COMPILATION OF ELECTRON CROSS SECTIONS USED BY A. V. PHELPS

Please refer to these data using the sources cited for each gas. Please do not refer to any of them as "JILA cross sections", because a) the data shown here for a given gas may come from several sources that should be referred to by the respective authors names; b) in most cases no one else at JILA or NIST has approved the data or even looked at it. Reference to this data as "JILA data" could be interpreted incorrectly as indicating NIST approval and could jepordize my Web site usage.

GASES COMPILED: O2, N2, CO, CO2, H2, H2O, NO, SF6, He, Ne, Ar, Xe, Na, and Mg

Comments are made on cross sections from other sources for some of these and other gases.

WE MAKE NO CLAIMS FOR THESE CROSS SECTIONS BEYOND THOSE STATED IN THE PAPERS WHERE THEY ARE PUBLISHED OR CITED. IN MOST CASES THESE CROSS SECTIONS WERE ASSEMBLED IN THE 1970'S AND 1980'S. IN ONLY A FEW CASES HAVE THEY BEEN MODIFIED OR TESTED SINCE THAT TIME. I DO NOT PLAN ANY UPDATES. ADDITIONS HAVE BEEN MADE WHEN CROSS SECTIONS HAVE BEEN ASSEMBLED FOR OTHER PURPOSES. SINCE THE JILA INFORMATION CENTER WAS CLOSED BY NIST, THERE IS NO ONE THERE TO HELP YOU. OPINIONS EXPRESSED ARE THOSE OF A. V. PHELPS AND DO NOT IMPLY JILA, CU, OR NIST APPROVAL.

The cross sections are in 1E-16 cm2. The two-term Boltzmann code, BACKPRO, used in deriving our cross sections employs linear interpolation between points in the cross section tables. Therefore linear interpolation should be applied when using them. Except as noted below for N2, the cross sections listed in JILA Information Center Reports 26, 27, and 28 for N2, H2, and O2 should be the same as those listed here. (This aspect has not been checked in detail, so please inform me of discrepancies.)

It should be kept in mind that the momentum transfer cross sections tabulated are effective values that include the effects of inelastic collisions as is appropriate for use in the two-tern spherical harmonic expansion. See, for example, Baraff and Buchsbaum, Phys. Rev. 130, 1007 (1963) and Sec. IIB of Pitchford and Phelps, Phys. Rev. A 25, 540 (1982). Where data is available, the effective Qm is set equal to the sum of the inelastic cross sections plus the elastic momentum transfer cross section. This is an approximate relation.

Some of the terms used in the tables and the BACKPRO code are:

QSCALE is a factor by which the input cross sections from the various sources were multiplied to get the values shown here and used in the Boltzmann equation.

ENERGY LOSS is the inelastic energy loss in eV.

LOWER LIMIT and UPPER LIMIT were used by BACKPRO to limit the range within which the tables were interpolated. Interpolation was the most time-consuming step in the code.

EBR is a parameter used to describe the sharing of energy among the two electrons resulting from ionization. It is the parameter w in Yoshida, Phelps, and Pitchford, Phys. Rev. 27, 1345 (1983) and its choice is based on the data of Opal, Peterson, and Beaty, Phys. Rev. 55, 4100 (1971).

BACKPRO is the FORTRAN code for the solution of the electron Boltzmann equation developed by Frost and Phelps, Phys. Rev. 127, 1621 (1962) and modified by Phelps and coworkers in later papers. A detailed analysis of the code as of 1975 has been given by P.H. Luft, JILA Information Center Report No. 14, October 1975. Changes since then are minimally documented, but include accounting for the electrons produced by electron impact ionization during either a spatial or temporal exponential growth. See Yoshida et al as cited above.

These cross sections were derived to give a good fit to published electron transport, excitation coefficient, attachment coefficient, and ionization coefficient data for the pure gases. In many cases they have been tested satisfactorily against similar swarm data for gas mixtures, e.g., CO2 laser mixtures, H2-Ar mixtures, N2-SF6 mixtures, and atmospheric pressure dry and moist air. In several cases, e.g., He, Ar, and Xe, we have not attempted to distinguish among the various excited states and find the cross sections satisfactory for models of mixtures and of ionization and transport in the pure gases.

Please refer to the published articles where possible. Also, please inform me of any errors or inconsistencies.

Original file preparation 10/29/95.
Last revision of file 06/24/08.

A. V. Phelps, Retired
JILA
University of Colorado
Boulder, CO 80309-0440
e-mail: avp@jila.colorado.edu

General remarks on electron collision cross sections:

For a recent review of electron cross sections see:
T. D. Mark, Y. Hatano, and F. Linder, "Electron Collision Cross Sections" in "Atomic and molecular data for radiotherapy and radiation research" IAEA-TECDOC-799, May 1995, Chapt. 2. This chapter contains graphical compilations of cross sections for Ne, Ar, H2, H2O, CO2, CH4, and C3H8. These cross sections have not been compared to those given in this file.

M. Hayashi has prepared very extensive bibliographies of papers on electron collisions with Ar, H2, O2, N2, CO, H2O, halogen molecules, hydrogen halide molecules, CO2, CH4, NH3, and PH3. Some of these reoprts contain recommended cross sections. Available reports are entitled "Bibliography of electron and photon cross sections with atoms and molecules published in the 20th century - [name of gas] -", National Institute for Fusion Research, Report NIFS-Data Series NIFS-DATA-[??]. Unfortunately, most of these cross sections are not available on the Web. The Ar results are tabulated in the accompanying file Hayashi.txt.

Very extensive reviews and compilations of published electron-atom and electron-molecule cross sections have been prepared by A. Zecca, G. P. Karwasz, and Brusa, Riv. Nuovo Cimento 19, No. 3, 1-146 (1996) and G. P. Karwasz, R. S. Brusa, and A. Zecca, Riv. Nuovo Cimento 24, No. 1, 1-118 (2001) and No. 4, 1-101 (2001). Data shown are selected on the basis of "perceived quality", but no recommended values are given. Apparently floppy disk(s?) giving tabulations can be purchased from the Italian Physical Society. I have not seen the disks, i.e., they are too expensive. Unfortunately for gas discharge modeling, the data ranges in the review papers are limited, especially for momentum transfer cross sections that can differ greatly from "total" cross sections at the higher energies.

Stephen Biagi at sfb@hep.ph.liv.ac.uk has derived a sets of cross sections for electron collisions with ~ 50 different gases that are required to be consistent with electron swarm data. The ~50 gases include: N2, O2, H20, Ar, CO2, He, Ne, H2, D2, CH4, etc. Unfortunately, the tabulations of these cross sections are not available on the Web.

A recent review of electron-molecule collisions is Hotop, Ruf, Allan, and Frabrikant, "Resonances and threshold phenomena in low energy electron collisions with molecules and clusters", in Advances in Atomic, Molecular and Optical Physics, (Elsevier, 2003) Vol. 49.

A review of experimental integrated and differential cross section data for electron collisions with some diatomic molecules is Brunger and Buckman, Physics Reports, 357, 215 (2002). The gases discussed include H2, O2, N2, the halogens,NO, CO, and halogen halides. This data is tabulated in Landolt-Bornstein, Vol. 17, Subvol. C, pp. 35-55 (2003). Also, Vol 17, Subvol. A is concerned with electron and photon collisions with atoms, but I do not have access to this volume or its data.

GENERAL WARNING TO GAS DISCHARGE MODELERS:

IF AUTHORS DO NOT EXPLICITLY STATE THAT THERE IS AGREEMENT BETWEEN A) IONIZATION, EXCITATION, ATTACHMMENT (IF APPLICABLE), AND TRANSPORT COEFFICIENTS CALCULATED USING THEIR CROSS SECTIONS AND B) RELIABLE EXPERIMENTAL MEASUREMENTS OF THESE COEFFICIENTS, YOU SHOULD BE VERY SKEPTICAL OF ALL OF THEIR CROSS SECTIONS AND OF ELECTRON TRANSPORT AND REACTION COEFFICIENT RESULTS DERIVED FROM THEM. AGREEMENT WITH SWARM EXPERIMENTS SUCH AS IONIZATION COEFFICIENT, DRIFT VELOCITY, THE RATIO OF THE TRANSVERSE AND LOGITUDINAL DIFFUSION COEFFICIENT TO MOBILITY, ATTACHMENT COEFFICIENTS, AND EXCITATION COEFFICIENTS ARE CRICIAL EVIDENCE OF A RELIABLE SET OF INPUT CROSS SECTIONS FOR MODELING. FOR EACH GAS IN THIS FILE WE HAVE SUMMARIZED OUR TESTS OF THE CROSS SECTIONS AGAINST EXPERIMENTAL SWARM DATA.

OXYGEN - O2 - 1978
These cross sections are those developed in Lawton and Phelps, J. Chem. Phys. 69, 1055 (1978). The agreement of the transport and reaction coefficients is good and is discussed in detail in this paper. Information Center Report No. 28 is based on the same computer files as used to assemble the following data. As of 9/28/01 I know of no reason to change the cross sections.

Note that the "cross sections" listed under the heading of three-body attrachment are expressed as equivalent cross sections at an O2 density of 1 molecule/cm3. This means that the rate coefficients k and spatial attachment coefficients alpha/n calculated using BACKPRO must be multiplied by the O2 density in molecules/cm3 to obtain the equivalent of the two-body coefficients per molecule calculated for other processes, such as excitation and ionization.

O2 MOMENTUM-TRANSFER CROSS SECTION

	ENERGY	Effective Qm - Defined in introduction
1	0.0000	0.3500
2	0.0010	0.3500
3	0.0020	0.3600
4	0.0030	0.4000
5	0.0050	0.5000
6	0.0070	0.5800
7	0.0085	0.6400
8	0.0100	0.7000
9	0.0150	0.8700
10	0.0200	0.9900
11	0.0300	1.2400
12	0.0400	1.4400
13	0.0500	1.6000
14	0.0700	2.1000
15	0.1000	2.5000
16	0.1200	2.8000
17	0.1500	3.1000
18	0.1700	3.3000
19	0.2000	3.6000
20	0.2500	4.1000
21	0.3000	4.5000
22	0.3500	4.7000
23	0.4000	5.2000
24	0.5000	5.7000

25	0.7000	6.1000
26	1.0000	7.2000
27	1.2000	7.9000
28	1.3000	7.9000
29	1.5000	7.6000
30	1.7000	7.3000
31	1.9000	6.9000
32	2.1000	6.6000
33	2.2000	6.5000
34	2.5000	6.1000
35	2.8000	5.8000
36	3.0000	5.7000
37	3.3000	5.5000
38	3.6000	5.4500
39	4.0000	5.5000
40	4.5000	5.5500
41	5.0000	5.6000
42	6.0000	6.0000
43	7.0000	6.6000
44	8.0000	7.1000
45	10.0000	8.0000
46	12.0000	8.5000
47	15.0000	8.8000
48	17.0000	8.7000
49	20.0000	8.6000
50	25.0000	8.2000
51	30.0000	8.0000
52	50.0000	7.7000
53	75.0000	6.8000
54	100.0000	6.5000
55	150.0000	6.7000
56	200.0000	6.0000
57	300.0000	4.9000
58	500.0000	3.6000
59	700.0000	2.9000
60	1000.0000	2.1200
61	1500.0000	1.4800
62	2000.0000	1.1400
63	3000.0000	0.7900
64	5000.0000	0.5100
65	7000.0000	0.3800
66	10000.0000	0.2800

O2 THREE-BODY ATTACHMENT
ENERGY LOSS = 0.000 , LOWER LIMIT = 0.000 , UPPER LIMIT = 1.058 ,
QSCALE = 1.000000 (QSCALE USED ONLY FOR RECONSTRUCTING INPUT DATA)

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	0.0580	0.0000
3	0.0730	5.6E-21
4	0.0830	18.0E-21
5	0.0890	4.2E-21
6	0.0950	8.4E-21
7	0.1030	18.0E-21
8	0.1090	0.0000
9	0.1500	0.0000
10	0.1700	0.0000
11	0.2000	0.0000
12	0.2100	3.56E-21
13	0.2300	0.0000
14	0.3200	0.0000
15	0.3300	2.30E-21
16	0.3500	0.0000
17	0.4400	0.0000
18	0.4500	1.45E-21
19	0.4700	0.0000
20	0.5600	0.0000
21	0.5700	1.1E-21
22	0.5900	0.0000
23	0.6800	0.0000
24	0.6900	8.0E-22
25	0.7100	0.0000
26	0.7900	0.0000
27	0.8000	7.0E-22
28	0.8200	0.0000
29	0.9000	0.0000
30	0.9100	5.5E-22
31	0.9300	0.0000
32	1.0200	0.0000
33	1.0300	4.2E-22
34	1.0500	0.0000
35	1.5000	0.0000
36	10000.0000	0.0000

O2 TWO-BODY ATTACHMENT
ENERGY LOSS = 0.000 , LOWER LIMIT = 0.000 , UPPER LIMIT = 100.001 ,
QSCALE = 1.200000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	4.4000	0.0000
3	4.9000	0.0000
4	5.3800	0.0023
5	5.8600	0.0072
6	6.1000	0.0108
7	6.4800	0.0138
8	6.7700	0.0152
9	7.0500	0.0156
10	7.3000	0.0148
11	7.5300	0.0131
12	7.7700	0.0110
13	8.0000	0.0084
14	8.2500	0.0054
15	8.7300	0.0028
16	9.2000	0.0014

17	9.6800	0.0008
18	10.1500	0.0008
19	11.3500	0.0008
20	10000.0000	0.0000

O2 SINGL LEVEL ROT PKQ FOR 300K
ENERGY LOSS = 0.020 , LOWER LIMIT = 0.026 , UPPER LIMIT = 1.677 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION	ENERGY	CROSS SECTION
1	0.0000	0.0000		
2	0.0067	0.0000		
3	0.0700	0.0000		
4	0.0800	0.0054		
5	0.1000	0.0000		
6	0.2000	0.0000		
7	0.2100	0.0216		
8	0.2200	0.0000		
9	0.3200	0.0000		
10	0.3300	0.0384		
11	0.3500	0.0000		
12	0.4400	0.0000		
13	0.4500	0.0540		
14	0.4700	0.0000		
15	0.5600	0.0000		
16	0.5700	0.0672		
17	0.5900	0.0000		
18	0.6800	0.0000		
19	0.6900	0.0804		
20	0.7100	0.0000		
21	0.7900	0.0000		
22	0.8000	0.0936		
23	0.8100	0.0000		
24	0.9000	0.0000		
25	0.9100	0.0840		
26	0.9300	0.0000		
27	1.0200	0.0000		
28	1.0300	0.0720		
29	1.0500	0.0000		
30	1.1300	0.0000		
31	1.1400	0.0468		
32	1.1600	0.0000		
33	1.2300	0.0000		
34	1.2300	0.0600		
35	1.2600	0.0000		
36	1.3400	0.0000		
37	1.3500	0.0360		
38	1.3700	0.0000		
39	1.4400	0.0000		
40	1.4500	0.0240		
41	1.4700	0.0000		
42	1.5400	0.0000		
43	1.5500	0.0120		
44	1.5700	0.0000		
45	1.6400	0.0000		
46	1.6500	0.0048		
47	1.6700	0.0000		
48	10000.0000	0.0000		

O2 V=1 LINDER AND SCHMIDT WITH SPLIT PK
ENERGY LOSS = 0.190 , LOWER LIMIT = 0.181 , UPPER LIMIT = 5.005 ,
QSCALE = 2.500000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	0.1900	0.0000
3	0.2000	0.0010
4	0.2100	0.0010
5	0.2300	0.0000
6	0.3200	0.0000
7	0.3300	0.4150
8	0.3500	0.0000
9	0.4400	0.0000
10	0.4500	1.3500
11	0.4700	0.0000
12	0.5600	0.0000
13	0.5700	1.8500
14	0.5900	0.0000
15	0.6800	0.0000
16	0.6900	1.6500
17	0.7100	0.0000
18	0.7900	0.0000
19	0.8000	1.0000
20	0.8200	0.0000
21	0.9000	0.0000
22	0.9100	0.6000
23	0.9300	0.0000
24	1.0200	0.0000
25	1.0300	0.2850
26	1.0500	0.0000
27	1.1300	0.0000
28	1.1400	0.1125
29	1.1600	0.0000
30	1.2300	0.0000
31	1.2400	0.0475
32	1.2600	0.0000
33	1.3400	0.0000
34	1.3500	0.0165
35	1.3700	0.0000
36	1.4400	0.0000
37	1.4500	0.0055
38	1.4700	0.0000
39	1.5400	0.0000
40	1.5500	0.0019
41	1.5700	0.0000
42	1.6300	0.0000
43	1.6500	0.0006

44	1.6700	0.0000
45	3.5000	0.0000
46	4.0000	0.0000
47	5.0000	0.0000
48	10000.0000	0.0000

O2 V=2 LINDER AND SCHMIDT X2
ENERGY LOSS = 0.380 , LOWER LIMIT = 0.439 , UPPER LIMIT = 5.005 ,
QSCALE = 1.250000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	0.3800	0.0000
3	0.4400	0.0000
4	0.4500	0.0000
5	0.4700	0.0000
6	0.5600	0.0000
7	0.5700	0.1400
8	0.5900	0.0000
9	0.6800	0.0000
10	0.6900	0.4150
11	0.7100	0.0000
12	0.7900	0.0000
13	0.8000	0.5350
14	0.8200	0.0000
15	0.9000	0.0000
16	0.9100	0.4650
17	0.9300	0.0000
18	1.0200	0.0000
19	1.0300	0.3150
20	1.0500	0.0000
21	1.1300	0.0000
22	1.1400	0.2000
23	1.1600	0.0000
24	1.2300	0.0000
25	1.2400	0.0950
26	1.2600	0.0000
27	1.3400	0.0000
28	1.3500	0.0400
29	1.3700	0.0000
30	1.4400	0.0000
31	1.4500	0.0185
32	1.4700	0.0000
33	1.5400	0.0000
34	1.5500	0.0085
35	1.5700	0.0000
36	1.6300	0.0000
37	1.6500	0.0034
38	1.6700	0.0000
39	3.5000	0.0000
40	4.0000	0.0000
41	5.0000	0.0000
42	10000.0000	0.0000

O2 V=3 LINDER AND SCHMIDT X2 WITH 9EV RES FRM WONG-TRAJMAR

ENERGY LOSS = 0.570 , LOWER LIMIT = 0.671 , UPPER LIMIT = 44.995 ,
QSCALE = 1.250000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	0.5700	0.0000
3	0.6800	0.0000
4	0.6900	0.0037
5	0.7100	0.0000
6	0.7900	0.0000
7	0.8000	0.0215
8	0.8200	0.0000
9	0.9000	0.0000
10	0.9100	0.0900
11	0.9300	0.0000
12	1.0200	0.0000
13	1.0300	0.1200
14	1.0500	0.0000
15	1.1300	0.0000
16	1.1400	0.1150
17	1.1600	0.0000
18	1.2300	0.0000
19	1.2400	0.0950
20	1.2600	0.0000
21	1.3400	0.0000
22	1.3500	0.0550
23	1.3700	0.0000
24	1.4400	0.0000
25	1.4500	0.0300
26	1.4700	0.0000
27	1.5400	0.0000
28	1.5500	0.0165
29	1.5700	0.0000
30	1.6300	0.0000
31	1.6500	0.0080
32	1.6700	0.0000
33	3.5000	0.0000
34	4.0000	0.0000
35	5.0000	0.0000
36	6.0000	0.0125
37	7.0000	0.0363
38	8.0000	0.0588
39	9.0000	0.0750
40	10.0000	0.0675
41	11.0000	0.0563
42	12.0000	0.0475
43	13.0000	0.0300
44	14.0000	0.0175
45	15.0000	0.0088
46	20.0000	0.0000

47	45.0000	0.0000
48	10000.0000	0.0000

O2 V=4 LINDER AND SCHMIDT X2 WITH 9EV RES FRM WONG-TRAJMAR

ENERGY LOSS = 0.750 , LOWER LIMIT = 0.748 , UPPER LIMIT = 14.990 ,
QSCALE = 1.250000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	0.7500	0.0000
3	0.7900	0.0000
4	0.8000	0.0015
5	0.8200	0.0000
6	0.9000	0.0000
7	0.9100	0.0055
8	0.9300	0.0000
9	1.0200	0.0000
10	1.0300	0.0003
11	1.0500	0.0000
12	1.1300	0.0000
13	1.1400	0.0165
14	1.1600	0.0000
15	1.2300	0.0000
16	1.2400	0.0315
17	1.2600	0.0000
18	1.3400	0.0000
19	1.3500	0.0335
20	1.3700	0.0000
21	1.4400	0.0000
22	1.4500	0.0285
23	1.4700	0.0000
24	1.5400	0.0000
25	1.5500	0.0215
26	1.5700	0.0000
27	1.6300	0.0000
28	1.6500	0.0165
29	1.6700	0.0000
30	6.0000	0.0000
31	7.0000	0.0275
32	8.0000	0.0350
33	9.0000	0.0413
34	10.0000	0.0462
35	11.0000	0.0313
36	12.0000	0.0250
37	13.0000	0.0175
38	14.0000	0.0088
39	15.0000	0.0000
40	10000.0000	0.0000

O2 SING DELTA FROM LINDER-SCHMIDT AND TRAJMAR ET AL

ENERGY LOSS = 0.977 , LOWER LIMIT = 0.929 , UPPER LIMIT = 100.001 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	0.9770	0.0000
3	1.5000	0.0058
4	2.0000	0.0153
5	3.0000	0.0380
6	3.5000	0.0490
7	4.0000	0.0570
8	5.0000	0.0740
9	5.6200	0.0825
10	5.9100	0.0862
11	6.1900	0.0888
12	6.5300	0.0908
13	6.9900	0.0914
14	7.6100	0.0891
15	7.8900	0.0863
16	8.9600	0.0768
17	10.0400	0.0679
18	13.0000	0.0527
19	15.1000	0.0455
20	17.5000	0.0387
21	20.5000	0.0324
22	24.9000	0.0256
23	30.9000	0.0196
24	41.0000	0.0137
25	45.0000	0.0120
26	10000.0000	0.0000

