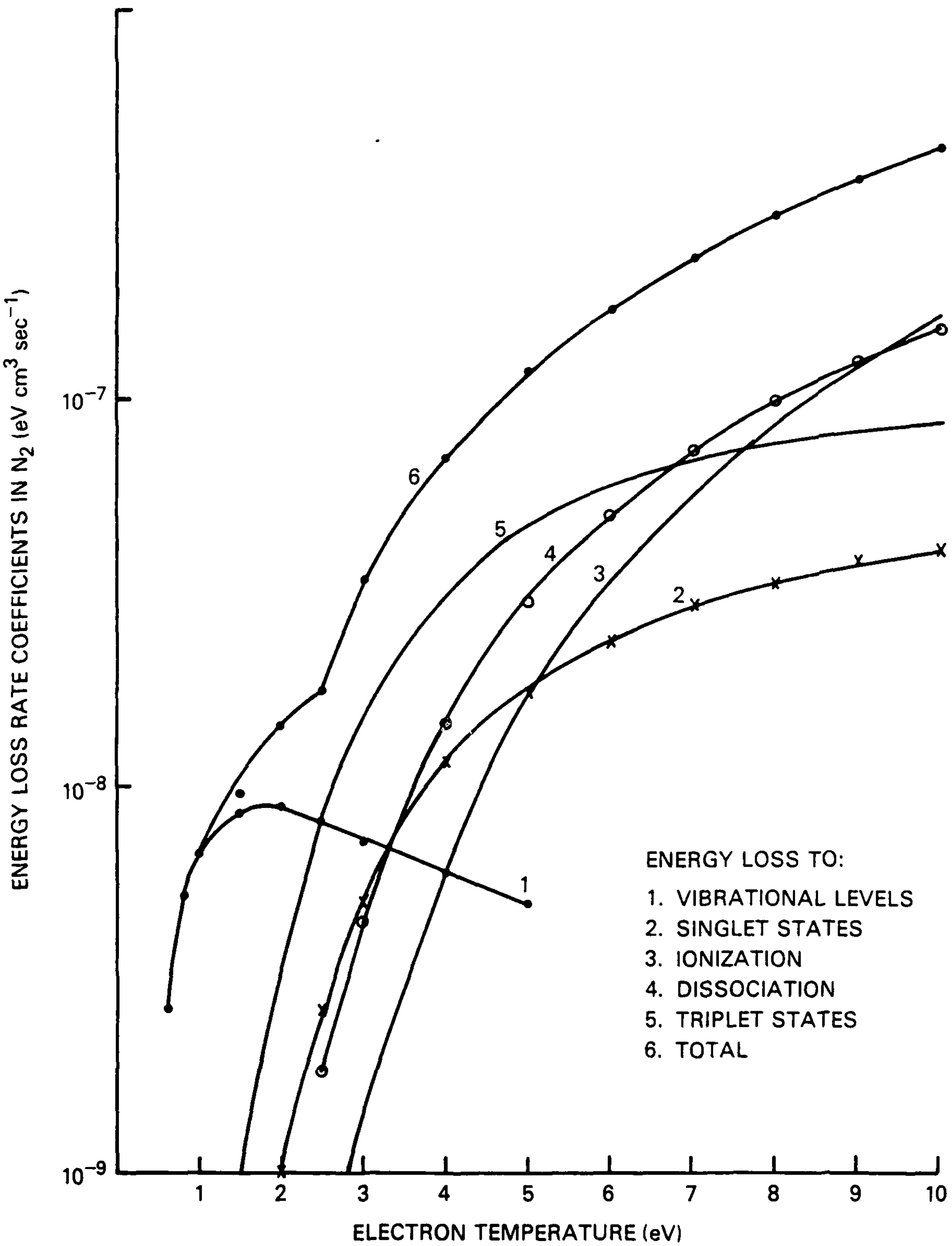

Figure 5 Total electron energy loss rate coefficient and its components in nitrogen

