6.4 Excitation cross sections

6.4.1 Introduction

In this section of Chapter 6 preferred integral cross sections for discrete inelastic (i.e. rotation, vibration and electronic) excitation for a wide range of molecules are presented. Ionisation, dissociation and attachment phenomena are not considered. If a molecule does not appear in this section then its omission reflects either the absence of any relevant cross section data, or that there was insufficient data available for us to construct a preferred set.

Definition of the integral cross section in terms of the differential cross section and the scattering phase shifts was given previously in 6.2. Consequently those details are not repeated again here.

6.4.2 Experimental determinations

6.4.2.1 From swarm experiments

The technique involves high precision measurements of characteristic transport properties, the transport coefficients, of an ensemble or swarm of electrons as they drift and diffuse through a gas under the influence of an applied electric (***E***), or crossed electric and magnetic (***B***), fields at pressures ranging from a few torr to many atmospheres.

Procedures for measurement of these transport coefficients (commonly the drift velocity, v_{dr}, ratio of the lateral diffusion coefficient D_T, to the electron mobility, μ, and when there is a magnetic field transverse to ***E***, the ratio $v_\perp/v_{dr}$, where $v_\perp$ is the drift velocity at right angles to ***E*** and ***B***) include the Bradbury-Nielsen [74Hux1], photon flux [89Kel1] and voltage transient [89Pur1] techniques. For a given gas, in the hydrodynamic regime, all these transport coefficients are functions only of the ratio E/N, the gas temperature T, and when a magnetic field is present, of B/N.

The macroscopic transport coefficients are related to the desired microscopic quantities (integral cross sections as a function of energy) through an energy distribution function which is usually non-Maxwellian and often complex in form. The microscopic properties have to be determined in a complicated and somewhat cumbersome [74Hux1] unfolding procedure by seeking a self-consistent set of cross sections which produce the experimental coefficients via an appropriate (either "two term" or "multiterm", see 6.3.2.1 for more details) formulation of the Boltzmann transport equation [84Kum1]. Alternatively, one can use Monte Carlo simulation to describe the kinetics of the swarm, from which the same transport coefficients can be derived. The beauty of this approach is that it is mathematically very simple and also versatile in its applicability; its weakness is the computational overhead associated with the repetitive calculations required for statistical accuracy [97Nol1].

When applied to atomic systems at low "mean energies" swarm experiments can provide very accurate integral and momentum transfer cross sections. However in molecular systems there are particular problems in obtaining a unique set of cross sections from swarm experiments [84Kum1, 93Bren1], as is evidenced by the molecular hydrogen (H_2) $\nu = 0 \rightarrow 1$ rotationally-averaged vibrational integral cross section of Schmidt et al. [94Sch1]. Here they [94Sch1] derived a H_2 $\nu = 0 \rightarrow 1$ integral cross section which is some 14 % different to that which had hitherto been considered the definitive swarm result for this process [88Eng1]. This discrepancy between [88Eng1] and [94Sch1] is probably due to [94Sch1] being able to measure a more extensive set of transport parameters with their $\boldsymbol{E} \times \boldsymbol{B}$ technique. Consequently a more rigorous constraint is placed on the integral cross sections derived from their Boltzmann analysis. However, the point here is not that the cross section of Schmidt et al. [94Sch1] is arguably in better agreement with theory [90Buc1, 93Res1] and beam experiments [91Bru1] than was the earlier swarm data [88Eng1], but that two quite similar analyses of swarm data produced two significantly different results for the $0 \rightarrow 1$ H_2 integral cross section. This lack of uniqueness problem

with the swarm technique, which grows as more inelastic channels become open, is a major limitation in its application to deriving integral excitation cross sections in molecules. Consequently, we have been very circumspect in using swarm-derived excitation integral cross sections when constructing our preferred cross section sets.

Nonetheless we note that the power of the swarm technique, in electron scattering from molecular systems, is its ability to test the consistency of a proposed set of cross sections with accurately measured transport data.

6.4.2.2 From crossed beam experiments

The integral excitation cross section $\sigma(\varepsilon)$ can be derived from absolute measurements of the corresponding differential cross section $d\sigma/d\Omega$ from:

$$\sigma(\varepsilon) = 2\pi \int_0^{\pi} \frac{d\sigma}{d\Omega} \sin\theta \, d\theta \tag{1}$$

There are several complications with this technique. Firstly, in the measurement of the absolute excitation differential cross section the establishment of the relative detector response function for the energy loss range corresponding to the elastic and inelastic events can be problematic [94Traj1]. Secondly, the excitation processes of interest may be strongly overlapping in energy loss, thereby requiring the use of spectral deconvolution procedures [97Cam1]. Finally in most measurements of $d\sigma/d\Omega$ the entire range of scattering angles between 0 and π, due to the presence of primary beam and other geometrical constraints, cannot be covered. Consequently some extrapolation procedure is required to extend these measurements to 0 and π. Various techniques have been applied to enable this extrapolation and they, and the uncertainties involved, have been discused by various authors (e.g. [83Tra1]). We note that the recent experimental development of Read and Channing [96Rea1], in which a localised magnetic field is added to the interaction region of a conventional electrostatic electron spectrometer to increase the angular range of electrons that the analyser receives, provides a possible solution to the extrapolation problem.

Integral excitation cross sections, for optically allowed transitions, can also be determined by measurement of the number of emitted photons as a function of the incident electron energy i.e. the so-called optical excitation function. Normalisation to an absolute scale is usually achieved by application of the Bethe-Born approximation [30Bet1] at a high enough energy at which the Born approximation is expected to be valid [71Ino1]. There are also several complications with this technique. They include that the emitted radiation is polarised, so that there will be some angular distribution of the intensity of the photons. In addition cascade effects can be a serious problem.

References for 6.4.2

30Bet1 Bethe, H.A.: Ann. Phys. **5** (1930) 325

71Ino1 Inokuti, M.: Rev. Mod. Phys. **43** (1971) 297

74Hux1 Huxley, L.G.H., Crompton, R.W.: The diffusion and drift of electrons in gases, NewYork: Wiley-Interscience, 1974

83Traj1 Trajmar, S., Register, D.F., Chutjian, A.: Phys. Rep. **97** (1983) 219

84Kum1 Kumar, K.: Phys. Rep. **112** (1984) 319

88Eng1 England, J.P., Elford, M.T., Crompton, R.W.: Aust. J. Phys. **41** (1988) 573

89Kel1 Kelly, L.J., Brennan, M.J., Wedding, A.B.: Aust. J. Phys. **42** (1989) 365

89Pur1 Purdie, P.H., Fletcher, J.: J. Phys. D **22** (1989) 759

90Buc1 Buckman, S.J., Brunger, M.J., Newman, D.S., Snitchler, G., Alston, S., Norcross, D.W., Morrison, M.A., Saha, B.C., Danby, G., Trail, W.K.: Phys. Rev. Lett. **65** (1990) 3253

91Bru1 Brunger, M.J. Buckman, S.J., Newman, D.S., Alle, D.T.: J. Phys. B: At. Mol. Opt. Phys. **24** (1991) 1435

93Bren1 Brennan, M.J., Ness, K.F.: Aust. J. Phys. **45** (1993) 249
93Res1 Rescigno, T.N., Elza, B.K., Lengsfield III, B.H.: J. Phys. B: At. Mol. Opt. Phys. **26** (1993) L567
94Sch1 Schmidt, B., Berkhan, K., Götz, B., Möller, M.: Phys. Scr. **53** (1994) 30
94Traj1 Trajmar, S., McConkey, J.W.: Adv. At. Mol. Opt. Phys. **33** (1994) 63
96Rea1 Read, F.H., Channing, J.M.: Rev. Sci. Instrum. **67** (1996) 2372
97Cam1 Campbell, L., Brunger, M.J., Teubner, P.J.O., Mojarrabi, B., Cartwright, D.C.: Aust. J. Phys. **50** (1997) 525
97Nol1 Nolan, A.M., Brennan, M.J. Ness, K.F., Wedding, A.B.: J. Phys. D: Appl. Phys. **30** (1997) 2865

6.4.3 Determination of preferred cross sections

The preferred integral excitation cross sections for each molecule have been derived from a consideration of all available (published) experimental and theoretical work. In general, we do not consider those cases where only theoretical values exist, unless there is substantial corroboration between two or more different calculations. More weight has been placed on recent measurements which have realistic and well quantified uncertainties. The uncertainty estimates on the preferred cross sections indicate the level of concurrence between the various individual measurements and calculations.

6.4.4 Units

Cross sections are given in square Ångström ($1 Å^2 = 10^{-16}$ cm^2) and electron energies in electron volt (eV).

6.4.5 Molecules

6.4.5.1 Hydrogen (H_2)

6.4.5.1.1 $J = 0 \rightarrow 2$

Below the threshold for vibrational excitation ($\Delta E \approx 0.5$ eV), accurate integral cross sections for the $J = 0 \rightarrow 2$ rotational excitation process in H_2 can be found in the electron swarm work of [70Crom1, 70Gib1, 88Eng1]. The relatively recent work of [88Eng1] is considered to be the definitive swarm measurement and it forms the basis for our preferred integral cross section set, as tabulated in Table 6.4.1 and plotted in Fig. 6.4.1

The uncertainty on the cross sections is estimated to be ± 5 %.

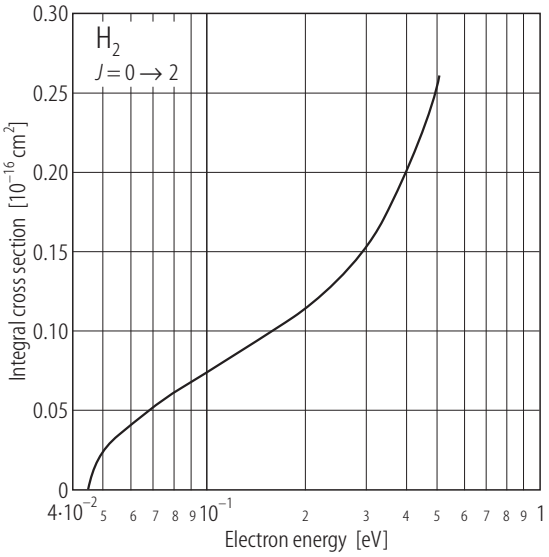

Fig. 6.4.1. Recommended integral cross section for $J = 0 \rightarrow 2$ in H_2.

Table 6.4.1. Preferred values of the integral $J = 0 \rightarrow 2$ rotational excitation cross section ($\sigma_{0\text{-}2}$) for electrons in molecular hydrogen.

Energy [eV]	$\sigma_{0\text{-}2}$ [Å^2]	Energy [eV]	$\sigma_{0\text{-}2}$ [Å^2]
0.044	0	0.13	0.088
0.047	0.0185	0.15	0.097
0.050	0.027	0.20	0.115
0.060	0.042	0.25	0.132
0.065	0.048	0.30	0.152
0.070	0.053	0.35	0.175
0.080	0.062	0.40	0.200
0.090	0.068	0.45	0.228
0.10	0.074	0.50	0.260
0.11	0.079		

References for 6.4.5.1.1

70Crom1 Crompton, R.W., Gibson, D.K., Robertson, A.G.: Phys. Rev. A **2** (1970) 1386
70Gib1 Gibson, D.K.: Aust. J. Phys. **23** (1970) 683
88Eng1 England, J.P., Elford, M.T., Crompton, R.W.: Aust. J. Phys. **41** (1988) 573

6.4.5.1.2 $J = 1 \rightarrow 3$

The preferred integral cross section for electron impact excitation of the $J = 1 \rightarrow 3$ rotational transition is presented over the energy range from threshold to 0.5 eV. The data are tabulated in Table 6.4.2 and plotted in Fig. 6.4.2. For the $J = 1 \rightarrow 3$ transition there are swarm cross sections due to [88Eng1] and beam cross sections due to [71Lin1]. The accurate calculation of [87Mor1] favours the swarm determination over that of the beam measurements, in the energy range considered, and so our preferred cross section is based on the work of [88Eng1].

The uncertainty is estimated to be ± 10 %.

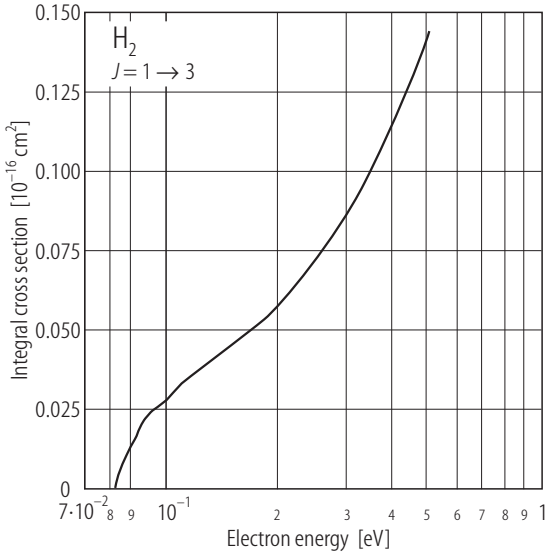

Fig. 6.4.2. Recommended integral cross section for $J = 1 \rightarrow 3$ in H_2.

Table 6.4.2. Preferred values of the integral $J = 1 \rightarrow 3$ rotational excitation cross section ($\sigma_{1\text{-}3}$) for electrons in molecular hydrogen.

Energy [eV]	$\sigma_{1\text{-}3}$ [Å^2]	Energy [eV]	$\sigma_{1\text{-}3}$ [Å^2]	Energy [eV]	$\sigma_{1\text{-}3}$ [Å^2]
0.073	0	0.10	0.028	0.25	0.072
0.075	0.007	0.11	0.033	0.3	0.086
0.08	0.014	0.12	0.0364	0.35	0.10
0.085	0.0198	0.13	0.039	0.40	0.114
0.09	0.0237	0.15	0.045	0.45	0.129
0.095	0.0265	0.20	0.058	0.50	0.144

References for 6.4.5.1.2

71Lin1 Linder, F., Schmidt, H.: Z. Naturforsch A **26** (1971) 1603
87Mor1 Morrison, M.A., Crompton, R.W., Saha, B.C., Petrovic, Z.Lj.: Aust. J. Phys. **40** (1987) 239
88Eng1 England, J.P., Elford, M.T., Crompton, R.W.: Aust. J. Phys. **41** (1988) 573

6.4.5.1.3 $\nu' = 0 \rightarrow 1$

There have been several experimental, both swarm and crossed beam, determinations of integral cross sections for the $\nu' = 0 \rightarrow 1$ vibrational excitation in molecular hydrogen. These include [70Cro1, 88Eng1, 68Ehr1, 71Lin1, 85Nis1, 90Buc1, 91Bru1, 94Sch1]. The differential cross section measurements of [85Nis1] are in poor agreement with the other crossed beam determinations [68Ehr1, 71Lin1, 91Bru1] and with theory [90Buc1, 93Res1], and so we do not use their [85Nis1] integral cross sections in determining our preferred integral cross section set.

The preferred cross section set was constructed in the following manner. For $\varepsilon < 1$ eV an average of the integral cross sections from [68Ehr1, 88Eng1, 94Sch1] was used. For 1 eV $\leq \varepsilon \leq$ 2.4 eV an average of the integral cross sections from [68Ehr1, 88Eng1, 91Bru1, 94Sch1] was employed, while for 2.4 eV $\leq \varepsilon \leq$ 5 eV an average of the integral cross sections from [68Ehr1, 71Lin1, 88Eng1, 91Bru1] was used. Finally, for 5 eV $< \varepsilon \leq$ 7 eV the preferred integral cross section was formed from an average of the measurements of [68Ehr1] and [88Eng1]. The preferred cross sections are listed in Table 6.4.3 and plotted in Fig. 6.4.3.

The uncertainty on the cross sections is estimated to be: ± 50 % for $\varepsilon < 0.60$ eV, ± 30 % for 0.60 eV $\leq \varepsilon < 1.25$ eV, ± 20 % for 1.25 eV $\leq \varepsilon \leq 2$ eV and ± 15 % for $\varepsilon > 2$ eV.

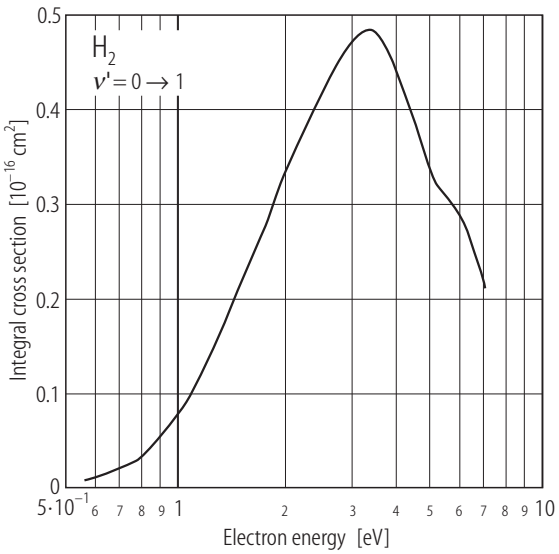

Fig. 6.4.3. Recommended integral cross section for $\nu' = 0 \rightarrow 1$ in H_2.

Table 6.4.3. Preferred values of the integral $\nu' = 0 \rightarrow 1$ vibrational excitation cross section ($\sigma_{0\text{-}1}$) for electrons in molecular hydrogen.

Energy [eV]	$\sigma_{0\text{-}1}$ [Å^2]	Energy [eV]	$\sigma_{0\text{-}1}$ [Å^2]	Energy [eV]	$\sigma_{0\text{-}1}$ [Å^2]
0.56	0.0065	1	0.073	3.4	0.483
0.60	0.0097	1.25	0.141	3.8	0.458
0.65	0.0138	1.5	0.211	4.5	0.382
0.75	0.0261	2	0.339	5	0.330
0.85	0.040	2.5	0.419	6	0.284
0.95	0.062	3	0.470	7	0.210

References for 6.4.5.1.3

68Ehr1 Ehrhardt, H., Langhans, L., Linder, F., Taylor, H.S.: Phys. Rev. **173** (1968) 222
70Cro1 Crompton, R.W., Gibson, D.K., Robertson, A.G.: Phys. Rev. A **2** (1970) 1386
71Lin1 Linder, F., Schmidt, H.: Z. Naturforsch A **26** (1971) 1603
85Nis1 Nishimura, H., Danjo, A., Sugahara, H.: J. Phys. Soc. Jpn. **54** (1985) 1757
88Eng1 England, J.P., Elford, M.T., Crompton, R.W.: Aust. J. Phys. **41** (1988) 573
90Buc1 Buckman, S.J., Brunger, M.J., Newman, D.S., Snitchler, G., Alston, S., Norcross, D.W., Morrison, M.A., Saha, B.C., Danby, G., Trail, W.K.: Phys. Rev. Lett. **65** (1990) 3253
91Bru1 Brunger, M.J., Buckman, S.J., Newman, D.S., Alle, D.T.: J. Phys. B: At. Mol. Opt. Phys. **24** (1991) 1435
93Res1 Rescigno, T.N., Elza, B.K., Lengsfield III, B.H.: J. Phys. B: At. Mol. Opt. Phys. **26** (1993) L567
94Sch1 Schmidt, B., Berkhan, K., Götz, B., Möller, M.: Phys. Scr. **53** (1994) 30

6.4.5.1.4 $X^1\Sigma_g^+ \rightarrow B^1\Sigma_u^+$

There appears to be three experimental determinations of integral cross sections for excitation of the $B^1\Sigma_u^+$ electronic-state of molecular hydrogen. The first, from 15 to 60 eV, is due to [77Sri1] while the second, from 20 to 60 eV is due to [86Kha1]. Both [77Sri1] and [86Kha1] are crossed beam measurements. The final determination is an optical emission cross section from [85She1], at energies from near-threshold to around 300 eV. All three sets of integral cross sections appear to be in fair agreement with one another, and as such they form the basis for our preferred cross section set. This set is tabulated in Table 6.4.4 and plotted in Fig. 6.4.4.

The uncertainty on the integral cross section is estimated to be ± 20 % over the entire range of electron energies.

Table 6.4.4. Preferred values of the integral $X^1\Sigma_g^+ \rightarrow B^1\Sigma_u^+$ electronic-state excitation cross section ($\sigma_{X\text{-}B}$) for electrons in molecular hydrogen.

Energy [eV]	$\sigma_{X\text{-}B}$ [Å^2]	Energy [eV]	$\sigma_{X\text{-}B}$ [Å^2]	Energy [eV]	$\sigma_{X\text{-}B}$ [Å^2]
13.00	0.010	16.1	0.082	32	0.309
13.15	0.013	16.9	0.104	41	0.331
13.41	0.015	17.6	0.125	47	0.338
13.55	0.020	18.2	0.144	55	0.331
13.83	0.026	18.5	0.153	70	0.318
13.97	0.032	19.9	0.187	90	0.291
14.4	0.040	21.3	0.213	101	0.279
15.0	0.053	23.9	0.248		
15.6	0.067	27.2	0.279		

References for 6.4.5.1.4

77Sri1 Srivastava, S.K., Jansen, S.: J. Phys. B: At. Mol. Phys. **10** (1977) 3341
85She1 Shemansky, D.E., Ajello, J.M., Hall, D.T.: Astrophys. J. **296** (1985) 765
86Kha1 Khakoo, M.A., Trajmar, S.: Phys. Rev. A **34** (1986) 146

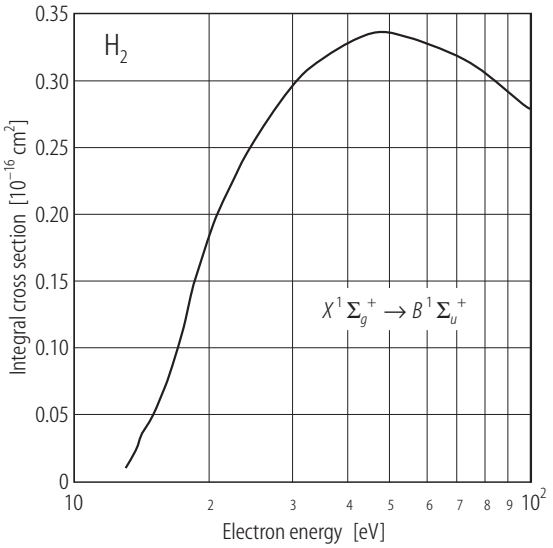

Fig. 6.4.4. Recommended integral cross section for $X^1\Sigma^+_g \rightarrow B^1\Sigma_u^+$ in H_2.