O2 B SINGLET SIGMA FROM LINDER-SCHMIDT AND TRAJMAR ET AL

ENERGY LOSS = 1.627 , LOWER LIMIT = 1.496 , UPPER LIMIT = 100.001 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	1.6270	0.0000
3	2.0000	0.0026
4	3.0000	0.0097
5	3.5000	0.0133
6	4.0000	0.0149
7	5.0000	0.0182
8	5.6900	0.0194
9	6.5400	0.0194
10	7.3400	0.0191
11	8.4100	0.0183
12	9.2600	0.0174
13	10.0000	0.0160
14	13.0000	0.0130
15	14.9000	0.0130
16	17.0000	0.0130
17	19.4000	0.0125
18	20.7000	0.0125

19	22.5000	0.0110
20	24.0000	0.0100
21	28.0000	0.0080
22	35.1000	0.0063
23	41.9000	0.0018
24	45.1000	0.0005
25	1000.0000	0.0000
26	10000.0000	0.0000

O2 V=1 9V RES OF WONG ET AL NORM TO TRAJMAR ET AL
ENERGY LOSS = 0.190 , LOWER LIMIT = 3.999 , UPPER LIMIT = 44.995 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	4.0000	0.0000
3	5.0000	0.0420
4	6.0000	0.1000
5	7.0000	0.1760
6	8.0000	0.2310
7	9.0000	0.2470
8	10.0000	0.2340
9	11.0000	0.1860
10	12.0000	0.1430
11	13.0000	0.1020
12	14.0000	0.0710
13	15.0000	0.0400
14	20.0000	0.0100
15	45.0000	0.0000
16	10000.0000	0.0000

O2 V=2 9V RES OF WONG ET AL NORM TO TRAJMAR ET AL
ENERGY LOSS = 0.380 , LOWER LIMIT = 3.999 , UPPER LIMIT = 44.995 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	4.0000	0.0000
3	5.0000	0.0280
4	6.0000	0.0400
5	7.0000	0.0730
6	8.0000	0.0940
7	9.0000	0.1100
8	10.0000	0.1090
9	11.0000	0.0930
10	12.0000	0.0730
11	13.0000	0.0510
12	14.0000	0.0280
13	15.0000	0.0130
14	20.0000	0.0050
15	45.0000	0.0000
16	10000.0000	0.0000

O2 4.5 LOSS
ENERGY LOSS = 4.500 , LOWER LIMIT = 4.386 , UPPER LIMIT = 14.990 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	4.5000	0.0000
3	4.8000	0.0030
4	5.0000	0.0090
5	5.5000	0.0300
6	6.0000	0.0650
7	6.5000	0.0850
8	7.0000	0.0950
9	7.5000	0.1000
10	8.0000	0.1000
11	9.0000	0.0850
12	10.0000	0.0700
13	12.0000	0.0450
14	15.0000	0.0000
15	50.0000	0.0000
16	10000.0000	0.0000

O2 6.0 LOSS
ENERGY LOSS = 6.000 , LOWER LIMIT = 5.882 , UPPER LIMIT = 100.001 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	6.0000	0.0000
3	7.0000	0.1500
4	7.8000	0.2300
5	9.0000	0.2300
6	10.0000	0.2100
7	12.0000	0.1650
8	15.0000	0.1050
9	17.0000	0.0650
10	20.0000	0.0475
11	45.0000	0.0190
12	10000.0000	0.0000

O2 8.4 LOSS HAYASHI ABOVE 20EV - CHANTRY BELOW
ENERGY LOSS = 8.400 , LOWER LIMIT = 8.282 , UPPER LIMIT = 100.001 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	8.4000	0.0000
3	9.4000	1.0000
4	30.0000	0.9000
5	50.0000	0.7000
6	100.0000	0.5400
7	150.0000	0.3200
8	200.0000	0.2700

9	300.0000	0.1700
10	500.0000	0.1090
11	700.0000	0.0800
12	1000.0000	0.0580
13	1500.0000	0.0420
14	2000.0000	0.0330
15	3000.0000	0.0240
16	5000.0000	0.0160
17	7000.0000	0.0120
18	10000.0000	0.0090

O2 9.97 LOSS TRAJMAR
ENERGY LOSS =   10.000 ,   LOWER LIMIT =   9.778 ,   UPPER LIMIT = 100.001 ,
QSCALE =   1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	10.0000	0.0000
3	20.0000	0.0130
4	30.0000	0.0260
5	40.0000	0.0400
6	50.0000	0.0500
7	60.0000	0.0600
8	70.0000	0.0650
9	80.0000	0.0700
10	100.0000	0.0700
11	120.0000	0.0500
12	150.0000	0.0400
13	170.0000	0.0350
14	200.0000	0.0300
15	300.0000	0.0200
16	500.0000	0.0120
17	700.0000	0.0080
18	1000.0000	0.0050
19	1500.0000	0.0000
20	2000.0000	0.0000
21	3000.0000	0.0000
22	5000.0000	0.0000
23	7000.0000	0.0000
24	10000.0000	0.0000

O2 IONIZATION
ENERGY LOSS =   12.060 ,   LOWER LIMIT =   11.894 ,   UPPER LIMIT = 100.001 ,
WEIGHT = 31.740000, EBR=   17.400000, QSCALE=   1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	12.0600	0.0000
3	13.0000	0.0230
4	18.0000	0.2000
5	28.0000	0.7400
6	38.0000	1.3200
7	48.0000	1.8000
8	58.0000	2.1000
9	68.0000	2.3300
10	78.0000	2.5000
11	88.0000	2.6000
12	100.0000	2.7000
13	150.0000	2.7000
14	200.0000	2.5000
15	300.0000	2.1700
16	500.0000	1.6600
17	700.0000	1.3500
18	1000.0000	1.0400
19	1500.0000	0.7600
20	2000.0000	0.6000
21	3000.0000	0.4200
22	5000.0000	0.2700
23	7000.0000	0.2000
24	10000.0000	0.1400

O2 130 NM LINE MUMMA-ZIPF
ENERGY LOSS =   14.700 ,   LOWER LIMIT =   14.500 ,   UPPER LIMIT = 100.001 ,
QSCALE =   1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	14.7000	0.0000
3	20.0000	0.0085
4	25.0000	0.0160
5	30.0000	0.0225
6	40.0000	0.0280
7	60.0000	0.0370
8	70.0000	0.0380
9	80.0000	0.0390
10	100.0000	0.0380
11	500.0000	0.0000
12	10000.0000	0.0000

THE FOLLOWING IS NOT PART OF THE ABOVE 1978 SET OF CROSS SECTIONS:

O2 DISSOCIATION - BASED ON TABLE I OF
P. C. Cosby, J. Chem. Phys. 98, 9560 (1993).

For use in BACKPRO one would need to extend this to the maximum energy of the calculation. I haven't looked to see what would make the best cross section to use as a guide - probably the 9.97 eV loss cross section.

ENERGY	CROSS SECTION
0	0
8	0
13.5	0.22
18.5	0.53
21	0.56
23.5	0.52
28.5	0.59
33.5	0.66

38.5	0.61
48.5	0.53
58.5	0.44
73.5	0.37
98.5	0.33
148.5	0.30
198.5	0.29

A rough estimate of the dissociation of O2 by electrons at high energies is to use the cross section and rate coefficient for the "O2 8.4 LOSS" process given in the above tabe. This approximation will considerably over estimate the dissociation according to Cosby at below 30 eV and most usual E/n. The similarity to the estimated Schuman-Runge excitation in the 1978 set is not surprising, but the discrepancy at energies below 30 eV is very bothersome.

A way to calculate the rate coefficients for dissociation of O2 by electrons is to use the "O2 DISSOCIATION" cross section listed above by first multiplying it by, for example, 1E-4; using BACKPRO or equivalent to calculate rate coefficients for the combined set of cross sections; and multiplying the rate coefficient for dissociation by 1E4. This procedure preserves the energy balance, transport coefficients, and ionization coefficients of the 1978 set.

ELECTRON ATTACHMENT TO EXCITED O2

These notes were assembled in response to an inquiry as to the data available data on electron attachment to excited O2.

1) The dissociative attachment cross section for O2a-state appears to have been measured most recently by Jaffke, Meinke, Hashemi, Christophorou, and Illenberger, Chem. Phys. Lett. 193, 62 (1992). The cross section is roughly a Gaussian with a peak magnitude of 5.7E-18 cm^2 at 5.3 eV. Other measurements give significantly lower peak cross sections of 4.6+-1.3E-18 (Burrow, 1973) and 3.8+-1.2E-18 cm^2 (Belic and Hall, 1981). Note that if the Belic and Hall value for the fractional excitation of the O2a-state were high, e.g., if they missed gas density reduction because of possible gas heating and flow effects, their cross section would be low. I suggest using a peak value of 5E-18 cm^2.

Note that some of the experiments show a second peak in the dissociative attachment cross section from the O2a-state. It peaks at 7.5 eV and has a magnitude of 1.7E-18 cm^2.

A very rough estimate of the effects of including dissociative attachment to the O2a-state is a factor of two increase in the rate of O formation at typical discharge electron average energies. The rate coefficient for this process would decrease as the average electron energy is decreased.

2) One should also consider dissociative attachment from the b-state. Unfortunately there appear to be no cross sections. I would expect the cross section to be roughly a Gaussian shifted down in energy from that of the O2a-state dissociative attachment curve by about the difference in the O2a- and O2b-state thresholds of 0.65 eV. It should be larger in magnitude by a significant factor because of a higher survival factor.

I would suggest a peak magnitude of 10E-17 cm^2, which is close to the maximum allowed for a peak of reasonable energy width. Apparently, the dissociative process is expected to have a second peak at about 6.9 eV. I would guess this peak to be roughly 5E-18 cm^2.

Overall these processes mean perhaps a factor of 1.5 increase in O formation at high O2b-state concentration. Again, the rate coefficient for this process would decrease as the average electron energyHas is decreased.

3) Dissociative attachment to vibrationally excited O2 has been measured, but probably theory is more useful. See O'Malley, Phys. Rev. 155, 59 (1967). Because of the fast relaxation of vibrationally excited O2 by O, this may not increase the O- formation significantly.

4) Three-body attachment of electrons to the O2a-state molecules has been predicted theoretically to be as much as 1000 times smaller than that for O2X-state molecules. See Aleksandrov, Chem. Phys. Lett. 212, 409 (1993). This will result in a some decrease in the calculated overall three-body attachment rate coefficient when the O2a-state fraction becomes significant.

REVISION OF TOTAL AND PARTIAL IONIZATION CROSS SECTIONS:

See Straub et al, Phys. Rev. A 54, 2146 (1996) and Stebbings and Lindsay, J. Chem. Phys. 114, 4741 (2001).

RECENT DEVELOPMENTS:

Stephen Biagi at sfb@hep.ph.liv.ac.uk has derived a set of electron-O2 cross sections that differ somewhat from the above set. I still prefer the low energy cross sections given above. However, the available experimental and theoretical data does not provide definitive values. Communicated January 2002

Ionin et al, J. Phys. D 40, R25 (2007), Supplementary Tables available at stacks.iop.org/JPhysD/40/R25 have published a set of electron-O2 cross sections. These authors seem to say their cross sections yield better fits of Boltzmann results to measured oxygen a1Delta and atomic O production, particulary in mixtures with Ar. It is not clear what comparisons the authors made with published transport, ionization, and excitation coefficient measurements using swarm techniques in pure O2. Our tests of the cross section set Ionin et al were made using the Boltzmann equation solver BOLSIGPLUS from Hagelaar and Pitchford, PLasma Sources Sci. Tech. 14, 722 (2005). I conclude that the differences in the transport and direct a1Delta excitation coefficients were less than 20% and are within the uncretanties of the respective cross section sets and Boltzmann solutions.

Latest O2 changes 01/11/07

****

NITROGEN - N2 - 1985 SET OF PHELPS AND PITCHFORD

These cross sections are those used in Phelps and Pitchford, Phys. Rev. 31, 2932 (1985). The values tabulated in JILA Information Center Report No. 26 are from the same computer files. Since this report was issued, we have recommended that the values listed in the report for the C^3Pi_u excitation cross section with a threshold at 11.03 eV be multiplied by 0.67. See footnote 15 of Jelenkovic and Phelps, Phys. Rev. 36, 5310 (1987). A few errors in Report No. 26 pointed out by M. Hayashi have been corrected, i.e., entry 21 for the 11.03 eV loss and entry 3 for the 11.88 eV loss. Here the ionization cross section of Report 26 has been divided into two parts so as to facilitate calculation of the production N2 1st Negative band emission.

For each of the electronic excitation cross sections in this 1985 set one can recover the cross section obtained by Phelps and Pitchford from analyses of electron beam experiments and theory. To do this simply divide the tabulated cross sections by the quantity QSCALE listed at the head of the table for that process.

The QSCALE factors in this file are given only so that one can recover the input data to BACKPRO, e.g., the input data used by P&P (1985). These QSCALE values should NOT be used when the tabulated data is used as input for BACKPRO, i.e., use QSCALE=1. For N2 these input data were either Schulz□s published vibrational excitation cross sections with modification near threshold or the electronic excitation cross sections derived by P&P (1985) from the literature. The tabulated numbers in Report 26 and ELECTRON.TXT (this file) are the result of applying the QSCALE factors to the input. These tabulated values (except for C^3Pi_u - see above) were used in the Boltzmann calculations of P&P (1985).

It has been pointed out by several authors that the vibrational excitation cross sections tabilated here (based on Schulz) should be updated on the basis of later beam experiments and theory. However, we find good agreement with six (6) different experimental transport and rate coefficients using these cross sections and BACKPRO (Levron and Phelps, unpublished). These coefficients are drift velocity, characteristic energy, ionization, metastable (A^3 Sigma) excitation, C^3 Pi excitation, and N2 heating at E/n < 40 Td via rotational excitation and anharmonic relaxation of vibrational excitation. We therefore believe one would have to have a very strong reason before making any significant change in these cross sections. For example, a preliminary investigation (Haddad and Phelps, unpublished) suggests that the changes in cross sections accompanying the use of a multiterm spherical harmaonic code are small. As a second example, Hadded and Phelps found that the resonance in the rotational excitation cross section found theoretically by Onda and included in the cross sections recommended by Itikawa et al. J. Phys. Chem. Ref. Data 15, 985 (1986) is inconsistent with swarm data and should be ignored.

A good estimate of the dissociation of N2 by electrons is to use 0.7 times the cross section and rate coefficient for the "N2 SUM OF SINGLET STATES" given below. This approximation will be too low for electron energies below 15 eV and very low E/n. An alternative is to use the "N2 DISSOCIATION" cross section as described below.

See below, for comments on a new set of electron-N2 excitation cross sections published by Campbell et al (2001).

N2 MOMENTUM-TRANSFER CROSS SECTION

For guidance when extracting an elastic momentum transfer cross section from this data see Fig. 1 of Phelps and Pitchford (1985).

	ENERGY	Effective Qm - Defined in introduction
1	0.0000	1.1000
2	0.0010	1.3600
3	0.0020	1.4900
4	0.0030	1.6200
5	0.0050	1.8100
6	0.0070	2.0000
7	0.0085	2.1000
8	0.0100	2.1900
9	0.0150	2.5500
10	0.0200	2.8500
11	0.0300	3.4000
12	0.0400	3.8500
13	0.0500	4.3300
14	0.0700	5.1000
15	0.1000	5.9500

16	0.1200	6.4500
17	0.1500	7.1000
18	0.1700	7.4000
19	0.2000	7.9000
20	0.2500	8.5000
21	0.3000	9.0000
22	0.3500	9.4000
23	0.4000	9.7000
24	0.5000	9.9000
25	0.7000	10.0000
26	1.0000	10.0000
27	1.2000	10.4000
28	1.3000	11.0000
29	1.5000	12.0000
30	1.7000	13.8000
31	1.9000	19.6000
32	2.1000	27.0000
33	2.2000	28.5000
34	2.5000	30.0000
35	2.8000	28.0000
36	3.0000	21.7000
37	3.3000	17.2000
38	3.6000	14.7000
39	4.0000	12.6000
40	4.5000	11.3000
41	5.0000	10.9000
42	6.0000	10.4000
43	7.0000	10.1000
44	8.0000	10.0000
45	10.0000	10.4000
46	12.0000	10.9000
47	15.0000	11.0000
48	17.0000	10.7000
49	20.0000	10.2000
50	25.0000	9.5000
51	30.0000	9.0000
52	50.0000	8.6000
53	75.0000	6.6000
54	100.0000	5.8000
55	150.0000	4.9000
56	200.0000	4.2000
57	300.0000	3.3000
58	500.0000	2.4400
59	700.0000	1.9600
60	1000.0000	1.5500
61	1500.0000	1.1200
62	2000.0000	0.8100
63	3000.0000	0.6300
64	5000.0000	0.4000
65	7000.0000	0.2900
66	10000.0000	0.2100

N2 ROT EXT USING SUM OF SCHULZ VIBRATION IN A SINGLE-LEVEL
APPROXIMATION.
THIS IS TO BE USED IN ADDTION TO THE CAR APPROXIMATION.
ENERGY LOSS = 0.020 , LOWER LIMIT = 0.000 , UPPER LIMIT = 5.005 ,
QSCALE = 1.000000 (QSCALE USED ONLY FOR RECONSTRUCTING INPUT DATA - SEE INTRO.)

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	0.0200	0.0000
3	0.0300	0.0000
4	0.4000	0.0000
5	0.8000	0.0000
6	1.2000	0.0600
7	1.6000	0.1800
8	1.7000	0.2300
9	1.8000	0.4000
10	1.9000	1.4100
11	2.0000	5.1300
12	2.1000	5.4200
13	2.2000	5.1400
14	2.3000	6.9000
15	2.4000	6.0400
16	2.5000	6.4500
17	2.6000	5.1000
18	2.7000	4.2400
19	2.8000	3.7500
20	2.9000	2.1100
21	3.0000	2.3200
22	3.1000	1.9400
23	3.2000	1.4000
24	3.3000	0.9400
25	3.6000	0.3800
26	5.0000	0.0000
27	20.0000	0.0000
28	1000.0000	0.0000

N2 V=1 ENGELHARDT, PHELPS, & RISK BELOW 1.6 PLUS 2.3 EV RES MODIFED FEB
82
ENERGY LOSS = 0.290, LOWER LIMIT = 0.258, UPPER LIMIT = 80.006,
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	0.2900	0.0000
3	0.3000	0.0010
4	0.3300	0.0017
5	0.4000	0.0025
6	0.7500	0.0037
7	0.9000	0.0055
8	1.0000	0.0065
9	1.1000	0.0090
10	1.1600	0.0110
11	1.2000	0.0125
12	1.2200	0.0135

13	1.4000	0.0700
14	1.5000	0.1000
15	1.6000	0.1500
16	1.6500	0.0000
17	3.6000	0.0000
18	4.0000	0.0550
19	5.0000	0.0350
20	15.0000	0.0350
21	18.0000	0.0400
22	20.0000	0.0650
23	22.0000	0.0850
24	23.0000	0.0850
25	25.0000	0.0600
26	29.0000	0.0300
27	32.0000	0.0150
28	50.0000	0.0120
29	80.0000	0.0000
30	1000.0000	0.0000

N2 V=1 RES SCHULZ 64
ENERGY LOSS = 0.291 , LOWER LIMIT = 1.600 , UPPER LIMIT = 3.999 ,
QSCALE = 1.500000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	0.2910	0.0000
3	1.6000	0.0000
4	1.6500	0.2700
5	1.7000	0.3150
6	1.8000	0.5400
7	1.9000	1.4850
8	2.0000	4.8000
9	2.1000	2.5650
10	2.2000	1.2000
11	2.3000	4.5000
12	2.4000	2.7600
13	2.5000	1.5900
14	2.6000	3.1500
15	2.7000	1.5450
16	2.7500	0.6000
17	2.8000	1.3500
18	2.9000	0.5250
19	3.0000	0.8700
20	3.1000	1.1700
21	3.2000	0.8550
22	3.3000	0.6600
23	3.4000	0.6000
24	3.5000	0.5850
25	3.6000	0.5700
26	4.0000	0.0000
27	100.0000	0.0000
28	1000.0000	0.0000

N2 V=2 SCHULZ 64
ENERGY LOSS = 0.590 , LOWER LIMIT = 1.677 , UPPER LIMIT = 3.612 ,
QSCALE = 1.500000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	0.5900	0.0000
3	1.7000	0.0000
4	1.8000	0.0150
5	1.9000	0.6300
6	2.0000	1.9350
7	2.1000	3.3000
8	2.2000	1.4700
9	2.3000	0.5400
10	2.4000	2.1150
11	2.5000	3.0000
12	2.6000	0.5400
13	2.7000	1.0500
14	2.7500	1.7250
15	2.8000	1.2750
16	2.9000	0.3300
17	3.0000	0.9000
18	3.1000	0.6450
19	3.2000	0.3750
20	3.3000	0.3450
21	3.4000	0.3000
22	3.5000	0.2130
23	3.6000	0.0000
24	1000.0000	0.0000

N2 V=3 SCHULZ 64
ENERGY LOSS = 0.880 , LOWER LIMIT = 1.677 , UPPER LIMIT = 3.406 ,
QSCALE = 1.500000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	0.8800	0.0000
3	1.9000	0.0000
4	2.0000	0.9600
5	2.1000	2.0550
6	2.2000	2.7000
7	2.3000	1.6950
8	2.4000	0.0750
9	2.5000	0.9600
10	2.6000	1.4700
11	2.7000	0.4500
12	2.7500	0.9600
13	2.8000	0.5400
14	2.9000	0.8550
15	3.0000	0.4050
16	3.1000	0.2820
17	3.2000	0.2910
18	3.3000	0.0615
19	3.4000	0.0000

20	1000.0000	0.0000

N2 V=4 SCHULZ 64
ENERGY LOSS = 1.170 , LOWER LIMIT = 1.883 , UPPER LIMIT = 3.302 ,
QSCALE = 1.500000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	1.1700	0.0000
3	2.0000	0.0000
4	2.1000	0.2025
5	2.2000	1.5150
6	2.3000	2.3850
7	2.4000	1.4400
8	2.5000	0.5550
9	2.6000	0.0825
10	2.7000	1.2000
11	2.7500	1.0950
12	2.8000	0.6750
13	2.9000	0.0300
14	3.0000	0.3300
15	3.1000	0.3150
16	3.2000	0.0600
17	3.3000	0.0000
18	1000.0000	0.0000