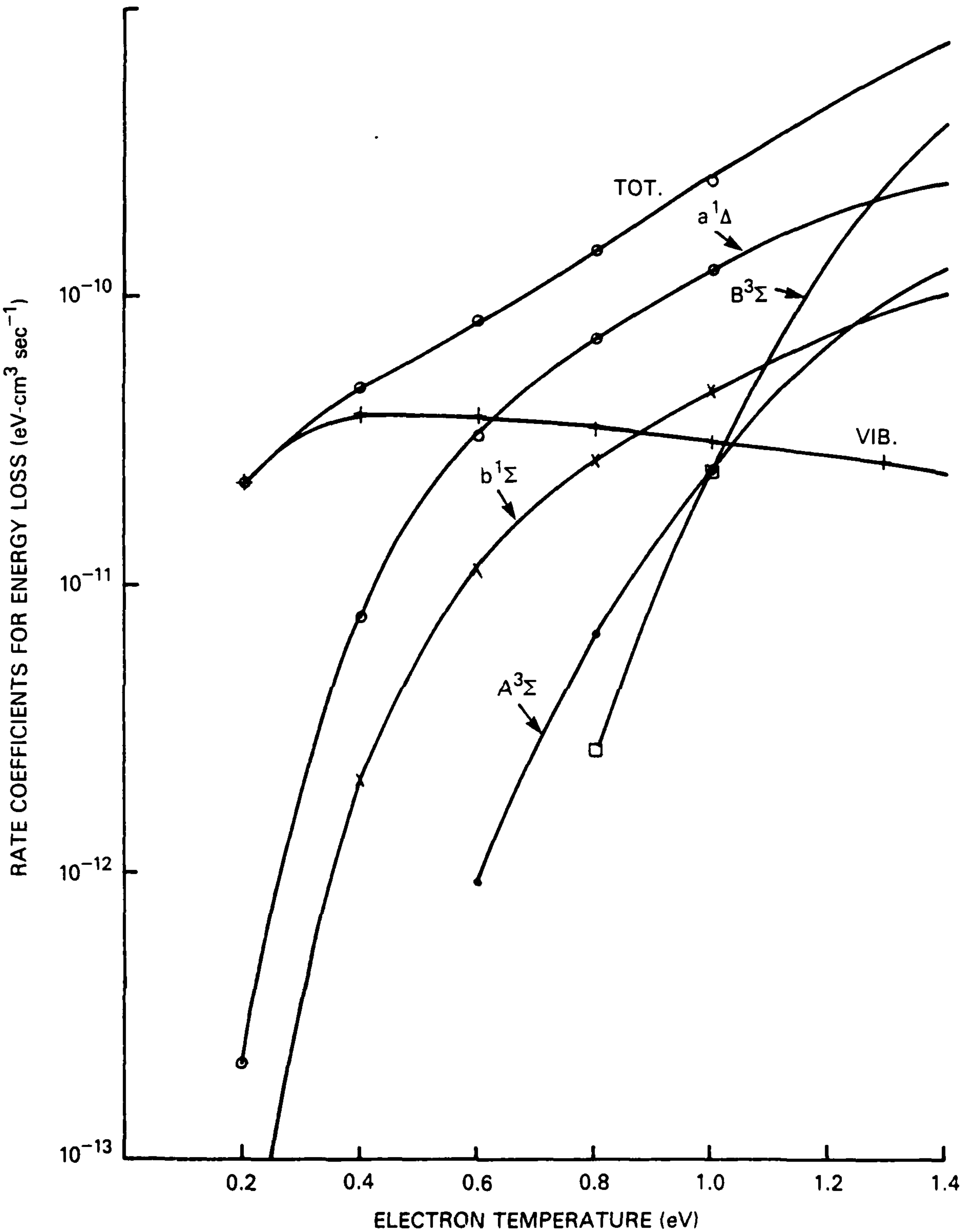

Figure 6a Total electron energy loss rate coefficient and its components in oxygen