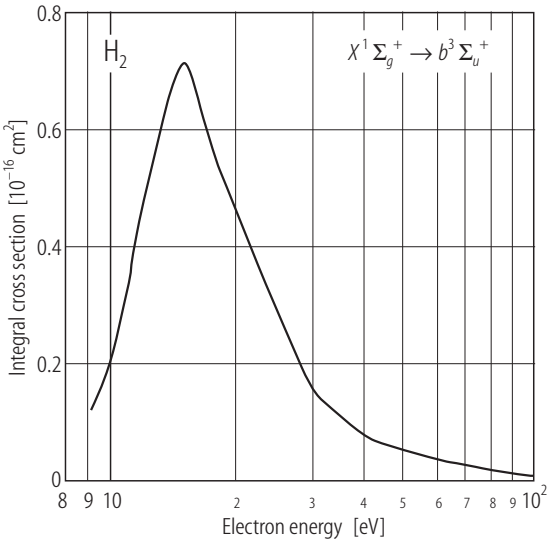

Fig. 6.4.5. Recommended integral cross section for $X^1\Sigma_g^+ \rightarrow b^3\Sigma_u^+$ in H_2.

6.4.5.1.5 $X^1\Sigma_g^+ \rightarrow b^3\Sigma_u^+$

There are four sets of crossed beam measurements of integral cross sections for excitation of the $b^3\Sigma_u^+$ electronic state of molecular hydrogen. These are due to [84Hal1, 86Nis1, 87Kha1, 94Kha1] and in general, to within their respective uncertainty of measurement, they are in fair agreement with one another. Our preferred cross section set is constructed using all four of these measurements and it covers the energy range 9.2 to 100 eV. This data is plotted in Fig. 6.4.5 and tabulated in Table 6.4.5.

The uncertainty on the integral cross section is estimated to be ± 20 % over the entire range of electron energies.

Table 6.4.5. Preferred values of the integral $X^1\Sigma^+_g \rightarrow b^3\Sigma^+_u$ electronic-state excitation cross section ($\sigma_{X\text{-}b}$) for electrons in molecular hydrogen.

Energy [eV]	$\sigma_{X\text{-}b}$ [Å^2]	Energy [eV]	$\sigma_{X\text{-}b}$ [Å^2]	Energy [eV]	$\sigma_{X\text{-}b}$ [Å^2]
9.2	0.121	15.1	0.717	40	0.080
10.2	0.208	17.2	0.573	60	0.038
12	0.470	20	0.456	100	0.007
12.2	0.494	30	0.164		

References for 6.4.5.1.5

84Hal1 Hall, R.I., Andric, L.: J. Phys. B: At. Mol. Phys. **17** (1984) 3815
86Nis1 Nishimura, H., Danjo, A.: J. Phys. Soc. Jpn. **55** (1986) 3031
87Kha1 Khakoo, M.A., Trajmar, S., McAdams, R., Shyn, T.: Phys. Rev. A **35** (1987) 2832
94Kha1 Khakoo, M.A., Segura, J.: J. Phys. B: At. Mol. Opt. Phys. **27** (1994) 2355

6.4.5.1.6 $X^1\Sigma_g^+ \rightarrow c^3\Pi_u$

Integral cross sections for electron impact excitation of the $c^3\Pi_u$ electronic-state of H_2 have been reported by [86Kha1] and [86Mas1]. The crossed beam measurement of [86Kha1] covers the energy range 20 to 60 eV, while the metastable time-of-flight study of [86Mas1] is from threshold to about 60 eV. Note that the relative data of [86Mas1] were put on an absolute scale by normalisation to the 20 eV integral cross section of [86Kha1]. For $\varepsilon > 20$ eV the data of Mason and Newell [86Mas1] is significantly higher in magnitude than that of [86Kha1], perhaps due to cascade contributions in the formers work. Our preferred cross section is constructed from the data of [86Mas1] for $\varepsilon < 20$ eV and from [86Kha1] for 20 eV $\leq \varepsilon \leq$ 60 eV. It is tabulated in Table 6.4.6 and plotted in Fig. 6.4.6.

The uncertainty in the integral cross section is estimated to be ± 30 % for $\varepsilon < 20$ eV and ± 25 % for $\varepsilon \geq 20$ eV.

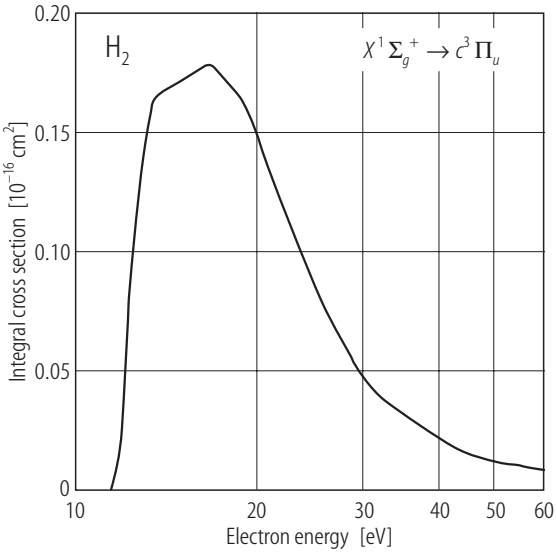

Fig. 6.4.6. Recommended integral cross section for $X^1\Sigma_g^+ \rightarrow c^3\Pi_u$ in H_2.

Table 6.4.6. Preferred values of the integral $X^1\Sigma_g^+ \rightarrow c^3\Pi_u$ electronic-state excitation cross section ($\sigma_{X\text{-}c}$) for electrons in molecular hydrogen.

Energy [eV]	$\sigma_{X\text{-}c}$ [Å^2]
11.52	0.001
11.91	0.021
12.28	0.080
13.4	0.162
15.7	0.174
16.6	0.178
17.4	0.173
18.6	0.164
19.5	0.155
20.0	0.147
30.0	0.046
40.0	0.021
50.0	0.008

References for 6.4.5.1.6

86Kha1 Khakoo, M.A., Trajmar, S.: Phys. Rev. A **34** (1986) 146
86Mas1 Mason, N.J., Newell, W.R.: J. Phys. B: At. Mol. Phys. **19** (1986) L587

6.4.5.1.7 $X^1\Sigma_g^+ \rightarrow a^3\Sigma_g^+$

Integral cross sections for electron impact excitation of the $a^3\Sigma_g^+$ electronic-state of H_2 have been reported by [86Kha1] and [85Aje1]. The crossed beam measurement of [86Kha1] covers the energy range 20 to 60 eV, while the optical emission cross section data of [85Aje1] is from threshold to about 60 eV. Note that the relative data of [85Aje1] were put on an absolute scale by normalisation to the 20 eV integral cross

section of [86Kha1]. Except at 60 eV, the cross sections of [86Kha1] and [85Aje1] are in good agreement, with our preferred set being constructed from the data of [85Aje1] for $\varepsilon \leq 30$ eV and from [86Kha1] for 30 eV $< \varepsilon \leq 60$ eV. Our preferred integral cross section is plotted in Fig. 6.4.7 and tabulated in Table 6.4.7.

The uncertainty in the integral cross section is estimated to be ± 20 % over the entire range of electron energies.

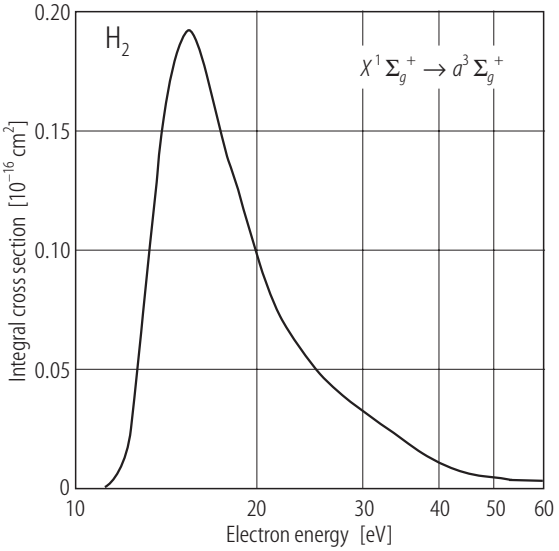

Fig. 6.4.7. Recommended integral cross section for $X^1\Sigma_g^+ \rightarrow a^3\Sigma_g^+$ in H_2.

Table 6.4.7. Preferred values of the integral $X^1\Sigma_g^+ \rightarrow a^3\Sigma_g^+$ electronic-state excitation cross section ($\sigma_{X\text{-}a}$) for electrons in molecular hydrogen.

Energy [eV]	$\sigma_{X\text{-}a}$ [Å^2]	Energy [eV]	$\sigma_{X\text{-}a}$ [Å^2]	Energy [eV]	$\sigma_{X\text{-}a}$ [Å^2]
11.29	0.001	15.2	0.193	21.6	0.076
11.5	0.002	15.5	0.193	22.5	0.068
11.75	0.005	15.6	0.193	23.6	0.060
12.1	0.013	15.8	0.190	24.5	0.054
12.5	0.028	16.2	0.183	25.8	0.047
12.8	0.056	16.8	0.169	26.8	0.043
13.2	0.087	17.7	0.145	27.8	0.039
13.5	0.118	18.5	0.129	29.2	0.035
14.0	0.152	19.4	0.110	30.0	0.033
14.3	0.167	20.0	0.100	40.0	0.011
14.8	0.184	20.5	0.092	60.0	0.003

References for 6.4.5.1.7

85Aje1 Ajello, J.M., Pang, K.D., Franklin, B., Fram, F.: EOS Transactions, Am. Geophys. Union **66** (1985) 989

86Kha1 Khakoo, M.A., Trajmar, S.: Phys. Rev. A **34** (1986) 146

6.4.5.1.8 $X^1\Sigma_g^+ \rightarrow C^1\Pi_u$

There appears to be only two experimental determinations of integral cross sections for excitation of the $C^1\Pi_u$ electronic-state of molecular hydrogen. The first, from near-threshold to about 300 eV, is an optical emission cross section from [85She1], while the other is a crossed beam measurement from [86Kha1] for energies in the range 20 eV to 60 eV. At 30 eV and 40 eV the integral cross sections of [85She1] and [86Kha1] are in fair agreement. However, at 20 eV and 60 eV there is an important discrepancy between them. In this case our preferred cross section set is drawn largely from the optical study of [85She1]. It is tabulated in Table 6.4.8 and plotted in Fig. 6.4.8.

The uncertainty in the integral cross section is estimated to be ± 25 % over the entire range of electron energies.

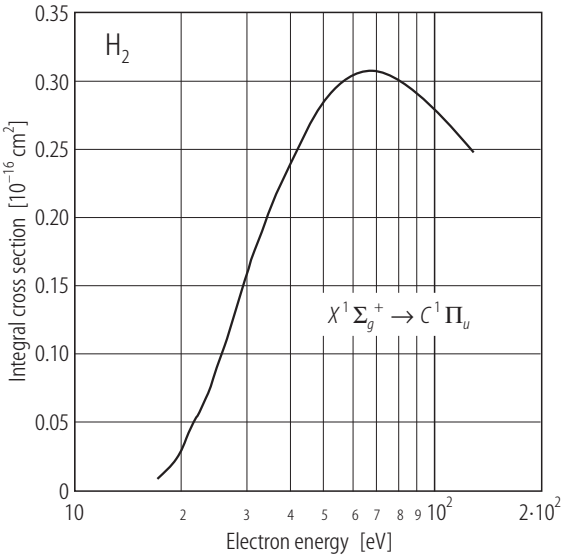

Fig. 6.4.8. Recommended integral cross section for $X^1\Sigma_g^+ \rightarrow C^1\Pi_u$ in H_2.

Table 6.4.8. Preferred values of the integral $X^1\Sigma_g^+ \rightarrow C^1\Pi_u$ electronic-state excitation cross section ($\sigma_{X\text{-}C}$) for electrons in molecular hydrogen.

Energy [eV]	$\sigma_{X\text{-}C}$ [Å^2]	Energy [eV]	$\sigma_{X\text{-}C}$ [Å^2]	Energy [eV]	$\sigma_{X\text{-}C}$ [Å^2]
16.9	0.010	24.6	0.090	53.5	0.294
17.4	0.013	26.4	0.112	66.1	0.306
18.2	0.017	28.6	0.140	76.1	0.303
18.9	0.023	29.2	0.149	99.0	0.279
19.7	0.030	31.6	0.176	129	0.248
20.5	0.041	35.0	0.207		
22.2	0.059	39.9	0.240		
23.6	0.074	44.6	0.266		

References for 6.4.5.1.8

85She1 Shemansky, D.E., Ajello, J.M., Hall, D.T.: Astrophys. J. **296** (1985) 765
86Kha1 Khakoo, M.A., Trajmar, S.: Phys. Rev. A **34** (1986) 146

6.4.5.2 Molecular nitrogen (N_2)

6.4.5.2.1a $J = 0 \rightarrow 2$

Integral cross sections for the $J = 0 \rightarrow 2$ rotational excitation process in N_2 were originally devised by [84Had1]. The validity of these cross sections and their agreement with the quadrupole Born approximation were recently reassessed by [97Rob1]. These swarm-derived ICS form the basis of our preferred integral cross section set, as tabulated in Table 6.4.9a and plotted in Fig. 6.4.9a. We also note the crossed beam study of [82Jun1] at the single electron energy of 2.47 eV ($\nu' = 0 \rightarrow 0$).

The uncertainty on the cross sections is estimated to be ± 10 %.

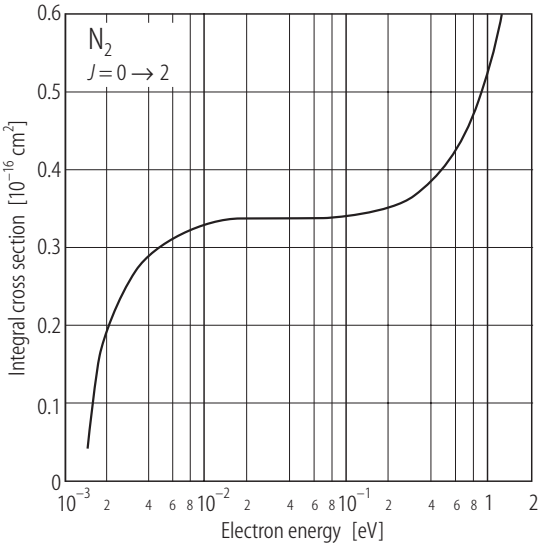

Fig. 6.4.9a. Recommended integral cross section for $J = 0 \rightarrow 2$ in N_2.

Table 6.4.9a. Preferred values of the integral $J = 0 \rightarrow 2$ rotational excitation cross section ($\sigma_{0\text{-}2}$) for electrons in molecular nitrogen.

Energy [eV]	$\sigma_{0\text{-}2}$ [Å^2]	Energy [eV]	$\sigma_{0\text{-}2}$ [Å^2]	Energy [eV]	$\sigma_{0\text{-}2}$ [Å^2]
0.0015	0.043	0.0070	0.319	0.120	0.342
0.0017	0.134	0.0080	0.324	0.140	0.344
0.0020	0.190	0.009	0.327	0.160	0.346
0.0025	0.236	0.010	0.329	0.200	0.351
0.0030	0.262	0.015	0.335	0.350	0.375
0.0035	0.278	0.020	0.337	0.550	0.415
0.0040	0.290	0.030	0.338	0.700	0.450
0.0045	0.298	0.040	0.338	0.800	0.475
0.0050	0.305	0.060	0.338	1.000	0.529
0.0055	0.309	0.080	0.339	1.250	0.608
0.0060	0.313	0.100	0.340		

References for 6.4.5.2.1a

82Jun1 Jung, K., Antoni, Th., Müller, R., Kochem, K-H., Ehrhardt, H.: J. Phys. B: At. Mol. Phys. **15** (1982) 3535

84Had1 Haddad, G.N.: Aust. J. Phys. **37** (1984) 487

97Rob1 Robertson, A.G., Elford, M.T., Crompton, R.W., Morrison, M.M., Sun, W., Trail, W.K.: Aust. J. Phys. **50** (1997) 441

6.4.5.2.1b $\nu' = 0 \rightarrow 1$

Integral cross sections for electron impact excitation of the first vibrational quantum ($\nu' = 0 \rightarrow 1$) in N_2 have been measured by [81Tan1, 86Soh1, 92Bre1, 95Sun1]. We have used all these data sets in constructing our preferred cross section, which is tabulated in Table 6.4.9b and plotted in Fig. 6.4.9b. Specifically, for $\varepsilon \leq 1$ eV we have employed the data of [86Soh1], for 1.5 eV $\leq \varepsilon \leq$ 5 eV we have used the integral cross sections of [92Bre1] and [95Sun1] and, finally, for 7.5 eV $\leq \varepsilon \leq$ 30 eV we have made use of the work of [81Tan1].

The uncertainties in the integral cross sections are estimated to be ± 30 % for $\varepsilon \leq 1$ eV, ± 25 % for 1.5 eV $\leq \varepsilon \leq$ 5 eV and ± 26 % for 7.5 eV $\leq \varepsilon \leq$ 30 eV.

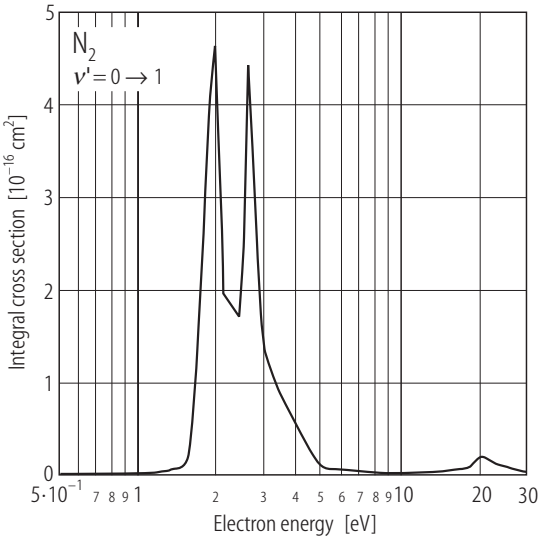

Fig. 6.4.9b. Recommended integral cross section for $\nu' = 0 \rightarrow 1$ in N_2.

Table 6.4.9b. Preferred values of the integral $\nu' = 0 \rightarrow 1$ vibrational excitation cross section ($\sigma_{0\text{-}1}$) for electrons in molecular nitrogen.

Energy [eV]	$\sigma_{0\text{-}1}$ [Å^2]	Energy [eV]	$\sigma_{0\text{-}1}$ [Å^2]	Energy [eV]	$\sigma_{0\text{-}1}$ [Å^2]
0.5	0.005	2.605	4.400	18	0.076
1.0	0.009	3.0	1.370	20	0.195
1.5	0.089	5.0	0.080	22.5	0.126
1.98	4.560	7.5	0.031	25	0.082
2.1	1.970	10	0.015	30	0.027
2.46	1.650	15	0.039		

References for 6.4.5.2.1b

81Tan1 Tanaka, H., Yamamoto, T., Okada, T.: J. Phys. B: At. Mol. Phys. **14** (1981) 2081

86Soh1 Sohn, W., Kochem, K-H., Scheuerlein, K-M., Jung, K., Ehrhardt, H.: J. Phys. B: At. Mol. Phys. **19** (1986) 4017

92Bre1 Brennan, M.J., Alle, D.T., Euripides, P., Buckman, S.J., Brunger, M.J.: J. Phys. B: At. Mol. Opt. Phys. **25** (1992) 2669

95Sun1 Sun, W., Morrison, M.A., Isaacs, W.A., Trail, W.K., Alle, D.T., Gulley, R.J., Brennan, M.J., Buckman, S.J.: Phys. Rev. A **52** (1995) 1229

6.4.5.2.2 $\nu' = 0 \rightarrow 2$

Integral cross sections for electron impact excitation of the second vibrational quantum ($\nu' = 0 \rightarrow 2$) in N_2 have only been reported by [92Bre1]. Furthermore, this data is only given for two energies (ε = 2.1 and 3.0 eV) in the region where the effects of the $^2\Pi_g$ resonance are important. Our preferred integral cross section is taken directly from the data of [92Bre1] and it is tabulated in Table 6.4.10.

The uncertainty in the preferred integral cross section is estimated to be ± 26 %.

Table 6.4.10. Preferred values of the integral $\nu' = 0 \rightarrow 2$ vibrational excitation cross section ($\sigma_{0\text{-}2}$) for electrons in molecular nitrogen.

Energy [eV]	$\sigma_{0\text{-}2}$ [Å^2]
2.1	1.32
3.0	0.90

References for 6.4.5.2.2

92Bre1 Brennan, M.J., Alle, D.T., Euripides, P., Buckman, S.J., Brunger, M.J.: J. Phys. B: At. Mol. Opt. Phys. **25** (1992) 2669

6.4.5.2.3 $\nu' = 0 \rightarrow 3$

Integral cross sections for electron impact excitation of the third vibrational quantum ($\nu' = 0 \rightarrow 3$) in N_2 have also only been reported by [92Bre1], and again only for two energies (ε = 2.1 and 3.0 eV). Our preferred integral cross section is thus taken directly from the data of [92Bre1] and it is tabulated in Table 6.4.11.

The uncertainty in the preferred integral cross section is estimated to be ± 27 %.

Table 6.4.11. Preferred values of the integral v' = 0 → 3 vibrational excitation cross section ($\sigma_{0\text{-}3}$) for electrons in molecular nitrogen.