N2 V=5 SCHULZ 64
ENERGY LOSS = 1.470 , LOWER LIMIT = 1.883 , UPPER LIMIT = 3.406 ,
QSCALE = 1.500000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	1.4700	0.0000
3	2.1000	0.0000
4	2.2000	0.8250
5	2.3000	1.2300
6	2.4000	1.5300
7	2.5000	1.4400
8	2.6000	0.3450
9	2.7000	0.0225
10	2.7500	0.3450
11	2.8000	0.5400
12	2.9000	0.6600
13	3.0000	0.2175
14	3.1000	0.1050
15	3.2000	0.3150
16	3.3000	0.1035
17	3.4000	0.0000
18	1000.0000	0.0000

N2 V=6 SCHULZ 64
ENERGY LOSS = 1.760 , LOWER LIMIT = 2.193 , UPPER LIMIT = 3.199 ,
QSCALE = 1.500000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	1.7600	0.0000
3	2.2000	0.0000
4	2.3000	0.0063
5	2.4000	1.1250
6	2.5000	1.7400
7	2.6000	1.3800
8	2.7000	0.7800
9	2.7500	0.4500
10	2.8000	0.3150
11	2.9000	0.2460
12	3.0000	0.4800
13	3.1000	0.1635
14	3.2000	0.0000
15	100.0000	0.0000
16	1000.0000	0.0000

N2 V=7 SCHULZ 64
ENERGY LOSS = 2.060 , LOWER LIMIT = 2.296 , UPPER LIMIT = 3.509 ,
QSCALE = 1.500000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	2.0600	0.0000
3	2.3000	0.0000
4	2.4000	0.0126
5	2.5000	0.3900
6	2.6000	0.6600
7	2.7000	0.9600
8	2.7500	0.7950
9	2.8000	0.6000
10	2.9000	0.1800
11	3.0000	0.0063
12	3.1000	0.1920
13	3.2000	0.2040
14	3.3000	0.0780
15	3.4000	0.0189
16	3.5000	0.0000
17	100.0000	0.0000
18	1000.0000	0.0000

N2 V=8 SCHULZ 64
ENERGY LOSS = 2.350 , LOWER LIMIT = 2.477 , UPPER LIMIT = 3.509 ,
QSCALE = 1.500000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	2.3500	0.0000
3	2.5000	0.0000
4	2.6000	0.0189
5	2.7000	0.3600
6	2.7500	0.3600

7	2.8000	0.3300
8	2.9000	0.3450
9	3.0000	0.2640
10	3.1000	0.0375
11	3.2000	0.0063
12	3.3000	0.1545
13	3.4000	0.0252
14	3.5000	0.0000
15	100.0000	0.0000
16	1000.0000	0.0000

N2 A3SIGMA-CARTWRIGHT 1977 V=0-4
ENERGY LOSS = 6.170 , LOWER LIMIT = 5.986 , UPPER LIMIT = 150.001 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	6.1700	0.0000
3	7.0000	0.0010
4	7.8000	0.0028
5	8.5000	0.0043
6	9.0000	0.0057
7	10.0000	0.0082
8	11.0000	0.0100
9	12.0000	0.0120
10	13.0000	0.0130
11	14.0000	0.0140
12	16.0000	0.0150
13	17.0000	0.0150
14	18.0000	0.0140
15	20.0000	0.0120
16	22.0000	0.0100
17	24.0000	0.0089
18	26.0000	0.0076
19	30.0000	0.0059
20	34.0000	0.0049
21	40.0000	0.0039
22	50.0000	0.0034
23	70.0000	0.0007
24	150.0000	0.0000
25	500.0000	0.0000
26	1000.0000	0.0000

N2 A3SIGMA-CARTWRIGHT 1977 V=5-9
ENERGY LOSS = 7.000 , LOWER LIMIT = 6.785 , UPPER LIMIT = 150.001 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	7.0000	0.0000
3	7.3000	0.0020
4	7.8000	0.0050
5	8.5000	0.0150
6	9.0000	0.0220
7	10.0000	0.0340
8	11.0000	0.0430
9	12.0000	0.0500
10	13.0000	0.0550
11	14.0000	0.0600
12	16.0000	0.0650
13	17.0000	0.0650
14	18.0000	0.0620
15	20.0000	0.0530
16	22.0000	0.0450
17	24.0000	0.0380
18	26.0000	0.0330
19	30.0000	0.0250
20	34.0000	0.0210
21	40.0000	0.0170
22	50.0000	0.0140
23	70.0000	0.0029
24	150.0000	0.0000
25	500.0000	0.0000
26	1000.0000	0.0000

N2 B3PI-CARTWRIGHT 1977
ENERGY LOSS = 7.350 , LOWER LIMIT = 6.992 , UPPER LIMIT = 150.001 ,
QSCALE = 0.670000(QSCALE USED ONLY FOR RECONSTRUCTING INPUT DATA - SEE N2 INTRO.)

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	7.3500	0.0000
3	8.0000	0.0362
4	9.0000	0.0938
5	10.0000	0.1508
6	11.0000	0.1863
7	12.0000	0.2003
8	13.0000	0.1990
9	14.0000	0.1816
10	15.0000	0.1615
11	16.0000	0.1447
12	17.0000	0.1307
13	18.0000	0.1199
14	20.0000	0.1112
15	22.0000	0.0951
16	26.0000	0.0804
17	30.0000	0.0677
18	34.0000	0.0563
19	40.0000	0.0429
20	50.0000	0.0268
21	70.0000	0.0067
22	150.0000	0.0000
23	500.0000	0.0000
24	1000.0000	0.0000

N2 W3DELTA-CARTWRIGHT 1977

ENERGY LOSS = 7.360 , LOWER LIMIT = 7.198 , UPPER LIMIT = 150.001 ,
QSCALE = 0.670000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	7.3600	0.0000
3	8.0000	0.0181
4	9.0000	0.0496
5	10.0000	0.0804
6	11.0000	0.1112
7	12.0000	0.1427
8	14.0000	0.2050
9	15.0000	0.2352
10	16.0000	0.2546
11	17.0000	0.2519
12	18.0000	0.2345
13	20.0000	0.1776
14	22.0000	0.1320
15	24.0000	0.1025
16	26.0000	0.0844
17	28.0000	0.0724
18	30.0000	0.0630
19	34.0000	0.0496
20	40.0000	0.0348
21	50.0000	0.0201
22	70.0000	0.0100
23	100.0000	0.0047
24	150.0000	0.0000
25	500.0000	0.0000
26	1000.0000	0.0000

N2 A3SIGMA-CARTWRIGHT 1977 V=10-
ENERGY LOSS = 7.800 , LOWER LIMIT = 7.585 , UPPER LIMIT = 150.001 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	7.8000	0.0000
3	8.1000	0.0015
4	8.5000	0.0040
5	8.7000	0.0070
6	9.0000	0.0110
7	10.0000	0.0290
8	11.0000	0.0440
9	12.0000	0.0510
10	13.0000	0.0560
11	14.0000	0.0600
12	16.0000	0.0660
13	17.0000	0.0670
14	18.0000	0.0630
15	20.0000	0.0540
16	22.0000	0.0460
17	24.0000	0.0390
18	26.0000	0.0330
19	30.0000	0.0260
20	34.0000	0.0210
21	40.0000	0.0170
22	50.0000	0.0150
23	70.0000	0.0030
24	150.0000	0.0000
25	500.0000	0.0000
26	1000.0000	0.0000

N2 BPRI3SIGMA-CARTWRIGHT 1977
ENERGY LOSS = 8.160 , LOWER LIMIT = 7.998 , UPPER LIMIT = 150.001 ,
QSCALE = 0.670000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	8.1600	0.0000
3	9.0000	0.0107
4	10.0000	0.0235
5	11.0000	0.0369
6	12.0000	0.0496
7	13.0000	0.0630
8	14.0000	0.0757
9	15.0000	0.0838
10	16.0000	0.0764
11	17.0000	0.0616
12	18.0000	0.0489
13	19.0000	0.0409
14	20.0000	0.0362
15	22.0000	0.0315
16	26.0000	0.0268
17	30.0000	0.0228
18	34.0000	0.0194
19	40.0000	0.0161
20	50.0000	0.0127
21	70.0000	0.0067
22	150.0000	0.0000
23	500.0000	0.0000
24	1000.0000	0.0000

N2 APRI1SIGMA-CARTWRIGHT 1977
ENERGY LOSS = 8.400 , LOWER LIMIT = 8.179 , UPPER LIMIT = 500.004 ,
QSCALE = 0.670000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	8.4000	0.0000
3	9.0000	0.0067
4	11.0000	0.0301
5	13.0000	0.0536
6	14.0000	0.0643
7	15.0000	0.0697

8	16.0000	0.0570
9	17.0000	0.0429
10	18.0000	0.0348
11	19.0000	0.0308
12	20.0000	0.0275
13	24.0000	0.0201
14	30.0000	0.0154
15	40.0000	0.0124
16	50.0000	0.0121
17	70.0000	0.0100
18	150.0000	0.0067
19	500.0000	0.0000
20	1000.0000	0.0000

N2 A1PI-CARTWRIGHT 1977
ENERGY LOSS = 8.550 , LOWER LIMIT = 8.282 , UPPER LIMIT = 999.002 ,
QSCALE = 0.670000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	8.5500	0.0000
3	9.0000	0.0127
4	14.0000	0.1474
5	15.0000	0.1715
6	16.0000	0.1916
7	17.0000	0.2023
8	18.0000	0.1990
9	19.0000	0.1923
10	20.0000	0.1849
11	24.0000	0.1621
12	26.0000	0.1528
13	30.0000	0.1367
14	40.0000	0.1065
15	50.0000	0.0851
16	70.0000	0.0603
17	100.0000	0.0402
18	150.0000	0.0268
19	200.0000	0.0201
20	250.0000	0.0161
21	300.0000	0.0134
22	500.0000	0.0082
23	700.0000	0.0060
24	1000.0000	0.0042

N2 W1DELTA-CARTWRIGHT 1977
ENERGY LOSS = 8.890 , LOWER LIMIT = 8.488 , UPPER LIMIT = 150.001 ,
QSCALE = 0.670000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	8.8900	0.0000
3	9.0000	0.0013
4	10.0000	0.0261
5	11.0000	0.0476
6	12.0000	0.0663
7	13.0000	0.0784
8	14.0000	0.0771
9	15.0000	0.0670
10	16.0000	0.0543
11	17.0000	0.0442
12	18.0000	0.0375
13	20.0000	0.0288
14	22.0000	0.0241
15	30.0000	0.0154
16	38.0000	0.0094
17	50.0000	0.0047
18	150.0000	0.0000
19	500.0000	0.0000
20	1000.0000	0.0000

N2 C3PI-CARTWRIGHT 1977 -FINN-KISKER THRESHOLD SCALED BY PHELPS

ENERGY LOSS = 11.030 , LOWER LIMIT = 10.784 , UPPER LIMIT = 150.001 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	11.0300	0.0000
3	11.5000	0.0270
4	12.0000	0.0620
5	12.5000	0.1310
6	13.0000	0.2900
7	13.5000	0.4900
8	13.8000	0.6200
9	14.0000	0.6500
10	14.2000	0.6400
11	14.5000	0.6300
12	15.0000	0.5500
13	16.0000	0.4300
14	17.0000	0.3500
15	18.0000	0.3000
16	19.0000	0.2700
17	20.0000	0.2500
18	22.0000	0.2100
19	24.0000	0.1770
20	26.0000	0.1500
21	28.0000	0.1280
22	30.0000	0.1110
23	36.0000	0.0780
24	40.0000	0.0630
25	50.0000	0.0390
26	70.0000	0.0150
27	100.0000	0.0015
28	150.0000	0.0000
29	500.0000	0.0000
30	1000.0000	0.0000

N2 E3SIGMA-CARTWRIGHT 1977
ENERGY LOSS = 11.880 , LOWER LIMIT = 11.481 , UPPER LIMIT = 150.001 ,
QSCALE = 0.670000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	11.8700	0.0000
3	11.9200	0.0496
4	12.7000	0.0007
5	17.0000	0.0034
6	19.0000	0.0042
7	20.0000	0.0047
8	22.0000	0.0052
9	24.0000	0.0054
10	26.0000	0.0054
11	28.0000	0.0044
12	30.0000	0.0034
13	32.0000	0.0027
14	40.0000	0.0012
15	50.0000	0.0005
16	150.0000	0.0000
17	500.0000	0.0000
18	1000.0000	0.0000

N2 ADPRI1SIGMA-CARTWRIGHT 1977
ENERGY LOSS = 12.250 , LOWER LIMIT = 11.997 , UPPER LIMIT = 999.002 ,
QSCALE = 0.670000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	12.2500	0.0000
3	13.0000	0.0054
4	15.0000	0.0188
5	16.0000	0.0248
6	17.0000	0.0301
7	18.0000	0.0348
8	19.0000	0.0382
9	20.0000	0.0389
10	22.0000	0.0342
11	24.0000	0.0275
12	26.0000	0.0228
13	30.0000	0.0154
14	36.0000	0.0114
15	40.0000	0.0107
16	50.0000	0.0090
17	70.0000	0.0068
18	100.0000	0.0050
19	150.0000	0.0036
20	200.0000	0.0029
21	300.0000	0.0020
22	500.0000	0.0013
23	700.0000	0.0010
24	1000.0000	0.0008

N2 SUM OF SINGLET STATES-ZIPF-MCLAUGHLIN 1978
ENERGY LOSS = 13.000 , LOWER LIMIT = 12.487 , UPPER LIMIT = 999.002 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	13.0000	0.0000
3	14.0000	0.0810
4	15.0000	0.1900
5	16.0000	0.2500
6	17.0000	0.4200
7	18.0000	0.5200
8	20.0000	0.7500
9	22.0000	0.9600
10	25.0000	1.1900
11	30.0000	1.4800
12	40.0000	1.6500
13	60.0000	1.7600
14	80.0000	1.6800
15	100.0000	1.5800
16	150.0000	1.3300
17	200.0000	1.1600
18	250.0000	1.0500
19	300.0000	0.9600
20	500.0000	0.7400
21	700.0000	0.6400
22	1000.0000	0.5300

BASED ON RAPP,ENGLANDER-GOLDEN,1965 AND BORST-ZIPF. PRODUCTION OF X^2Sigma AND A^2Pi STATES OF N2+
ENERGY LOSS = 15.600 , LOWER LIMIT = 15.480 , UPPER LIMIT = 999.002 ,
EBR= 13.000000, QSCALE= 0.930000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	15.6000	0.0000
3	16.0000	0.0195
4	16.5000	0.0428
5	17.0000	0.0660
6	17.5000	0.0911
7	18.0000	0.1200
8	18.5000	0.1516
9	19.0000	0.1841
10	19.5000	0.2130
11	20.0000	0.2502
12	21.0000	0.3181
13	22.0000	0.3869
14	23.0000	0.4557
15	25.0000	0.5924
16	30.0000	0.9579
17	34.0000	1.1718

18	45.0000	1.6461
19	60.0000	2.0181
20	75.0000	2.2134
21	100.0000	2.3436
22	150.0000	2.2692
23	200.0000	2.1018
24	300.0000	1.7763
25	500.0000	1.3485
26	700.0000	1.0788
27	1000.0000	0.8556
28	1500.0000	0.7440

N2+ B2SIGMA EXCITATION - BORST ZIPF. PRODUCTION OF B^2Sigma STATE OF N2+
ENERGY LOSS = 18.800 , LOWER LIMIT = 17.983 , UPPER LIMIT =10000.003 ,
EBR= 13.000000, QSCALE= 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	18.8000	0.0000
3	19.0000	0.0012
4	19.6000	0.0048
5	20.0000	0.0071
6	30.0000	0.0720
7	35.0000	0.1010
8	40.0000	0.1210
9	45.0000	0.1360
10	50.0000	0.1470
11	60.0000	0.1600
12	80.0000	0.1710
13	90.0000	0.1730
14	100.0000	0.1740
15	150.0000	0.1700
16	300.0000	0.1320
17	500.0000	0.1030
18	700.0000	0.0830
19	1000.0000	0.0640
20	1500.0000	0.0570
21	2000.0000	0.0370
22	4000.0000	0.0215
23	7000.0000	0.0138
24	10000.0000	0.0104

END OF PHELPS AND PITCHFORD 1985 SET.

THE FOLLOWING ARE NOT PART OF THE PHELPS AND PITCHFORD (1985) SET OF CROSS SECTIONS AND ARE NOT LISTED IN JILA REPOT #26.

RECENT EXCITATION CROSS SECTION RESUTS AND THEIR INTERPRETATION

Very recently Campbell, Brunger, Nolan, Kelly, Wedding, Harrison, Teubner, Cartwright, and McLaughlin, J. Phys. B 34, 1185 (2001) have re-evaluated the published excitation cross section data for the important ten lowest electronic states of N2 and have used this data for a re-analysis of electron transport data in N2. They conclude that the integrated cross sections recommended by Phelps and Pitchford (P&P), Phys. Rev. 31, 2932 (1985) and tabulated above in this file are too small by a significant factor. My analysis of this important work is outlined below.

1) A study of their paper finds that their published electronic excitation cross sections (their Table 1) for the first ten excited states of N2 are in rather good agreement with the cross sections derived by (P&P) from the literature. The disagreement between these 10 cross sections of Campbell et al and the values tabulated above arises because of the application by P&P of scaling factors of 2/3 to several of the subject cross sections. See the QSCALE values listed above. In other words, if the QSCALE factors from the above table were reset to 1.0 there would be no disagreement outside stated uncertainties as to the cross sections for excitation of the first 10 levels and no significant disagreement as to the interpretation of beam experiments and theory for these states.

2) For the higher threshold excited states of N2, i.e., primarily the singlet states, we believe that the cross sections of P&P (1985) are the more reliable. Apparently the cross section set of Campbell et al (2001), other than the first ten states, is from the work of Nolan and of Kelly and was "intended for the simulation of low to moderate" E/N.

3) The comparisons of the results of P&P (1985) with experiment in both Fig. 8 of P&P and in Figs. 5 through 9 of Campbell et al (2001) require clarification because of the changes in the magnitude of the various transport coefficients with the experimental technique being modeled. See Tagashira et al, J. Phys. D 10, 1051 (1977) and Blevin et al, Aust. J. Phys. 37, 593 (1984). As stated in the text of P&P, but not in Fig. 8, the calculations are almost all made for an exponentially growing and spatially uniform electron swarm (no density gradients), whereas as the experiments shown are mostly of the time-of-flight type. As a result, one expects the experimental values to lie above the P&P model results. See Taniguchi et al, J. Phys. D 11, 1757 (1978) for comparisons of results for various types of experiments obtained using a somewhat different set of cross sections for electrons in N2. Similarly, one does not expect the the temporal growth results of P&P (1985) to agree closely with the time-of flight calculations of Campbell et al (2001) or with the some what divergent time-of-flight experiments of Wedding et al, J. Phys. D 18, 2361 (1985) and Roznerski, J. Phys. D 29, 614 (1996).

4) It should be kept in mind that the experimental values for the electron drift velocities and characteristic energies

have changed since the experiments cited by P&P.
Assuming that tne newer experimental results are better, the QSCALE factors used by P&P and tabulated above probably have to be changed toward unity and the cross sections for the first 10 states changed toward the Campbell et al (2001) values.

5) The net result of the inconsistencies in the published comparisons of the results of P&P (1985) with experiments and with the calculated results of Campbell et al (2001) is that we do not know the errors resulting from the use of the P&P (1985) cross sections. Note that according to A. Nolan (private communication), Campbell et al (2001) did not calculate transport coefficients using the cross sections of P&P (1985) - unfortunately designated as the "JILA" set by Campbell et al. These and related questions have been investigated by A. Cenian and collaborators using Monte Carlo techniques. See Cenian et al, J. Phys. B 35, 5163 (2002); Cenian and Chernykho, Radiation Physics and Chemistry 68, 103 (2003).

6) My present guess (5/23/02) is that the uncertainties in the experimental transport data will turn out to be comparable with the differences in calculated drift velocities, characteristic energies, and ionization coefficients when using the cross sections of Campbell et al (2001) or those of P&P (1985) as tabulated above. If this is the case, then the fact that the Campbell et al cross sections for the first 10 states are derived from electron beam experiments and theory would favor the use of the Campbell et al cross sections for the first 10 states and those listed above from P&P (1985) for the higher states. Because of the problems in obtaining a listing of the Campbell et al cross sections and in dealing with the ~ 1 million entries, it is suggested that one obtain a very nearly equivalent cross section set for all electronic excitation by dividing the entries given above for P&P (1985) by their associated QSCALE factors. The vibrational excitation cross sections listed above should not be rescaled.

I thank A. Nolan and A. B. Wedding (private communication) for listings of the cross section sets of Campbell et al (2001). I thank A. Cenian for several emails and preliminary Monte Carlo results leading to the analysis given here.

This discussion revised 12/18/2003

N2 DISSOCIATION - FROM TABLE II OF
P. C. Cosby, J. Chem. Phys. 98, 9544 (1993).

For use in BACKPRO one would need to extend this to the maximum energy of the calculation using the "SUM OF SINGLETS" cross section as a guide.

DO NOT ADD THIS TO THE SET OF CROSS SECTIONS GIVEN ABOVE. SUCH AN ERROR WOULD COUNT DISSOCIATION TWICE IN THE BOLTZMANN CALCULATION. SIMILARLY, FOR THE DISSOCIATION CROSS SECTION OF WINTERS (1966).

To use this cross section listed below with any Boltzmann code that uses the cross section set given above:
1) multiply it by a small number, for example, 1E-4;
2) use BACKPRO or equivalent to calculate rate coefficients for the combined set of cross sections;
3) multiply the rate coefficient for dissociation by 1E4.
This procedure preserves the energy balance, transport coefficients, and ionization coefficients of the 1985 set.

ENERGY	CROSS SECTION
0	0
10	0
12	0.01
14	0.04
16	0.20
18	0.36
20	0.52
25	0.87
30	1.04
40	1.15
50	1.23
60	1.23
80	1.20
100	1.16
125	1.10
150	1.04
175	0.99
200	0.95

.....

For a recent prediction of cross sections and rate coefficients for electron induced transitions between vibrationallly excited levels of the N2(X) state, see Mihajlov, Stojanovic, and Petrovic, J. Phys. B 32, 2620 (1999).

N2 - ANALYTICAL APPROXIMATIONS TO DIFFERENTIAL SCATTERING CROSS SECTIONS FOR ELECTRON SCATTERING

We use a screened-Coulomb type scattering formula to approximate the angular distributions of scattered electrons. Our choice allows fitting data that is predominantly backward scattering, e.g., O2 at low energies, and goes over to predominantly forward scattering at high energies.