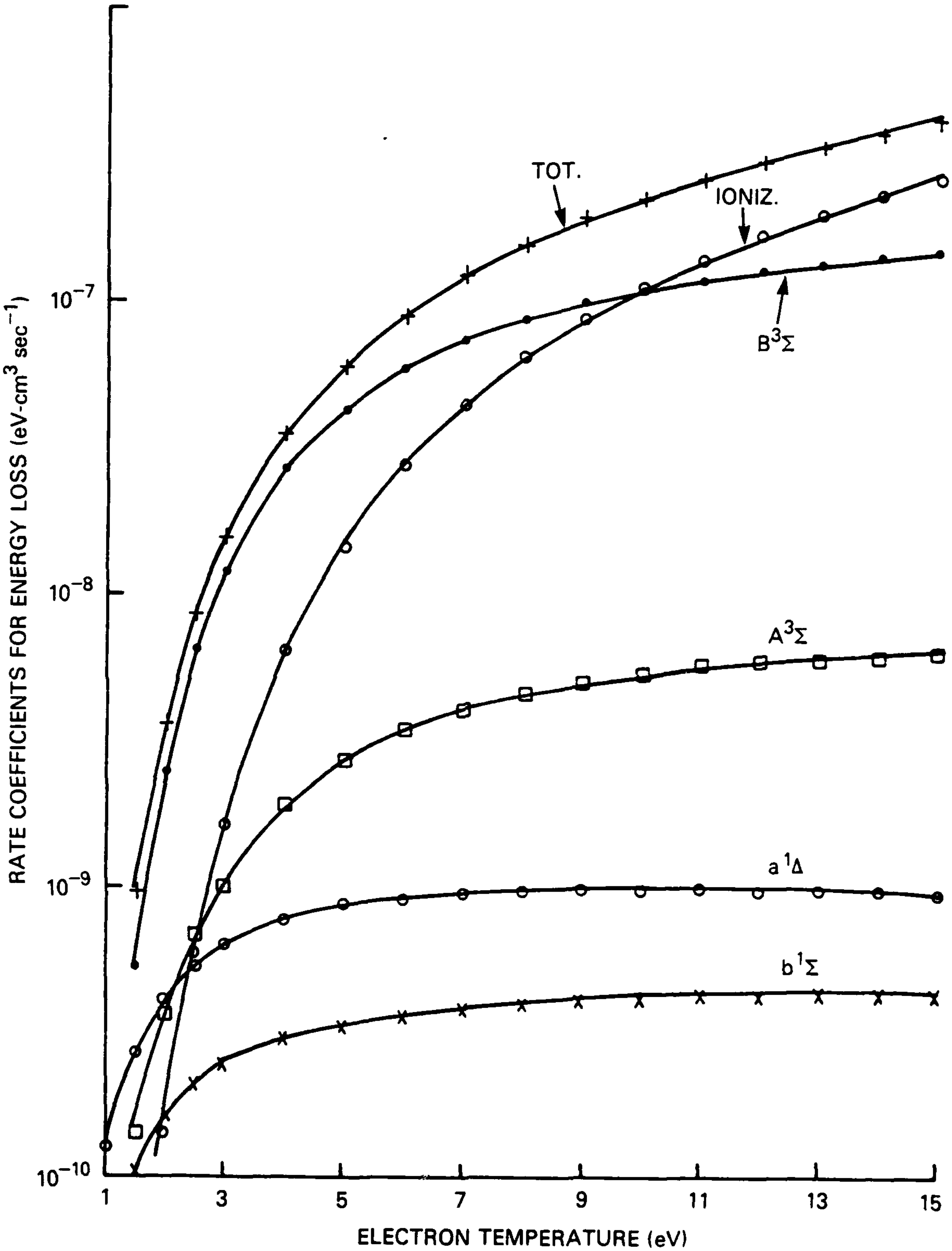

Figure 6b Total electron energy loss rate coefficient and its components in oxygen