Energy [eV]	$\sigma_{0\text{-}3}$ [Å^2]
2.1	0.34
3.0	0.26

References for 6.4.5.2.3

92Bre1 Brennan, M.J., Alle, D.T., Euripides, P., Buckman, S.J., Brunger, M.J.: J. Phys. B: At. Mol. Opt. Phys. **25** (1992) 2669

6.4.5.2.4 $X^1\Sigma_g^+ \rightarrow A^3\Sigma_u^+$

The electron impact excitation of the $A^3\Sigma_u^+$ electronic-state of molecular nitrogen ($X^1\Sigma_g^+ \rightarrow A^3\Sigma_u^+$) has been studied in crossed beam measurements by [77Car1] and [01Cam1]. The integral cross sections of [77Car1] were later renormalised by [83Tra1] and it is these latter cross sections that we consider here. The integral cross sections of [01Cam1] were derived from the original differential cross section data of [90Bru1] using a molecular phase shift analysis procedure from [91Boe1]. In addition there are several swarm-based derivations we could consider, with one of the more recent ones by [88Ohm1] being employed in our deliberations in constructing the preferred cross section set. Finally there are two calculations, an R-matrix type from [96Gil1] and a Z-matrix type from [99Huo1], which while not being in perfect agreement with one another, both indicate important near-threshold structure in the integral cross section. The calculations of [96Gil1] and [99Huo1] are both in good agreement with the data of [01Cam1] at the higher overlap energies of 15 eV and 17.5 eV and so we have, for $\varepsilon < 15$ eV, adopted the

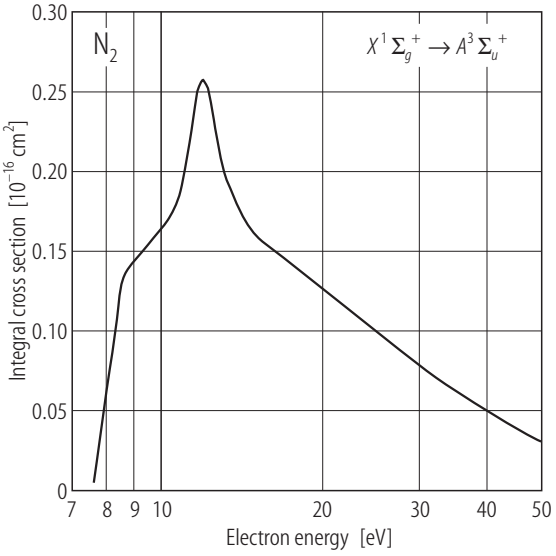

Fig. 6.4.10. Recommended integral cross section for $X^1\Sigma_g^+ \rightarrow A^3\Sigma_u^+$ in N_2.

calculation of [96Gil1] as our preferred cross section set. For $\varepsilon \geq 15$ eV we avoid any potential personal bias by performing a polynomial least squares fit to all the data of [83Tra1, 88Ohm1, 01Cam1] to determine our preferred integral cross section. This preferred cross section is tabulated in Table 6.4.12 and plotted in Fig. 6.4.10.

The uncertainties in the integral cross sections are estimated to be ± 40 % for $\varepsilon < 15$ eV and ± 35 % for 15 eV $\leq \varepsilon \leq$ 50 eV.

Table 6.4.12. Preferred values of the integral $X^1\Sigma_g^+ \rightarrow A^3\Sigma_u^+$ electronic-state excitation cross section ($\sigma_{X\text{-}A}$) for electrons in molecular nitrogen.

Energy [eV]	$\sigma_{X\text{-}A}$ [Å^2]	Energy [eV]	$\sigma_{X\text{-}A}$ [Å^2]	Energy [eV]	$\sigma_{X\text{-}A}$ [Å^2]
7.65	0.005	11.97	0.254	18.0	0.138
7.96	0.048	12.10	0.257	19.0	0.132
8.26	0.085	12.23	0.254	20.0	0.126
8.52	0.125	12.54	0.239	25.0	0.099
8.74	0.137	13.15	0.202	30.0	0.078
9.57	0.153	13.90	0.180	35.0	0.062
10.40	0.168	14.85	0.162	40.0	0.049
10.96	0.183	15.0	0.160	45.0	0.038
11.53	0.226	16.0	0.152	50.0	0.030
11.88	0.251	17.0	0.145		

References for 6.4.5.2.4

77Car1 Cartwright, D.C., Trajmar, S., Chutjian, A., Williams, W.: Phys. Rev. A **16** (1977) 1041
83Tra1 Trajmar, S., Register, D.F., Chutjian, A.: Phys. Rep. **97** (1983) 219
88Ohm1 Ohmori, Y., Shimozuma, M., Tagashira, H.: J. Phys. D: Appl. Phys. **21** (1988) 724
90Bru1 Brunger, M.J., Teubner, P.J.O.: Phys. Rev. A **41** (1990) 1413
91Boe1 Boesten, L., Tanaka, H.: J. Phys. B: At. Mol. Opt. Phys. **24** (1991) 821
96Gil1 Gillan, C.J., Tennyson, J., McLaughlin, B.M., Burke, P.G.: J. Phys. B: At. Mol. Opt. Phys. **29** (1996) 1531
99Huo1 Huo, W.M., Dateo, C.E.: Proc. 21st ICPEAC (1999) 294
01Cam1 Campbell, L., Cartwright, D.C., Harrison, J., Brunger, M.J., Teubner, P.J.O.: J. Phys. B: At. Mol. Opt. Phys. **34** (2001) 1185

6.4.5.2.5 $X^1\Sigma_g^+ \rightarrow B^3\Pi_g$

Integral cross sections for electron impact excitation of the $B^3\Pi_g$ electronic-state of molecular nitrogen ($X^1\Sigma_g^+ \rightarrow B^3\Pi_g$) have been reported by [77Car1, 83Tra1, 88Ohm1, 01Cam1] and an optical measurement by [69Sta1]. In addition, there is a R-matrix theory result from [96Gil1]. With the exception of the work of [77Car1], which was renormalised in [83Tra1], and the optical measurement of [69Sta1], which contained a significant cascade contribution, all of the above were considered when constructing our preferred $B^3\Pi_g$ cross section. Again, to avoid any possible bias, a polynomial least squares fit was made to the available integral cross section data in order to derive our preferred integral cross section. Note that the value of the integral cross section at threshold (7.353 eV) was assumed to be zero. Our preferred integral cross section is tabulated in Table 6.4.13 and plotted in Fig. 6.4.11.

The uncertainty in the integral cross section is estimated to be ± 35 % over the entire energy range considered.

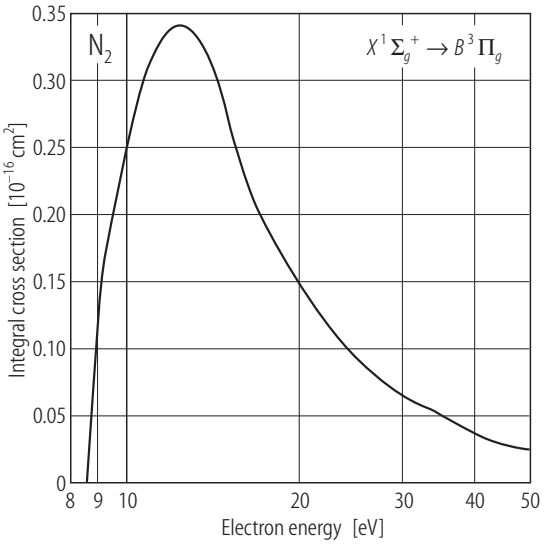

Fig. 6.4.11. Recommended integral cross section for $X^1\Sigma_g^+ \rightarrow B^3\Pi_g$ in N_2.

Table 6.4.13. Preferred values of the integral $X^1\Sigma_g^+ \rightarrow B^3\Pi_g$ electronic-state excitation cross section ($\sigma_{X\text{-}B}$) for electrons in molecular nitrogen.

Energy [eV]	$\sigma_{X\text{-}B}$ [Å^2]	Energy [eV]	$\sigma_{X\text{-}B}$ [Å^2]	Energy [eV]	$\sigma_{X\text{-}B}$ [Å^2]
8.55	0.002	13	0.333	20	0.144
9.0	0.141	13.5	0.323	25	0.092
9.5	0.202	14	0.308	30	0.064
10	0.250	14.5	0.290	35	0.049
10.5	0.287	15	0.270	40	0.036
11	0.313	16	0.224	45	0.028
11.5	0.330	17	0.199	50	0.023
12	0.338	18	0.177		
12.5	0.339	19	0.159		

References for 6.4.5.2.5

69Sta1 Stanton, P.N., St. John, R.M.: J. Opt. Soc. Am. **59** (1969) 252
77Car1 Cartwright, D.C., Trajmar, S., Chutjian, A., Williams, W.: Phys. Rev. A **16** (1977) 1041
83Tra1 Trajmar, S., Register, D.F., Chutjian, A.: Phys. Rep. **97** (1983) 219
88Ohm1 Ohmori, Y., Shimozuma, M., Tagashira, H.: J. Phys. D: Appl. Phys. **21** (1988) 724
96Gil1 Gillan, C.J., Tennyson, J., McLaughlin, B.M., Burke, P.G.: J. Phys. B: At. Mol. Opt. Phys. **29** (1996) 1531
01Cam1 Campbell, L., Cartwright, D.C., Harrison, J., Brunger, M.J., Teubner, P.J.O.: J. Phys. B: At. Mol. Opt. Phys. **34** (2001) 1185

6.4.5.2.6 $X^1\Sigma_g^+ \rightarrow W^3\Delta_u$

The electron impact excitation of the $W^3\Delta_u$ electronic-state of molecular nitrogen ($X^1\Sigma_g^+ \rightarrow W^3\Delta_u$) has been studied in crossed beam measurements by [77Car1] and [01Cam1]. The integral cross sections of [77Car1] were later renormalised by [83Tra1] and it is these latter cross sections that we consider here. Note that the cross sections in [01Cam1] were derived from the original differential cross section measurements of [90Bru1]. There are also several swarm-based cross sections we could consider, with the one from [88Ohm1] being employed in our deliverations in constructing the preferred cross section set. Finally there is an R-matrix calculation from [96Gil1] which, being in excellent agreement with [01Cam1] at ε = 15 and 17.5 eV, we have used to aid us in constructing the near-threshold behaviour of the $W^3\Delta_u$ integral cross section. Our preferred cross section is tabulated in Table 6.4.14 and plotted in Fig. 6.4.12. Note that once again, to avoid any possible potential bias, for $\varepsilon \geq 15$ eV we have used a polynomial least squares fit to the available data to determine our preferred integral cross section.

The uncertainty in the integral cross section is estimated to be ± 35 % over the entire energy range considered.

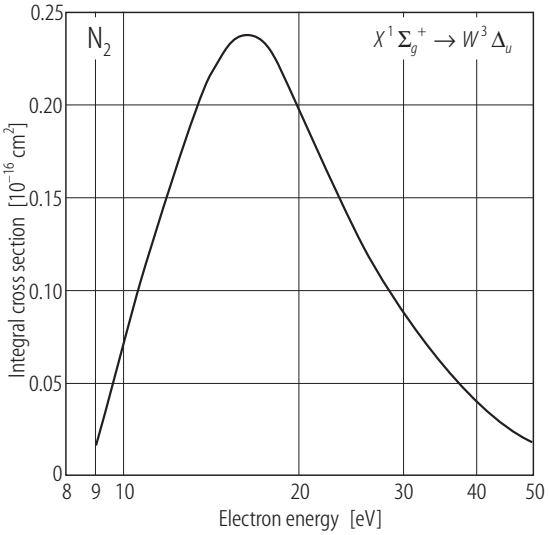

Fig. 6.4.12. Recommended integral cross section for $X^1\Sigma_g^+ \rightarrow W^3\Delta_u$ in N_2.

Table 6.4.14. Preferred values of the integral $X^1\Sigma_g^+ \rightarrow W^3\Delta_u$ electronic-state excitation cross section ($\sigma_{X\text{-}W}$) for electrons in molecular nitrogen.

Energy [eV]	$\sigma_{X\text{-}W}$ [Å^2]	Energy [eV]	$\sigma_{X\text{-}W}$ [Å^2]	Energy [eV]	$\sigma_{X\text{-}W}$ [Å^2]
9	0.017	13.5	0.205	20	0.194
9.5	0.045	14	0.216	25	0.131
10	0.072	14.5	0.224	30	0.088
10.5	0.096	15	0.231	35	0.059
11	0.119	16	0.238	40	0.040
11.5	0.140	16.5	0.238	45	0.027
12	0.159	17	0.236	50	0.018
12.5	0.176	18	0.227		
13	0.191	19	0.209		

References for 6.4.5.2.6

77Car1 Cartwright, D.C., Trajmar, S., Chutjian, A., Williams, W.: Phys. Rev. A **16** (1977) 1041
83Tra1 Trajmar, S., Register, D.F., Chutjian, A.: Phys. Rep. **97** (1983) 219
88Ohm1 Ohmori, Y., Shimozuma, M., Tagashira, H.: J. Phys. D: Appl. Phys. **21** (1988) 724
90Bru1 Brunger, M.J., Teubner, P.J.O.: Phys. Rev. A **41** (1990) 1413
96Gil1 Gillan, C.J., Tennyson, J., McLaughlin, B.M., Burke, P.G.: J. Phys. B: At. Mol. Opt. Phys. **29** (1996) 1531
01Cam1 Campbell, L., Cartwright, D.C., Harrison, J., Brunger, M.J., Teubner, P.J.O.: J. Phys. B: At. Mol. Opt. Phys. **34** (2001) 1185

6.4.5.2.7 $X^1\Sigma_g^+ \rightarrow B'^3\Sigma_u^-$

Integral cross sections for electron impact excitation of the $B'^3\Sigma_u^-$ electronic-state of molecular nitrogen ($X^1\Sigma_g^+ \rightarrow B'^3\Sigma_u^-$) have been reported by [77Car1, 83Tra1, 88Ohm1, 01Cam1]. In addition, there is an R-matrix theory result from [96Gil1]. With the exception of the work of [77Car1], which was renormalised by [83Tra1], all of the above were considered when constructing our preferred $B'^3\Sigma_u^-$ cross section. To avoid any possible bias, a polynomial least squares fit was made to the available integral cross section data in order to derive our preferred integral cross section. Our preferred cross section is tabulated in Table 6.4.15 and plotted in Fig. 6.4.13.

The uncertainty in the integral cross section is estimated to be ± 40 % over the entire energy range considered.

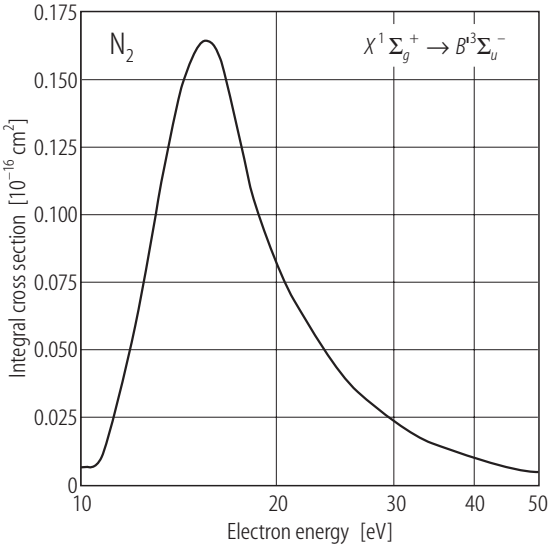

Fig. 6.4.13. Recommended integral cross section for $X^1\Sigma_g^+ \rightarrow B'^3\Sigma_u^-$ in N_2.

Table 6.4.15. Preferred values of the integral $X^1\Sigma_g^+ \rightarrow B'^3\Sigma_u^-$ electronic-state excitation cross section ($\sigma_{X\text{-}B'}$) for electrons in molecular nitrogen.

Energy [eV]	$\sigma_{X\text{-}B'}$ [Å^2]	Energy [eV]	$\sigma_{X\text{-}B'}$ [Å^2]	Energy [eV]	$\sigma_{X\text{-}B'}$ [Å^2]
10	0.007	14.5	0.155	19	0.093
10.5	0.008	15	0.163	19.5	0.086
11	0.019	15.5	0.165	20	0.080
11.5	0.037	16	0.162	25	0.041
12	0.058	16.5	0.153	30	0.024
12.5	0.082	17	0.140	35	0.015
13	0.105	17.5	0.124	40	0.010
13.5	0.125	18	0.110	45	0.007
14	0.143	18.5	0.101	50	0.005

References for 6.4.5.2.7

77Car1 Cartwright, D.C., Trajmar, S., Chutjian, A., Williams, W.: Phys. Rev. A **16** (1977) 1041
83Tra1 Trajmar, S., Register, D.F., Chutjian, A.: Phys. Rep. **97** (1983) 219
88Ohm1 Ohmori, Y., Shimozuma, M., Tagashira, H.: J. Phys. D: Appl. Phys. **21** (1988) 724
96Gil1 Gillan, C.J., Tennyson, J., McLaughlin, B.M., Burke, P.G.: J. Phys. B: At. Mol. Opt. Phys. **29** (1996) 1531
01Cam1 Campbell, L., Cartwright, D.C., Harrison, J., Brunger, M.J., Teubner, P.J.O.: J. Phys. B: At. Mol. Opt. Phys. **34** (2001) 1185

6.4.5.2.8 $X^1\Sigma_g^+ \rightarrow a'^1\Sigma_u^-$

There is a very good level of agreement between all the reported integral cross sections for electron impact excitation of the $a'^1\Sigma_u^-$ electronic-state of molecular nitrogen ($X^1\Sigma_g^+ \rightarrow a'^1\Sigma_u^-$). This work is due to [83Tra1, 88Ohm1, 01Cam1]. Nonetheless, a polynomial least squares fit was still made to the available data in order to derive our preferred integral $a'^1\Sigma_u^-$ cross section. This cross section is tabulated in Table 6.4.16 and plotted in Fig. 6.4.14. Note that the value of the integral cross section at threshold (8.398 eV) was assumed to be zero.

The uncertainty in the integral cross section is estimated to be ± 30 % over the entire energy range considered.

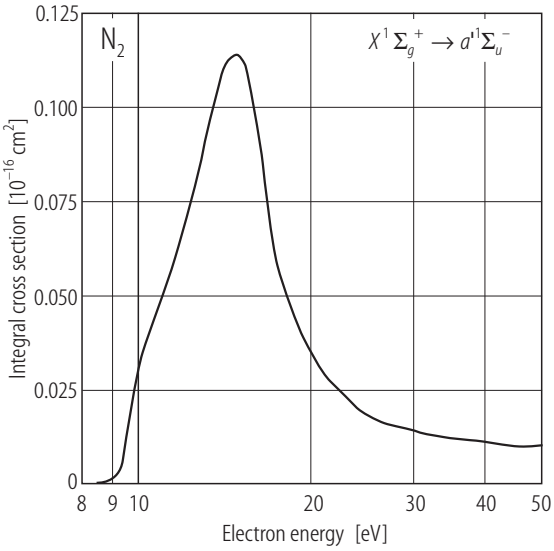

Fig. 6.4.14. Recommended integral cross section for $X^1\Sigma_g^+ \rightarrow a'^1\Sigma_u^-$ in N_2.

Table 6.4.16. Preferred values of the integral $X^1\Sigma_g^+ \rightarrow a'^1\Sigma_u^-$ electronic-state excitation cross section ($\sigma_{X\text{-}a'}$) for electrons in molecular nitrogen.

Energy [eV]	$\sigma_{X\text{-}a'}$ [Å^2]	Energy [eV]	$\sigma_{X\text{-}a'}$ [Å^2]	Energy [eV]	$\sigma_{X\text{-}a'}$ [Å^2]
8.4	0.000	13.5	0.101	18.5	0.045
9.4	0.006	14	0.110	19	0.041
9.5	0.011	14.5	0.113	20	0.034
10	0.031	15	0.113	25	0.018
10.5	0.042	15.5	0.107	30	0.014
11	0.051	16	0.095	35	0.012
11.5	0.059	16.5	0.079	40	0.011
12	0.069	17	0.063	45	0.010
12.5	0.080	17.5	0.056	50	0.010
13	0.091	18	0.050		

References for 6.4.5.2.8

83Tra1 Trajmar, S., Register, D.F., Chutjian, A.: Phys. Rep. **97** (1983) 219
88Ohm1 Ohmori, Y., Shimozuma, M., Tagashira, H.: J. Phys. D: Appl. Phys. **21** (1988) 724
01Cam1 Campbell, L., Cartwright, D.C., Harrison, J., Brunger, M.J., Teubner, P.J.O.: J. Phys. B: At. Mol. Opt. Phys.**34** (2001) 1185

6.4.5.2.9 $X^1\Sigma_g^+ \rightarrow a^1\Pi_g$

The electron impact excitation of the $a^1\Pi_g$ electronic-state of molecular nitrogen ($X^1\Sigma_g^+ \rightarrow a^1\Pi_g$) has been studied in detail by the crossed beam measurements of [77Car1, 76Fin1, 83Tra1, 87Mas1, 01Cam1]. We also note the swarm-based determination from [88Ohm1]. With the exception of the work of [77Car1], which was renormalised by [83Tra1], all of the above integral cross section determinations were considered by us in constructing our preferred cross section set. As before, we avoid any possible bias by employing a polynomial least squares fit to the available data to determine our preferred integral cross section. This cross section is tabulated in Table 6.4.17 and plotted in Fig. 6.4.15.

The uncertainty in the integral cross section is estimated to be ± 25 % over the entire energy range considered.

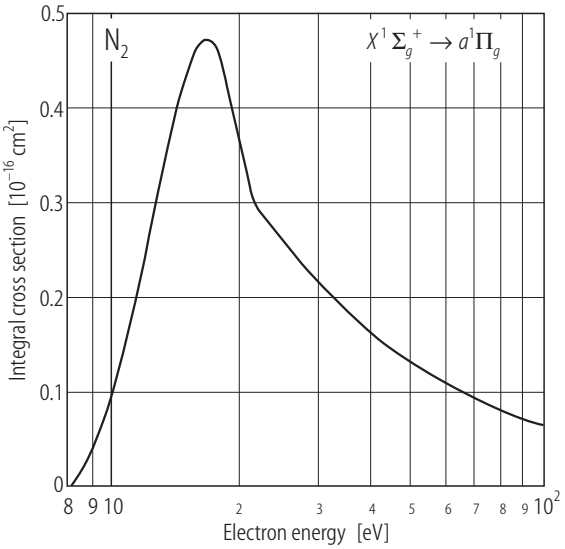

Fig. 6.4.15. Recommended integral cross section for $X^1\Sigma_g^+ \rightarrow a^1\Pi_g$ in N_2.

Table 6.4.17. Preferred values of the integral $X^1\Sigma_g^+ \rightarrow a^1\Pi_g$ electronic-state excitation cross section ($\sigma_{X\text{-}a}$) for electrons in molecular nitrogen.