The differential scattering cross section i(theta,beta,en) is assumed to be

```
i = a*(1 -(1 - 2*beta[en])*Cos[theta])^-2
```

where theta is the scattering angle, beta is a screening parameter and is a function of the electron energy, and en is the electron energy. Here a is the conventional magnitude factor for Coulomb scattering and is a function of electron energy only.

Integration yields the total cross section qt

```
qt = -((a*Pi)/((-1 + beta)*beta));
```

and the momentum transfer cross section qm

```
qm = (2*Pi*(a - 2*a*beta - a*Ln[2 - 2*beta] +
      a*beta*Ln[2 - 2*beta] + a*Ln[2*beta] -
      a*beta*Ln[2*beta]))/((-1 + beta)*(-1 + 2*beta)^2)
```

so that the ratio of the momentum transfer cross section to the total cross sections qm/qt is

```
ratio = (2*beta*(-1 + 2*beta +
         Ln[2 - 2*beta] - beta*Ln[2 - 2*beta] -
         Ln[2*beta] + beta*Ln[2*beta]))/
        (-1 + 2*beta)^2;
```

The differential scattering cross sections normalized to the total cross section is

```
normi = i[theta,eta]/qt[beta]
```

so that probability of scattering through an angle less than theta0 is

```
prob = (1 - Cos[theta0])*(1 - beta)/
  (1 - (1 - 2*beta)Cos[theta0]);
```

For theta0 = Pi this is 1 as expected.
We set prob equal to a random number, randomnum, and solve for the scattering angle theta0.

```
theta0 = ArcCos[(1 - beta - randomnum)/
      (1 - beta - randomnum + 2*beta*randomnum)]
```

Application to the scattering of electrons by N2:

As in Phelps and Pitchford, Phys. Rev. A 31, 2932 (1985), we only attempt to fit the experimental angular distributions at energies for which the particular scattering cross section is important to the solution of the electron Boltzmann equation. See Table I.

The empirical expressions used for the lowest two spherical harmonic components of the angular scattering are taken from Table I of this reference. The magnitudes of the effective Qm and angular integrated qt for the various inelastic scattering processes can be taken from the tables given earlier in this file.

From Phelps and Pitchford, Phys. Rev. A 31, 2932 (1985), Table I, one obtains values of qm(en)/q0(en). The empirical q1/q0 expressions are then set equal to the expression for "ratio" and the value of beta is evaluated numerically, not algebraically. A graph of such beta values is then fitted by an algebraic expression for "empiricalbeta" by trial and error. Note that here qm is the elastic momentum transfer cross secton, not the effective Qm.

```
q1/q0 = -0.2*en^0.5/(0.025+en^0.5)+
         1.2*(16*en^0.5+en)/(100+16*en^0.5+en);
qm/q0 = 1 - q1/q0; (q0 = qt everywhere);
empiricalbeta = .6/(1+(en/50.0)^0.5+(en/20.0)^1.01)^0.99;
```

Resonant vibrational excitation:
Since the scattering is roughly isotropic, beta = 0.5.
(Corrected 12/10/96 thanks to A. Gilardini)

Lower triplet states- A, B, and W:

```
q1/q0 = -en^2/(1500+en^2);
qm/q0 = 1 - q1/q0;
empiricalbeta = .5*(1+(en/20.0)^2)/(1+(en/28.2)^2);
```

Upper triplet state - C:

```
q1/q0 = -0.2;
qm/q0 = 1 - q1/q0;
empiricalbeta = .647;
```

Lower singlet state - a1Pi:

```
q1/q0 = (200000+ 160*en^2+en^4)/(200000+2600*en^2+en^4);
qm/q0 = 1 - q1/q0;
empiricalbeta = 0.4*(en/15.0)^2/(1+(en/30.0)^2+(en/22.0)^4);
```

Sum of singlets:

```
q1/q0 = en^2/(2500+en^2);
qm/q0 = 1 - q1/q0;
empiricalbeta = .5/(1+(en/37.0)^2.5);
```

The differential cross sections derived from the preceding tabulation have not been used in Boltzmann or Monte Carlo calculations so as to compare with the more detailed angular distributions used by others, e.g., Kunhardt and Tzeng, Phys. Rev. A 34, 2148 and 2158 (1986), Stojanovic, Jelenkovic, and Petrovic, J. Appl. Phys. 81, 1601 (1997), and Stojanovic and Petrovic, J. Phys. D 31, 834 (1998). A similar approximation to the differential cross section was made for N2 by Pitchford, Physics and Applications of Pseudo Sparks, (Wiley, New York, 1990) p. 319. Also, Jelenkovic and Phelps (unpublished) (1995) have used such an approximation for Monte Carlo calculations for electrons in H2. Belenguer and Pitchford, J. Appl. Phys. 86, 4780 (1999) used this form for anisotropic electron-Ar collisions.

A very thorough and more detailed representation of the differential cross sections for electrons in N2 at energies from 2.3 to 1000 eV is given by Porter et al, J. Geophys. Res. 92, 5933 (1987).

We thank A. Okhrimovskyy (8/27/00 and 3/8/01) for pointing out a typographical in the equation for i, poor terminology in the discusstion of the cumulative probability, an inconsistency in the energy scales for the empirical beta formulas, and the need for more detail in the description of the evaluation the empirical beta.

Added 11/10/01 Modified 02/28/02

REVISION OF PARTIAL IONIZATION CROSS SECTIONS

See Straub et al, Phys. Rev. A 54, 2146 (1996) and Stebbings and Lindsay, J. Chem. Phys. 114, 4741 (2001).

Stephen Biagi at sfb@hep.ph.liv.ac.uk has derived a set of electron-N2 cross sections that differ somewhat from our set and somewhat from the set of Campbell et al.
Communicated June 2002

latest N2 changes 12/18/03
****

PURE CO2- DEC 1978

CO2 MOMENTUM-TRANSFER CROSS SECTION

	ENERGY	Effective Qm - Defined in introduction
1	0.0000	600.0000
2	0.0010	540.0000
3	0.0020	380.0000
4	0.0030	307.0000
5	0.0050	237.0000
6	0.0070	200.0000
7	0.0085	182.0000
8	0.0100	170.0000
9	0.0150	138.0000
10	0.0200	120.0000
11	0.0300	97.0000
12	0.0400	85.0000
13	0.0500	76.0000
14	0.0700	63.0000
15	0.1000	50.0000
16	0.1200	44.0000
17	0.1500	39.0000
18	0.1700	34.0000
19	0.2000	29.0000
20	0.2500	24.0000
21	0.3000	18.0000
22	0.3500	15.0000
23	0.4000	13.0000
24	0.5000	10.0000
25	0.7000	7.1000
26	1.0000	5.2000
27	1.2000	4.8000
28	1.3000	4.7000
29	1.5000	4.6500
30	1.7000	4.6500
31	1.9000	4.8500
32	2.1000	5.0500
33	2.2000	5.2000
34	2.5000	6.4000
35	2.8000	7.6000
36	3.0000	9.0000
37	3.3000	11.5000
38	3.6000	14.0000
39	4.0000	15.2000
40	4.5000	14.8000
41	5.0000	12.7000
42	6.0000	10.0000
43	7.0000	10.0000
44	8.0000	10.8000
45	10.0000	12.1000
46	12.0000	13.1000
47	15.0000	14.4000
48	17.0000	15.0000
49	20.0000	15.8000
50	25.0000	16.0000
51	30.0000	15.8000
52	50.0000	12.6000
53	75.0000	9.5000
54	100.0000	8.0000
55	150.0000	6.0000
56	200.0000	4.0000
57	300.0000	3.7000
58	500.0000	2.5000
59	700.0000	2.0000
60	1000.0000	1.6000

CO2 VIBRATIONAL EXCITATION - ASYMMETRIC STRETCH - BULOS & PHELPS
ENERGY LOSS = 0.083 , LOWER LIMIT = 0.050 , UPPER LIMIT = 20.009
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	0.0830	0.0000

3	0.0844	0.8500
4	0.0862	1.1600
5	0.0932	1.8500
6	0.1035	2.3000
7	0.1208	2.6000
8	0.1382	2.6800
9	0.1726	2.5400
10	0.2070	2.2000
11	0.2750	1.7200
12	0.3450	1.4300
13	0.5000	1.0800
14	0.7000	0.8000
15	0.9000	0.6600
16	1.1000	0.5700
17	1.4000	0.4500
18	1.6000	0.4200
19	1.8000	0.4400
20	2.3000	0.7000
21	2.6000	0.9300
22	3.0000	1.3400
23	3.2000	1.5800
24	3.4000	1.7500
25	3.6000	1.8000
26	3.8000	1.7900
27	4.0000	1.7000
28	4.2000	1.5200
29	4.6000	1.0500
30	5.1000	0.5700
31	5.5000	0.5100
32	6.0000	0.5000
33	7.0000	0.4800
34	8.0000	0.4500
35	10.0000	0.2000
36	20.0000	0.0000
37	50.0000	0.0000
38	100.0000	0.0000

CO2 VIBRATIONAL EXCITATION - BULOS & PHELPS
ENERGY LOSS = 0.167 , LOWER LIMIT = 0.126 , UPPER LIMIT = 20.009
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	0.1670	0.0000
3	0.1720	0.3000
4	0.1800	0.3300
5	0.2000	0.3500
6	0.2500	0.3250
7	0.5000	0.1170
8	1.0000	0.0500
9	1.5000	0.0400
10	1.9000	0.0600
11	2.0000	0.0800
12	2.2500	0.2000
13	2.5000	0.4000
14	3.0000	1.2800
15	3.2000	1.5700
16	3.4000	1.7700
17	3.5500	1.7800
18	3.7000	1.7500
19	3.9000	1.6000
20	4.1000	1.2800
21	4.5000	0.8800
22	4.9000	0.3900
23	5.2000	0.3300
24	6.0000	0.2700
25	8.0000	0.2500
26	10.0000	0.2100
27	20.0000	0.0000
28	100.0000	0.0000

CO2 VIBRATIOAL EXCITATION - BULOS & PHELPS
ENERGY LOSS = 0.291 , LOWER LIMIT = 0.277 , UPPER LIMIT = 99.994
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	0.2910	0.0000
3	0.3000	0.9500
4	0.3100	1.7000
5	0.3200	1.8500
6	0.3300	2.0000
7	0.3500	2.1500
8	0.3800	2.2000
9	0.4000	2.1500
10	0.4500	2.0000
11	0.5000	1.8500
12	0.6000	1.5500
13	0.8000	1.2300
14	1.0000	1.0000
15	1.5000	0.7600
16	2.0000	0.6400
17	3.0000	0.4900
18	4.5000	0.4400
19	6.0000	0.4100
20	8.0000	0.4800
21	10.0000	0.2600
22	25.0000	0.1350
23	30.0000	0.1000
24	100.0000	0.0000

CO2 ENERGY LOSS = 0.339 , LOWER LIMIT = 1.386 , UPPER LIMIT = 5.065
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	0.3390	0.0000

3	1.5000	0.0000
4	1.9500	0.0700
5	2.5000	0.2000
6	3.0000	0.4100
7	3.5600	0.6600
8	4.1000	0.3400
9	4.5000	0.1550
10	5.0600	0.0000
11	6.0000	0.0000
12	150.0000	0.0000

CO2 ENERGY LOSS = 0.252 , LOWER LIMIT = 2.394 , UPPER LIMIT = 5.998
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	0.2520	0.0000
3	1.5000	0.0000
4	1.9500	0.0000
5	2.5000	0.0000
6	3.0000	0.3200
7	3.5600	0.5400
8	4.1000	0.3400
9	4.5000	0.1600
10	5.0600	0.0440
11	6.0000	0.0000
12	150.0000	0.0000

CO2 ENERGY LOSS = 0.422 , LOWER LIMIT = 2.394 , UPPER LIMIT = 4.511
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	0.4220	0.0000
3	1.5000	0.0000
4	1.9500	0.0000
5	2.5000	0.0000
6	3.0000	0.1050
7	3.5600	0.2250
8	4.1000	0.1000
9	4.5000	0.0000
10	5.0600	0.0000
11	6.0000	0.0000
12	200.0000	0.0000

CO2 ENERGY LOSS = 0.505 , LOWER LIMIT = 2.394 , UPPER LIMIT = 4.511
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	0.5050	0.0000
3	1.5000	0.0000
4	1.9500	0.0000
5	2.5000	0.0000
6	3.0000	0.1560
7	3.5600	0.3300
8	4.1000	0.1560
9	4.5000	0.0000
10	5.0600	0.0000
11	6.0000	0.0000
12	200.0000	0.0000

CO2 ENERGY LOSS = 2.500 , LOWER LIMIT = 2.394 , UPPER LIMIT = 4.511
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	2.5000	0.0000
3	3.0000	0.1800
4	3.6000	0.2500
5	4.1000	0.1800
6	4.5000	0.0000
7	100.0000	0.0000

CO2 ENERGY LOSS = 3.850 , LOWER LIMIT = 3.679 , UPPER LIMIT = 9.702
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	3.8500	0.0000
3	4.3000	0.0014
4	4.5000	0.0014
5	5.1000	0.0000
6	6.6000	0.0000
7	7.2000	0.0007
8	8.2000	0.0045
9	8.4000	0.0042
10	8.9000	0.0010
11	9.7000	0.0000
12	200.0000	0.0000

CO2 ENERGY LOSS = 7.000 , LOWER LIMIT = 6.880 , UPPER LIMIT = 11.012
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	7.0000	0.0000
3	8.0000	0.6000
4	8.5000	0.6000
5	11.0000	0.0000
6	100.0000	0.0000

CO2 ENERGY LOSS = 10.500 , LOWER LIMIT = 10.382 , UPPER LIMIT = 99.994
QSCALE = 1.000000

	ENERGY	CROSS SECTION

1	0.0000	0.0000
2	10.5000	0.0000
3	12.0000	0.6900
4	12.7000	0.7300
5	13.5000	0.7800
6	15.0000	0.8800
7	17.0000	1.0400
8	20.0000	1.2400
9	40.0000	3.6000
10	100.0000	6.3000

CO2 ENERGY LOSS = 13.300 , LOWER LIMIT = 13.180 , UPPER LIMIT = 99.994
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	13.3000	0.0000
3	14.5000	0.0600
4	15.0000	0.1040
5	16.0000	0.1880
6	18.0000	0.3590
7	20.0000	0.5320
8	30.0000	1.6300
9	40.0000	2.2800
10	50.0000	2.7900
11	70.0000	3.4300
12	100.0000	3.7900

We thank Prof. A. Dickinson for pointing out an inconsistency in the Qm table at 0.0085 eV.

For temperature depedent transport coefficients at low E/n see Haddad and Elford, J. Phys. B 12, L743 (1979); Elford and Haddad, Aust. J. Phys. 33, 317 (1980); and Hergerberg, Elford, and Crompton, ibid, 33, 985 (1980).

REVISION OF TOTAL AND PARTIAL IONIZATION CROSS SECTIONS

See Straub et al, J. Chem. Phys. 105, 4015 (1996).

M. Hayashi has assembled references and derived an electron-Ar cross section set in a report entitled "Bibliography of electron and photon cross sections with atoms and molecules published in the 20th century - carbon dioxide", National Institute for Fusion Research Research, Report NIFS-Data Series NIFS-DATA-74, Apr. 2003. The report cited is one of a series that reviews electron collisions with Ar, Xe, SF6, and N2.

Latest CO2 change 12/29/03

****

CARBON MONOXIDE

These cross sections are very similar to those developed by Land, J. Appl. Phys. 49, 5716 (1978). As of 10/95 I know of no reason to change them.

USE CAR DIPOLE (0.046 e*ao) AND QUADRUPOLE (1.38E-4 e*ao^2) FOR ROTATIONAL EXCITATION. THE QUADRUPOLE CONTRIBUTION IS SMALL.
(SEE LUFT -1975- FOR UNITS USED IN BACKPRO)

CO MOMENTUM-TRANSFER CROSS SECTION

	ENERGY	Effective Qm - Defined in introduction
1	0.0000	60.0000
2	0.0010	40.0000
3	0.0020	25.0000
4	0.0030	17.7000
5	0.0050	12.3000
6	0.0070	9.8000
7	0.0085	8.6000
8	0.0100	7.8000
9	0.0150	6.5000
10	0.0200	5.9000
11	0.0300	5.4000
12	0.0400	5.2000
13	0.0500	5.4000
14	0.0700	6.1000
15	0.1000	7.3000
16	0.1200	7.7000
17	0.1500	8.8000
18	0.1700	9.3000
19	0.2000	10.0000
20	0.2500	11.2000
21	0.3000	12.1000
22	0.3500	13.0000
23	0.4000	13.8500
24	0.5000	15.4000
25	0.7000	16.5000
26	1.0000	18.5000
27	1.2000	28.0000
28	1.3000	37.0000
29	1.5000	42.0000
30	1.7000	40.0000
31	1.9000	32.0000
32	2.1000	23.5000
33	2.2000	21.5000
34	2.5000	17.5000
35	2.8000	16.0000
36	3.0000	15.4000
37	3.3000	14.6000
38	3.6000	14.2000
39	4.0000	13.8000
40	4.5000	13.3000
41	5.0000	12.9000
42	6.0000	12.3000

43	7.0000	11.8000
44	8.0000	11.3000
45	10.0000	10.6000
46	12.0000	10.4000
47	15.0000	10.2000
48	17.0000	10.1000
49	20.0000	9.8000
50	25.0000	9.1000
51	30.0000	8.6000
52	50.0000	7.1000
53	75.0000	6.1000
54	100.0000	5.5000
55	150.0000	4.9000
56	200.0000	4.2000
57	300.0000	3.3000
58	500.0000	2.4400
59	700.0000	1.9600
60	1000.0000	1.55000

CO V=1 HAKE & PHELPS THRESHOLD*.95 TO EHRHARDT*1.9

ENERGY LOSS = 0.266 , LOWER LIMIT = 0.258 , UPPER LIMIT = 4.911 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	0.2660	0.0000
3	0.2900	0.0950
4	0.3200	0.1250
5	0.3500	0.1440
6	0.4000	0.1560
7	0.5000	0.1590
8	0.6000	0.1570
9	0.7000	0.1540
10	0.8000	0.1650
11	0.8500	0.2240
12	0.9000	0.3000
13	0.9500	0.3970
14	1.0000	0.5130
15	1.0310	0.6040
16	1.0730	0.7360
17	1.1300	0.9240
18	1.1800	1.1210
19	1.2150	1.3500
20	1.2420	1.5730
21	1.3070	2.1370
22	1.3640	2.9030
23	1.4100	3.6020
24	1.4450	4.1760
25	1.4760	4.8390
26	1.5140	5.3770
27	1.5910	5.3410
28	1.6450	5.0540
29	1.7400	5.9340
30	1.8210	6.5780
31	1.9020	5.8430
32	1.9820	5.2160
33	2.0860	5.6830
34	2.1700	4.9650
35	2.2810	4.1760
36	2.3160	4.2850
37	2.4040	3.7470
38	2.5080	3.1200
39	2.6880	2.4550
40	2.8720	1.8280
41	3.0720	1.2900
42	3.2940	0.8610
43	3.5280	0.5550
44	3.8160	0.2870
45	5.0000	0.0000
46	100.0000	0.0000

CO EHRHARDT V=2
ENERGY LOSS = 0.528 , LOWER LIMIT = 1.034 , UPPER LIMIT = 3.877 ,
QSCALE = 1.900000(QSCALE USED ONLY FOR RECONSTRUCTING INPUT DATA - SEE N2 INTRO.)