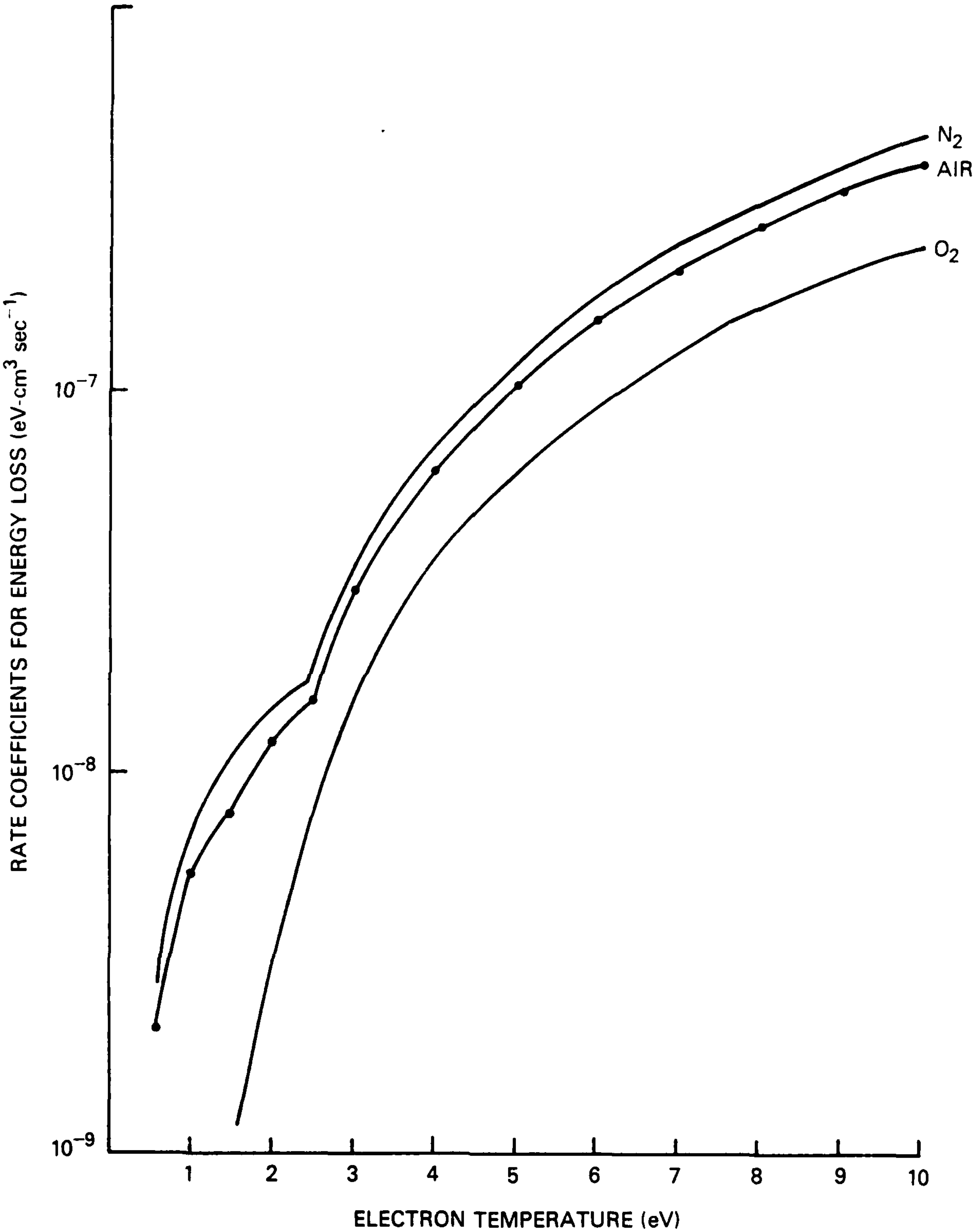

Figure 7 Total electron energy loss rate coefficients in N_2, O_2 and air

REFERENCES

1. A. W. Ali "Excitation and Ionization Cross Section For Electron Beam and Microwave Energy Deposition in Air", NRL Memorandum Report 4598 (1981). (AD-A103 106)

2. A. W. Ali and A. D. Anderson "Low Energy Electron Impact Rate Coefficients for Some Atmospheric Species", NRL Report 7432 (1972). (AD-747 244)

3. S. Slinker and A. W. Ali "Electron Excitation and Ionization Rate Coefficients For N_2, O_2, NO, N and O", NRL Memorandum Report 4756 (1982). (ADA 110988)

4. A. W. Ali, R. H. Kummler, F. R. Gilmore and J. William McGowan "Upper Atmospheric Excitation Processes", NRL Memorandum Report 3920 (1979). (ADA067330)

5. G. Herzberg "Molecular Spectra and Molecular Structure", I. Spectra of Diatomic Molecules, Van Nostrand, New York (1966).

6. A. W. Ali "The Electron Avalanche Ionization of Air and a Simple Air Chemistry Model", NRL Memorandum Report 4794 (1982).

7. E. C. Zipf and R. W. McLaughlin, Planet Space Science 26, 449 (1978).

DISTRIBUTION LIST

Chief of Naval Operations
Washington, D.C. 20350
ATTN: Dr. C. F. Sharn (OP0987B)

U. S. Army Ballistics Research Laboratory
Aberdeen Proving Ground, Maryland 21005
ATTN: Dr. Donald Eccleshall (DRXBR-BM)
Dr. Anand Prakash

Office of Under Secretary of Defense
Research and Engineering
Room 3E1034
The Pentagon
Washington, D.C. 20301
ATTN: Mr. John M. Bachkosky

Office of Naval Research
800 North Quincy Street
Arlington, VA 22217
ATTN: Dr. C. W. Roberson

Chief of Naval Material
Office of Naval Technology
MAT-0712, Room 503
800 North Quincy Street
Arlington, VA 22217
ATTN: Er. Eli Zimet

Commander
Naval Sea Systems Command
PMS-405
Washington, D.C. 20362
ATTN: Capt. Robert L. Topping
Cmdr. W. Bassett

Air Force Office of Scientific Research
Physical and Geophysical Sciences
Bolling Air Force Base
Washington, D.C. 20332
ATTN: Capt. Henry L. Pugh, Jr.