Energy [eV]	$\sigma_{X\text{-}a}$ [Å^2]	Energy [eV]	$\sigma_{X\text{-}a}$ [Å^2]	Energy [eV]	$\sigma_{X\text{-}a}$ [Å^2]
8	0.001	15.5	0.459	35	0.185
8.5	0.016	16	0.469	40	0.161
9	0.038	16.5	0.473	45	0.144
9.5	0.066	17	0.471	50	0.129
10	0.099	17.5	0.462	60	0.108
11	0.174	18	0.446	70	0.092
12	0.254	19	0.394	80	0.081
13	0.329	21.5	0.300	90	0.072
14	0.394	25	0.258	100	0.065
15	0.443	30	0.215		

References for 6.4.5.2.9

76Fin1 Finn, T.G., Doering, J.P.: J. Chem. Phys. **64** (1976) 4490
77Car1 Cartwright, D.C., Trajmar, S., Chutjian, A., Williams, W.: Phys. Rev. A **16** (1977) 1041
83Tra1 Trajmar, S., Register, D.F., Chutjian, A.: Phys. Rep. **97** (1983) 219
87Mas1 Mason, N.J., Newell, W.R.: J. Phys. B **20** (1987) 3913
88Ohm1 Ohmori, Y., Shimozuma, M., Tagashira, H.: J. Phys. D: Appl. Phys. **21** (1988) 724
01Cam1 Campbell, L., Cartwright, D.C., Harrison, J., Brunger, M.J., Teubner, P.J.O.: J. Phys. B: At. Mol. Opt. Phys. **34** (2001) 1185

6.4.5.2.10 $X^1\Sigma_g^+ \rightarrow w^1\Delta_u$

There is a very good level of agreement between all the available integral cross sections for electron impact excitation of the $w^1\Delta_u$ electronic-state of molecular nitrogen ($X^1\Sigma_g^+ \rightarrow w^1\Delta_u$). Specifically we refer to the work of [83Tra1, 88Ohm1, 01Cam1]. A polynomial least squares fit to this data is again used to construct our preferred integral cross section, which is tabulated in Table 6.4.18 and plotted in Fig. 6.4.16.

The uncertainty in the integral cross section is estimated to be ± 30 % over the entire energy range considered.

Table 6.4.18. Preferred values of the integral $X^1\Sigma_g^+ \rightarrow w^1\Delta_u$ electronic-state excitation cross section ($\sigma_{X\text{-}w}$) for electrons in molecular nitrogen.

Energy [eV]	$\sigma_{X\text{-}w}$ [Å^2]	Energy [eV]	$\sigma_{X\text{-}w}$ [Å^2]	Energy [eV]	$\sigma_{X\text{-}w}$ [Å^2]
8.9	0.0001	13.0	0.105	19.0	0.044
9.0	0.002	13.5	0.105	20.0	0.040
9.5	0.024	14.0	0.103	25.0	0.026
10.0	0.043	14.5	0.099	30.0	0.018
10.5	0.061	15.0	0.093	35.0	0.013
11.0	0.076	15.5	0.086	40.0	0.010
11.5	0.088	16.0	0.078	45.0	0.008
12.0	0.096	17.0	0.062	50.0	0.006
12.5	0.102	18.0	0.049		

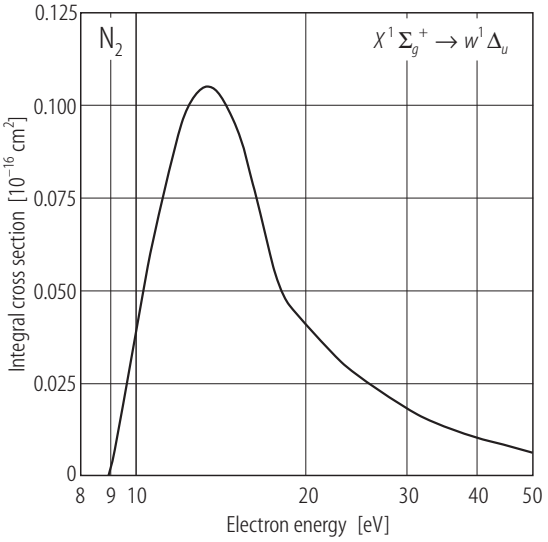

Fig. 6.4.16. Recommended integral cross section for $X^1\Sigma_g^+ \rightarrow w^1\Delta_u$ in N_2.

References for 6.4.5.2.10

83Tra1 Trajmar, S., Register, D.F., Chutjian, A.: Phys. Rep. **97** (1983) 219

88Ohm1 Ohmori, Y., Shimozuma, M., Tagashira, H.: J. Phys. D: Appl. Phys. **21** (1988) 724

01Cam1 Campbell, L., Cartwright, D.C., Harrison, J., Brunger, M.J., Teubner, P.J.O.: J. Phys. B: At. Mol. Opt. Phys. **34** (2001) 1185

6.4.5.2.11 $X^1\Sigma_g^+ \rightarrow C^3\Pi_u$

Integral cross sections for electron impact excitation of the $C^3\Pi_u$ electronic-state of molecular nitrogen ($X^1\Sigma_g^+ \rightarrow C^3\Pi_u$) have been reported by [77Car1, 83Tra1, 88Ohm1 94Zub1, 99Pop1, 01Cam1]. With the exception of the work of [77Car1], which was renormalised by [83Tra1], all of the above were considered when constructing our preferred $C^3\Pi_u$ cross section. This is particularly the case for $\varepsilon \geq 20$ eV where [83Tra1, 94Zub1, 01Cam1] are all in good accord with one another. On the other hand, for $\varepsilon < 20$ eV the data of [94Zub1, 99Pop1, 01Cam1] are in better agreement with one another than with [83Tra1]. Consequently for $\varepsilon < 20$ eV only the data of [94Zub1, 99Pop1, 01Cam1] were employed in our polynomial least squares fit procedure. Indeed we note that for $\varepsilon < 15$ eV the preferred integral cross section was essentially constructed entirely from the recent measurement of [99Pop1]. Our preferred integral cross section is tabulated in Table 6.4.19 and plotted in Fig. 6.4.17.

The uncertainty in the integral cross section is estimated to be ± 30 % over the entire energy range considered.

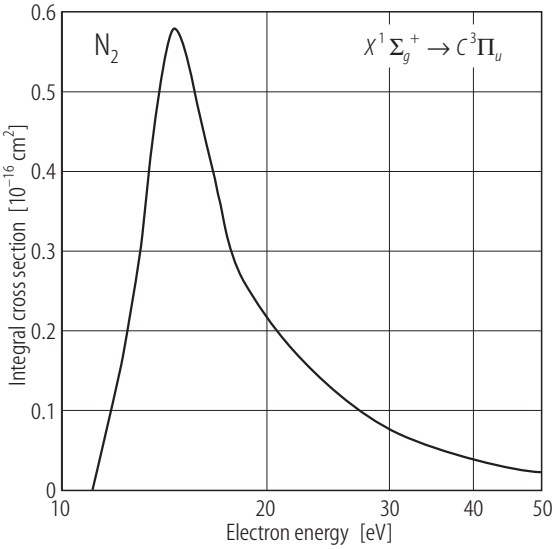

Fig. 6.4.17. Recommended integral cross section for $X^1\Sigma_g^+ \rightarrow C^3\Pi_u$ in N_2.

Table 6.4.19. Preferred values of the integral $X^1\Sigma_g^+ \rightarrow C^3\Pi_u$ electronic-state excitation cross section ($\sigma_{X\text{-}C}$) for electrons in molecular nitrogen.

Energy [eV]	$\sigma_{X\text{-}C}$ [Å^2]	Energy [eV]	$\sigma_{X\text{-}C}$ [Å^2]	Energy [eV]	$\sigma_{X\text{-}C}$ [Å^2]
11.0	0.001	15.7	0.478	20.0	0.212
11.5	0.074	16.0	0.447	25.0	0.122
12.0	0.147	16.5	0.403	30.0	0.077
12.5	0.229	17.0	0.353	35.0	0.052
13.0	0.335	17.5	0.302	40.0	0.038
13.5	0.455	18.0	0.276	45.0	0.028
14.0	0.551	18.5	0.258	50.0	0.022
14.5	0.583	19.0	0.242		
15.0	0.551	19.5	0.226		

References for 6.4.5.2.11

77Car1 Cartwright, D.C., Trajmar, S., Chutjian, A., Williams, W.: Phys. Rev. A **16** (1977) 1041
83Tra1 Trajmar, S., Register, D.F., Chutjian, A.: Phys. Rep. **97** (1983) 219
88Ohm1 Ohmori, Y., Shimozuma, M., Tagashira, H.: J. Phys. D: Appl. Phys. **21** (1988) 724
94Zub1 Zubek, M., King, G.C.: J. Phys. B: At. Mol. Opt. Phys. **27** (1994) 2613
99Pop1 Poparic, G., Vicic, M., Belic, D.S.: Chem. Phys. **240** (1999) 283
01Cam1 Campbell, L., Cartwright, D.C., Harrison, J., Brunger, M.J., Teubner, P.J.O.: J. Phys. B: At. Mol. Opt. Phys. **34** (2001) 1185

6.4.5.2.12 $X^1\Sigma_g^+ \rightarrow E^3\Sigma_g^+$

For $\varepsilon \geq 15$ eV there is a quite good level of agreement between the crossed-beam measurements of [83Tra1, 94Zub1, 01Cam1], for electron impact excitation of the $E^3\Sigma_g^+$ electronic-state of molecular nitrogen ($X^1\Sigma_g^+ \rightarrow E^3\Sigma_g^+$). Consequently a polynomial least squares fit was made to all this data in order, for $\varepsilon \geq 15$ eV, to derive our preferred $E^3\Sigma_g^+$ integral cross section. Near-threshold, however, there had been a serious discrepancy between [72Bor1] and [88Bru1] as to the magnitude and position of the resonance-enhanced cross section. This discrepancy was recently resolved by [99Pop2] in favour of [88Bru1]. Thus the near-threshold behaviour of our preferred integral cross section was constructed from [88Bru1] and [99Pop2]. Our preferred integral cross section is tabulated in Table 6.4.20 and plotted in Fig. 6.4.18.

The uncertainty in the integral cross section is estimated to be ± 40 % over the entire energy range considered.

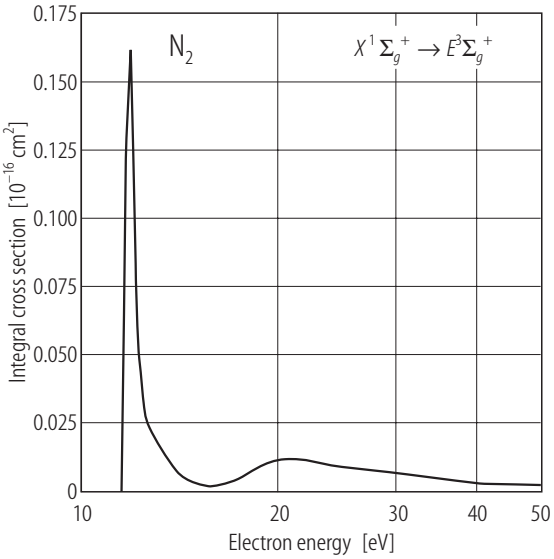

Fig. 6.4.18. Recommended integral cross section for $X^1\Sigma_g^+ \rightarrow E^3\Sigma_g^+$ in N_2.

Table 6.4.20. Preferred values of the integral $X^1\Sigma_g^+ \rightarrow E^3\Sigma_g^+$ electronic-state excitation cross section ($\sigma_{X\text{-}E}$) for electrons in molecular nitrogen.

Energy [eV]	$\sigma_{X\text{-}E}$ [Å^2]	Energy [eV]	$\sigma_{X\text{-}E}$ [Å^2]	Energy [eV]	$\sigma_{X\text{-}E}$ [Å^2]
11.5	0.000	15.0	0.003	25.0	0.009
11.9	0.148	16.0	0.002	30.0	0.007
11.95	0.120	17.0	0.004	35.0	0.005
12.0	0.095	18.0	0.007	40.0	0.003
12.5	0.029	19.0	0.010	45.0	0.0025
13.0	0.020	20.0	0.012	50.0	0.0018
14.0	0.008	21.0	0.012		

References for 6.4.5.2.12

72Bor1 Borst, W.L., Wells, W.C., Zipf, E.: Phys. Rev. A **5** (1972) 1744
83Tra1 Trajmar, S., Register, D.F., Chutjian, A.: Phys. Rep. **97** (1983) 219
88Bru1 Brunger, M.J., Teubner, P.J.O., Buckman, S.J.: Phys. Rev. A **37** (1988) 3570
88Ohm1 Ohmori, Y., Shimozuma, M., Tagashira, H.: J. Phys. D: Appl. Phys. **21** (1988) 724
94Zub1 Zubek, M., King, G.C.: J. Phys. B: At. Mol. Opt. Phys. **27** (1994) 2613
99Pop2 Poparic, G., Vicic, M., Belic, D.S.: Phys. Rev. A **60** (1999) 4542
01Cam1 Campbell, L., Cartwright, D.C., Harrison, J., Brunger, M.J., Teubner, P.J.O.: J. Phys. B: At. Mol. Opt. Phys. **34** (2001) 1185

6.4.5.2.13 $X^1\Sigma_g^+ \rightarrow a''^1\Sigma_g^+$

Integral cross sections for electron impact excitation of the $a''^1\Sigma_g^+$ electronic-state in N_2 ($X^1\Sigma_g^+ \rightarrow a''^1\Sigma_g^+$) have been reported by [83Tra1, 88Ohm1, 01Cam1]. The crossed-beam data of [83Tra1] and [01Cam1] are generally in good agreement with each other, although both are somewhat stronger in magnitude than the swarm-derived result from [88Ohm1]. We have employed a least squares polynomial fit to the integral cross sections of [83Tra1] and [01Cam1] in order to derive our preferred $a''^1\Sigma_g^+$ cross section, with the result being tabulated in Table 6.4.21 and plotted in Fig. 6.4.19.

The uncertainty in the integral cross section is estimated to be ± 33 % over the entire energy range considered.

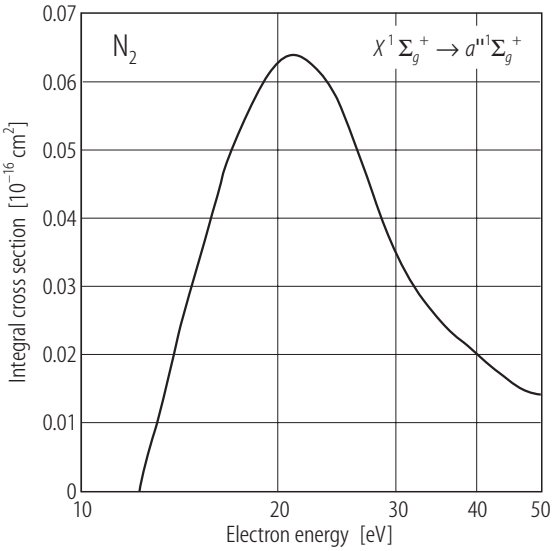

Fig. 6.4.19. Recommended integral cross section for $X^1\Sigma_g^+ \rightarrow a''^1\Sigma_g^+$ in N_2.

Table 6.4.21. Preferred values of the integral $X^1\Sigma_g^+ \rightarrow a''^1\Sigma_g^+$ electronic-state excitation cross section ($\sigma_{X\text{-}a''}$) for electrons in molecular nitrogen.

Energy [eV]	$\sigma_{X\text{-}a''}$ [Å^2]	Energy [eV]	$\sigma_{X\text{-}a''}$ [Å^2]
12.25	0.000	22.0	0.063
13.0	0.009	23.0	0.062
14.0	0.022	24.0	0.059
15.0	0.033	25.0	0.055
16.0	0.042	27.5	0.044
17.0	0.050	30.0	0.035
18.0	0.056	35.0	0.025
19.0	0.060	40.0	0.020
20.0	0.063	45.0	0.016
21.0	0.064	50.0	0.014

References for 6.4.5.2.13

83Tra1 Trajmar, S., Register, D.F., Chutjian, A.: Phys. Rep. **97** (1983) 219
88Ohm1 Ohmori, Y., Shimozuma, M., Tagashira, H.: J. Phys. D: Appl. Phys. **21** (1988) 724
01Cam1 Campbell, L., Cartwright, D.C., Harrison, J., Brunger, M.J., Teubner, P.J.O.: J. Phys. B: At. Mol. Opt. Phys. **34** (2001) 1185

6.4.5.3 Oxygen (O_2)

6.4.5.3.1 $\nu' = 0 \rightarrow 1$

There are two integral cross section measurements for $\nu' = 0 \rightarrow 1$ rovibrational excitation in O_2 available in the literature. They are due to [93Shy1], at 5, 7, 10 and 15 eV, and [96Nob1] at 10 energies in the range 5 eV to 20 eV. The agreement between these two measurements, in terms of the magnitude of the ICS at common energies, is generally fair. Consequently, we have constructed our preferred set from the more extensive measurements of [96Nob1]. These data are tabulated in Table 6.4.22 and plotted in Fig. 6.4.20.

The uncertainty in the integral cross section is estimated to be ± 20 % over the entire range of electron energies.

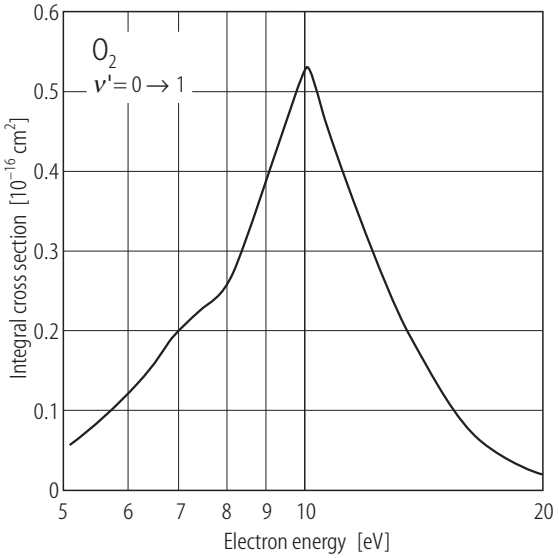

Fig. 6.4.20. Recommended integral cross section for $\nu' = 0 \rightarrow 1$ in O_2.

Table 6.4.22. Preferred values of the integral $\nu' = 0 \rightarrow 1$ vibrational excitation cross section ($\sigma_{0\text{-}1}$) for electrons in molecular oxygen.

Energy [eV]	$\sigma_{0\text{-}1}$ [Å^2]	Energy [eV]	$\sigma_{0\text{-}1}$ [Å^2]
5	0.052	9.5	0.464
6	0.116	10	0.536
7	0.202	11	0.406
8	0.256	15	0.116
9	0.403	20	0.018

References for 6.4.5.3.1

93Shy1 Shyn, T.W., Sweeney, C.J.: Phys. Rev. A **48** (1993) 1214
96Nob1 Noble, C.J., Higgins, K., Wöste, G., Duddy, P., Burke, P.G., Teubner, P.J.O., Middleton, A.G., Brunger, M.J.: Phys. Rev. Lett. **76** (1996) 3534

6.4.5.3.2 $\nu' = 0 \rightarrow 2$

The available integral cross section measurements for $\nu' = 0 \rightarrow 2$ rovibrational excitation in O_2 are again due to [93Shy1] and [96Nob1]. In this case the ICS of [96Nob1] were measured at eight energies in the range 6 - 15 eV, while [93Shy1] reported data at 5 eV, 7 eV, 10 eV, 15 eV. Agreement between the two measurements is not so good in this case, the R-matrix calculation of [96Nob1] indicating their data has the more physical shape. Thus we have constructed our preferred set (see Table 6.4.23 and Fig. 6.4.21) from the measurements of [96Nob1].

The uncertainty in the integral cross section is estimated to be ± 22 % over the entire range of electron energies.

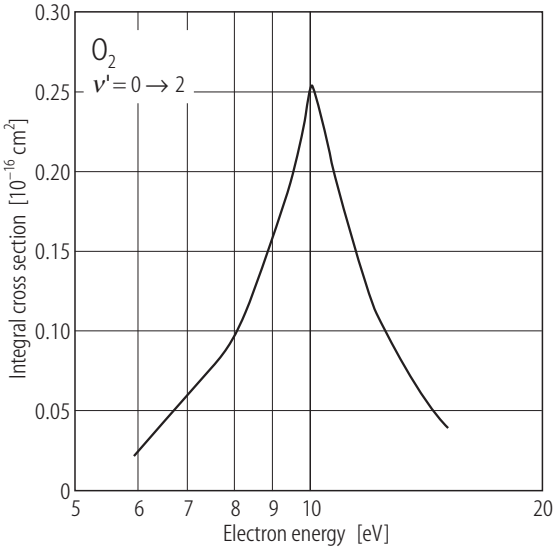

Fig. 6.4.21. Recommended integral cross section for $\nu' = 0 \rightarrow 2$ in O_2.

Table 6.4.23. Preferred values of the integral $\nu' = 0 \rightarrow 2$ vibrational excitation cross section ($\sigma_{0\text{-}2}$) for electrons in molecular oxygen.

Energy [eV]	$\sigma_{0\text{-}2}$ [Å^2]
6	0.023
7	0.060
8	0.096
9	0.163
9.5	0.201
10	0.255
11	0.175
15	0.039

References for 6.4.5.3.2

93Shy1 Shyn, T.W., Sweeney, C.J.: Phys. Rev. A **48** (1993) 1214

96Nob1 Noble, C.J., Higgins, K., Wöste, G., Duddy, P., Burke, P.G., Teubner, P.J.O., Middleton, A.G., Brunger, M.J.: Phys. Rev. Lett. **76** (1996) 3534

6.4.5.3.3 $\nu' = 0 \rightarrow 3$

The integral cross section measurements for $\nu' = 0 \rightarrow 3$ rovibrational excitation in O_2 are due to [93Shy1] and [96Nob1] and both are restricted to the energy range 7 - 15 eV. In this case [93Shy1] and [96Nob1] are in fair agreement with one another and so we have used the more comprehensive data base of [96Nob1] to construct our preferred integral cross section set. These data are tabulated in Table 6.4.24 and plotted in Fig. 6.4.22.

The uncertainty in the integral cross section is estimated to be ± 24 % over the entire range of electron energies.

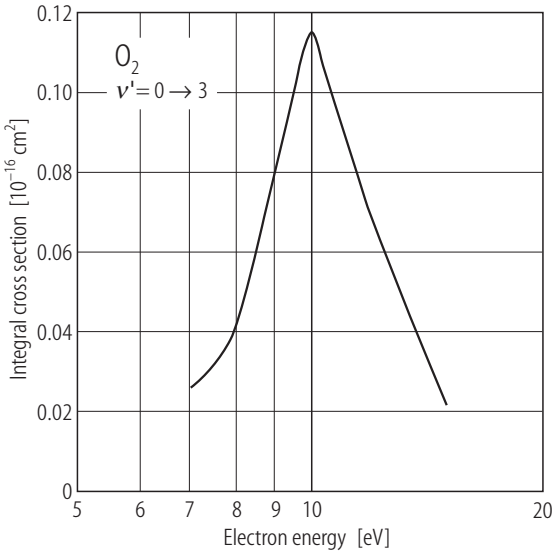

Fig. 6.4.22. Recommended integral cross section for $\nu' = 0 \rightarrow 3$ in O_2.