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	0.5280	0.0000
3	1.2660	0.0000
4	1.3470	0.2679
5	1.4200	0.7144
6	1.4850	1.3414
7	1.5350	1.9855
8	1.5700	2.2705
9	1.6280	2.4320
10	1.6820	2.1280
11	1.7780	1.7879
12	1.8630	2.1812
13	1.9400	2.5745
14	2.0280	2.0387
15	2.0670	1.6986
16	2.1050	1.5371
17	2.2170	1.7518
18	2.3250	1.2692
19	2.4830	1.0184
20	2.5980	0.7144
21	2.7100	0.6080
22	2.8250	0.3933
23	3.0370	0.1976
24	3.2990	0.0361
25	4.0000	0.0000
26	100.0000	0.0000

CO EHRHARDT V=3
ENERGY LOSS = 0.787 , LOWER LIMIT = 1.292 , UPPER LIMIT = 3.877 ,
QSCALE = 1.900000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	0.7870	0.0000
3	1.3820	0.0000
4	1.4730	0.2679
5	1.5190	0.5548
6	1.5690	0.8398
7	1.6150	1.2160
8	1.6530	1.4668
9	1.7180	1.6454
10	1.7600	1.4478
11	1.8020	1.2521
12	1.8590	0.8398
13	1.9050	0.7144
14	1.9770	0.9120
15	2.0460	1.2692
16	2.1150	1.0906
17	2.2020	0.5909
18	2.2860	0.5358
19	2.3400	0.6802
20	2.4050	0.5548
21	2.5110	0.2679
22	2.6260	0.3401
23	2.7290	0.1064
24	2.8890	0.1615
25	2.9730	0.0893
26	3.0460	0.0361
27	4.0000	0.0000
28	100.0000	0.0000

CO EHRHARDT V=4
ENERGY LOSS = 1.040 , LOWER LIMIT = 1.292 , UPPER LIMIT = 2.843 ,
QSCALE = 1.900000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	1.0400	0.0000
3	1.5140	0.0000
4	1.5710	0.4294
5	1.6400	0.7353
6	1.7240	1.1647
7	1.7810	1.2901
8	1.8760	1.0393
9	1.9640	0.4484
10	2.0170	0.3230
11	2.1010	0.5548
12	2.1850	0.6802
13	2.2760	0.3762
14	2.3680	0.1615
15	2.4700	0.3230
16	2.5540	0.1615
17	2.8000	0.0000
18	100.0000	0.0000

CO EHRHARDT V=6
ENERGY LOSS = 1.540 , LOWER LIMIT = 1.292 , UPPER LIMIT = 2.585 ,
QSCALE = 1.900000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	1.5400	0.0000
3	1.6850	0.1976
4	1.8680	0.5016
5	2.0100	0.6992
6	2.1470	0.3591
7	2.2960	0.0893
8	2.4530	0.2337
9	2.6000	0.0000
10	100.0000	0.0000

CO EHRHARDT V=5
ENERGY LOSS = 1.300 , LOWER LIMIT = 1.551 , UPPER LIMIT = 2.585 ,
QSCALE = 1.900000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	1.3000	0.0000
3	1.6080	0.0000
4	1.6620	0.2869
5	1.8150	0.6802
6	1.9140	0.8968
7	2.0440	0.4123
8	2.1590	0.0893
9	2.2850	0.3401
10	2.4000	0.1786
11	2.5220	0.0361
12	2.5680	0.0722
13	2.7000	0.0000
14	100.0000	0.0000

CO EHRHARDT V=7
ENERGY LOSS = 1.790 , LOWER LIMIT = 1.551 , UPPER LIMIT = 2.843 ,
QSCALE = 1.900000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	1.7900	0.0000
3	2.0060	0.3401
4	2.1360	0.5548

5	2.2580	0.4294
6	2.4230	0.1615
7	2.4840	0.1254
8	2.5790	0.1615
9	2.7500	0.0000
10	100.0000	0.0000

CO BONESS V=8
ENERGY LOSS = 2.030 , LOWER LIMIT = 1.809 , UPPER LIMIT = 3.102 ,
QSCALE = 1.900000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	2.0300	0.0000
3	2.2000	0.0684
4	2.3000	0.1330
5	2.4000	0.0665
6	2.5000	0.0114
7	2.6000	0.0152
8	2.7000	0.0095
9	2.8000	0.0038
10	2.9000	0.0057
11	3.0000	0.0000
12	100.0000	0.0000

CO BONESS V=9
ENERGY LOSS = 2.270 , LOWER LIMIT = 2.068 , UPPER LIMIT = 2.843 ,
QSCALE = 1.900000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	2.2700	0.0000
3	2.3000	0.0068
4	2.4000	0.0665
5	2.5000	0.0513
6	2.6000	0.0082
7	2.7000	0.0068
8	2.8000	0.0095
9	2.9000	0.0000
10	3.0000	0.0000
11	5.0000	0.0000
12	100.0000	0.0000

CO BONESS V=10
ENERGY LOSS = 2.510 , LOWER LIMIT = 2.326 , UPPER LIMIT = 3.102 ,
QSCALE = 1.900000

	ENERGY	CROSS SECTION	SECTION
1	0.0000	0.0000	
2	2.5100	0.0000	
3	2.5200	0.0114	
4	2.6000	0.0399	
5	2.7000	0.0133	
6	2.8000	0.0057	
7	2.9000	0.0076	
8	3.0000	0.0000	
9	5.0000	0.0000	
10	100.0000	0.0000	

CO SAWADA A3PI
ENERGY LOSS = 6.220 , LOWER LIMIT = 6.204 , UPPER LIMIT = 200.070 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	6.2200	0.0000
3	7.1000	0.1000
4	7.4000	0.3000
5	8.0000	0.6400
6	8.5000	0.7800
7	9.0000	0.9700
8	10.0000	1.0800
9	11.0000	1.1000
10	12.0000	1.0300
11	15.0000	0.7000
12	20.0000	0.4100
13	24.0000	0.3000
14	30.0000	0.2400
15	40.0000	0.2050
16	60.0000	0.1750
17	80.0000	0.1500
18	100.0000	0.1300

CO ENERGY LOSS = 6.800 , LOWER LIMIT = 6.721 , UPPER LIMIT = 100.035 ,
LIN A PRIME 3 SIGMA
QSCALE = 0.350000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	6.8000	0.0000
3	6.9000	0.0035
4	7.4000	0.0350
5	8.7590	0.3115
6	9.6910	0.4585
7	10.5400	0.5215
8	11.1600	0.5390
9	12.1900	0.5180
10	15.4400	0.4270
11	24.2900	0.2030
12	40.0600	0.0560
13	61.0400	0.0175
14	100.0000	0.0000

CO SAWADA A1PI

ENERGY LOSS = 7.900 , LOWER LIMIT = 8.272 , UPPER LIMIT = 200.070 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION	SECTION
1	0.0000	0.0000	
2	7.9000	0.0000	
3	9.0000	0.1100	
4	10.0000	0.2000	
5	12.5000	0.3000	
6	15.0000	0.3700	
7	20.0000	0.4250	
8	27.0000	0.4400	
9	40.0000	0.4250	
10	60.0000	0.3800	
11	80.0000	0.3500	
12	100.0000	0.3250	

CO SAWADA B3SIG
ENERGY LOSS = 10.400 , LOWER LIMIT = 10.340 , UPPER LIMIT = 100.035 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	10.4000	0.0000
3	12.0000	0.0350
4	14.0000	0.0700
5	16.0000	0.0820
6	18.0000	0.0620
7	21.0000	0.0450
8	25.0000	0.0250
9	35.0000	0.0145
10	50.0000	0.0130
11	70.0000	0.0120
12	100.0000	0.0110

CO SAWADA C1SIG + E1PI
ENERGY LOSS = 10.600 , LOWER LIMIT = 10.598 , UPPER LIMIT = 100.035 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	10.6000	0.0000
3	12.0000	0.0560
4	15.0000	0.1430
5	20.0000	0.2270
6	25.0000	0.2700
7	50.0000	0.2700
8	100.0000	0.2300

CO SAWADA 13.5 LOSS
ENERGY LOSS = 13.500 , LOWER LIMIT = 13.441 , UPPER LIMIT = 100.035 ,
QSCALE = 1.500000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	13.5000	0.0000
3	14.5000	0.1350
4	17.0000	0.3000
5	20.0000	0.4050
6	30.0000	0.5400
7	40.0000	0.5625
8	60.0000	0.5400
9	80.0000	0.5250
10	100.0000	0.4875

CO ENERGY LOSS = 14.010 , LOWER LIMIT = 13.958 , UPPER LIMIT = 100.035 ,
CO RAPP IONIZATION
EBR= 14.200000, QSCALE= 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	14.0100	0.0000
3	14.5000	0.0273
4	16.0000	0.1060
5	17.0000	0.1770
6	18.0000	0.2540
7	19.0000	0.3400
8	20.0000	0.4280
9	22.0000	0.6000
10	24.0000	0.7700
11	28.0000	1.0900
12	32.0000	1.3800
13	40.0000	1.7900
14	50.0000	2.1200
15	70.0000	2.5000
16	100.0000	2.6500

REVISION OF TOTAL AND PARTIAL IONIZATION CROSS SECTIONS

Mangan et al, J. Phys. B 33, 3225 (2000).

RECENT DEVELOPMENTS:

Stephen Biagi at sfb@hep.ph.liv.ac.uk has derived a set of electron-CO cross sections that differ somewhat from the above set.
Communicated December 2003

Latest CO change 012/18/03

****

HYDROGEN

These cross sections are those used by Buckman and Phelps,

J. Chem. Phys. 82, 4999 (1985). The values tabulated in JILA Information Center Report No. 27 are derived from the same computer files and should be the same as those given here. This has not been checked. Although these cross sections give good agreement with experimental transport, dissociation, vuv excitation, and ionization coeffieient data, it is now known that the division of cross sections among the triplet levels needs to be improved. This problem does not introduce significant errors in the overall energy balance or the sums of excitation rates for the H2 singlet and triplet levels.

H2 MOMENTUM-TRANSFER CROSS SECTION

	ENERGY	Effective Qm - Defined in introduction
1	0.0000	6.4000
2	0.0010	6.4000
3	0.0020	6.5000
4	0.0030	6.6000
5	0.0050	6.8000
6	0.0070	7.1000
7	0.0085	7.2000
8	0.0100	7.3000
9	0.0150	7.7000
10	0.0200	8.0000
11	0.0300	8.5000
12	0.0400	8.9600
13	0.0500	9.2800
14	0.0700	9.8500
15	0.1000	10.5000
16	0.1200	10.8500
17	0.1500	11.4000
18	0.1700	11.6000
19	0.2000	12.0000
20	0.2500	12.5000
21	0.3000	13.0000
22	0.3500	13.4500
23	0.4000	13.9000
24	0.5000	14.7000
25	0.7000	16.3000
26	1.0000	17.4000
27	1.2000	17.8000
28	1.3000	18.0000
29	1.5000	18.2500
30	1.7000	18.2500
31	1.9000	18.1000
32	2.1000	17.9000
33	2.2000	17.7000
34	2.5000	17.0000
35	2.8000	16.4000
36	3.0000	16.0000
37	3.3000	15.6000
38	3.6000	14.8000
39	4.0000	14.0000
40	4.5000	13.1000
41	5.0000	12.2000
42	6.0000	10.4000
43	7.0000	8.9000
44	8.0000	7.8500
45	10.0000	6.0000
46	12.0000	5.2000
47	15.0000	4.5000
48	17.0000	4.2000
49	20.0000	3.9000
50	25.0000	3.6000
51	30.0000	3.4000
52	50.0000	2.9000
53	75.0000	2.6000
54	100.0000	2.3000
55	150.0000	1.9000
56	200.0000	1.6200
57	300.0000	1.2800
58	500.0000	0.9200
59	700.0000	0.7200
60	1000.0000	0.5400
61	1500.0000	0.3700
62	2000.0000	0.2900
63	3000.0000	0.2100
64	5000.0000	0.1400
65	7000.0000	0.1040
66	10000.0000	0.0770

H2 J=0-J=2 CROMPTON ET AL (1969),HENRY-LANE (1969)
ENERGY LOSS = 0.044 , LOWER LIMIT = 0.026 , UPPER LIMIT =10000.003 ,
QSCALE = 0.250000(QSCALE USED ONLY FOR RECONSTRUCTING INPUT DATA - SEE N2 INTRO.)

06/24/08 St. Kolev and L.C. Pitchford have pointed out that the following rotational excitation cross sections should be divided by the scale factors listed, i.e., for J = 0 to 2 divide by 0.25, in order to agree with Fig. 13 of Buckmann and Phelps (1985) and references therein.

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	0.0440	0.0000
3	0.0470	0.0046
4	0.0500	0.0067
5	0.0550	0.0088
6	0.0600	0.0105
7	0.0700	0.0132
8	0.0900	0.0170
9	0.1100	0.0198
10	0.2000	0.0300
11	0.4000	0.0525
12	0.6000	0.0762
13	0.8000	0.1125
14	1.0000	0.1500
15	2.0000	0.3275
16	3.0000	0.4500

17	4.0000	0.4500
18	6.0000	0.3800
19	10.0000	0.2900
20	20.0000	0.1650
21	30.0000	0.1250
22	50.0000	0.0850
23	70.0000	0.0660
24	100.0000	0.0500
25	125.0000	0.0425
26	150.0000	0.0365
27	500.0000	0.0130
28	1000.0000	0.0070
29	3000.0000	0.0025
30	10000.0000	0.0010

H2 J=1-J=3 GIBSON (1970), HEAPS AND GREEN (1975),CALD.(1976)
ENERGY LOSSS = 0.073 , LOWER LIMIT = 0.052 , UPPER LIMIT = 1000.008 ,
QSCALE = 0.750000

06/24/08 St. Kolev and L.C. Pitchford have pointed out that the following rotational excitation cross sections should be divided by the scale factors listed, i.e., for J = 1 to 3 divide by 0.75, in order to agree with Fig. 13 of Buckmann and Phelps (1985) and references therein.

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	0.0730	0.0000
3	0.0750	0.0075
4	0.0800	0.0128
5	0.0850	0.0161
6	0.0900	0.0188
7	0.1000	0.0221
8	0.1200	0.0285
9	0.1500	0.0353
10	0.2000	0.0450
11	0.3000	0.0660
12	0.4000	0.0885
13	0.5000	0.1125
14	0.7000	0.1650
15	1.0000	0.2625
16	1.4000	0.3750
17	2.0000	0.5625
18	2.7000	0.7500
19	3.3000	0.8250
20	5.0000	0.7500
21	7.0000	0.6525
22	10.0000	0.5250
23	20.0000	0.3000
24	30.0000	0.2250
25	50.0000	0.1530
26	100.0000	0.0870
27	125.0000	0.0743
28	150.0000	0.0630
29	500.0000	0.0232
30	1000.0000	0.0135
31	1500.0000	0.0000
32	2000.0000	0.0000
33	3000.0000	0.0000
34	5000.0000	0.0000
35	7000.0000	0.0000
36	10000.0000	0.0000

H2 V=1 EHRHARDT ET AL 1968 EXCPT CROMPTON THRESHOLD
ENERGY LOSS = 0.516 , LOWER LIMIT = 0.490 , UPPER LIMIT = 1000.008 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	0.5160	0.0000
3	0.7000	0.0200
4	1.0000	0.0600
5	1.5000	0.2000
6	2.0000	0.4000
7	2.5000	0.4900
8	3.0000	0.5100
9	3.3000	0.5000
10	4.0000	0.4400
11	5.0000	0.3600
12	7.0000	0.2200
13	8.0000	0.1600
14	10.0000	0.0900
15	12.0000	0.0600
16	16.0000	0.0200
17	50.0000	0.0090
18	100.0000	0.0080
19	150.0000	0.0080
20	200.0000	0.0080
21	300.0000	0.0070
22	500.0000	0.0070
23	700.0000	0.0070
24	1000.0000	0.0060
25	1500.0000	0.0000
26	2000.0000	0.0000
27	3000.0000	0.0000
28	5000.0000	0.0000
29	7000.0000	0.0000
30	10000.0000	0.0000

H2 V=2 EHRHARDT ET AL 1968
ENERGY LOSS = 1.000 , LOWER LIMIT = 0.877 , UPPER LIMIT = 15.996 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	1.0000	0.0000
3	1.3000	0.0000
4	1.5000	0.0030

5	1.8000	0.0080
6	2.1500	0.0180
7	2.3000	0.0240
8	2.5000	0.0290
9	3.0000	0.0360
10	3.6000	0.0380
11	4.0000	0.0380
12	6.0000	0.0300
13	9.0000	0.0170
14	12.0000	0.0080
15	16.0000	0.0000
16	20.0000	0.0000
17	50.0000	0.0000
18	10000.0000	0.0000

H2 V=3 EHRHARDT ET AL 1968
ENERGY LOSS = 1.500 , LOWER LIMIT = 1.471 , UPPER LIMIT = 15.996 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	1.5000	0.0000
3	1.8000	0.0003
4	1.9000	0.0010
5	2.0000	0.0013
6	2.2000	0.0020
7	2.5000	0.0029
8	3.0000	0.0037
9	3.3000	0.0041
10	3.7000	0.0041
11	5.0000	0.0034
12	7.0000	0.0023
13	10.0000	0.0012
14	12.0000	0.0006
15	14.0000	0.0001
16	16.0000	0.0000
17	50.0000	0.0000
18	10000.0000	0.0000

H2 (B3SIG) EXCITATION - 84/07/06
ENERGY LOSS = 8.900 , LOWER LIMIT = 8.488 , UPPER LIMIT = 100.001 ,
QSCALE = 1.150000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	8.9000	0.0000
3	10.0000	0.1150
4	12.0000	0.2990
5	17.0000	0.3335
6	20.0000	0.2875
7	25.0000	0.2070
8	30.0000	0.1380
9	40.0000	0.0575
10	50.0000	0.0287
11	60.0000	0.0138
12	80.0000	0.0034
13	100.0000	0.0000
14	10000.0000	0.0000

H2 (B1SIG) EXCITATION - 84/07/06
ENERGY LOSS = 11.300 , LOWER LIMIT = 11.197 , UPPER LIMIT =10000.003 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	11.3000	0.0000
3	11.7000	0.1000
4	12.5000	0.0900
5	16.0000	0.2000
6	20.0000	0.3000
7	25.0000	0.4100
8	30.0000	0.4500
9	40.0000	0.4800
10	50.0000	0.4700
11	70.0000	0.4200
12	100.0000	0.3800
13	150.0000	0.3200
14	200.0000	0.2800
15	300.0000	0.2300
16	500.0000	0.1700
17	700.0000	0.1350
18	1000.0000	0.1000
19	1500.0000	0.0750
20	2000.0000	0.0600
21	3000.0000	0.0440
22	5000.0000	0.0290
23	7000.0000	0.0210
24	10000.0000	0.0160

H2 (C3PI) EXCITATION - 84/07/06
ENERGY LOSS = 11.750 , LOWER LIMIT = 11.584 , UPPER LIMIT = 150.001 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	11.7500	0.0000
3	11.8800	0.0800
4	12.2500	0.1400
5	12.9000	0.1200
6	13.5000	0.1400
7	15.5000	0.2000
8	20.0000	0.1200
9	25.0000	0.0720
10	30.0000	0.0430
11	35.0000	0.0300
12	40.0000	0.0200
13	50.0000	0.0104

14	60.0000	0.0070
15	70.0000	0.0040
16	100.0000	0.0014
17	150.0000	0.0000
18	10000.0000	0.0000

H2 (A3SIG) EXCITATION - 84/05/25
ENERGY LOSS = 11.800 , LOWER LIMIT = 11.687 , UPPER LIMIT = 69.995 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	11.8000	0.0000
3	13.0000	0.1100
4	14.0000	0.1200
5	15.0000	0.1220
6	16.0000	0.1210
7	17.0000	0.1160
8	20.0000	0.0850
9	25.0000	0.0550
10	30.0000	0.0350
11	50.0000	0.0080
12	70.0000	0.0000
13	100.0000	0.0000
14	10000.0000	0.0000

H2 (C1PI) EXCITATION - 84/05/25
ENERGY LOSS = 12.400 , LOWER LIMIT = 12.178 , UPPER LIMIT =10000.003 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION	SECTION
1	0.0000	0.0000	
2	12.4000	0.0000	
3	13.0000	0.0300	
4	14.0000	0.1000	
5	16.0000	0.1800	
6	18.0000	0.2300	
7	22.0000	0.3200	
8	30.0000	0.3900	
9	40.0000	0.4000	
10	60.0000	0.4000	
11	80.0000	0.3800	
12	100.0000	0.3600	
13	150.0000	0.3000	
14	200.0000	0.2600	
15	300.0000	0.2100	
16	500.0000	0.1600	
17	700.0000	0.1200	
18	1000.0000	0.0900	
19	1500.0000	0.0660	
20	2000.0000	0.0530	
21	3000.0000	0.0380	
22	5000.0000	0.0250	
23	7000.0000	0.0190	
24	10000.0000	0.0140	

H2 G1SIG V = 2 EXCITATION (DAY, ANDERSON AND SHARPTON, 79)
ENERGY LOSS = 13.860 , LOWER LIMIT = 13.493 , UPPER LIMIT =10000.003 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	13.8600	0.0000
3	14.0000	0.0000
4	15.0000	0.0000
5	16.0000	0.0000
6	18.0000	0.0000
7	20.0000	0.0000
8	25.0000	0.0000
9	28.0000	0.0001
10	30.0000	0.0001
11	35.0000	0.0001
12	50.0000	0.0001
13	70.0000	0.0000
14	100.0000	0.0000
15	200.0000	0.0000
16	500.0000	0.0000
17	700.0000	0.0000
18	1000.0000	0.0000
19	1500.0000	0.0000
20	2000.0000	0.0000
21	3000.0000	0.0000
22	5000.0000	0.0000
23	7000.0000	0.0000
24	10000.0000	0.0000

H2 (D3PI) EXCITATION - 84/05/25
ENERGY LOSS = 14.000 , LOWER LIMIT = 13.880 , UPPER LIMIT = 150.001 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION	SECTION
1	0.0000	0.0000	
2	14.0000	0.0000	
3	15.6000	0.0410	
4	20.0000	0.0310	
5	25.0000	0.0200	
6	30.0000	0.0120	
7	40.0000	0.0053	
8	50.0000	0.0028	
9	70.0000	0.0010	
10	100.0000	0.0004	
11	150.0000	0.0000	
12	10000.0000	0.0000	

H2 DISSOCIATIVE EXCITATION TO N = 2 (LYMAN ALPHA)
ENERGY LOSS = 15.000 , LOWER LIMIT = 14.783 , UPPER LIMIT =10000.003 ,

QSCALE = 1.000000

	ENERGY	CROSS SECTION	SECTION
1	0.0000	0.0000	
2	15.0000	0.0000	
3	17.0000	0.0000	
4	20.0000	0.0500	
5	25.0000	0.0700	
6	30.0000	0.0950	
7	35.0000	0.1050	
8	40.0000	0.1150	
9	50.0000	0.1250	
10	60.0000	0.1300	
11	70.0000	0.1300	
12	100.0000	0.1250	
13	150.0000	0.1100	
14	200.0000	0.0900	
15	300.0000	0.0700	
16	500.0000	0.0500	
17	700.0000	0.0400	
18	1000.0000	0.0360	
19	1500.0000	0.0190	
20	2000.0000	0.0154	
21	3000.0000	0.1130	
22	5000.0000	0.0073	
23	7000.0000	0.0056	
24	10000.0000	0.0042	

H2 (RYDBERG SUM) EXCITATION - from Garvey et al, J. Appl. Phys. 48, 4353 (1977)
ENERGY LOSS = 15.200 , LOWER LIMIT = 15.093 , UPPER LIMIT =10000.003 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	15.2000	0.0000
3	16.0000	0.0000
4	17.0000	0.0130
5	18.0000	0.0300
6	20.0000	0.0630
7	22.0000	0.0950
8	30.0000	0.1900
9	40.0000	0.2200
10	60.0000	0.2400
11	80.0000	0.2300
12	100.0000	0.2100
13	150.0000	0.1750
14	200.0000	0.1500
15	300.0000	0.1200
16	500.0000	0.0850
17	700.0000	0.0670
18	1000.0000	0.0520
19	1500.0000	0.0385
20	2000.0000	0.0310
21	3000.0000	0.0226
22	5000.0000	0.0150
23	7000.0000	0.0114
24	10000.0000	0.0085

H2 ENERGY LOSS = 15.400 , LOWER LIMIT = 15.299 , UPPER LIMIT =10000.003 ,
H2 IONIZATION, RAPP AND ENGLANDER-GOLDEN (1965)
EBR= 8.300000, QSCALE= 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	15.4000	0.0000
3	19.5000	0.2490
4	21.0000	0.3360
5	23.0000	0.4390
6	25.0000	0.5240
7	28.0000	0.6310
8	32.0000	0.7300
9	40.0000	0.8650
10	50.0000	0.9400
11	70.0000	0.9670
12	100.0000	0.9320
13	150.0000	0.8000
14	200.0000	0.7120
15	300.0000	0.5710
16	500.0000	0.4040
17	700.0000	0.3160
18	1000.0000	0.2370
19	1500.0000	0.1720
20	2000.0000	0.1340
21	3000.0000	0.0970
22	5000.0000	0.0610
23	7000.0000	0.0460
24	10000.0000	0.0340

H2 DISSOCIATIVE EXCITATION TO N = 3 (BALMER ALPHA)
ENERGY LOSS = 16.600 , LOWER LIMIT = 16.383 , UPPER LIMIT =10000.003 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	16.6000	0.0000
3	18.0000	0.0045
4	19.0000	0.0056
5	20.0000	0.0058
6	25.0000	0.0060
7	30.0000	0.0068
8	40.0000	0.0080
9	50.0000	0.0092
10	60.0000	0.0094
11	80.0000	0.0094
12	100.0000	0.0087
13	150.0000	0.0072

14	200.0000	0.0060
15	300.0000	0.0043
16	500.0000	0.0028
17	700.0000	0.0021
18	1000.0000	0.0015
19	1500.0000	0.0011
20	2000.0000	0.0008
21	3000.0000	0.0006
22	5000.0000	0.0004
23	7000.0000	0.0003
24	10000.0000	0.0002

REVISION OF PARTIAL IONIZATION CROSS SECTIONS

See Straub et al, Phys. Rev. A 54, 2146 (1996) and
Stebbings and Lindsay, J. Chem. Phys. 114, 4741 (2001).