Department of Energy
Washington, D.C. 20545
ATTN: Dr. Terry F. Godlove (C-404)
Dr. James E. Leiss (G-256)
Mr. Gerald J. Peters (G-256)

PREVIOUS PAGE IS BLANK

Joint Institute for Laboratory Astrophysics
National Bureau of Standards and
University of Colorado
Boulder, CO 80309
ATTN: Dr. Arthur V. Phelps

Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720
ATTN: Dr. Edward P. Lee

Ballistic Missile Defense Advanced Technology Center
P. O. Box 1500
Huntsville, AL 35807
ATTN: Dr. M. Hawie (BMDSATC-1)

Intelcom Rad Tech.
P. O. Box 81087
San Diego, CA 92138
ATTN: Dr. W. Selph

Lawrence Livermore National Laboratory
University of California
Livermore, CA 94550
ATTN: Dr. Richard J. Briggs
Dr. Thomas Fessenden
Dr. Frank Chambers
Dr. James W.-K. Mark, L-477
Dr. William Fawley
Dr. Jon Masamitsu
Dr. William Barletta
Dr. William Sharp
Dr. D. S. Prono
Dr. J. K. Boyd
Dr. K. W. Struve
Dr. John Clark
Dr. G. J. Caporaso
Dr. William E. Martin
Dr. D. Prosnitz

Mission Research Corporation
735 State Street
Santa Barbara, CA 93102
ATTN: Dr. C. Longmire
Dr. N. Carron

National Bureau of Standards
Gaithersburg, MD 20760
ATTN: Dr. Mark Wilson

Science Applications, Inc.
1200 Prospect Street
La Jolla, CA 92037
ATTN: Dr. M. P. Fricke
Dr. W. A. Woolson

Science Applications, Inc.
5 Palo Alto Square, Suite 200
Palo Alto, CA 94304
ATTN: Dr. R. R. Johnston
Dr. Leon Feinstein
Dr. Douglas Keeley

Science Applications, Inc.
1651 Old Meadow Road
McLean, VA 22101
ATTN: Mr. W. Chadsey

Naval Surface Weapons Center
White Oak Laboratory
Silver Spring, MD 20910
ATTN: Mr. R. J. Biegalski
Dr. R. Cawley
Dr. J. W. Forbes
Dr. D. L. Love
Dr. C. M. Huddleston
Dr. G. E. Hudson
Mr. W. M. Hinckley
Mr. N. E. Scofield
Dr. E. C. Whitman
Dr. M. H. Cha
Dr. H. S. Uhm
Dr. R. Fiorito

C. S. Draper Laboratories
Cambridge, MA 02139
ATTN: Dr. E. Olsson
Dr. L. Matson

Physical Dynamics, Inc.
P. O. Box 1883
La Jolla, CA 92038
ATTN: Dr. K. Brueckner

Office of Naval Research
Department of the Navy
Arlington, VA 22217
ATTN: Dr. W. J. Condell (Code 421)

Avco Everett Research Laboratory
2385 Revere Beach Pkwy
Everett, MA 02149
ATTN: Dr. R. Patrick
Dr. Dennis Reilly
Dr. D. H. Douglas-Hamilton

Defense Technical Information Center
Cameron Station
5010 Duke Street
Alexandria, VA 22314 (2 copies)

Mission Research Corporation
1720 Randolph Road, S.E.
Albuquerque, NM 87106
ATTN: Dr. Brendan Godfrey
Dr. Richard Adler
Dr. Thomas Hughes
Dr. Lawrence Wright

Princeton University
Plasma Physics Laboratory
Princeton, NJ 08540
ATTN: Dr. Francis Perkins, Jr.