Table 6.4.24. Preferred values of the integral $\nu' = 0 \rightarrow 3$ vibrational excitation cross section ($\sigma_{0\text{-}3}$) for electrons in molecular oxygen.

Energy [eV]	$\sigma_{0\text{-}3}$ [Å^2]
7	0.026
8	0.041
9	0.081
9.5	0.101
10	0.115
11	0.090
15	0.022

References for 6.4.5.3.3

93Shy1 Shyn, T.W., Sweeney, C.J.: Phys. Rev. A **48** (1993) 1214
96Nob1 Noble, C.J., Higgins, K., Wöste, G., Duddy, P., Burke, P.G., Teubner, P.J.O., Middleton, A.G., Brunger, M.J.: Phys. Rev. Lett. **76** (1996) 3534

6.4.5.3.4 $\nu' = 0 \rightarrow 4$

Our preferred integral cross section set for $\nu' = 0 \rightarrow 4$ rovibrational excitation in O_2 is taken from [96Nob1]. These data are tabulated in Table 6.4.25 and plotted in Fig. 6.4.23.

The uncertainty in the integral cross section is estimated to be ± 26 % over the entire range of electron energies.

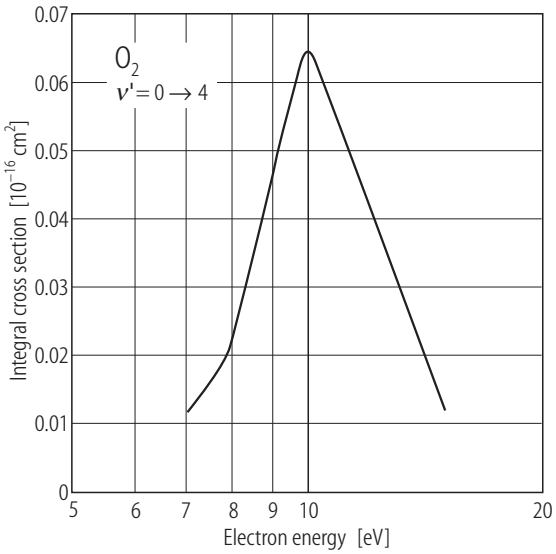

Fig. 6.4.23. Recommended integral cross section for $\nu' = 0 \rightarrow 4$ in O_2.

Table 6.4.25. Preferred values of the integral $\nu' = 0 \rightarrow 4$ vibrational excitation cross section ($\sigma_{0\text{-}4}$) for electrons in molecular oxygen.

Energy [eV]	$\sigma_{0\text{-}4}$ [Å^2]
7	0.012
8	0.023
9	0.047
9.5	0.058
10	0.065
11	0.053
15	0.012

References for 6.4.5.3.4

96Nob1 Noble, C.J., Higgins, K., Wöste, G., Duddy, P., Burke, P.G., Teubner, P.J.O., Middleton, A.G., Brunger, M.J.: Phys. Rev. Lett. 76 (1996) 3534

6.4.5.3.5 $X^3\Sigma_g^- \rightarrow a^1\Delta_g$

Experimental integral cross sections for electron impact excitation of the $a^1\Delta_g$ electronic state of O_2 have been reported by many groups. These include [71Lin2, 71Traj1, 70Kon1, 78Wak1, 92Doe1, 93Shy2, 92Mid1]. Away from the characteristic $^2\Pi_u$ resonance the data of [71Traj1] and [92Mid1] are in quite good agreement, although their agreement with the other measurements is "patchy". This observation is, at least in part, reflected in the uncertainty estimates we provide for our preferred integral cross section set. At and near resonance only the data of [92Mid1] provides a fine enough energy grid for the structure to be observed. Consequently our preferred integral cross section set for 5 eV < $\varepsilon \leq$ 20 eV is largely drawn from the work of [92Mid1]. Below 5 eV our preferred cross section, given the limited availability of experimental data, is taken from the reliable R-matrix calculation of [92Nob1]. The recommended integral cross section for $X^3\Sigma_g^- \rightarrow a^1\Delta_g$ is tabulated in Table 6.4.26 and plotted in Fig. 6.4.24.

The uncertainty in the integral cross section is estimated to be ± 30 % for ε < 5 eV and ± 28 % for 5 eV ≤ $\varepsilon \leq$ 20 eV.

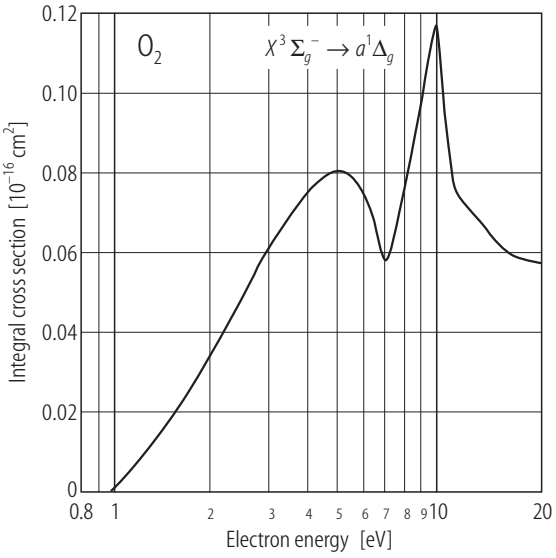

Fig. 6.4.24. Recommended integral cross section for $X^3\Sigma_g^- \rightarrow a^1\Delta_g$ in O_2.

Table 6.4.26. Preferred values of the integral $X^3\Sigma_g^- \rightarrow a^1\Delta_g$ electronic-state excitation cross section ($\sigma_{X\text{-}a}$) for electrons in molecular oxygen.

Energy [eV]	$\sigma_{X\text{-}a}$ [Å^2]	Energy [eV]	$\sigma_{X\text{-}a}$ [Å^2]
0.98	0.000	8	0.078
2	0.034	9	0.098
3	0.061	9.5	0.111
4	0.075	10	0.117
5	0.080	11	0.081
6	0.073	15	0.063
7	0.057	20	0.057

References for 6.4.5.3.5

70Kon1 Konishi, A., Wakiya, K., Yamamoto, M., Suzuki, H.: J. Phys. Soc. Jpn. **29** (1970) 526
71Lin2 Linder, F., Schmidt, H.: Z. Naturforsch. A **26** (1971) 1617
71Traj1 Trajmar, S., Cartwright, D.C., Williams, W.: Phys. Rev. A **4** (1971) 1482
78Wak1 Wakiya, K.: J. Phys. B: At. Mol. Phys. **11** (1978) 3931
92Doe1 Doering, J.P.: J. Geophys. Res. **97** (1992) 12267
92Mid1 Middleton, A.G., Teubner, P.J.O., Brunger, M.J.: Phys. Rev. Lett. **69** (1992) 2495
92Nob1 Noble, C.J., Burke, P.G.: Phys. Rev. Lett. **68** (1992) 2011
93Shy2 Shyn, T.W., Sweeney, C.J.: Phys. Rev. A **47** (1993), 1006

6.4.5.3.6 $X^3\Sigma_g^- \rightarrow b^1\Sigma_g^+$

Measurements of integral cross sections for electron impact excitation of the $b^1\Sigma_g^+$ electronic state of O_2 are due to [71Lin2, 71Traj1, 70Kon1, 78Wak1, 92Doe1, 93Shy2, 92Mid1]. Agreement between these various measurements ranges from very good to marginal, with perhaps best accord being found between the data of [71Traj1] and [92Mid1]. This scatter in the available data has led to somewhat larger estimates in the uncertainties on our preferred integral cross sections than would otherwise be the case. Our preferred integral cross section, for $\varepsilon \geq 7$ eV, is largely drawn from the work of [92Mid1], with some modest adjustments. For $\varepsilon < 7$ eV we have employed the R-matrix calculation of [92Nob1]. These data are tabulated in Table 6.4.27 and plotted in Fig. 6.4.25.

The uncertainty in the integral cross section is estimated to be ± 35 % for $\varepsilon < 7$ eV and ± 31 % for 7 eV $\leq \varepsilon \leq$ 20 eV.

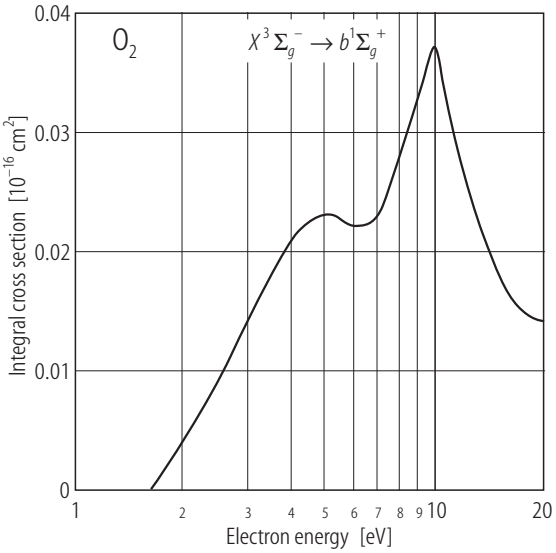

Fig. 6.4.25. Recommended integral cross section for $X^3\Sigma_g \rightarrow b^1\Sigma_g^+$ in O_2.

Table 6.4.27. Preferred values of the integral $X^3\Sigma_g^- \rightarrow b^1\Sigma_g^+$ electronic-state excitation cross section ($\sigma_{X\text{-}b}$) for electrons in molecular oxygen.

Energy [eV]	$\sigma_{X\text{-}b}$ [Å^2]	Energy [eV]	$\sigma_{X\text{-}b}$ [Å^2]
1.63	0	8	0.028
2	0.004	9	0.033
3	0.014	9.5	0.036
4	0.021	10	0.037
5	0.023	11	0.031
6	0.022	15	0.018
7	0.023	20	0.014

References for 6.4.5.3.6

70Kon1 Konishi, A., Wakiya, K., Yamamoto, M., Suzuki, H.: J. Phys. Soc. Jpn. **29** (1970) 526
71Lin2 Linder, F., Schmidt, H.: Z. Naturforsch. A **26** (1971) 1617
71Traj1 Trajmar, S., Cartwright, D.C., Williams, W.: Phys. Rev. A **4** (1971) 1482
78Wak1 Wakiya, K.: J. Phys. B: At. Mol. Phys. **11** (1978) 3931
92Doe1 Doering, J.P.: J. Geophys. Res. **97** (1992) 12267
92Mid1 Middleton, A.G., Teubner, P.J.O., Brunger, M.J.: Phys. Rev. Lett. **69** (1992) 2495
92Nob1 Noble, C.J., Burke, P.G.: Phys. Rev. Lett. **68** (1992) 2011
93Shy2 Shyn, T.W., Sweeney, C.J.: Phys. Rev. A **47** (1993) 1006

6.4.5.3.7 $c^1\Sigma_u^- + A'^3\Delta_u + A^3\Sigma_u^+$

The summed integral cross section for electron impact excitation of the three electronic states that comprise the Herzberg continuum have been measured by [70Kon1, 72Tra1, 00Cam1, 01Gre1]. Our preferred cross section set for the excitation of the $c^1\Sigma_u^- + A'^3\Delta_u + A^3\Sigma_u^+$ states is constructed from the data of [72Tra1, 00Cam1, 00Gre1]. They are tabulated in Table 6.4.28 and plotted in Fig. 6.4.26.

The uncertainty in the integral cross section is estimated to be ± 38 % over the entire range of electron energies.

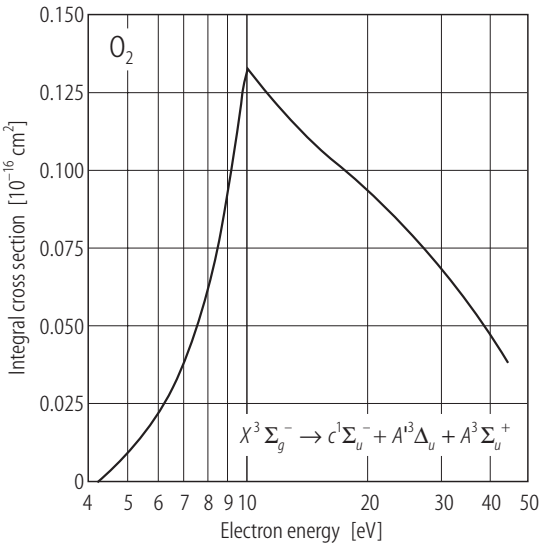

Fig. 6.4.26. Recommended integral cross section for $X^3\Sigma_g^- \rightarrow c^1\Sigma_u^- + A'^3\Delta_u + A^3\Sigma_u^+$ in O_2.

Table 6.4.28. Preferred values of the integral $c^1\Sigma_u^- + A'^3\Delta_u + A^3\Sigma_u^+$ electronic-states excitation cross section ($\sigma_{X\text{-}c+A'+A}$) for electrons in molecular oxygen.

Energy [eV]	$\sigma_{X\text{-}c+A'+A}$ [Å^2]
4.23	0.000
9	0.092
10	0.132
12	0.120
15	0.107
20	0.094
45	0.038

References for 6.4.5.3.7

70Kon1 Konishi, A., Wakiya, K., Yamamoto, M., Suzuki, H.: J. Phys. Soc. Jpn. **29** (1970) 526
72Tra1 Trajmar, S., Williams, W., Kuppermann, A.: J. Chem. Phys. **56** (1972) 3759
00Cam1 Campbell, L., Green, M.A., Brunger, M.J., Teubner, P.J.O., Cartwright, D.C.: Phys. Rev. A **61** (2000) 022706
01Gre1 Green, M.A., Campbell, L., Cartwright, D.C., Teunber, P.J.O., Brunger, M.J., J. Phys. B **34** (2001) L157

6.4.5.4 Carbon monoxide (CO)

6.4.5.4.1 $J = 0 \rightarrow 1$

Our preferred integral cross sections for the $J = 0 \rightarrow 1$ rotationally inelastic excitation of the CO ground molecular state are taken from [96Ran1]. These data are tabulated in Table 6.4.29 and plotted in Fig. 6.4.27.

The uncertainty on these cross sections is estimated to be ± 30 %.

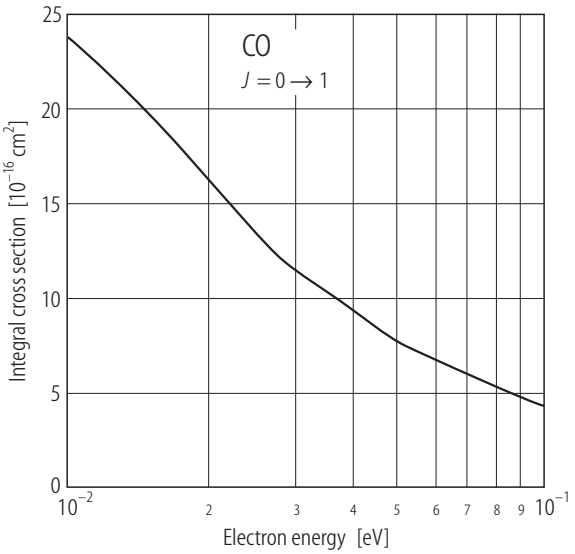

Fig. 6.4.27. Recommended integral cross section for $J = 0 \rightarrow 1$ in CO.

Table 6.4.29. Preferred values of the integral $J = 0 \rightarrow 1$ rotationally inelastic cross section ($\sigma_{0\text{-}1}$) for electron impact excitation of the ground molecular state in carbon monoxide.

Energy [eV]	$\sigma_{0\text{-}1}$ [Å^2]
0.002	34.6
0.003	31.5
0.004	30.2
0.005	29.4
0.010	23.8
0.030	11.4
0.050	7.5
0.100	4.2

References for 6.4.5.4.1

96Ran1 Randell, J., Gulley, R.J., Lunt, S.L., Ziesel, J.P., Field, D.: J. Phys. B: At. Mol. Opt. Phys. **29** (1996) 2049

6.4.5.4.2 $J = 1 \rightarrow 2$

Our preferred integral cross sections for the $J = 1 \rightarrow 2$ rotationally inelastic excitation of the CO ground molecular state are also taken from [96Ran1]. These data are tabulated in Table 6.4.30 and plotted in Fig. 6.4.28.

The uncertainty on these cross sections is estimated to be ± 30 %.

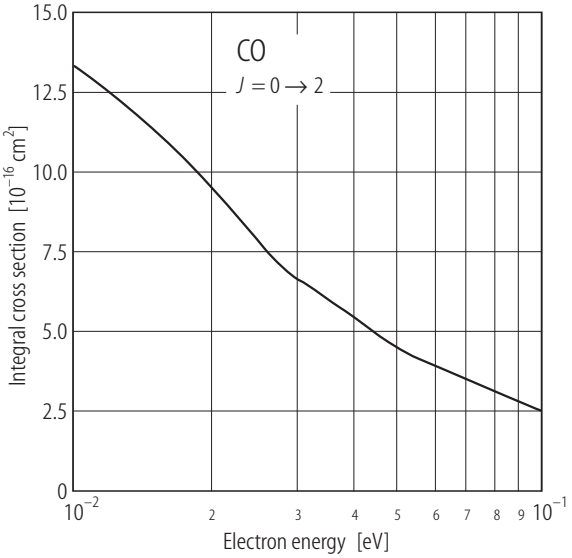

Fig. 6.4.28. Recommended integral cross section for $J = 1 \rightarrow 2$ in CO.

Table 6.4.30. Preferred values of the integral $J = 1 \rightarrow 2$ rotationally inelastic cross section ($\sigma_{1\text{-}2}$) for electron impact excitation of the ground molecular state in carbon monoxide.

Energy [eV]	$\sigma_{1\text{-}2}$ [Å^2]
0.003	15.7
0.004	15.7
0.005	15.6
0.010	13.3
0.030	6.6
0.050	4.4
0.100	2.5

References for 6.4.5.4.2

96Ran1 Randell, J., Gulley, R.J., Lunt, S.L., Ziesel, J.P., Field, D.: J. Phys. B: At. Mol. Opt. Phys. **29** (1996) 2049.

6.4.5.4.3 $\nu' = 0 \rightarrow 1$

Experimental integral cross sections for electron impact excitation of the first vibrational quantum ($\nu' = 0 \rightarrow 1$) in carbon monoxide are due to [78Lan1, 80Chu1, 85Soh1, 96Gib1]. Theoretical calculations include a Born Dipole approximation result from [85Soh1], and an R-matrix result from [96Gib1]. In constructing our preferred integral cross section we have employed all of the available experimental data except that from the swarm-based measurement of [78Lan1]. Specifically, for 0.37 eV $\leq \varepsilon \leq$ 30 eV we used [96Gib1] and for ε = 5 and 9 eV we have used [80Chu1]. Our preferred $\nu' = 0 \rightarrow 1$ integral cross section is tabulated in Table 6.4.31 and plotted in Fig. 6.4.29.

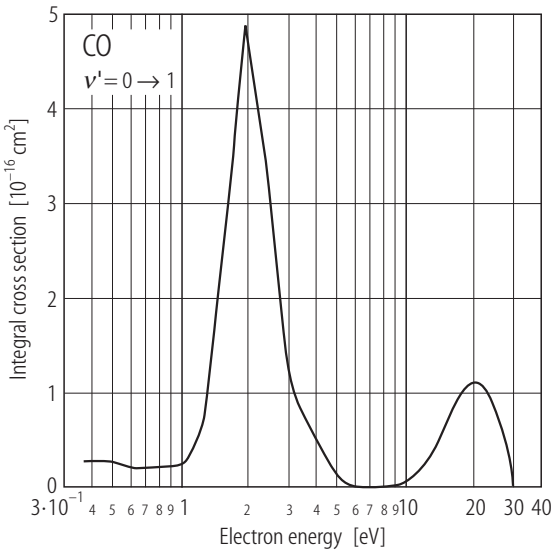

Fig. 6.4.29. Recommended integral cross section for $v' = 0 \rightarrow 1$ in CO.

Table 6.4.31. Preferred values of the integral $v' = 0 \rightarrow 1$ vibrational excitation cross section ($\sigma_{0\text{-}1}$) for electron impact excitation in carbon monoxide.

Energy [eV]	$\sigma_{0\text{-}1}$ [Å^2]	Energy [eV]	$\sigma_{0\text{-}1}$ [Å^2]
0.37	0.274	1.91	4.874
0.45	0.276	2.45	3.131
0.64	0.189	3	1.200
0.85	0.215	5	0.104
1.00	0.240	9	0.024
1.25	0.654	20	1.107
1.50	2.361	30	0.035

References for 6.4.5.4.3

78Lan1 Land, J.E.: J. Appl. Phys. **49** (1978) 5716
80Chu1 Chutjian, A., Tanaka, H.: J. Phys. B: At. Mol. Phys. **13** (1980) 1901
85Soh1 Sohn, W., Kochem, K-H., Jung, K., Ehrhardt, H., Chang, E.S.: J. Phys. B: At. Mol. Phys. **18** (1985) 2049
96Gib1 Gibson, J.C., Morgan, L.A., Gulley, R.J., Brunger, M.J., Bundschu, C.T., Buckman, S.J.: J. Phys. B: At. Mol. Opt. Phys. **29** (1996) 3197

6.4.5.4.4 $X^1\Sigma^+ \rightarrow a^3\Pi$

The preferred integral cross section for the electron impact excitation of the $a^3\Pi$ electronic-state is presented over the energy range 6 to 50 eV. The data are tabulated in Table 6.4.32 and plotted in Fig. 6.4.30. For 6 eV $\leq \varepsilon \leq$ 9.5 eV we have used the measurement of [96Zob1], for ε = 12.5 and 15 eV we have employed the integral cross sections of [98Zet1], while for $\varepsilon \geq$ 20 eV we have used the data of [94Liu1], as derived by them from the differential measurements of [93Mid1], to construct our preferred set.

The only other available data in the literature is due to [96Fur1]. This work was not considered when we constructed our preferred cross section because its shape and absolute magnitude are very different to those of [96Zob1], [98Zet1] and [94Liu1].

The uncertainty on our preferred integral cross section is estimated to be ± 25 % for ε < 20 eV and ± 35 % for $\varepsilon \geq$ 20 eV.