M. Hayashi has assembled references and derived an electron-H2 cross section set in a report entitled "Bibliography of electron and photon cross sections with atoms and molecules published in the 20th century - Hydrogen Molecules", National Institute for Fusion Research Research, Report NIFS-Data Series NIFS-DATA-82, Feb. 2004. The report does not contain a set of recommended cross sections, but has some relevant comments at the end. The report cited is one of a series that gives bibliographies of papers on electron collisions with various gases.

Latest H2 change 04/30/04

****

H2O NOV 1983

Badly in need of updata. However, when this set is used for moist air it gives good agreement with experiment (Davies unpublished). The only adjustable parameter was the probability of collisional stabilization of excited O2- by H2O in three-body attachment (Phelps unpublished).

H2O MOMENTUM-TRANSFER CROSS SECTION

	ENERGY	Effective Qm - defined in introduction
1	0.0000	50000.0000
2	0.0010	33000.0000
3	0.0020	16500.0000
4	0.0030	11000.0000
5	0.0050	6600.0000
6	0.0070	4710.0000
7	0.0085	3880.0000
8	0.0100	3300.0000
9	0.0150	2170.0000
10	0.0200	1610.0000
11	0.0300	1060.0000
12	0.0400	830.0000
13	0.0500	650.0000
14	0.0700	456.0000
15	0.1000	318.0000
16	0.1200	265.0000
17	0.1500	210.0000
18	0.1700	184.0000
19	0.2000	153.0000
20	0.2500	124.0000
21	0.3000	102.0000
22	0.3500	89.0000
23	0.4000	78.0000
24	0.5000	63.5000
25	0.7000	46.3000
26	1.0000	33.1000
27	1.2000	28.0000
28	1.3000	26.0000
29	1.5000	22.9000
30	1.7000	20.0000
31	1.9000	18.2000
32	2.1000	16.6000
33	2.2000	16.0000
34	2.5000	14.4000
35	2.8000	13.2000
36	3.0000	12.4000
37	3.3000	11.6000
38	3.6000	10.8000
39	4.0000	10.0000
40	4.5000	9.3000
41	5.0000	8.6000
42	6.0000	7.5500
43	7.0000	7.0500
44	8.0000	6.7000
45	10.0000	6.6000
46	12.0000	6.6500
47	15.0000	7.4000
48	17.0000	7.9000
49	20.0000	8.4000
50	25.0000	8.6000
51	30.0000	8.3000
52	50.0000	5.0000
53	75.0000	4.1000
54	100.0000	3.5000
55	150.0000	2.5000
56	200.0000	2.0000

H2O VIB EXCITATION DATA FROM LINDER
ENERGY LOSS =   0.198 ,   LOWER LIMIT =   0.178 ,   UPPER LIMIT = 200.000 ,
QSCALE =   1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	0.1980	0.0000
3	0.3500	1.8470
4	0.6000	0.8330
5	0.8000	0.4030

6	1.0000	0.3780
7	2.0000	0.2000
8	3.0000	0.1580
9	4.0000	0.1490
10	5.0000	0.1530
11	6.0000	0.1600
12	7.0000	0.1620
13	8.0000	0.1620
14	9.0000	0.1560
15	10.0000	0.1490
16	100.0000	0.0000
17	150.0000	0.0000
18	200.0000	0.0000

H2O VIBRATIONAL EXCITATION   DATA FROM LINDER
ENERGY LOSS =   0.469 ,   LOWER LIMIT =   0.432 ,   UPPER LIMIT = 100.000 ,
QSCALE =   1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	0.4690	0.0000
3	0.6000	3.7700
4	0.8000	0.8000
5	1.0000	0.5090
6	2.0000	0.2960
7	3.0000	0.3070
8	4.0000	0.3730
9	5.0000	0.4380
10	6.0000	0.4880
11	7.0000	0.5110
12	8.0000	0.5020
13	9.0000	0.4510
14	10.0000	0.3530
15	100.0000	0.0000
16	150.0000	0.0000

H2O ENERGY LOSS =   1.100 ,   LOWER LIMIT =   4.877 ,   UPPER LIMIT =   6.604 ,
QSCALE =   1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	5.0000	0.0000
3	5.5000	1.5000
4	6.0000	1.5000
5	6.5000	0.0000
6	200.0000	0.0000

H2O DISSOCIATIVE ATTACHMENT
ENERGY LOSS =   5.600 ,   LOWER LIMIT =   5.486 ,   UPPER LIMIT = 100.000 ,
QSCALE =   1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	5.6000	0.0000
3	6.0000	0.0212
4	6.2000	0.0378
5	6.3500	0.0500
6	6.6000	0.0486
7	6.8000	0.0378
8	7.0000	0.0272
9	7.2000	0.0189
10	7.4000	0.0114
11	7.6000	0.0083
12	7.7500	0.0070
13	8.2000	0.0098
14	8.4000	0.0121
15	8.6000	0.0136
16	8.8000	0.0136
17	9.0000	0.0126
18	9.6000	0.0071
19	10.0000	0.0052
20	10.2000	0.0044
21	10.8000	0.0044
22	11.4000	0.0053
23	11.7000	0.0067
24	12.0000	0.0064
25	13.0000	0.0037
26	17.0000	0.0000
27	100.0000	0.0000
28	200.0000	0.0000

H2O ENERGY LOSS =   6.300 ,   LOWER LIMIT =   6.198 ,   UPPER LIMIT =   11.100 ,
QSCALE =   1.000000

	ENERGY	CROSS SECTION	SECTION
1	0.0000	0.0000	
2	6.3000	0.0000	
3	8.0000	0.1000	
4	9.0000	0.1000	
5	11.0000	0.0000	
6	200.0000	0.0000	

H2O ENERGY LOSS =   9.000 ,   LOWER LIMIT =   8.890 ,   UPPER LIMIT =   19.990 ,
QSCALE =   1.000000

	ENERGY	CROSS SECTION	SECTION
1	0.0000	0.0000	
2	9.0000	0.0000	
3	11.0000	0.1200	
4	13.0000	0.1200	
5	20.0000	0.0000	
6	200.0000	0.0000	

H2O ENERGY LOSS =   12.000 ,   LOWER LIMIT =   11.887 ,   UPPER LIMIT =   24.994 ,
QSCALE =   1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	12.0000	0.0000
3	13.0000	0.7000
4	16.0000	0.7000
5	25.0000	0.0000
6	200.0000	0.0000

H2O ENERGY LOSS = 12.500 , LOWER LIMIT = 12.395 , UPPER LIMIT = 100.000 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION	SECTION
1	0.0000	0.0000	
2	12.6000	0.0000	
3	16.0000	1.0000	
4	50.0000	0.0000	
5	100.0000	0.0000	
6	200.0000	0.0000	

H2O IONIZATION FROM SHUTTEN ET AL
ENERGY LOSS = 12.600 , LOWER LIMIT = 12.497 , UPPER LIMIT = 100.000 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	12.6000	0.0000
3	14.5000	0.0730
4	18.0000	0.2830
5	20.0000	0.4600
6	30.0000	0.9700
7	50.0000	1.5700
8	100.0000	2.1000
9	150.0000	1.9000
10	200.0000	1.7500

REVISION OF PARTIAL IONIZATION CROSS SECTIONS

See Straub et al, Phys. Rev. A 54, 2146 (1996) and
Stebbings and Lindsay, J. Chem. Phys. 114, 4741 (2001).

RECENT DEVELOPMENTS:

Stephen Biagi at sfb@hep.ph.liv.ac.uk has derived a set of
electron-H2O cross sections.
Communicated December 2003

M. Hayashi has assembled references and plots an electron-Ar cross
section set in a report entitled "Bibliography of electron and photon
cross sections with atoms and molecules published in the 20th century
- water vapour -", National Institute for Fusion Research, Report
NIFS-Data Series NIFS-DATA-81, Dec. 2003. The report cited is one of
a series that reviews electron collisions with Ar, Xe, SF6, N2, etc.

Latest H2O change 03/11/04

****

CROSS SECTIONS FOR NO FROM COHEN and PHELPS (unpublished) - 1969

Badly in need of revision, but fit swarm experiments reasonably well.

NO MOMENTUM-TRANSFER CROSS SECTION

	ENERGY	Effective Qm - Defined in introduction
1	0.0000	149.0000
2	0.0010	136.0000
3	0.0020	82.0000
4	0.0030	56.5000
5	0.0050	35.0000
6	0.0070	25.7000
7	0.0085	21.3000
8	0.0100	18.2000
9	0.0150	12.6000
10	0.0200	9.6000
11	0.0300	6.6000
12	0.0400	5.0000
13	0.0500	4.3000
14	0.0700	3.5500
15	0.1000	3.2000
16	0.1200	3.4000
17	0.1500	4.0000
18	0.1700	4.4000
19	0.2000	5.3000
20	0.2500	8.1000
21	0.3000	12.9000
22	0.3500	16.7000
23	0.4000	22.5000
24	0.5000	28.5000
25	0.7000	27.0000
26	1.0000	21.3000
27	1.2000	19.0000
28	1.3000	18.0000
29	1.5000	16.9000
30	1.7000	15.2000
31	1.9000	14.1000
32	2.1000	13.1000
33	2.2000	12.7000
34	2.5000	11.5000
35	2.8000	10.4000
36	3.0000	10.0000
37	3.3000	9.2000
38	3.6000	8.6000
39	4.0000	8.1000
40	4.5000	8.0000
41	5.0000	8.1000

42	6.0000	9.0000
43	7.0000	9.9000
44	8.0000	10.4000
45	10.0000	11.7000
46	12.0000	12.9000
47	15.0000	14.3000
48	17.0000	14.9000
49	20.0000	14.9000
50	25.0000	14.3000
51	30.0000	13.9000
52	50.0000	12.3000
53	75.0000	10.8000
54	100.0000	10.0000

NO VIBRATIONAL EXCITATION
ENERGY LOSS = 0.230 , LOWER LIMIT = 0.284 , UPPER LIMIT = 100.001 ,
QSCALE = 0.200000(QSCALE USED ONLY FOR RECONSTRUCTING INPUT DATA - SEE N2 INTRO.)

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	0.3000	0.0000
3	0.3500	0.7000
4	0.4000	0.0000
5	100.0000	0.0000

NO VIBRATIONAL EXCITATION
ENERGY LOSS = 0.460 , LOWER LIMIT = 0.413 , UPPER LIMIT = 100.001 ,
QSCALE = 1.500000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	0.4500	0.0000
3	0.5000	14.2500
4	0.5500	0.0000
5	0.6000	0.0000
6	0.6500	10.5000
7	0.7000	0.0000
8	100.0000	0.0000

NO VIBRATIONAL EXCITATION
ENERGY LOSS = 0.690 , LOWER LIMIT = 0.697 , UPPER LIMIT = 100.001 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	0.7500	0.0000
3	0.8000	6.0000
4	0.8500	0.0000
5	100.0000	0.0000

NO VIBRATIONAL EXCITATION
ENERGY LOSS = 0.910 , LOWER LIMIT = 0.826 , UPPER LIMIT = 100.001 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	0.9000	0.0000
3	0.9500	4.0000
4	1.0000	0.0000
5	1.0500	0.0000
6	1.1000	2.5000
7	1.1500	0.0000
8	100.0000	0.0000

NO VIBRATIONAL EXCITATION
ENERGY LOSS = 1.200 , LOWER LIMIT = 1.084 , UPPER LIMIT = 100.001 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	1.2000	0.0000
3	1.2500	1.0000
4	1.3000	0.0000
5	100.0000	0.0000

NO VIBRATIONAL EXCITATION
ENERGY LOSS = 1.350 , LOWER LIMIT = 1.290 , UPPER LIMIT = 100.001 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	1.3500	0.0000
3	1.4000	0.5000
4	1.4500	0.0000
5	100.0000	0.0000

NO ENERGY LOSS = 5.500 , LOWER LIMIT = 5.392 , UPPER LIMIT = 100.001 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	5.5000	0.0000
3	5.7000	3.0000
4	6.0000	3.0000
5	13.0000	0.0000
6	100.0000	0.0000

NO ENERGY LOSS = 6.600 , LOWER LIMIT = 6.476 , UPPER LIMIT = 100.001 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	6.6000	0.0000
3	7.0000	0.0008
4	7.7000	0.0103
5	8.1000	0.0111

6	8.4000	0.0110
7	8.6000	0.0110
8	9.0000	0.0103
9	10.0000	0.0038
10	10.5000	0.0014
11	11.0000	0.0006
12	100.0000	0.0000

NO ENERGY LOSS = 9.500 , LOWER LIMIT = 9.391 , UPPER LIMIT = 100.001 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	9.5000	0.0000
3	22.0000	0.9560
4	30.0000	1.5200
5	38.0000	1.9800
6	45.0000	2.3000
7	50.0000	2.4700
8	60.0000	2.7300
9	70.0000	2.9000
10	80.0000	3.0300
11	90.0000	3.1000
12	100.0000	3.1300

For a recent analysis of beam and swarm data for electrons in NO see L. Josic, T. Wroblewski, Z. Lj. Petrovic, J. Mechlinska-Drewko, and G.P. Karwasz, Chem. Phys. Lett. (in press) (2001). added 11/28/01

REVISION OF TOTAL AND PARTIAL IONIZATION CROSS SECTIONS

See Lindsay et al, J. Chem. Phys. 112, 9404 (2000) and
Stebbings and Lindsay, J. Chem. Phys. 114, 4741 (2001).

Latest NO change 01/10/02

****

SF6

See Phelps and Van Brunt, J. Appl. Phys. 64, 4269 (1988)

SF6 MOMENTUM-TRANSFER CROSS SECTION

	ENERGY	Effective Qm - Defined in introduction
1	0.0000	2700.0000
2	0.0010	2600.0000
3	0.0020	1900.0000
4	0.0030	1559.0000
5	0.0050	1200.0000
6	0.0070	1000.0000
7	0.0085	890.0000
8	0.0100	800.0000
9	0.0150	660.0000
10	0.0200	560.0000
11	0.0300	430.0000
12	0.0400	340.0000
13	0.0500	270.0000
14	0.0700	175.0000
15	0.1000	90.0000
16	0.1200	62.0000
17	0.1500	35.0000
18	0.1700	27.0000
19	0.2000	19.0000
20	0.2500	12.5000
21	0.3000	9.7000
22	0.3500	8.0000
23	0.4000	7.3000
24	0.5000	7.0000
25	0.7000	7.1000
26	1.0000	7.7000
27	1.2000	8.0000
28	1.3000	8.2000
29	1.5000	8.8000
30	1.7000	9.2000
31	1.9000	9.7000
32	2.1000	10.0000
33	2.2000	10.1000
34	2.5000	10.8000
35	2.8000	11.5000
36	3.0000	11.6000
37	3.3000	12.0000
38	3.6000	12.1000
39	4.0000	12.5000
40	4.5000	13.1000
41	5.0000	13.5000
42	6.0000	14.0000
43	7.0000	14.5000
44	8.0000	15.0000
45	10.0000	16.0000
46	12.0000	16.2000
47	15.0000	16.5000
48	17.0000	16.5000
49	20.0000	16.5000
50	25.0000	16.0000
51	30.0000	15.0000
52	50.0000	14.0000
53	70.0000	12.7000
54	100.0000	10.8000
55	150.0000	9.0000
56	200.0000	7.9000
57	300.0000	6.6000
58	500.0000	5.0000
59	700.0000	4.2000
60	1000.0000	3.5000

ATTACHMENT TO FORM SF6- PHELPS 5/85
ENERGY LOSS = 0.000 , LOWER LIMIT = 0.000 , UPPER LIMIT = 0.490 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION	ION
1	0.0000	1400.0000	
2	0.0010	1300.0000	
3	0.0020	900.0000	
4	0.0050	570.0000	
5	0.0070	480.0000	
6	0.0100	400.0000	
7	0.0200	285.0000	
8	0.0300	230.0000	
9	0.0500	147.0000	
10	0.0700	95.0000	
11	0.1000	49.0000	
12	0.1200	33.0000	
13	0.1500	16.0000	
14	0.1700	9.5000	
15	0.2000	4.2000	
16	0.2500	1.0000	
17	0.3000	0.0000	
18	1000.0000	0.0000	

SF6 ENERGY LOSS = 0.000 , LOWER LIMIT = 0.000 , UPPER LIMIT = 2.012 ,
ATTACHMENT TO FORM SF5- KLINE ET AL
QSCALE = 0.650000(QSCALE USED ONLY FOR RECONSTRUCTING INPUT DATA - SEE N2 INTRO.)

	ENERGY	CROSS SECTION	ION
1	0.0000	2.2750	
2	0.0200	2.0800	
3	0.0500	1.6250	
4	0.0750	1.4950	
5	0.1000	1.6640	
6	0.2000	2.5480	
7	0.3000	2.9835	
8	0.3500	3.0680	
9	0.4000	2.8990	
10	0.6000	1.4040	
11	0.8000	0.6142	
12	1.5000	0.0000	
13	10.0000	0.0000	
14	1000.0000	0.0000	

SF6 ATTACHMENT TO FORM F-, F2-, AND SF4-. CHANTRY 2/78
ENERGY LOSS = 0.000 , LOWER LIMIT = 0.000 , UPPER LIMIT = 19.995 ,
QSCALE = 0.650000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	1.3000	0.0000
3	1.6000	0.0001
4	1.9000	0.0001
5	2.1000	0.0002
6	2.4000	0.0013
7	2.5000	0.0020
8	2.7000	0.0017
9	2.9000	0.0002
10	3.1000	0.0000
11	3.5000	0.0007
12	4.0000	0.0065
13	4.5000	0.0228
14	5.0000	0.0370
15	5.5000	0.0345
16	6.0000	0.0215
17	6.5000	0.0104
18	7.0000	0.0042
19	7.5000	0.0027
20	8.0000	0.0052
21	9.0000	0.0084
22	10.0000	0.0055
23	11.0000	0.0117
24	12.0000	0.0097
25	13.0000	0.0049
26	15.0000	0.0000
27	100.0000	0.0000
28	1000.0000	0.0000

SF6 VIBRATIONAL EXCITATION ROHR AND HAYASHI
ENERGY LOSS = 0.095 , LOWER LIMIT = 0.077 , UPPER LIMIT = 1000.008 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	0.0950	0.0000
3	0.1500	34.0000
4	0.2000	20.0000
5	0.2500	14.8000
6	0.3000	12.6000
7	0.5000	11.1000
8	1.0000	10.0000
9	1.5000	6.5000
10	2.0000	4.6000
11	2.5000	3.5000
12	5.0000	1.8000
13	10.0000	0.9000
14	20.0000	0.4500
15	100.0000	0.0900
16	1000.0000	0.0090

SF6 ELECTRONIC EXCITATION FROM HAYASHI
ENERGY LOSS = 10.000 , LOWER LIMIT = 9.494 , UPPER LIMIT = 1000.008 ,
QSCALE = 0.500000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	10.0000	0.0000

3	12.0000	0.5000
4	14.0000	0.9000
5	20.0000	0.5000
6	25.0000	0.4000
7	40.0000	0.2250
8	70.0000	0.1350
9	100.0000	0.1000
10	150.0000	0.0700
11	200.0000	0.0550
12	400.0000	0.0300
13	700.0000	0.0185
14	1000.0000	0.0125

SF6 EXCITATION - ALLOWED TRANSITION - SIMPSON,HITCHCOCK
ENERGY LOSS = 11.700 , LOWER LIMIT = 10.991 , UPPER LIMIT = 1000.008 ,
QSCALE = 0.900000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	11.7000	0.0000
3	14.5000	0.0756
4	17.5000	0.1710
5	22.5000	0.5580
6	26.0000	1.0260
7	30.0000	1.7370
8	36.0000	2.7360
9	45.0000	3.7800
10	60.0000	4.5720
11	90.0000	5.6520
12	120.0000	6.1650
13	150.0000	6.2730
14	200.0000	6.1470
15	250.0000	5.7600
16	300.0000	5.4810
17	500.0000	4.4100
18	1000.0000	2.8800

SF6 EXCITATION - ALLOWED TRANSITION - SIMPSON,HITCHCOCK
ENERGY LOSS = 15.000 , LOWER LIMIT = 14.500 , UPPER LIMIT = 1000.008 ,
QSCALE = 0.720000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	15.0000	0.0000
3	17.5000	0.0605
4	19.0000	0.1368
5	22.5000	0.4464
6	26.0000	0.8208
7	30.0000	1.3896
8	36.0000	2.1888
9	45.0000	3.0240
10	60.0000	3.6576
11	90.0000	4.5216
12	120.0000	4.9320
13	150.0000	5.0184
14	200.0000	4.9176
15	250.0000	4.6080
16	300.0000	4.3848
17	500.0000	3.5280
18	1000.0000	2.3040

SF6 IONIZATION CHANTRY THRESHOLD THEN RAPP
ENERGY LOSS = 15.700 , LOWER LIMIT = 15.583 , UPPER LIMIT = 1000.008 ,
EBR= 10.000000, QSCALE= 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	15.7000	0.0000
3	16.4500	0.0080
4	17.3000	0.0330
5	18.1000	0.0770
6	19.5000	0.1200
7	20.5000	0.1550
8	21.0000	0.3200
9	22.0000	0.4600
10	23.0000	0.6200
11	24.0000	0.8200
12	26.0000	1.2600
13	30.0000	1.9300
14	36.0000	3.0400
15	45.0000	4.1000
16	60.0000	5.3000
17	90.0000	6.2800
18	120.0000	6.8500
19	150.0000	6.9700
20	200.0000	6.8300
21	250.0000	6.4000
22	300.0000	6.0900
23	500.0000	4.9000
24	1000.0000	3.1000

REVISION OF PARTIAL IONIZATION CROSS SECTIONS

See Rejoub et al, J. Phys. B 34, 1289 (2001).