McDonnell Douglas Research Laboratories
Dept. 223, Bldg. 33, Level 45
Box 516
St. Louis, MO 63166
ATTN: Dr. Michael Greenspan
Dr. Carl Leader

Cornell University
Ithaca, NY 14853
ATTN: Prof. David Hammer

Sandia National Laboratory
Albuquerque, NM 87115
ATTN: Dr. Bruce Miller
Dr. Barbara Epstein
Dr. John Freeman
Dr. John Brandenburg
Dr. Gordon T. Leifeste
Dr. Carl A. Ekdahl, Jr.
Dr. Gerald N. Hays
Dr. James Chang
Dr. Michael G. Mazerakis

University of California
Physics Department
Irvine, CA 92664
ATTN: Dr. Gregory Benford

Air Force Weapons Laboratory
Kirtland Air Force Base
Albuquerque, NM 87117
ATTN: D. Straw (AFWL/NTYP)
R. Lemke (AFWL/NTYP)
C. Clark (AFWL/NTYP)
W. Baker (AFWL/NTYP)
Lt. Col. J. Head

R&D Associates
P. O. Box 9695
Marina del Rey, CA 90291
ATTN: Dr. R. E. LeLevier

Pulse Sciences, Inc.
14796 Wicks Blvd.
San Leandro, CA 94577
ATTN: Dr. Sidney Putnam

Los Alamos National Scientific Laboratory
P. O. Box 1663
Los Alamos, NM 87545
ATTN: Dr. L. Thode
Dr. A. B. Newberger, X-3, MS-608
Dr. M. A. Mostrom, MS-608
Dr. T. P. Starke, MS-942
Dr. H. Dogliani, MS-5000

Western Research Corp.
8616 Commerce Avenue
San Diego, CA 92121
ATTN: Dr. Frank Felber

Institute for Fusion Studies
University of Texas at Austin
RLM 11.218
Austin, TX 87712
ATTN: Prof. Marshall N. Rosenbluth

University of Michigan
Dept. of Nuclear Engineering
An Arbor, MI 48109
ATTN: Prof. Terry Kammash
Prof. R. Gilgenbach

TRW Electronics and Defense Sector
One Space Park - R1/1078
Redondo Beach, CA 90278
ATTN: Dr. John R. Bayless

Directed Technologies, Inc.
226 Potomac School Road
McLean, VA 22101
ATTN: Dr. Ira F. Kuhn
Dr. Nancy Chesser

Titan Systems, Inc.
8950 Villa La Jolla Drive-Suite 2232
La Jolla, CA 92037
ATTN: Dr. H. L. Buchanon
Dr. R. M. Dowe

Naval Research Laboratory
Washington, D. C. 20375
ATTN: M. Lampe - Code 4792
M. Friedman - Code 4700.1
J. R. Greig - Code 4763
I. M. Vitkovitsky - Code 4701
J. B. Aviles - Code 4665
M. Haftel - Code 4665
T. Coffey - Code 1001
S. Ossakow - Code 4700 (26 copies)
P. Sprangle - Code 4790
Library - Code 2628 (20 copies)
A. W. Ali - Code 4700.1 (30 copies)
D. Book - Code 4040
J. Boris - Code 4040
I. Haber - Code 4790
B. Hui - Code 4790
S. Kainer - Code 4790
G. Joyce - Code 4790
D. Murphy - Code 4763
D. Colombant - Code 4790
M. Picone - Code 4040
M. Raleigh - Code 4760
R. Pechacek - Code 4763
Y. Lau - Code 4790

Defense Advanced Research Projects Agency
1400 Wilson Blvd.
Arlington, VA 22209
ATTN: Dr. J. Mangano
Lt. Col. R. L. Gullickson

JAYCOR
5705A General Washington Drive
Alexandria, VA 22312
ATTN: Dr. D. Tidman
Dr. R. Hubbard
Dr. S. Slinker

Physics International, Inc.
2700 Merced Street
San Leandro, CA 94577
ATTN: Dr. E. Goldman

Standford Linear Accelerator Center
P. O. Box 4349
Stanford, CA 94305
ATTN: Dr. Simon S. Yu

Lockheed Palo Alto Laboratory
3251 Hanover Street
Bldg. 203, Dept. 52-11
Palo Alto, CA 94304
ATTN: Dr. John Siambis

University of Maryland
Physics Department
College Park, MD 20742
ATTN: Dr. Y. C. Lee
Dr. C. Grebogi

Maxwell Laboratories, Inc.
8835 Balboa Avenue
San Diego, CA 92123
ATTN: Dr. Nino Pereira

Science Applications, Inc.
1710 Goodridge Drive
McLean, VA 22102
ATTN: Dr. A. Drobot
Dr. K. Papadopoulos