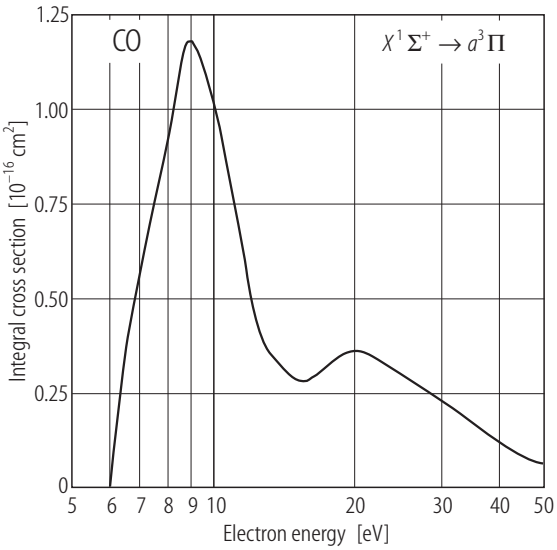

Fig. 6.4.30. Recommended integral cross section for $X^1\Sigma^+ \rightarrow a^3\Pi$ in CO.

Table 6.4.32. Preferred values of the integral $X^1\Sigma^+ \rightarrow a^3\Pi$ electronic state cross section ($\sigma_{a^3\Pi}$) for electron impact excitation in carbon monoxide.

Energy [eV]	$\sigma_{a^3\Pi}$ [Å^2]	Energy [eV]	$\sigma_{a^3\Pi}$ [Å^2]
6.01	0.000	9.5	1.110
6.5	0.355	12.5	0.417
7.0	0.595	15.0	0.285
7.5	0.760	20.0	0.369
8.0	0.915	30.0	0.237
8.5	1.130	40.0	0.119
9.0	1.190	50.0	0.065

References for 6.4.5.4.4

93Mid1 Middleton, A.G., Brunger, M.J., Teubner, P.J.O.: J. Phys. B: At. Mol. Opt. Phys. **26** (1993) 1743
94Liu1 Liu, W., Victor, G.A.: Astrophys. J. **435** (1994) 909
96Fur1 Furlong, J.M., Newell, W.R.: J. Phys. B: At. Mol. Opt. Phys. **29** (1996) 331
96Zob1 Zobel, J., Mayer, U., Jung, K., Ehrhardt, H.: J. Phys. B: At. Mol. Opt. Phys. **29** (1996) 813
98Zet1 Zetner, P.W., Kanik, I., Trajmar, S.: J. Phys. B: At. Mol. Opt. Phys. **31** (1998) 2395

6.4.5.4.5 $X^1\Sigma^+ \rightarrow a'^3\Sigma^+$

Integral cross sections for the electron impact excitation of the $a'^3\Sigma^+$ electronic-state of carbon monoxide have been reported by [94Liu1, 96Zob1, 98Zet1]. We note that the data of [94Liu1] was derived from the differential cross section measurements of [93Mid1]. All of these three sets of integral cross sections have been used to derive our preferred integral cross section, which is tabulated in Table 6.4.33 and plotted in Fig. 6.4.31.

The uncertainty on our preferred integral cross section is estimated to be ± 25 % for $\varepsilon < 20$ eV and ± 35 % for $\varepsilon \geq 20$ eV.

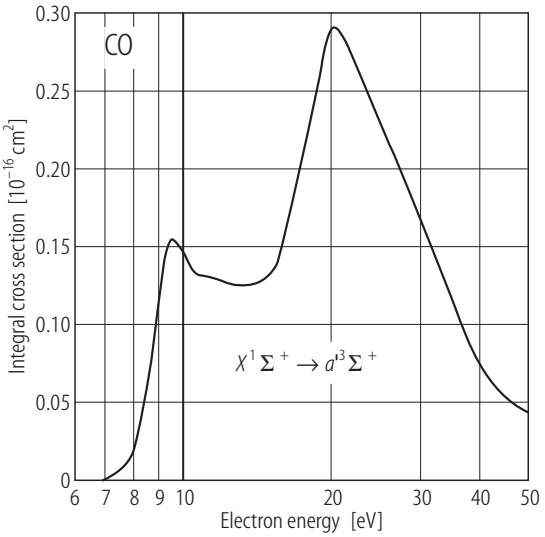

Fig. 6.4.31. Recommended integral cross section for $X^1\Sigma^+ \rightarrow a'^3\Sigma^+$ in CO.

Table 6.4.33. Preferred values of the integral $X^1\Sigma^+ \rightarrow a'^3\Sigma^+$ electronic-state cross section ($\sigma_{a'^3\Sigma^+}$) for electron impact excitation in carbon monoxide.

Energy [eV]	$\sigma_{a'^3\Sigma^+}$ [Å^2]	Energy [eV]	$\sigma_{a'^3\Sigma^+}$ [Å^2]	Energy [eV]	$\sigma_{a'^3\Sigma^+}$ [Å^2]
6.863	0.000	10.0	0.145	20.0	0.289
8.0	0.020	10.5	0.132	30.0	0.170
8.5	0.055	11.0	0.131	40.0	0.073
9.0	0.120	12.5	0.125	50.0	0.043
9.5	0.155	15.0	0.131		

References for 6.4.5.4.5

93Mid1 Middleton, A.G., Brunger, M.J., Teubner, P.J.O.: J. Phys. B: At. Mol. Opt. Phys. **26** (1993) 1743
94Liu1 Liu, W., Victor, G.A.: Astrophys. J. **435** (1994) 909
96Zob1 Zobel, J., Mayer, U., Jung, K., Ehrhardt, H.: J. Phys. B: At. Mol. Opt. Phys. **29** (1996) 813
98Zet1 Zetner, P.W., Kanik, I., Trajmar, S.: J. Phys. B: At. Mol. Opt. Phys. **31** (1998) 2395

6.4.5.4.6 $X^1\Sigma^+ \rightarrow d^3\Delta + e^3\Sigma^- + I^1\Sigma^- + D^1\Delta$

There is only one integral cross section for the unresolved sum of the $d^3\Delta$, $e^3\Sigma^-$, $I^1\Sigma^-$ and $D^1\Delta$ electronic-states in carbon monoxide. This is due to [94Liu1] and again note their values were derived from the differential cross section measurements of [93Mid1]. Our preferred integral cross section is taken directly from [94Liu1] and it is tabulated in Table 6.4.34.

For completeness we note the resolved $d^3\Delta$ integral cross section measurement of [96Zob1] and the resolved $I^1\Sigma$-integral cross section data of [88Mas1], neither of which are considered further here.

The uncertainty on our preferred integral cross section is estimated to be ± 35 % over the entire measured energy range.

Table 6.4.34. Preferred values of the integral $X^1\Sigma^+ \rightarrow d^3\Delta + e^3\Sigma^- + I^1\Sigma^- + D^1\Delta$ electronic-states cross section ($\sigma_{d^3\Delta+e^3\Sigma^-+I^1\Sigma^-+D^1\Delta}$) for electron impact excitation in carbon monoxide.

Energy [eV]	$\sigma_{d^3\Delta+e^3\Sigma^-+I^1\Sigma^-+D^1\Delta}$ [Å^2]
20	0.092
30	0.051
40	0.029
50	0.021

References for 6.4.5.4.6

88Mas1 Mason, N.J., Newell, W.R.: J. Phys. B: At. Mol. Opt. Phys. **21** (1988) 1293
93Mid1 Middleton, A.G., Brunger, M.J., Teubner, P.J.O.: J. Phys. B: At. Mol. Opt. Phys. **26** (1993) 1743
94Liu1 Liu, W., Victor, G.A.: Astrophys. J. **435** (1994) 909
96Zob1 Zobel, J., Mayer, U., Jung, K., Ehrhardt, H.: J. Phys. B: At. Mol. Opt. Phys. **29** (1996) 813

6.4.5.4.7 $X^1\Sigma^+ \rightarrow A^1\Pi$

The preferred integral cross section for the electron impact excitation of the $A^1\Pi$ electronic-state is presented over the energy range 8 to 50 eV. The data are tabulated in Table 6.4.35 and plotted in Fig. 6.4.32. For 8 eV ≤ ε ≤ 11.5 eV we have used the data of [96Zob1], for ε = 12.5 and 15 eV we have

employed the measurement of [98Zet1], while for $\varepsilon \geq 20$ eV we have used the data of [94Liu1], as derived by them from the differential measurements of [93Mid1], to construct our preferred set.

The uncertainty on our preferred integral cross section set is estimated to be ± 25 % for $\varepsilon < 20$ eV and ± 35 % for $\varepsilon \geq 20$ eV.

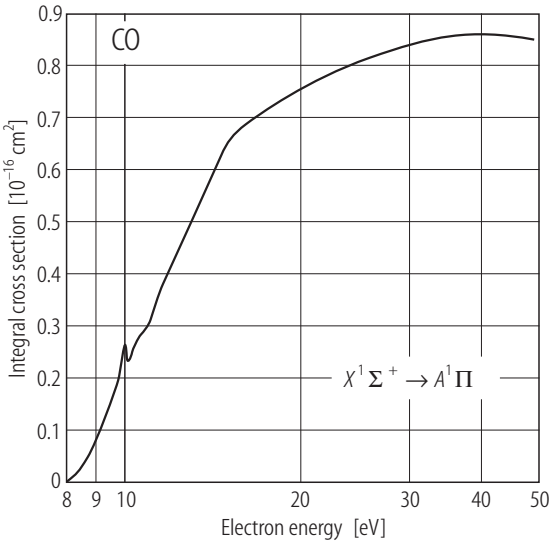

Fig. 6.4.32. Recommended integral cross section for $X^1\Sigma^+ \rightarrow A^1\Pi$ in CO.

Table 6.4.35. Preferred values of the integral $X^1\Sigma^+ \rightarrow A^1\Pi$ electronic-state cross section ($\sigma_{A^1\Pi}$) for electron impact excitation in carbon monoxide.

Energy [eV]	$\sigma_{A^1\Pi}$ [Å^2]	Energy [eV]	$\sigma_{A^1\Pi}$ [Å^2]
8.028	0.000	11.0	0.300
8.5	0.025	11.5	0.365
9.0	0.082	12.5	0.453
9.5	0.150	15.0	0.650
10.0	0.230	20.0	0.756
10.04	0.290	30.0	0.837
10.15	0.230	40.0	0.859
10.5	0.270	50.0	0.847

References for 6.4.5.4.7

93Mid1 Middleton, A.G., Brunger, M.J., Teubner, P.J.O.: J. Phys. B: At. Mol. Opt. Phys. **26** (1993) 1743
94Liu1 Liu, W., Victor, G.A.: G.A.: Astrophys. J. **435** (1994) 909
96Zob1 Zobel, J., Mayer, U., Jung, K., Ehrhardt, H.: J. Phys. B: At. Mol. Opt. Phys. **29** (1996) 813
98Zet1 Zetner, P.W., Kanik, I., Trajmar, S.: J. Phys. B: At. Mol. Opt. Phys. **31** (1998) 2395

6.4.5.4.8 $X^1\Sigma^+ \rightarrow b^3\Sigma^+$

Integral cross sections for the electron impact excitation of the $b^3\Sigma^+$ electronic-state of carbon monoxide have been reported by [94Liu1, 96Zob2, 97Zub1]. We again note that the data of [94Liu1] was derived from the differential cross section measurements of [93Mid1]. All of these three sets of integral cross sections have been used to derive our preferred integral cross section, which is tabulated in Table 6.4.36 and plotted in Fig. 6.4.33.

The uncertainty on our preferred integral cross section set is estimated to be ± 25 % for $\varepsilon \leq 14$ eV and ± 35 % for $\varepsilon > 14$ eV.

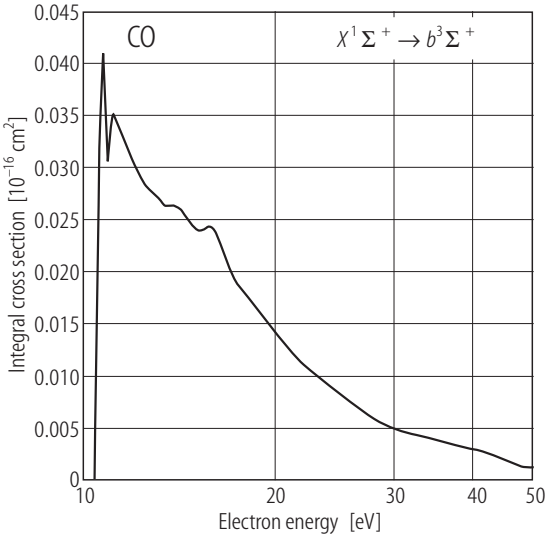

Fig. 6.4.33. Recommended integral cross section for $X^1\Sigma^+ \rightarrow b^3\Sigma^+$ in CO.

Table 6.4.36. Preferred values of the integral $X^1\Sigma^+ \rightarrow b^3\Sigma^+$ electronic-state cross section ($\sigma_{b^3\Sigma^+}$) for electron impact excitation in carbon monoxide.

Energy [eV]	$\sigma_{b^3\Sigma^+}$ [Å^2]	Energy [eV]	$\sigma_{b^3\Sigma^+}$ [Å^2]	Energy [eV]	$\sigma_{b^3\Sigma^+}$ [Å^2]
10.394	0.000	12.0	0.030	16.0	0.024
10.5	0.025	12.5	0.028	17.0	0.020
10.75	0.040	13.0	0.027	20.0	0.014
10.875	0.030	13.5	0.026	30.0	0.005
11.0	0.035	14.0	0.026	40.0	0.003
11.5	0.033	15.0	0.024	50.0	0.001

References for 6.4.5.4.8

93Mid1 Middleton, A.G., Brunger, M.J. and Teubner, P.J.O.: J. Phys. B: At. Mol. Opt. Phys. **26** (1993) 1743

94Liu1 Liu, W. and Victor, G.A.: G.A.: Astrophys. J. **435** (1994) 909

96Zob2 Zobel, J., Mayer, U., Jung, K., Ehrhardt, H., Pritchard, H., Winstead, C. and McKoy, V.: J. Phys. B: At. Mol. Opt. Phys. **29** (1996) 839

97Zub1 Zubek, M., Olszewski, R. and Wolinski, P.: J. Phys. B: At. Mol. Opt. Phys. **30** (1997) L791

6.4.5.4.9 $X^1\Sigma^+ \rightarrow B^1\Sigma^+$

Integral cross sections for the electron impact excitation of the $B^1\Sigma^+$ electronic-state of carbon monoxide have been reported by [94Liu1] for 20 eV ≤ ε ≤ 50 eV, [96Zob2] for 10.77 6 eV ≤ ε ≤ 14.5 eV and by [93Kan1] at ε = 100 eV. We once again note that the data of [94Liu1] was derived from the differential cross section measurements of [93Mid1]. All of the above three sets of integral cross sections have been used to derive our preferred integral cross section, which is tabulated in Table 6.4.37 and plotted in Fig. 6.4.34.

The uncertainty on our preferred integral cross section set is estimated to be ± 25 % for ε ≤ 14.5 eV, ± 35 % for 14 eV < ε ≤ 50 eV and ± 30 % at ε = 100 eV.

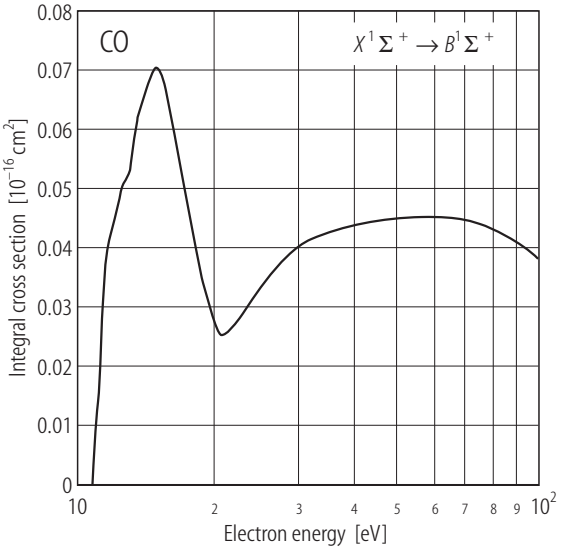

Fig. 6.4.34. Recommended integral cross section for $X^1\Sigma^+ \rightarrow B^1\Sigma^+$ in CO.

Table 6.4.37. Preferred values of the integral $X^1\Sigma^+ \rightarrow B^1\Sigma^+$ electronic-state cross section ($\sigma_{B^1\Sigma^+}$) for electron impact excitation in carbon monoxide.

Energy [eV]	$\sigma_{B^1\Sigma^+}$ [Å^2]	Energy [eV]	$\sigma_{B^1\Sigma^+}$ [Å^2]
10.776	0.000	14.0	0.066
11.0	0.010	14.5	0.070
11.5	0.038	20	0.026
12.0	0.045	30	0.040
12.5	0.050	40	0.044
13.0	0.053	50	0.045
13.5	0.062	100	0.038

References for 6.4.5.4.9

93Kan1 Kanik, I., Ratliff, M. and Trajmar, S.: Chem. Phys. Lett. **208** (1993) 341

93Mid1 Middleton, A.G., Brunger, M.J. and Teubner, P.J.O.: J. Phys. B: At. Mol. Opt. Phys. **26** (1993) 1743

94Liu1 Liu, W. and Victor, G.A.: G.A.: Astrophys. J. **435** (1994) 909

96Zob2 Zobel, J., Mayer, U., Jung, K., Ehrhardt, H., Pritchard, H., Winstead, C. and McKoy, V.: J. Phys. B: At. Mol. Opt. Phys. **29** (1996) 839

6.4.5.4.10 $X^1\Sigma^+ \rightarrow (C^1\Sigma^+ + c^3\Pi)$

The preferred integral cross section for the electron impact excitation of the unresolved $C^1\Sigma^+ + c^3\Pi$ electronic-states is presented over the energy range 20 to 100 eV. The data are tabulated in Table 6.4.38 and plotted in Fig. 6.4.35. For 20 eV $\leq \varepsilon \leq$ 50 eV we have employed the data of [94Liu1], as derived from the differential cross section measurements of [93Mid1], while at ε = 100 eV we have used the integral cross section of [93Kan1], to construct our preferred set.

The uncertainty on our preferred integral cross section is estimated to be ± 35 % for 20 eV $\leq \varepsilon \leq$ 50 eV and ± 25 % at ε = 100 eV.

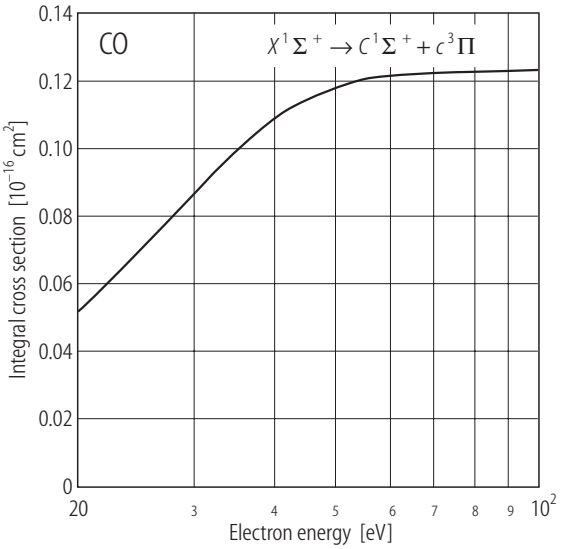

Fig. 6.4.35. Recommended integral cross section for $X^1\Sigma^+ \rightarrow C^1\Sigma^+ + c^3\Pi$ in CO.

Table 6.4.38. Preferred values of the integral $X^1\Sigma^+ \rightarrow C^1\Sigma^+ + c^3\Pi$ electronic-states cross section ($\sigma_{C^1\Sigma^+ + c^3\Pi}$) for electron impact excitation in carbon monoxide.

Energy [eV]	$\sigma_{C^1\Sigma^+ + c^3\Pi}$ [Å^2]
20.0	0.051
30.0	0.086
40.0	0.109
50.0	0.118
100.0	0.123

References for 6.4.5.4.10

93Mid1 Middleton, A.G., Brunger, M.J. and Teubner, P.J.O.: J. Phys. B: At. Mol. Opt. Phys. **26** (1993) 1743

93Kan1 Kanik, I., Ratliff, M. and Trajmar, S.: Chem. Phys. Lett. **208** (1993) 341

94Liu1 Liu, W. and Victor, G.A.: G.A.: Astrophys. J. **435** (1994) 909

6.4.5.4.11 $X^1\Sigma^+ \rightarrow E^1\Pi$

Integral cross sections for the electron impact excitation of the $E^1\Pi$ electronic-state of carbon monoxide have been reported by [94Liu1, 96Zob2, 93Kan1]. We note that the data of [94Liu1] was derived from the differential cross section measurements of [93Mid1]. All of these three sets of integral cross sections have been used to derive our preferred integral cross section, which is tabulated in Table 6.4.39 and plotted in Fig. 6.4.36.

The uncertainty on our preferred integral cross section set is estimated to be ± 25 % for $\varepsilon \leq 15$ eV and at $\varepsilon = 100$ eV and ± 35 % for 20 eV $\leq \varepsilon \leq$ 50 eV.

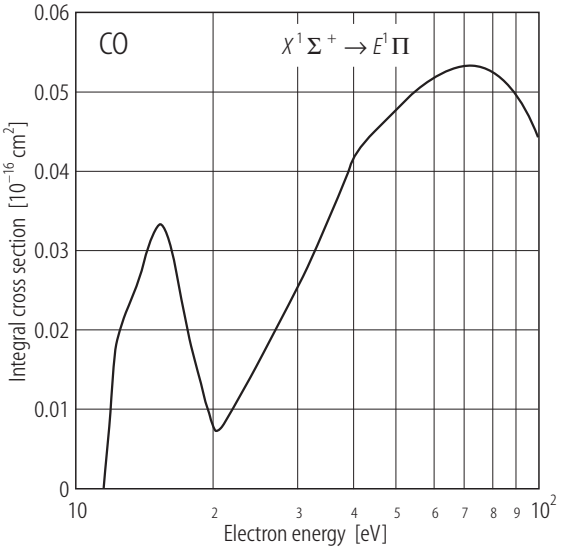

Fig. 6.4.36. Recommended integral cross section for $X^1\Sigma^+ \rightarrow E^1\Pi$ in CO.