M. Hayashi has assembled references and derived an electron-Ar cross section set in a report entitled "Bibliography of electron and photon cross sections with atoms and molecules published in the 20th century - sulphur hexafluoride", National Institute for Fusion Research Research, Report NIFS-Data Series NIFS-DATA-76, May 2003. In an appendix to this reoprt Hayashi gives a set of recommended electron-SF6 cross sections. The report cited is one of a series that reviews electron collisions with Ar, Xe, and N2.

Latest SF6 change 12/29/03

****

HELIUM - 1987
10:38:36

He MOMENTUM TRANSFER -
FROM Crompton, Elford, and Jory, Australian J. Phys. 20, 369 (1967); Crompton, Elford, and Robertson, ibid 23, 667 (1970); Miloy and Crompton, Phys. Rev. A 15, 1847 (1977) AT LOW ENERGY, and from Hayashi, Institute of Plasma Physics Report No. IPPJ-AM-19, (1981) AT HIGH ENERGIES

entry #	en(eV)	Effective Qm - Defined in introduction(1E-16*cm^2)
1	0	4.96
2	0.001	4.98
3	0.002	5.02
4	0.003	5.07
5	0.005	5.12
6	0.007	5.15
7	0.0085	5.18
8	0.01	5.21
9	0.015	5.28
10	0.02	5.35
11	0.03	5.46
12	0.04	5.54
13	0.05	5.62
14	0.07	5.74
15	0.1	5.86
16	0.12	5.94
17	0.15	6.04
18	0.17	6.08
19	0.2	6.16
20	0.25	6.27
21	0.3	6.35
22	0.35	6.42
23	0.4	6.49
24	0.5	6.59
25	0.7	6.73
26	1	6.85
27	1.2	6.91
28	1.3	6.92
29	1.5	6.96
30	1.7	6.97
31	1.9	6.98
32	2.1	6.98
33	2.2	6.98
34	2.5	6.96
35	2.8	6.92
36	3	6.89
37	3.3	6.82
38	3.6	6.73
39	4	6.6
40	4.5	6.49
41	5	6.31
42	6	6
43	7	5.68
44	8	5.35
45	10	4.72
46	12	4.2
47	15	3.5
48	17	3.15
49	20	2.64
50	25	2.05
51	30	1.74
52	50	1.1
53	75	0.88
54	100	0.75
55	150	0.605
56	200	0.52
57	300	0.41
58	500	0.3
59	750	0.235
60	1000	0.17

HE EXCITATION - FROM 1960'S ANALYSIS OF MEIR-LEIBNITZ AND OTHERS BY PHELPS
ELOSS=19.80,EMIN=19.6,EMAX=1000.,QSCALE=1.0

1	0	0
2	19.8	0
3	20.02	0.041
4	20.24	0.046
5	21.45	0.042
6	21.8	0.055
7	22.45	0.055
8	24.22	0.073
9	25.32	0.092
10	27.53	0.108
11	29.75	0.116
12	34.18	0.121
13	46.3	0.121
14	100	0.115
15	200	0.1
16	400	0.06
17	700	0.035
18	1000	0.025

HE TOTAL IONIZATION - RAPP AND ENGLANDER-GOLDEN, 1965
ELOSS=24.6,EMIN=24.0,EMAX=1000.,QSCALE=1.0,EBR=15.8
(30 eV entry corrected 3/23/02)

1	0	0
2	24.6	0
3	30	0.071

4	34	0.121
5	40	0.178
6	45	0.212
7	50	0.242
8	60	0.289
9	70	0.313
10	80	0.332
11	90	0.344
12	100	0.351
13	150	0.346
14	200	0.324
15	300	0.29
16	500	0.22
17	700	0.18
18	1000	0.14

Our recommendataion for a "complete" set of electron-helium cross sections is Alves and Ferreira, J. Phys. D 24, 561 (1991). This set has the very important adavantage that the authors show the consistency of their cross section set with swarm experiments. Unfortunately, this set does not appear to be available in tabulated or analytic form in a publication or on the Web.

2/20/01
A new set of electron helium cross sections has been published by Ralchenko et al, Research Report NIFS-Data-59, Nagoya, October 2000. As far as I know this set has not been tested against experimental swarm data. I do not know whether it is available on the Web.

****

NEON - BASED ON TACHIBANA, Phys. Rev. 1986

Because of the use of the 2-term spherical harmonic the Qm values listed here are effective values as defined in the introduction.

MOMENTUM-TRANSFER CROSS SECTION

	ENERGY	Effective Qm - Defined in introduction
1	0.0000	0.2030
2	0.0010	0.2550
3	0.0020	0.2800
4	0.0030	0.3000
5	0.0050	0.3250
6	0.0070	0.3370
7	0.0085	0.3500
8	0.0100	0.3700
9	0.0150	0.4000
10	0.0200	0.4230
11	0.0300	0.4650
12	0.0400	0.5050
13	0.0500	0.5400
14	0.0700	0.6000
15	0.1000	0.7000
16	0.1200	0.7600
17	0.1500	0.8250
18	0.1700	0.8700
19	0.2000	0.9300
20	0.2500	1.0200
21	0.3000	1.0900
22	0.3500	1.1400
23	0.4000	1.2100
24	0.5000	1.3100
25	0.7000	1.4800
26	1.0000	1.6200
27	1.2000	1.6900
28	1.3000	1.7000
29	1.5000	1.7500
30	1.7000	1.7700
31	1.9000	1.7900
32	2.1000	1.8000
33	2.2000	1.8100
34	2.5000	1.8500
35	2.8000	1.8800
36	3.0000	1.9000
37	3.3000	1.9300
38	3.6000	1.9600
39	4.0000	1.9800
40	4.5000	2.0300
41	5.0000	2.0800
42	6.0000	2.1300
43	7.0000	2.2300
44	8.0000	2.3500
45	10.0000	2.4500
46	12.0000	2.6000
47	15.0000	2.8300
48	17.0000	2.9500
49	20.0000	3.1500
50	25.0000	3.2000
51	30.0000	3.2000
52	50.0000	2.8000
53	75.0000	2.5000
54	100.0000	2.4000
55	150.0000	2.3000
56	200.0000	2.1000

NE 3P2 EXCITATION - TACHIBANA - 86
ENERGY LOSS = 16.200 , LOWER LIMIT = 15.977 , UPPER LIMIT = 200.000 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	16.2000	0.0000
3	16.8000	0.0022

4	16.9000	0.0056
5	17.0000	0.0036
6	17.2000	0.0025
7	17.4000	0.0025
8	17.6000	0.0029
9	17.8000	0.0033
10	18.0000	0.0038
11	18.2000	0.0043
12	18.4000	0.0046
13	18.5000	0.0043
14	18.5700	0.0096
15	18.6000	0.0057
16	18.6700	0.0107
17	18.7000	0.0071
18	18.8000	0.0045
19	19.0000	0.0050
20	20.0000	0.0065
21	25.0000	0.0103
22	30.0000	0.0101
23	35.0000	0.0076
24	40.0000	0.0058
25	50.0000	0.0043
26	60.0000	0.0034
27	70.0000	0.0026
28	80.0000	0.0020
29	100.0000	0.0012
30	200.0000	0.0000

ENERGY LOSS = 16.670 , LOWER LIMIT = 15.977 , UPPER LIMIT = 200.000 ,
NE 3P1 EXCITATION - TACHIBANA - 86
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	16.6700	0.0000
3	16.8000	0.0008
4	16.8500	0.0011
5	16.9500	0.0028
6	17.0000	0.0026
7	17.2000	0.0019
8	17.4000	0.0018
9	17.6000	0.0018
10	17.8000	0.0020
11	18.0000	0.0022
12	18.2000	0.0024
13	18.4000	0.0026
14	18.6000	0.0029
15	18.7000	0.0040
16	18.8000	0.0030
17	19.0000	0.0033
18	20.0000	0.0048
19	25.0000	0.0084
20	30.0000	0.0116
21	40.0000	0.0119
22	60.0000	0.0099
23	80.0000	0.0087
24	100.0000	0.0078
25	120.0000	0.0072
26	140.0000	0.0066
27	160.0000	0.0061
28	200.0000	0.0053

NE 3P0 EXCITATION - TACHIBANA - 86
ENERGY LOSS = 16.720 , LOWER LIMIT = 16.383 , UPPER LIMIT = 200.000 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	16.7200	0.0000
3	16.8000	0.0005
4	16.9000	0.0013
5	17.0000	0.0008
6	17.2000	0.0006
7	17.4000	0.0006
8	17.6000	0.0007
9	17.8000	0.0008
10	18.0000	0.0009
11	18.2000	0.0010
12	18.4000	0.0011
13	18.5000	0.0010
14	18.5700	0.0022
15	18.6000	0.0013
16	18.6700	0.0025
17	18.7000	0.0016
18	18.8000	0.0010
19	19.0000	0.0012
20	20.0000	0.0015
21	25.0000	0.0024
22	30.0000	0.0023
23	35.0000	0.0019
24	40.0000	0.0016
25	50.0000	0.0012
26	60.0000	0.0010
27	70.0000	0.0008
28	80.0000	0.0007
29	100.0000	0.0004
30	200.0000	0.0000

NE 1P1 EXCITATION - TACHIBANA - 86
ENERGY LOSS = 16.850 , LOWER LIMIT = 16.485 , UPPER LIMIT = 200.000 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	16.8500	0.0000
3	16.9500	0.0119
4	17.0000	0.0110

5	17.2000	0.0080
6	17.4000	0.0076
7	17.6000	0.0078
8	17.8000	0.0085
9	18.0000	0.0094
10	18.2000	0.0103
11	18.4000	0.0110
12	18.6000	0.0124
13	18.7000	0.0170
14	18.8000	0.0129
15	19.0000	0.0140
16	20.0000	0.0195
17	25.0000	0.0480
18	30.0000	0.0715
19	35.0000	0.0840
20	40.0000	0.0940
21	60.0000	0.1130
22	80.0000	0.1000
23	100.0000	0.1000
24	120.0000	0.0910
25	140.0000	0.0850
26	160.0000	0.0790
27	180.0000	0.0730
28	200.0000	0.0670

NE FORBIDDEN - TACHIBANA - 86
ENERGY LOSS = 18.380 , LOWER LIMIT = 18.491 , UPPER LIMIT = 200.000 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	18.3800	0.0000
3	19.0000	0.0064
4	20.0000	0.0156
5	21.0000	0.0235
6	22.0000	0.0300
7	24.0000	0.0395
8	28.0000	0.0503
9	30.0000	0.0525
10	32.0000	0.0537
11	36.0000	0.0545
12	40.0000	0.0538
13	50.0000	0.0487
14	60.0000	0.0426
15	80.0000	0.0260
16	100.0000	0.0150
17	120.0000	0.0100
18	140.0000	0.0060
19	160.0000	0.0030
20	180.0000	0.0010
21	200.0000	0.0005
22	300.0000	0.0000

NE ALLOWED - TACHIBANA - 86
ENERGY LOSS = 20.000 , LOWER LIMIT = 18.999 , UPPER LIMIT = 200.000 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	20.0000	0.0000
3	22.0000	0.0070
4	25.0000	0.0166
5	30.0000	0.0282
6	35.0000	0.0310
7	40.0000	0.0316
8	50.0000	0.0308
9	60.0000	0.0290
10	70.0000	0.0285
11	80.0000	0.0283
12	100.0000	0.0275
13	150.0000	0.0265
14	200.0000	0.0260

NE TOTAL IONIZATION
ENERGY LOSS = 21.560 , LOWER LIMIT = 20.980 , UPPER LIMIT = 200.000,
EBR= 24.200000, QSCALE= 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	21.5600	0.0000
3	22.0000	0.0033
4	23.0000	0.0146
5	24.0000	0.0260
6	25.0000	0.0380
7	27.0000	0.0632
8	30.0000	0.1082
9	40.0000	0.2279
10	50.0000	0.3379
11	60.0000	0.4356
12	70.0000	0.5139
13	80.0000	0.5773
14	90.0000	0.6283
15	100.0000	0.6670
16	150.0000	0.7726
17	200.0000	0.7814
18	300.0000	0.6500

A more detailed set of electron-neon excitation cross sections is given by Puech and Mizzi, J. Phys. D 24, 1974 (1991). This set has been compared with swarm experiments and is available in analytic form. A worrisome aspect of this set is that the authors find a large discrepancy between the calculated metastable excitation coefficients and the measured values of Tachibana and Phelps, Phys. Rev. A 36, 999 (1987). This discrepancy occurs even at E/N that are low enough so the cascade effects should be negligible.

****

ARGON

Originally from Yamabe, Buckman, and Phelps, Phys. Rev. 27, 1345 (1983). For energies below 3.0 eV these momentum transfer cross sections appear to have been based on Miloy, Crompton, Rees, and Robertson, Aust. J. Phys. 30, 61 (1977). For higher energies the elastic momentum transfer cross section appears to be based on the tabulation by M. Hayashi, Institute of Plasma Physics Report No. IPPJ-AM-19, 1981. See note at end of this Ar section.

REVISION OF 10/15/97.
The momentum transfer cross sections listed for high energies were been revised as of 10/15/97 because of an error in the previous listing. The previous listing appeares to be the elastic momentum transfer cross section for energies up to 100 eV and the effective momentum transfer cross section for higher energies. The effective momentum transfer cross section is the momentum transfer cross section that should be used in the two-term spherical harmonic expansion. It is equal to the sum of the elastic momentum transfer cross section and the sum of the "total" (angular integrated) inelastic cross sections. For discussions of this point see Baraff and Buchsbaum, Phys. Rev. 130, 1007 (1963) and Pitchford and Phelps, Phys. Rev. A 25, 540 (1982).

This revision also includes extension of the total excitation cross section to 10 keV. At energies above 30 eV we have used values based on deHeer et al. that are about 10% lower than those of Eggarater, J. Chem. Phys. 62, 833 (1975) and those based on Peterson and Allen, J. Chem. Phys. 56, 6068 (1972). The effects of these changes on electron transport and reaction rate coefficients have been incorporated in the file TRANSPOR.TXT.

EFFECTIVE MOMENTUM-TRANSFER CROSS SECTION

	ENERGY	Effective Qm - Defined in introduction
1	0.0000	7.50
2	0.0010	7.50
3	0.0020	7.10
4	0.0030	6.70
5	0.0050	6.10
6	0.0070	5.40
7	0.0085	5.05
8	0.0100	4.60
9	0.0150	3.75
10	0.0200	3.25
11	0.0300	2.50
12	0.0400	2.05
13	0.0500	1.73
14	0.0700	1.130
15	0.1000	0.590
16	0.1200	0.400
17	0.1500	0.230
18	0.1700	0.160
19	0.2000	0.103
20	0.2500	0.091
21	0.3000	0.153
22	0.3500	0.235
23	0.4000	0.33
24	0.5000	0.51
25	0.7000	0.86
26	1.0000	1.38
27	1.2000	1.66
28	1.3000	1.82
29	1.5000	2.10
30	1.7000	2.3
31	1.9000	2.5
32	2.1000	2.8
33	2.2000	2.9
34	2.5000	3.3
35	2.8000	3.8
36	3.0000	4.1
37	3.3000	4.5
38	3.6000	4.9
39	4.0000	5.4
40	4.5000	6.1
41	5.0000	6.7
42	6.0000	8.1
43	7.0000	9.6
44	8.0000	11.7
45	10.0000	15.0
46	12.0000	15.2
47	15.0000	14.1
48	17.0000	13.1
49	20.0000	11.0
50	25.0000	9.45
51	30.0000	8.74
52	50.0000	6.90
53	75.0000	5.85
54	100.0000	5.25
55	150.	4.24
56	200.	3.76
57	300.	3.02
58	500.	2.10
59	700.	1.64
60	1000.	1.21
61	1500.	0.88
62	2000.	0.66
63	3000.	0.45
64	5000.	0.31
65	7000.	0.23
66	10000.	0.175

TOTAL EXCITATION LOW E SCHAPERT-SCHEIBNER, HI E UNKNOWN
ENERGY LOSS = 11.500 , LOWER LIMIT = 11.378 , UPPER LIMIT = 10000.0 ,

QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	11.5000	0.0000
3	12.7000	0.0700
4	13.7000	0.1410
5	14.7000	0.2280
6	15.9000	0.3800
7	16.5000	0.4800
8	17.5000	0.6100
9	18.5000	0.7500
10	19.9000	0.9200
11	22.2000	1.1700
12	24.7000	1.3300
13	27.0000	1.4200
14	30.0000	1.4400
15	33.0000	1.4100
16	35.3000	1.3400
17	42.0000	1.2500
18	48.0000	1.1600
19	52.0000	1.1100
20	70.	0.94
21	100.	0.76
22	150.	0.60
23	200.	0.505
24	300.	0.395
25	500.	0.28
26	700.	0.225
27	1000.	0.177
28	1500.	0.136
29	2000.	0.11
30	3000.	0.083
31	5000.	0.058
32	7000.	0.045
33	10000.	0.035

AR IONIZATION - RAPP-SCHRAM
ENERGY LOSS = 15.800 , LOWER LIMIT = 15.686 , UPPER LIMIT = 10000.0 ,
EBR= 10.000000, QSCALE= 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	15.8000	0.0000
3	16.0000	0.0202
4	17.0000	0.1340
5	18.0000	0.2940
6	20.0000	0.6300
7	22.0000	0.9300
8	23.7500	1.1500
9	25.0000	1.3000
10	26.5000	1.4500
11	30.0000	1.8000
12	32.5000	1.9900
13	35.0000	2.1700
14	37.5000	2.3100
15	40.0000	2.3900
16	50.0000	2.5300
17	55.0000	2.6000
18	100.0000	2.8500
19	150.0000	2.5200
20	200.0000	2.3900
21	300.0000	2.0000
22	500.0000	1.4500
23	700.0000	1.1500
24	1000.0000	0.8600
25	1500.0000	0.6400
26	2000.0000	0.5200
27	3000.0000	0.3600
28	5000.0000	0.2400
29	7000.0000	0.1800
30	10000.0000	0.1350

ELASTIC MOMENTUM-TRANSFER CROSS SECTION - added 11/2/97

This elastic momentum transfer cross section is provided for use by modelers with, for example, Monte Carlo codes that require the elastic momentum cross section rather than the effective momentum transfer cross section given above. This cross section is the same as above for energies below the first excitation potential. For higher energies it is from the tabulation by M. Hayashi, Institute of Plasma Physics Report No. IPPJ-AM-19, 1981. When the sum of the inelastic cross sections given above is added to the elastic momentum transfer cross section we obtain an effective momentum transfer cross section in agreement with that tabulated above to within their respective uncertainties.

	ENERGY	CROSS SECTION
1	0	7.5
2	0.001	7.5
3	0.002	7.1
4	0.003	6.7
5	0.005	6.1
6	0.007	5.4
7	0.0085	5.05
8	0.01	4.6
9	0.015	3.75
10	0.02	3.25
11	0.03	2.5
12	0.04	2.05
13	0.05	1.73
14	0.07	1.13
15	0.1	0.59
16	0.12	0.4
17	0.15	0.23
18	0.17	0.16
19	0.2	0.103
20	0.25	0.091

21	0.3	0.153
22	0.35	0.235
23	0.4	0.33
24	0.5	0.51
25	0.7	0.86
26	1	1.38
27	1.2	1.66
28	1.3	1.82
29	1.5	2.1
30	1.7	2.3
31	1.9	2.5
32	2.1	2.8
33	2.2	2.9
34	2.5	3.3
35	2.8	3.8
36	3	4.1
37	3.3	4.5
38	3.6	4.9
39	4	5.4
40	4.5	6.1
41	5	6.7
42	6	8.1
43	7	9.6
44	8	11.7
45	10	15
46	12	14.5
47	15	13.7
48	17	11
49	20	9.2
50	25	6.8
51	30	5.5
52	50	3.2
53	75	2.15
54	100	1.6
55	150	1.1
56	200	0.88
57	300	0.6
58	500	0.37
59	700	0.26
60	1000	0.17
61	1500	0.098
62	2000	0.066
63	3000	0.035
64	5000	0.015
65	7000	0.0088
66	10000	0.0049

THE FOLLOWING ARE NOT PART OF THE SET OF CROSS SECTIONS USED TO CALCULATE THE TRANSPORT AND IONIZATION COEFFICIENTS FOR Ar LISTED IN THE FILE TRANSPOR.TXT.

Their contributions to the energy loss, etc. are included in the "total" excitation cross sections listed above.

Rate coefficients and spatial excitation coefficients for the following three levels of Ar can be calculated by using the cross sections listed below by first multiplying each cross section by, for example, 1E-4; using BACKPRO or equivalent to calculate rate coefficients for the combined set of cross sections; and multiplying the rate coefficient for these proceses by 1E4. This procedure preserves the energy balance, transport coefficients, and ionization coefficients calculated with the preceding set of cross sections.