Table 6.4.39. Preferred values of the integral $X^1\Sigma^+ \rightarrow E^1\Pi$ electronic-state cross section ($\sigma_{E^1\Pi}$) for electron impact excitation in carbon monoxide.

Energy [eV]	$\sigma_{E^1\Pi}$ [Å^2]	Energy [eV]	$\sigma_{E^1\Pi}$ [Å^2]
11.522	0.000	14.5	0.031
11.75	0.005	15.0	0.033
12.0	0.013	20.0	0.007
12.5	0.020	30.0	0.025
13.0	0.023	40.0	0.042
13.5	0.025	50.0	0.048
14.0	0.028	100.0	0.044

References for 6.4.5.4.11

93Kan1 Kanik, I., Ratliff, M. and Trajmar, S.: Chem. Phys. Lett. **208** (1993) 341

93Mid1 Middleton, A.G., Brunger, M.J. and Teubner, P.J.O.: J. Phys. B: At. Mol. Opt. Phys. **26** (1993) 1743

94Liu1 Liu, W. and Victor, G.A.: Astrophys. J. **435** (1994) 909

96Zob2 Zobel, J., Mayer, U., Jung, K., Ehrhardt, H., Pritchard, H., Winstead, C. and McKoy, V.: J. Phys. B: At. Mol. Opt. Phys. **29** (1996) 839

6.4.5.5 Nitric oxide (NO)

6.4.5.5.1 $\nu' = 0 \rightarrow 1$

There appears to be only one experimental determination for the $\nu' = 0 \rightarrow 1$ integral cross section of NO. This measurement is due to Mojarrabi et al. [95Moj1] and it forms the basis of our preferred cross section set for energies in the range 7.5 to 40 eV. The preferred cross sections are listed in Table 6.4.40 and shown in Fig. 6.4.37.

The uncertainty on the cross sections is estimated to be ± 25 %.

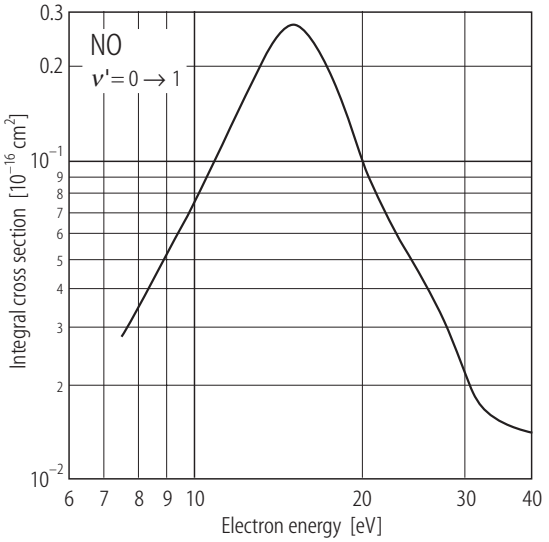

Fig. 6.4.37. Recommended integral cross section for $\nu' = 0 \rightarrow 1$ in NO.

Table 6.4.40. Preferred values of the integral $\nu' = 0 \rightarrow 1$ rovibration excitation cross section ($\sigma_{0\text{-}1}$) for electrons in nitric oxide.

Energy [eV]	$\sigma_{0\text{-}1}$ [Å^2]
7.5	0.028
10	0.074
15	0.270
20	0.097
30	0.022
40	0.014

References for 6.4.5.5.1

95Moj1 Mojarrabi, B., Gulley, R.J., Middleton, A.G., Cartwright, D.C., Teubner, P.J.O., Buckman, S.J., Brunger, M.J.: J. Phys. B: At. Mol. Opt. Phys. **28** (1995) 487

6.4.5.5.2 $\nu' = 0 \rightarrow 2$

There also appears to be only one experimental determination for the $\nu' = 0 \rightarrow 2$ integral cross section of NO. Again this measurement is due to Mojarrabi et al. [95Moj1] and it forms the basis of our preferred cross section set for energies in the range 10 to 20 eV. The preferred cross sections are listed in Table 6.4.41.

The uncertainty on the cross sections is estimated to be ± 30 %.

Table 6.4.41. Preferred values of the integral $\nu' = 0 \rightarrow 2$ rovibration excitation cross section ($\sigma_{0\text{-}2}$) for electrons in nitric oxide.

Energy [eV]	$\sigma_{0\text{-}2}$ [Å^2]
10	0.014
15	0.073
20	0.022

References for 6.4.5.5.2

95Moj1 Mojarrabi, B., Gulley, R.J., Middleton, A.G., Cartwright, D.C., Teubner, P.J.O., Buckman, S.J., Brunger, M.J.: J. Phys. B: At. Mol. Opt. Phys. **28** (1995) 487

6.4.5.5.3 $X^2\Pi \rightarrow A^2\Sigma^+$

The preferred integral cross section for the electron impact excitation of the $A^2\Sigma^+$ electronic state is presented over the energy range 15 to 50 eV. The data are tabulated in Table 6.4.42 and plotted in Fig. 6.4.38. At lower energies (ε < 15 eV) two emission cross sections due to [77Sku1] and [99Ols1] are in poor agreement, as to the existence of a strong near-threshold resonance, with one another. Hence no preferred cross section data are recommended below 15 eV. At higher energies (15 to 50 eV) the preferred cross section is based on the crossed beam measurements of Brunger et al. [00Bru1].

The uncertainty is estimated to be: ± 35 % at 15 and 50 eV, ± 30 % at 30 and 40 eV and ± 33 % at 20 eV.

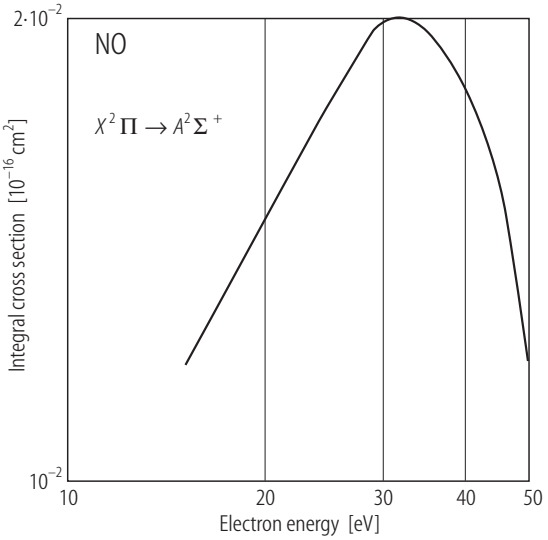

Fig. 6.4.38. Recommended integral cross section for $X^2\Pi \rightarrow A^2\Sigma^+$ in NO.

Table 6.4.42. Preferred values of the integral cross section ($\sigma_{X\text{-}A}$) for electron impact excitation of the $A^2\Sigma^+$ electronic state of nitric oxide.

Energy [eV]	$\sigma_{X\text{-}A}$ [Å^2]
15	0.012
20	0.015
30	0.020
40	0.018
50	0.012

References for 6.4.5.5.3

77Sku1 Skubenich, V.V., Povch, M.M., Zapesochnyi, I.P.: High Energy Chem. (USSR) **11** (1977) 92
99Ols1 Olszewski, R., Zubek, M.: Proc. 20th ICPEAC (Itikawa Y., Okuno, K., Tanaka, H., Yagishita, A., Matsuzawa, M., eds.), Sendai, Japan: 1999, p. 292
00Bru1 Brunger, M.J., Campbell, L., Cartwright, D.C., Middleton, A.G., Mojarrabi, B., Teubner, P.J.O.: J. Phys. B: At. Mol. Opt. Phys. **33** (2000) 809

6.4.5.5.4 $X^2\Pi \rightarrow C^2\Pi_r$

The only published values of integral cross sections for electron impact excitation of the $C^2\Pi_r$ electronic state are due to Brunger et al. [00Bru1] and Mojarrabi et al. [96Moj1]. In both cases the energy range was 15 to 50 eV, and we note their respective integral cross sections are identical. Consequently our preferred cross section is based on the recent crossed beam measurements of [00Bru1]. It can be found in Table 6.4.43.

The uncertainty is estimated to be: ± 27 % at 15 eV, ± 25 % at 20 eV, ± 23 % at 30 and 40 eV and ± 26 % at 50 eV.

Table 6.4.43. Preferred values of the integral cross section ($\sigma_{X\text{-}C}$) for electron impact excitation of the $C^2\Pi_r$ electronic state of nitric oxide.

Energy [eV]	$\sigma_{X\text{-}C}$ [Å^2]
15	0.023
20	0.033
30	0.041
40	0.047
50	0.033

References for 6.4.5.5.4

96Moj1 Mojarrabi, B., Campbell, L., Teubner, P.J.O., Brunger, M.J., Cartwright, D.C.: Phys. Rev. A **54** (1996) 2977
00Bru1 Brunger, M.J., Campbell, L., Cartwright, D.C., Middleton, A.G., Mojarrabi, B., Teubner, P.J.O.: J. Phys. B: At. Mol. Opt. Phys. **33** (2000) 809

6.4.5.5.5 $X^2\Pi \rightarrow F^2\Delta$

There appears to be only two experimental determinations of integral cross sections for the excitation of the $F^2\Delta$ electronic state of nitric oxide. The first, from threshold to 50 eV, is due to [77Sku1] while the second, from 15 to 50 eV is due to [00Bru1]. In this case the integral cross sections of [77Sku1] and [00Bru1] are in excellent agreement, at all common energies, between 15 and 50 eV. As such they form the basis for our preferred cross sections in this energy regime, as can be found in Table 6.4.44. Below 15 eV there is only the data of [77Sku1]. As this group's near-threshold measurements for the $A^2\Sigma^+$

electronic state (see 6.4.5.5.3) are in question, we do not incorporate their measurements of the $F^2\Delta$ electronic state integral cross sections, for $\varepsilon < 15$ eV, into our preferred set.

The uncertainty is estimated to be: ± 46 % at 15 eV, ± 44 % at 20 and 30 eV, ± 43 % at 40 eV and ± 45 % at 50 eV.

Table 6.4.44. Preferred values of the integral cross section ($\sigma_{X\text{-}F}$) for electron impact excitation of the $F^2\Delta$ electronic state of nitric oxide.

Energy [eV]	$\sigma_{X\text{-}F}$ [Å^2]
15	0.004
20	0.006
30	0.009
40	0.013
50	0.008

References for 6.4.5.5.5

77Sku1 Skubenich, V.V., Povch, M.M., Zapesochnyi, I.P.: High Energy Chem. (USSR) **11** (1977) 92

00Bru1 Brunger, M.J., Campbell, L., Cartwright, D.C., Middleton, A.G., Mojarrabi, B., Teubner, P.J.O.: J. Phys. B: At. Mol. Opt. Phys. **33** (2000) 809

6.4.5.5.6 $X^2\Pi \rightarrow B^2\Pi_r$

The preferred integral cross section for electron impact excitation of the $B^2\Pi$ valence electronic state of nitric oxide is presented over the energy range 15 to 50 eV. The data are tabulated in Table 6.4.45 and plotted in Fig. 6.4.39. The cross section of [00Bru1], at 30 eV, is in excellent agreement with the corresponding emission cross section of Schappe et al. [97Sch1], with both these data being a factor of 1.5 stronger in magnitude then that of [77Sku1]. Consequently our preferred cross section is based on the crossed beam measurement of [00Bru1].

The uncertainty is estimated to be: ± 56 % at 15 eV, ± 55 % at 20 eV, ± 53 % at 30 eV, ± 58 % at 40 eV and ± 60 % at 50 eV.

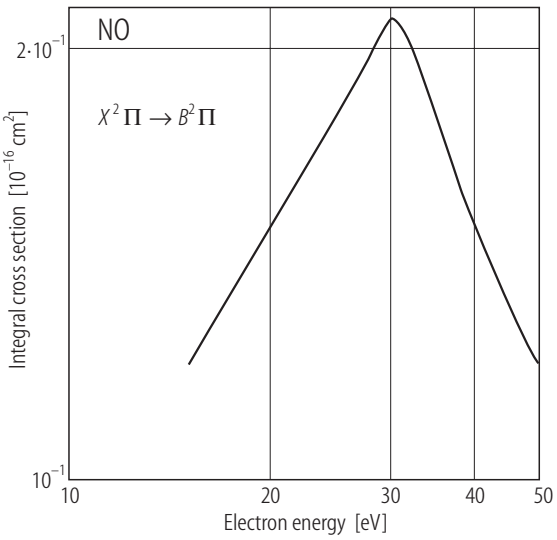

Fig. 6.4.39. Recommended integral cross section for $X^2\Pi \rightarrow B^2\Pi$ in NO.

Table 6.4.45. Preferred values of the integral cross section ($\sigma_{X\text{-}B}$) for electron impact excitation of the $B^2\Pi$ electronic state of nitric oxide.

Energy [eV]	$\sigma_{X\text{-}B}$ [Å^2]
15	0.012
20	0.015
30	0.021
40	0.015
50	0.012

References for 6.4.5.5.6

77Sku1 Skubenich, V.V., Povch, M.M., Zapesochnyi, I.P.: High Energy Chem. (USSR) **11** (1977) 92
97Sch1 Schappe, R.S., Hall, L., Wawrzyniak, M.: Bull. Am. Phys. Soc. **42** (1997) 1710
00Bru1 Brunger, M.J., Campbell, L., Cartwright, D.C., Middleton, A.G., Mojarrabi, B., Teubner, P.J.O.: J. Phys. B: At. Mol. Opt. Phys. **33** (2000) 809

6.4.5.5.7 $X^2\Pi \rightarrow b^4\Sigma^-$

The only published values of integral cross sections for electron impact excitation of the $b^4\Sigma^-$ valence electronic state are due to [00Bru1] and [77Sku1]. The measurement of [77Sku1] is restricted to near threshold energies and we do not consider it to be reliable. Thus our preferred cross section is again based solely on the recent crossed beam measurements of [00Bru1]. It can be found in Table 6.4.46.

The uncertainty is estimated to be: ± 45 % at 15 and 30 eV, ± 47 % at 40 eV and ± 49 % at 20 and 50 eV.

Table 6.4.46. Preferred values of the integral cross section ($\sigma_{X\text{-}b}$) for electron impact excitation of the $b^4\Sigma^-$ electronic state of nitric oxide.

Energy [eV]	$\sigma_{X\text{-}b}$ [Å^2]
15	0.047
20	0.047
30	0.041
40	0.020
50	0.009

References for 6.4.5.5.7

77Sku1 Skubenich, V.V., Povch, M.M., Zapesochnyi, I.P.: High Energy Chem. (USSR) **11** (1977) 92
00Bru1 Brunger, M.J., Campbell, L., Cartwright, D.C., Middleton, A.G., Mojarrabi, B., Teubner, P.J.O.: J. Phys. B: At. Mol. Opt. Phys. **33** (2000) 809

6.4.5.5.8 $X^2\Pi \rightarrow B'^2\Delta$

The level of agreement between the published integral cross sections of [00Bru1] and [77Sku1], for electron impact excitation of the $B'^2\Delta$ valence electronic state of NO, is quite poor in the 15 to 50 eV energy range. Given some of the problems, highlighted in earlier sections of this chapter, with the emission results of [77Sku1], our preferred cross section is taken from the data of [00Bru1] and is tabulated in Table 6.4.47.

The uncertainty is estimated to be: ± 35 % at 15 eV, ± 33 % at 20 eV, ± 30 % at 30 eV, ± 31 % at 40 eV and ± 34 % at 50 eV.

Table 6.4.47. Preferred values of the integral cross section ($\sigma_{X\text{-}B'}$) for electron impact excitation of the $B'^2\Delta$ electronic state of nitric oxide.

Energy [eV]	$\sigma_{X\text{-}B'}$ [Å^2]
15	0.032
20	0.065
30	0.084
40	0.058
50	0.022

References for 6.4.5.5.8

77Sku1 Skubenich, V.V., Povch, M.M., Zapesochnyi, I.P.: High Energy Chem. (USSR) **11** (1977) 92
00Bru1 Brunger, M.J., Campbell, L., Cartwright, D.C., Middleton, A.G., Mojarrabi, B., Teubner, P.J.O.: J. Phys. B: At. Mol. Opt. Phys. **33** (2000) 809

6.4.5.5.9 $X^2\Pi \rightarrow D^2\Sigma^+$

The only available data for electron impact excitation of the $D^2\Sigma^+$ electronic state of nitric oxide is from the crossed beam measurements of [00Bru1]. The energy range was 15 to 50 eV. It is from this data that the present preferred integral cross section of Table 6.4.48 was constructed.

The uncertainty is estimated to be: ± 35 % at 15 eV, ± 33 % at 20 eV, ± 30 % at 30 eV, ± 31 % at 40 eV and ± 34 % at 50 eV.

Table 6.4.48. Preferred values of the integral cross section ($\sigma_{X\text{-}D}$) for electron impact excitation of the $D^2\Sigma^+$ electronic state of nitric oxide.

Energy [eV]	$\sigma_{X\text{-}D}$ [Å^2]
15	0.014
20	0.019
30	0.025
40	0.030
50	0.022

References for 6.4.5.5.9

00Bru1 Brunger, M.J., Campbell, L., Cartwright, D.C., Middleton, A.G., Mojarrabi, B., Teubner, P.J.O.: J. Phys. B: At. Mol. Opt. Phys. **33** (2000) 809

6.4.5.5.10 $X^2\Pi \rightarrow a^4\Pi$

The preferred integral cross section for electron impact excitation of the $a^4\Pi$ electronic state of nitric oxide is presented over the energy range 15 to 50 eV. The data are tabulated in Table 6.4.49. As the crossed beam measurement of [00Bru1] is the only one available in the literature, our preferred set is taken directly from it.

The uncertainty is estimated to be: ± 65 % at 15, 30 and 40 eV and ± 63 % at 20 and 50 eV.

Table 6.4.49. Preferred values of the integral cross section ($\sigma_{X\text{-}a}$) for electron impact excitation of the $a^4\Pi$ valence electronic state of nitric oxide.

Energy [eV]	$\sigma_{X\text{-}a}$ [Å^2]
15	0.008
20	0.010
30	0.014
40	0.010
50	0.007

References for 6.4.5.5.10

00Bru1 Brunger, M.J., Campbell, L., Cartwright, D.C., Middleton, A.G., Mojarrabi, B., Teubner, P.J.O.: J. Phys. B: At. Mol. Opt. Phys. **33** (2000) 809

6.4.5.5.11 $X^2\Pi \rightarrow L'^2\Phi$

The only available data for electron excitation of the $L'^2\Phi$ valence electronic state of nitric oxide is from the crossed beam measurements of [00Bru1]. The energy range was 15 to 50 eV. It is from this data set that the present preferred integral cross section of Table 6.4.50 was constructed.

The uncertainty is estimated to be: ± 57 % at 15 and 50 eV, ± 62 % at 20 eV, ±55 % at 30 eV and ± 52 % at 40 eV.

Table 6.4.50. Preferred values of the integral cross section ($\sigma_{X\text{-}L'}$) for electron impact excitation of the $L'^2\Phi$ valence electronic state of nitric oxide.

Energy [eV]	$\sigma_{X\text{-}L'}$ [Å^2]
15	0.027
20	0.023
30	0.018
40	0.021
50	0.020

References for 6.4.5.5.11

00Bru1 Brunger, M.J., Campbell, L., Cartwright, D.C., Middleton, A.G., Mojarrabi, B., Teubner, P.J.O.: J. Phys. B: At. Mol. Opt. Phys. **33** (2000) 809

6.4.5.5.12 $X^2\Pi \rightarrow L^2\Pi$

The preferred integral cross section for electron impact excitation of the $L^2\Pi$ valence electronic state was constructed entirely from the crossed beam result of [00Bru1]. The data are tabulated, for energies between 15 and 50 eV, in Table 6.4.51 and plotted in Fig. 6.4.40.

The uncertainty is estimated to be: ± 42 % at 15 and 50 eV, ± 38 % at 20 and 30 eV and ± 39 % at 40 eV.

Table 6.4.51. Preferred values of the integral cross section ($\sigma_{X\text{-}L}$) for electron impact excitation of the $L^2\Pi$ valence electronic state of nitric oxide.

Energy [eV]	$\sigma_{X\text{-}L}$ [Å^2]
15	0.036
20	0.055
30	0.118
40	0.139
50	0.118

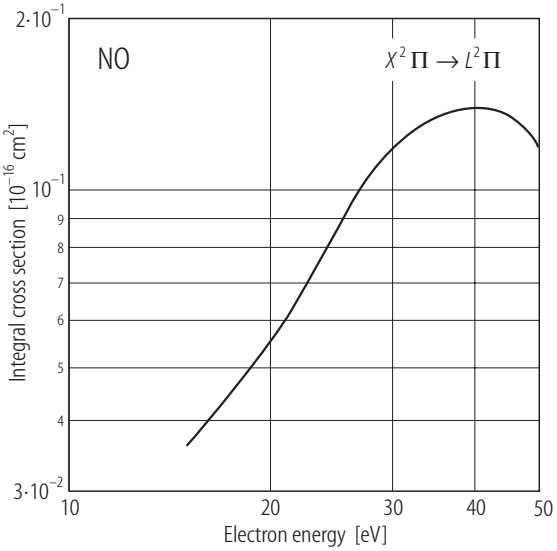

Fig. 6.4.40. Recommended integral cross section for $X^2\Pi \rightarrow L^2\Pi$ in NO.

References for 6.4.5.5.12

00Bru1 Brunger, M.J., Campbell, L., Cartwright, D.C., Middleton, A.G., Mojarrabi, B., Teubner, P.J.O.: J. Phys. B: At. Mol. Opt. Phys. **33** (2000) 809

6.4.5.5.13 $X^2\Pi \rightarrow K^2\Pi$

The preferred integral cross section for electron impact excitation of the $K^2\Pi$ electronic state of nitric oxide is presented over the energy range 15 to 50 eV. The data are tabulated in Table 6.4.52. As the crossed beam measurement of [00Bru1] is the only one available in the literature, our preferred set is taken directly from it.

The uncertainty is estimated to be: ± 38 % at 15 eV, ± 36 % at 20 eV, ± 34 % at 30 and 40 eV and ± 36 % at 50 eV.

Table 6.4.52. Preferred values of the integral cross section ($\sigma_{X\text{-}K}$) for electron impact excitation of the $K^2\Pi$ valence electronic state of nitric oxide.