Excitation of 2p9 level - 811.5 nm emission
ENERGY LOSS = 13.100 , LOWER LIMIT = 12.977 , UPPER LIMIT = 10000.0
QSCALE = 1.00

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	13.1000	0.0000
3	13.2000	0.0004
4	13.7000	0.0240
5	14.7000	0.0650
6	15.9000	0.1140
7	16.5000	0.1400
8	17.5000	0.1800
9	18.5000	0.2200
10	19.9000	0.2400
11	22.2000	0.2600
12	24.7000	0.2200
13	27.0000	0.1900
14	30.0000	0.1560
15	33.0000	0.1250
16	35.3000	0.1100
17	42.0000	0.0670
18	48.0000	0.0440
19	52.0000	0.0360
20	70.0000	0.0180
21	100.0000	0.0110
22	200.0000	0.0020
23	500.0000	0.0000
24	10000.0000	0.0000

Excitation of 2p7 level - 810.4 nm emission
ENERGY LOSS = 13.150 , LOWER LIMIT = 12.977 , UPPER LIMIT = 10000.0 ,
QSCALE = 1.00

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	13.1500	0.0000
3	13.3000	0.00045
4	13.5000	0.00135
5	14.5000	0.0044
6	16.0000	0.0085
7	16.5000	0.0104
8	17.5000	0.0134

9	18.1500	0.0150
10	20.0000	0.0460
11	22.5000	0.0500
12	25.0000	0.0390
13	27.0000	0.0350
14	30.0000	0.0300
15	33.0000	0.0270
16	35.0000	0.0250
17	42.0000	0.0210
18	48.0000	0.0190
19	52.0000	0.0180
20	70.0000	0.0155
21	100.0000	0.0130
22	200.0000	0.0100
23	500.0000	0.0056
24	10000.0000	0.00047

Excitation of 2s and 3d levels
ENERGY LOSS = 14.200 , LOWER LIMIT = 12.977 , UPPER LIMIT = 10000.00 ,
QSCALE = 1.00

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	14.2000	0.0000
3	14.5000	0.0225
4	15.0000	0.0600
5	16.0000	0.1350
6	16.2000	0.1500
7	16.5000	0.1900
8	17.5000	0.2100
9	18.5000	0.2400
10	20.0000	0.2500
11	22.5000	0.2400
12	25.0000	0.2300
13	27.0000	0.2200
14	30.0000	0.2100
15	33.0000	0.2070
16	35.0000	0.2050
17	42.0000	0.1900
18	48.0000	0.1750
19	52.0000	0.16500
20	70.0000	0.13000
21	100.0000	0.09600
22	200.0000	0.05400
23	500.0000	0.03200
24	10000.0000	0.00260.

ANALYTIC CROSS SECTIONS (corrected 04/27/02-Thanks to Z. Donko)

The following are analytic approximations to the elastic momentum transfer cross section Qmel, the effective momentum transfer cross section Qmeff, the total excitation cross section Qex, and the ionization cross section Qion. The combination Qmeff, Qex, and Qion has been used in the two-term Boltzmann code ELENDIF and to obtain calculated ionization coefficients that are within 15% of the experimental data of Kruithof (1940) for E/n from 30 to 300 Td. The cross sections are in m^2 and the energies, en, are in eV.

```
Qex = 0.85*(4E-22*(en-11.5)^1.1*(1+(en/15)^2.8)/(1+(en/23)^5.5)
             + 2.7E-22*(en-11.5)/(1+(en/80))^1.9)

Qion = 9.7E-18*(en-15.8)/(70+en)^2 + 6E-22*(en-15.8)^2*exp(-en/9)

Qmel = (ABS(6/(1+(en/0.1)+(en/0.6)^2)^3.3 -
         1.1*en^1.4/(1+(en/15)^1.2)/(1+(en/5.5)^2.5+(en/60)^4.1)^0.5) +
         0.05/(1+en/10)^2 + 0.01*en^3/(1+(en/12)^6))*1.0E-20
```

One should use Qmeff = Qmel + Qex + Qion for the effective momentum transfer cross section in the two-term Boltzmann equation.

OTHER CROSS SECTION SOURCES:

A detailed published set of electron-Ar cross sections is V. Puech and L. Torchin, J. Phys. D, 19, 2309 (1986). Unfortunately, tabulations of this cross section set do not appear to be publically available. A disturbing feature of the Puech and Torchin set of cross sections is the large discrepancy between calculated and measured [Tachibana, Phys. Rev. A 34, 1007 (1986)] metastable excitation coefficients.

See Pack, Voshall, and Phelps, J. Appl. Phys. 71, 5363 (1992) for an analysis of He, Ar, Kr, and Xe using the two-term approximation over a very wide range of E/n. I do not have files listing the inelastic cross sections used in these calculations.

Through the efforts of Professor K. Nanbu we have obtained permission to presnt a tabulation of the unpublished electron-Ar cross section set of Professor M. Hayashi in the file Hayashi.txt. As discussed in this file, Hayashi's cross section set has been shown to give fair agreement with swarm experiments by Nanbu and Kageyama, Vacuum 47, 1031 (1996). I have not attempted a direct comparison of Hayahsi's cross sections with those of Puech and Torchin (1986).

More recent experimental references include:
S. Tsurubuchi, T. Mirazaki, and K. Motohashi, J. Phys. B 29, 1785 (1996).
Excitation of 4p->4s, 5p->4s, and 4s->3p transitions.

J. E. Chilton, J. B. Boffard, R. S. Schappe, and C. C. Lin, Phys. Rev. A 57, 267 (1998).

Excitation out of metastable levels.
G. A. Piech, J. B. Boffard, M. F. Gehrke, L. W. Anderson, and C. C. Lin, Phys. Rev. A 81, 309 (1998).
For electron excitation of Ar:
Boffard et al, Phys. Rev A 59, 2749 (1999) and J. Phys. D 37, R143 (2004).

Stephen Biagi at sfb@hep.ph.liv.ac.uk has derived a set of electron-Ar cross sections that are consistent with swarm data.
Private communication March 2002

M. Hayashi has assembled references and derived an electron-Ar cross section set in a report entitled "Bibliography of electron and photon cross sections with atoms and molecules published in the 20th century - argon", National Institute for Fusion Research Research, Report NIFS-Data Series NIFS-DATA-72, Jan. 2003. In an appendix to this reoprt Hayashi gives a set of recommended electron-Ar cross sections. This set is the same as that tabulated in the file Hayashi.txt avialble in the present directory. The report cited is one of a NIFS series that reviews electron collisions with Xe, N2, SF6, CO2, etc.

An updated set of electron-Ar cross sections that are consistent with swarm experiments have been published by A. Yanguas-Gil, J. Cotrino, and L.L. Alves, J. Phys. D 38, 1588 (2005). Tabulated cross sections are provided in a supplement.

Latest Ar changes 03/29/07
****
KRYPTON

I do not know of a cross section tabulation for Kr.

The best set of cross sections for electrons in krypton that I know of is that of Date et al, J. Phys. D 22, 1478 (1989). They give cross sections for excitation of the metastable states, but it is difficult to know how much of the higher excited states cascade to the metastable states. One would have to model such things as the trapping of resonance radiation, collisional coupling by atoms and electrons, excited molecule formation, etc. A more recent momentum transfer cross section is given by Brennan and Ness, Australian J. Phys. 46, 249 (1993), but I would question the advisability of replacing the Date et al momentum transfer values with these results without a thorough analyses of the consequences.

****

XENON - 1989

Xenon MOMENTUM-TRANSFER CROSS SECTION

	ENERGY	Elastic Qm - Not effective Qm
1	0.0000	178.0000
2	0.0010	175.0000
3	0.0020	170.0000
4	0.0030	160.0000
5	0.0050	144.0000
6	0.0070	130.0000
7	0.0085	123.0000
8	0.0100	116.0000
9	0.0150	103.0000
10	0.0200	80.0000
11	0.0300	61.0000
12	0.0400	48.0000
13	0.0500	39.5000
14	0.0700	29.0000
15	0.1000	20.2000
16	0.1500	13.0000
17	0.2000	8.4000
18	0.2500	5.3500
19	0.3000	3.1500
20	0.3500	2.1000
21	0.4000	1.7500
22	0.5000	1.3800
23	0.7000	1.3600
24	1.0000	2.4800
25	1.2000	3.3500
26	1.3000	3.9000
27	1.5000	5.0000
28	1.7000	6.3000
29	1.9000	7.5000
30	2.1000	9.1000
31	2.2000	9.9000
32	2.5000	12.5000
33	2.8000	15.0000
34	3.0000	17.0000
35	3.3000	18.9000
36	3.6000	21.3000
37	4.0000	24.8000
38	4.5000	27.6000
39	5.0000	30.8000
40	6.0000	30.5000
41	7.0000	28.0000
42	8.0000	23.5000
43	10.0000	16.0000
44	12.0000	13.0000
45	15.0000	10.2000
46	17.0000	8.3000
47	20.0000	7.0000
48	25.0000	5.9000
49	30.0000	5.1000
50	40.0000	4.3000
51	50.0000	3.6000
52	60.0000	3.2000
53	75.0000	2.7500
54	100.0000	2.3500
55	150.0000	1.9000
56	200.0000	1.6000
57	300.0000	1.3000
58	500.0000	0.9700
59	700.0000	0.7800
60	1000.0000	0.5800
61	1500.0000	0.3700
62	2000.0000	0.2500
63	3000.0000	0.1500
64	5000.0000	0.0730
65	7000.0000	0.0450

66	10000.0000	0.0270

XE SINGLE LEVEL EXCITATION-SHAPER
ENERGY LOSS = 8.320 , LOWER LIMIT = 7.998 , UPPER LIMIT = 1000.008 ,
QSCALE = 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	8.3200	0.0000
3	9.0000	0.0915
4	9.2000	0.1300
5	9.3200	0.1330
6	9.4100	0.1310
7	9.5200	0.1260
8	9.6400	0.1340
9	12.0000	0.3750
10	15.0000	0.7500
11	17.5000	0.9000
12	20.0000	0.8000
13	22.5000	0.6000
14	25.0000	0.4000
15	28.0000	0.3200
16	32.0000	0.3000
17	35.0000	0.3200
18	40.0000	0.3200
19	40.0000	0.3200
20	45.0000	0.3200
21	50.0000	0.3300
22	70.0000	0.3500
23	100.0000	0.3700
24	150.0000	0.3000
25	500.0000	0.2000
26	1000.0000	0.1000
27	3000.0000	0.0330
28	10000.0000	0.0100

ENERGY LOSS = 12.100 , LOWER LIMIT = 10.991 , UPPER LIMIT = 9998.996 ,
XE IONIZATION RAPP,ENGLANDER-GOLDEN,1965
EBR= 8.700000, QSCALE= 1.000000

	ENERGY	CROSS SECTION
1	0.0000	0.0000
2	12.1000	0.0000
3	12.5000	0.1100
4	13.0000	0.2560
5	15.0000	0.9100
6	17.0000	1.5300
7	20.0000	2.2800
8	24.0000	3.1000
9	30.0000	3.8500
10	35.0000	4.1000
11	40.0000	4.4800
12	50.0000	4.8400
13	60.0000	5.0300
14	75.0000	5.2000
15	100.0000	5.3800
16	150.0000	5.2000
17	200.0000	4.6000
18	300.0000	3.9000
19	500.0000	2.9000
20	700.0000	2.4000
21	1000.0000	1.8800
22	1500.0000	1.2500
23	2000.0000	0.9400
24	3000.0000	0.6300
25	5000.0000	0.3800
26	7000.0000	0.2700
27	10000.0000	0.1900
28	15000.0000	0.1250

OTHER CROSS SECTION SOURCES FOR XENON

A detailed set of electron-xenon excitation cross sections is given by Puech and Mizzi, J. Phys. D 24, 1974 (1991). This set has been compared with swarm experiments and is available in analytic form. I have not had occasion to check or to use these cross sections. A word of caution: Note that although most coefficients calculated by Puech and Mizzi for Ne in the same paper agree with experiment, the calculated metastable excitation coefficients for Ne are not in agreement with the measurements and model of Tachibana and Phelps Phys. Rev. A 36, 999 (1987). How this problem carrys over to Xe is unknown.

See Pack, Voshall, and Phelps, J. Appl. Phys. 71, 5363 (1992) for an analysis of He, Ar, Kr, and Xe using the two-term approximation over a very wide range of E/n. I do not have files listing the inelastic cross sections used in these calculations.

M. Hayashi has assembled references and derived an electron-Xe cross section set in a report entitled "Bibliography of electron and photon cross sections with atoms and molecules published in the 20th century - xenon", National Institute for Fusion Research Research, Research Report NIFS-Data Series NIFS-DATA-79, Sept. 2003. In an appendix to this reoprt Hayashi gives a set of recommended electron-Xe cross sections. This set presumably replaces the cross sections in Hayashi, J. Phys. D 16, 581 and 591 (1983). The report cited is one of a series that reviews electron collisions with Ar, N2, SF6 and CO2.

Latest change for Xe on 12/29/03

****

SODIUM CROSS SECTIONS - 1980

Sodium cross sections from 5/28/80 run

for R. Shuker, A. V. Phelps, and A. Gallagher,
J. Appl. Phys. 51, 1306 (1980)

Na Qm 52 entries based on Moores et al
Actually the listed values appear to be total cross sections for elastic scattering. I have attempted to obtain better elastic Qm values from the authors of recent work on the inelastic scattering of electrons by Na, but it appears that such results are not available.

energy eV	Assumed Qm 10^-16cm2
0	115
0.001	78
0.002	66
0.003	61
0.005	57
0.007	57
0.0085	58
0.01	60
0.015	79
0.02	95
0.03	140
0.04	210
0.05	290
0.07	520
0.1	780
0.15	760
0.2	570
0.25	440
0.3	350
0.35	290
0.4	250
0.5	193
0.7	128
1	85
1.2	67
1.3	60
1.5	52
1.7	47
1.9	45
2.1	44
2.2	43.5
2.5	42
2.8	41
3	4.05
3.3	39.7
3.6	38.9
4	38
4.5	36.9
5	36.3
6	34.9
7	33.8
8	32.7
10	31
12	29.9
15	28.3
17	27.7
20	26.7
25	25.3
30	24.3
50	21.8
75	19.8
100	18.6

Na 3p-3s energy gain = 2.1 eV from Moores, Norcross, and Sheorey, J. Phys. B 7, 371 (1974)

energy eV	Xsect 10^-16cm2	12 entries
0	0	
0.01	0	
0.011	26	
0.02	19.5	
0.04	13.3	
0.07	9.6	
0.1	7.7	
0.2	5	
0.4	4	
0.7	3.5	
1	2.75	
2	2.05	
4	1.6	
7	1.35	
10	1.1	
20	0.82	
40	0.61	
100	0.35	

Na 3p-4s energy loss = 1.09 eV from Moores et al. ibid.

energy eV	Xsect 10^-16cm2	18 entries
0	0	
1.09	0	
1.25	5.2	
1.5	7.9	
1.9	10.3	
2.9	11.7	
4	11.7	
6	11.1	
10	9.7	
20	7.7	
50	5.7	
100	4.5	

Na 3p-4d energy loss = 1.51 eV from Moores et al. ibid.

```
  energy    Xsect         12 entries
      eV    10^-16cm2

       0        0
    1.51        0
     1.6       11
     1.7     17.5
     1.9       24
     2.5       32
       3       36
       4     36.5
       6     34.5
      10       29
      25       20
     100       11

Na 3s-3p  energy loss = 2.1 eV from Enemark and Gallagher
Phys. Rev. A 6, 192 (1972)
  energy    Xsect        14 entries
      eV    10^-16cm2

       0        0
     2.1        0
     2.5     20.2
       3     27.1
       4     33.4
       5       36
       7     38.3
    10.5     37.9
    15.6     35.8
    23.8     25.7
    38.7     25.7
    63.7     19.2
    99.2     14.4
     100       14

Na ionization of 3p    e-loss = 3.04 eV from Devyatov
  energy    Xsect            12 entries
      eV    10^-16cm2

       0        0
    3.04        0
    3.75       29
     4.6       49
     6.1       73
       9       97
    12.2      109
      15      111
      18      110
      24      101
      40       80
     100       47

Na ionization of 3s    e-loss = 5.14 eV
  energy    Xsect            16 entries
      eV    10^-16cm2

       0        0
    5.14        0
    7.07     3.97
    7.47     4.61
     8.2     5.42
    9.11     5.99
   10.39      6.4
   12.02     6.69
   13.55     6.76
   15.19     6.72
   17.95     6.58
   21.05     6.39
      26     6.09
      30     5.82
      50      4.7
     100     3.17

For more recent theory and experiment see, for example:
B. Marinkovic, P. Wang, A. Gallagher, Phys. Rev. A 46, 2553 (1992),
W. K. Trail et al, Phys Rev. A 49, 3620 (1994)

*********************************************************************

Mg cross sections

The following data is in the format appropriate to the Boltzmann
code "ELENDIF" available from http://www.csn.net so that electron-
electron and electron-ion effects can be included.  The
electron energy-cross section pairs are in eV and 10^-16 cm^2.

References are:
I. I. Frabrikant, J. Phys. B 7, 91 (1974)
D. Leep and A. Gallagher, Phys. Rev. A 13, 148 (1976)
W. Williams and S. trajmar, J. Phys. B 11, 2021 (1978)

See also:
J. K. Van Blerkom, J. Phys. B 3, 932 (1970)
F. Karstensen and M. Schneider, J. Phys. B 11, 167 (1978)
----------
species
Mg

# Vibr    # Elct    # Othr
   0         2         1

mol wt        g
24.32         1.

Mg momentum transfer Effective Qm - Defined in introduction
N pairs    scale
```

66 1.

0.00E+00	8.00E+00	4.00E-01	3.70E+01	1.00E+01	3.20E+01
1.00E-03	8.07E+00	5.00E-01	4.40E+01	1.20E+01	3.00E+01
2.00E-03	8.14E+00	7.00E-01	5.80E+01	1.50E+01	2.00E+01
3.00E-03	8.21E+00	1.00E+00	8.00E+01	1.70E+01	1.30E+01
5.00E-03	8.35E+00	1.20E+00	7.80E+01	2.00E+01	1.00E+01
7.00E-03	8.50E+00	1.30E+00	7.60E+01	2.50E+01	6.00E+00
8.50E-03	8.60E+00	1.50E+00	7.50E+01	3.00E+01	5.00E+00
1.00E-02	8.70E+00	1.70E+00	7.40E+01	5.00E+01	4.20E+00
1.50E-02	9.13E+00	1.90E+00	7.30E+01	7.50E+01	3.50E+00
2.00E-02	9.40E+00	2.10E+00	7.00E+01	1.00E+02	3.00E+00
3.00E-02	1.01E+01	2.20E+00	6.80E+01	1.50E+02	2.50E+00
4.00E-02	1.08E+01	2.50E+00	6.50E+01	2.00E+02	2.10E+00
5.00E-02	1.16E+01	2.80E+00	6.10E+01	3.00E+02	1.60E+00
7.00E-02	1.30E+01	3.00E+00	5.80E+01	5.00E+02	1.40E+00
1.00E-01	1.50E+01	3.30E+00	5.50E+01	7.00E+02	1.20E+00
1.20E-01	1.90E+01	3.60E+00	5.30E+01	1.00E+03	1.00E+00
1.50E-01	2.30E+01	4.00E+00	5.00E+01	1.50E+03	8.00E-01
1.70E-01	2.00E+01	4.50E+00	4.50E+01	2.00E+03	7.00E-01
2.00E-01	2.30E+01	5.00E+00	4.00E+01	3.00E+03	5.50E-01
2.50E-01	2.60E+01	6.00E+00	3.80E+01	5.00E+03	4.30E-01
3.00E-01	3.00E+01	7.00E+00	3.70E+01	7.00E+03	3.50E-01
3.50E-01	3.30E+01	8.00E+00	3.50E+01	1.00E+04	3.00E-01

Mg(3P) /Trajmar-unresolved triplet,Hussain-3P1-2.3 ms

2.710000E+00 9. 21 1.000000

2.71E+00	0.00E+00	2.00E+01	8.00E-01	1.00E+03	0.00E+00
3.00E+00	1.00E+01	2.50E+01	3.50E-01	1.50E+03	0.00E+00
4.00E+00	7.00E+00	3.50E+01	6.00E-02	2.00E+03	0.00E+00
5.00E+00	5.00E+00	3.50E+01	1.00E-02	3.00E+03	0.00E+00
8.00E+00	4.00E+00	2.00E+02	0.00E+00	5.00E+03	0.00E+00
1.00E+01	3.50E+00	3.00E+02	0.00E+00	7.00E+03	0.00E+00
1.20E+01	2.00E+00	5.00E+02	0.00E+00	1.00E+04	0.00E+00

Mg(1P1) /Leep and Gallagher

4.330000E+00 3. 29 1.000000

4.33E+00	0.00E+00	8.90E+00	1.65E+01	1.48E+02	8.26E+00
4.60E+00	2.10E+00	1.00E+01	1.60E+01	2.49E+02	5.80E+00
4.75E+00	2.85E+00	1.20E+01	1.64E+01	3.99E+02	4.06E+00
4.90E+00	3.86E+00	1.50E+01	1.70E+01	6.00E+02	2.96E+00
5.08E+00	5.03E+00	1.85E+01	1.73E+01	8.00E+02	2.35E+00
5.40E+00	6.09E+00	2.40E+01	1.71E+01	1.10E+03	1.81E+01
5.75E+00	7.67E+00	3.00E+01	1.66E+01	1.40E+03	1.48E+00
6.10E+00	9.13E+00	3.79E+01	1.59E+01	3.00E+03	1.00E-02
6.60E+00	1.07E+01	6.27E+01	1.33E+01	1.00E+04	1.00E-03
7.50E+00	1.42E+01	9.81E+01	1.06E+01		

Mg+

7.640000 1.000000 23 1.000000

7.64E+00	0.00E+00	8.00E+01	2.60E+00	1.00E+03	5.00E-01
1.00E+01	7.50E+00	1.00E+02	1.80E+00	1.50E+03	4.00E-01
1.20E+01	8.00E+00	2.00E+02	1.30E+00	2.00E+03	3.00E-01
2.00E+01	6.30E+00	2.80E+02	1.10E+00	3.00E+03	2.00E-01
3.00E+01	5.20E+00	3.00E+02	1.00E+00	5.00E+03	1.00E-01
4.00E+01	4.00E+00	5.00E+02	8.50E-01	7.00E+03	7.00E-02
5.00E+01	3.50E+00	7.00E+02	7.00E-01	1.00E+04	5.00E-02
6.00E+01	3.20E+00	8.00E+02	6.00E-01		

OZONE

Stephen Biagi at sfb@hep.ph.liv.ac.uk has derived a set of electron-O3 cross sections.
Private communication March 2002

HYDROGEN HALIDE MOLECULES

M. Hayashi has assembled references and derived an electron-HF, HCl, HBr, and HI cross section set in a report entitled "Bibliography of electron and photon cross sections with atoms and molecules published in the 20th century - Hydrogen Halide Molecules", National Institute for Fusion Research Research, Report NIFS-Data Series NIFS-DATA-83, Mar. 2004. The report does not contain sets of recommended cross sections, but has some relevant comments at the end. The report cited is one of a series that gives bibliographies of papers on electron collisions with various gases.