Energy [eV]	$\sigma_{X\text{-}K}$ [Å^2]
15	0.006
20	0.008
30	0.016
40	0.019
50	0.010

References for 6.4.5.5.13

00Bru1 Brunger, M.J., Campbell, L., Cartwright, D.C., Middleton, A.G., Mojarrabi, B., Teubner, P.J.O.: J. Phys. B: At. Mol. Opt. Phys. **33** (2000) 809

6.4.5.5.14 $X^2\Pi \rightarrow E^2\Sigma^+$

The only available data for electron impact excitation of the $E^2\Sigma^+$ electronic state of nitric oxide is from the crossed beam measurements of [00Bru1]. The energy range was 15 to 50 eV. It is from this data set that the present preferred integral cross section of Table 6.4.53 was constructed.

The uncertainty is estimated to be: ± 65 % at 15 eV, ± 63 % at 20 eV, ± 60 % at 30 and 40 eV and ± 62 % at 50 eV.

Table 6.4.53. Preferred values of the integral cross section ($\sigma_{X\text{-}E}$) for electron impact excitation of the $E^2\Sigma^+$ electronic state of nitric oxide.

Energy [eV]	$\sigma_{X\text{-}E}$ [Å^2]
15	0.002
20	0.003
30	0.003
40	0.004
50	0.003

References for 6.4.5.5.14

00Bru1 Brunger, M.J., Campbell, L., Cartwright, D.C., Middleton, A.G., Mojarrabi, B., Teubner, P.J.O.: J. Phys. B: At. Mol. Opt. Phys. **33** (2000) 809

6.4.5.5.15 $X^2\Pi \rightarrow Q^2\Pi$

The preferred integral cross section for electron impact excitation of the $Q^2\Pi$ electronic state was constructed entirely from the crossed beam measurement of [00Bru1]. The data are tabulated in Table 6.4.54.

The uncertainty is estimated to be: ± 43 % at 15 eV, ± 40 % at 20, 30 and 40 eV and ± 42 % at 50 eV.

Table 6.4.54. Preferred values of the integral cross section ($\sigma_{X\text{-}Q}$) for electron impact excitation of the $Q^2\Pi$ electronic state of nitric oxide.

Energy [eV]	$\sigma_{X\text{-}Q}$ [Å^2]
15	0.005
20	0.007
30	0.012
40	0.015
50	0.009

References for 6.4.5.5.15

00Bru1 Brunger, M.J., Campbell, L., Cartwright, D.C., Middleton, A.G., Mojarrabi, B., Teubner, P.J.O.: J. Phys. B: At. Mol. Opt. Phys. **33** (2000) 809

6.4.5.5.16 $X^2\Pi \rightarrow S^2\Sigma^+$

The preferred integral cross section for electron impact excitation of the $S^2\Sigma^+$ electronic state of nitric oxide is presented over the energy range 15 to 50 eV. The data are tabulated in Table 6.4.55. As the crossed beam measurement of [00Bru1] is the only one available in the literature, our preferred set is taken directly from it.

The uncertainty is estimated to be: ± 55 % at 15 eV, ± 53 % at 20 eV, ± 50 % at 30 and 40 eV and ± 51 % at 50 eV.

Table 6.4.55. Preferred values of the integral cross section ($\sigma_{X\text{-}S}$) for electron impact excitation of the $S^2\Sigma^+$ electronic state of nitric oxide.

Energy [eV]	$\sigma_{X\text{-}S}$ [Å^2]
15	0.004
20	0.009
30	0.015
40	0.011
50	0.007

References for 6.4.5.5.16

00Bru1 Brunger, M.J., Campbell, L., Cartwright, D.C., Middleton, A.G., Mojarrabi, B., Teubner, P.J.O.: J. Phys. B: At. Mol. Opt. Phys. **33** (2000) 809

6.4.5.5.17 $X^2\Pi \rightarrow M^2\Sigma^+$

The only available data for electron impact excitation of the $M^2\Sigma^+$ electronic state of nitric oxide is from the crossed beam measurement of [00Bru1]. The energy range was 15 to 50 eV. It is from this data set that the present preferred integral cross section of Table 6.4.56 was constructed.

The uncertainty is estimated to be: ± 43 % at 15 eV, ± 40 % at 20, 30 and 40 eV and ± 42 % at 50 eV.

Table 6.4.56. Preferred values of the integral cross section ($\sigma_{X\text{-}M}$) for electron impact excitation of the $M^2\Sigma^+$ electronic state of nitric oxide.

Energy [eV]	$\sigma_{X\text{-}M}$ [Å^2]
15	0.004
20	0.006
30	0.010
40	0.011
50	0.006

References for 6.4.5.5.17

00Bru1 Brunger, M.J., Campbell, L., Cartwright, D.C., Middleton, A.G., Mojarrabi, B., Teubner, P.J.O.: J. Phys. B: At. Mol. Opt. Phys. **33** (2000) 809

6.4.5.5.18 $X^2\Pi \rightarrow H'^2\Pi$

The preferred integral cross section for electron impact excitation of the $H'^2\Pi$ electronic state was constructed entirely from the crossed beam measurement of [00Bru1]. The data are tabulated in Table 6.4.57.

The uncertainty is estimated to be: ± 57 % at 15 and 20 eV, ± 53 % at 30 and 40 eV and ± 56 % at 50 eV.

Table 6.4.57. Preferred values of the integral cross section ($\sigma_{X\text{-}H'}$) for electron impact excitation of the $H'^2\Pi$ electronic state of nitric oxide.

Energy [eV]	$\sigma_{X\text{-}H'}$ [Å^2]
15	0.004
20	0.006
30	0.007
40	0.009
50	0.006

References for 6.4.5.5.18

00Bru1 Brunger, M.J., Campbell, L., Cartwright, D.C., Middleton, A.G., Mojarrabi, B., Teubner, P.J.O.: J. Phys. B: At. Mol. Opt. Phys. **33** (2000) 809

6.4.5.5.19 $X^2\Pi \rightarrow H^2\Sigma^+$

The preferred integral cross section for electron impact excitation of the $H^2\Sigma^+$ electronic state of nitric oxide is presented over the energy range 15 to 50 eV. The data are tabulated in Table 6.4.58 and plotted in Fig. 6.4.41. As the crossed beam measurement of [00Bru1] is the only one available in the literature, our preferred set is taken directly from it.

The uncertainty is estimated to be: ± 57 % at 15 eV, ± 54 % at 20 eV, ± 52 % at 30 eV, ± 50 % at 40 eV and ± 55 % at 50 eV.

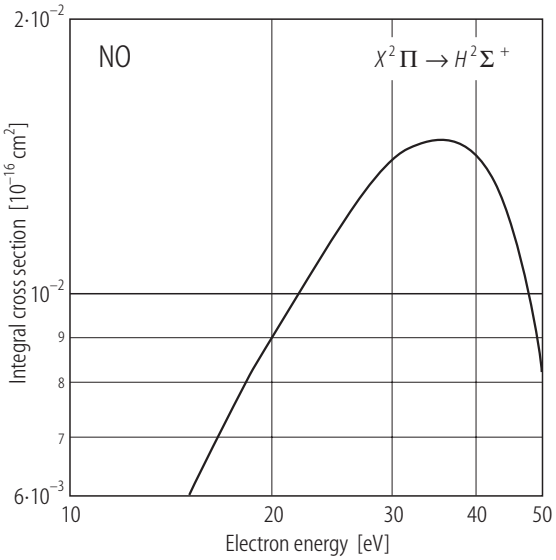

Fig. 6.4.41. Recommended integral cross section for $X^2\Pi \rightarrow H^2\Sigma^+$ in NO.

Table 6.4.58. Preferred values of the integral cross section ($\sigma_{X\text{-}H}$) for electron impact excitation of the $H^2\Sigma^+$ electronic state of nitric oxide.

Energy [eV]	$\sigma_{X\text{-}H}$ [Å^2]
15	0.006
20	0.009
30	0.014
40	0.014
50	0.008

References for 6.4.5.5.19

00Bru1 Brunger, M.J., Campbell, L., Cartwright, D.C., Middleton, A.G., Mojarrabi, B., Teubner, P.J.O.: J. Phys. B: At. Mol. Opt. Phys. **33** (2000) 809

6.4.5.5.20 $X^2\Pi \rightarrow N^2\Delta$

The only available data for electron impact excitation of the $N^2\Delta$ electronic state of nitric oxide is from the crossed beam measurement of [00Bru1]. The energy range was 15 to 50 eV. It is from this data set that the present preferred integral cross section of Table 6.4.59 was constructed.

The uncertainty is estimated to be: ± 117 % at 15 eV, ± 100 % at 30 eV and 40 eV and ± 90 % at 50 eV.

Table 6.4.59. Preferred values of the integral cross section ($\sigma_{X\text{-}N}$) for electron impact excitation of the $N^2\Delta$ electronic state of nitric oxide.

Energy [eV]	$\sigma_{X\text{-}N}$ [Å^2]
15	0.003
20	-
30	0.005
40	0.006
50	0.006

References for 6.4.5.5.20

00Bru1 Brunger, M.J., Campbell, L., Cartwright, D.C., Middleton, A.G., Mojarrabi, B., Teubner, P.J.O.: J. Phys. B: At. Mol. Opt. Phys. **33** (2000) 809

6.4.5.5.21 $X^2\Pi \rightarrow O'^2\Pi + O^2\Sigma^+$

At higher values of energy loss the unique spectral deconvolution of strongly overlapping electronic states becomes problematic. Under these circumstances cross sections are often expressed as a sum of two or more of these electronic states. The preferred integral cross section for electron impact excitation of the $O'^2\Pi + O^2\Sigma^+$ electronic states was constructed entirely from the crossed beam measurement of [00Bru1]. The data are tabulated in Table 6.4.60.

The uncertainty is estimated to be: ± 46 % at 15 and 20 eV, ± 43 % at 30 eV and 50 eV and ± 42 % at 40 eV.

Table 6.4.60. Preferred values of the integral cross section ($\sigma_{X\text{-}O'+O}$) for electron impact excitation of the $O'^2\Pi + O^2\Sigma^+$ electronic states of nitric oxide.

Energy [eV]	$\sigma_{X\text{-}O'+O}$ [Å^2]
15	0.005
20	0.007
30	0.015
40	0.013
50	0.009

References for 6.4.5.5.21

00Bru1 Brunger, M.J., Campbell, L., Cartwright, D.C., Middleton, A.G., Mojarrabi, B., Teubner, P.J.O.: J. Phys. B: At. Mol. Opt. Phys. **33** (2000) 809

6.4.5.5.22 $X^2\Pi \rightarrow W^2\Pi + Y^2\Sigma^+$

The preferred integral cross section for electron impact excitation of the $W^2\Pi + Y^2\Sigma^+$ electronic states of nitric oxide is presented over the energy range 15 to 50 eV. The data are tabulated in Table 6.4.61. Again the presented cross section is a sum for two strongly overlapping electronic states, due to uniqueness problems in the spectral deconvolution. As the crossed beam measurement of [00Bru1] is the only one available in the literature, our preferred set is taken directly from it.

The uncertainty is estimated to be: ± 36 % at 15 eV, ± 33 % at 20 eV, ± 30 % at 30 eV and 40 eV and ± 32 % at 50 eV.

Table 6.4.61. Preferred values of the integral cross section (σ_{X-W+Y}) for electron impact excitation of the $W^2\Pi + Y^2\Sigma^+$ electronic states of nitric oxide.

Energy [eV]	σ_{X+W+Y} [Å^2]
15	0.009
20	0.013
30	0.023
40	0.022
50	0.013

References for 6.4.5.5.22

00Bru1 Brunger, M.J., Campbell, L., Cartwright, D.C., Middleton, A.G., Mojarrabi, B., Teubner, P.J.O.: J. Phys. B: At. Mol. Opt. Phys. **33** (2000) 809

6.4.5.5.23 $X^2\Pi \rightarrow T^2\Sigma + U^2\Delta + 5f$

At higher values of energy loss the unique spectral deconvolution of strongly overlapping electronic states becomes problematic. Under these conditions cross sections are often expressed as a sum of two or more of these electronic states. The only available data for electron impact excitation of the $T^2\Sigma^+ + U^2\Delta +$ 5f electronic states of nitric oxide is from the crossed beam measurement of [00Bru1]. The energy range was 15 to 50 eV. It is from this data set that the present preferred integral cross section of Table 6.4.62 was constructed

The uncertainty is estimated to be: ± 65 % at 15 eV, ± 63 % at 20 eV and ± 60 % at 30, 40 and 50 eV.

Table 6.4.62. Preferred values of the integral cross section ($\sigma_{X\text{-}T+U+5f}$) for electron impact excitation of the $T^2\Sigma^+ + U^2\Delta + 5f$ electronic states of nitric oxide.

Energy [eV]	$\sigma_{X\text{-}T+U+5f}$ [Å^2]
15	0.002
20	0.002
30	0.005
40	0.004
50	0.002

References for 6.4.5.5.23

00Bru1 Brunger, M.J., Campbell, L., Cartwright, D.C., Middleton, A.G., Mojarrabi, B., Teubner, P.J.O.: J. Phys. B: At. Mol. Opt. Phys. **33** (2000) 809

6.4.5.5.24 $X^2\Pi \rightarrow Z^2\Sigma^+ + 6d\delta + 6f$

The preferred integral cross section for electron impact excitation of the $Z^2\Sigma^+ + 6d\delta + 6f$ electronic states was constructed entirely from the crossed beam measurement of [00Bru1]. The data are tabulated in Table 6.4.63. Again the presented cross section is a sum for three strongly overlapping electronic states, due to uniqueness problems in the spectral deconvolution.

The uncertainty is estimated to be: ± 69 % at 15 eV, ± 68 % at 20 eV and ± 65 % at 30, 40 and 50 eV.

Table 6.4.63. Preferred values of the integral cross section ($\sigma_{X\text{-}Z+6d+6f}$) for electron impact excitation of the $Z^2\Sigma^+ + 6d\delta + 6f$ electronic states of nitric oxide.

Energy [eV]	$\sigma_{X\text{-}Z+6d+6f}$ [Å^2]
15	0.001
20	0.001
30	0.002
40	0.002
50	0.002

References for 6.4.5.5.24

00Bru1 Brunger, M.J., Campbell, L., Cartwright, D.C., Middleton, A.G., Mojarrabi, B., Teubner, P.J.O.: J. Phys. B: At. Mol. Opt. Phys. **33** (2000) 809

6.4.5.6 Carbon dioxide (CO_2)

6.4.5.6.1 (000) → (010)

There are three integral cross section measurements for electron impact excitation of the bending mode of CO_2 ((000) → (010)), that are available to the community. They are due to [80Reg1, 70Dan1, 86Ant1] and we have used all of them in constructing our preferred set. These data are tabulated in Table 6.4.64 and plotted in Fig. 6.4.42.

The uncertainty in the integral cross sections is estimated to be ± 25 %.

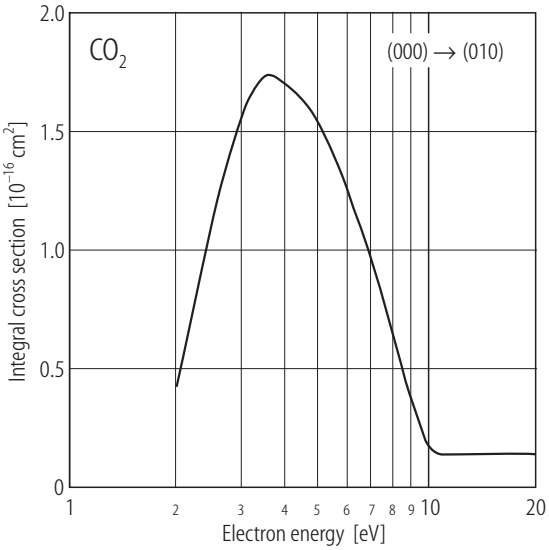

Fig. 6.4.42. Recommended integral cross section for (000) → (010) in CO_2.

Table 6.4.64. Preferred values of the integral (000) → (010) bending mode cross section (σ_{010}) for electron impact excitation in carbon dioxide.

Energy [eV]	σ_{010} [Å^2]
2	0.425
3.6	1.740
4	1.700
10	0.171
20	0.135

References for 6.4.5.6.1

70Dan1 Danner, D.: Diplomarbeit (unpublished), University of Freiburg, Germany, 1970
80Reg1 Register, D.F., Nishimura, H., Trajmar, S.: J. Phys. B: At. Mol. Phys. **13** (1980) 1651
86Ant1 Antoni, Th., Jung, K., Ehrhardt, H., Chang, E.S.: J. Phys. B: At. Mol. Opt. Phys. **19** (1986) 1377

6.4.5.6.2 (000) → (100)

There are only two integral cross section measurements for electron impact excitation of the symmetric stretch mode of CO_2 ((000) → (100)), that are currently available in the literature. They are due to [80Reg1] and [86Ant1] and we have used them both in constructing our preferred set. These data are tabulated in Table 6.4.65.

The uncertainty in the integral cross sections is estimated to be ± 25 %.

Table 6.4.65. Preferred values of the integral (000) → (100) symmetric stretch mode cross section (σ_{100}) for electron impact excitation in carbon dioxide.

Energy [eV]	σ_{100} [Å^2]
2	0.430
3.8	1.000
4	0.800
10	0.077

References for 6.4.5.6.2

80Reg1 Register, D.F., Nishimura, H., Trajmar, S.: J. Phys. B: At. Mol. Phys. **13** (1980) 1651

86Ant1 Antoni, Th., Jung, K., Ehrhardt, H., Chang, E.S.: J. Phys. B: At. Mol. Opt. Phys. **19** (1986) 1377

6.4.5.6.3 (000) → (001)

As for the bending mode, there are three integral cross section measurements for electron impact excitation of the asymmetric stretch mode of CO_2 ((000) → (001)), that are currently available to the community. They are due to [80Reg1, 70Dan1, 86Ant1] and we have used all of them in constructing our preferred set. These data are tabulated in Table 6.4.66 and plotted in Fig. 6.4.43.

The uncertainty in the integral cross sections is estimated to be ± 25 % fo $\varepsilon \leq$ 10eV, ± 30 % at ε = 20 eV and ± 50 % at ε = 50 eV.

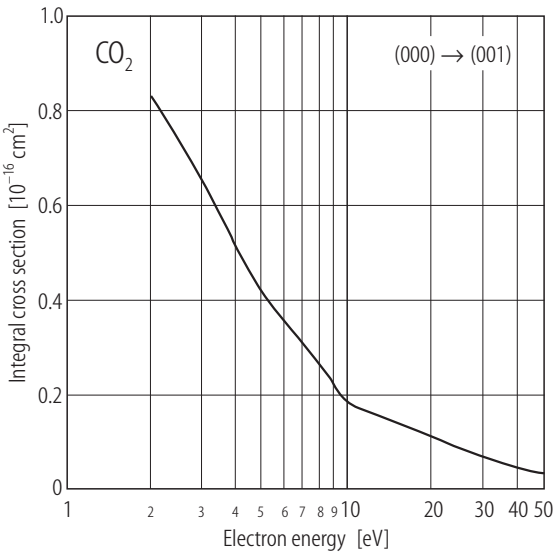

Fig. 6.4.43. Recommended integral cross section for (000) → (001) in CO_2.

Table 6.4.66. Preferred values of the integral (000) → (001) asymmetric stretch mode cross section (σ_{001}) for electron impact excitation in carbon dioxide.

Energy [eV]	σ_{001} [Å^2]
2	0.830
3.8	0.540
4	0.511
10	0.185
20	0.110
50	0.033

References for 6.4.5.6.3

70Dan1 Danner, D.: Diplomarbeit (unpublished), University of Freiburg (Germany, 1970)
80Reg1 Register, D.F., Nishimura, H., Trajmar, S.: J. Phys. B: At. Mol. Phys. **13** (1980) 1651
86Ant1 Antoni, Th., Jung, K., Ehrhardt, H., Chang, E.S.: J. Phys. B: At. Mol. Opt. Phys. **19** (1986) 1377

6.4.5.7 Nitrous oxide (N_2O)

6.4.5.7.1 (000) → (010)

The only available data, for excitation of the bending (010) mode of nitrous oxide by electron impact, is due to [00Kit1]. These integral cross sections are tabulated in Table 6.4.67.

The uncertainty in the integral cross sections is estimated to be ± 30 %.

Table 6.4.67. Preferred values of the integral (000) → (010) bending mode cross section (σ_{010}) for electron impact excitation in nitrous oxide.

Energy [eV]	σ_{010} [Å^2]
2.4	2.67
8.0	0.11

References for 6.4.5.7.1

00Kit1 Kitajima, M., Sakamoto, Y., Gulley, R.J., Hoshino, M., Gibson, J.C., Tanaka, H., Buckman, S.J.: J. Phys. B: At. Mol. Opt. Phys. **33** (2000) 1687

6.4.5.7.2 (000) → (100)

The only available data, for excitation of the symmetric stretch (100) mode of nitrous oxide by electron impact, is also due to due to [00Kit1]. These integral cross sections are tabulated in Table 6.4.68.

The uncertainty on the cross sections is estimated to be ± 30 %.

Table 6.4.68. Preferred values of the integral (000) → (100) symmetric stretch mode cross section (σ_{100}) for electron impact excitation in nitrous oxide.

Energy [eV]	σ_{100} [Å^2]
2.4	2.92
8.0	0.74

References for 6.4.5.7.2

00Kit1 Kitajima, M., Sakamoto, Y., Gulley, R.J., Hoshino, M., Gibson, J.C., Tanaka, H., Buckman, S.J.: J. Phys. B: At. Mol. Opt. Phys. **33** (2000) 1687

6.4.5.7.3 (000) → (001)

The only available data, for excitation of the asymmetric stretch (001) mode of nitrous oxide by electron impact, is again due to due to [00Kit1]. These integral cross sections are tabulated in Table 6.4.69.

The uncertainty on the cross sections is estimated to be ± 50 %.

Table 6.4.69. Preferred values of the integral (000) → (001) asymmetric stretch mode cross section (σ_{001}) for electron impact excitation in nitrous oxide.

Energy [eV]	σ_{001} [Å^2]
2.4	0.45
8.0	0.14

References for 6.4.5.7.3

00Kit1 Kitajima, M., Sakamoto, Y., Gulley, R.J., Hoshino, M., Gibson, J.C., Tanaka, H., Buckman, S.J.: J. Phys. B: At. Mol. Opt. Phys. **33** (2000) 1687

6.4.5.7.4 $2^1\Sigma^+$

Absolute differential cross sections for electron impact excitation of the $2^1\Sigma^+$ valence electronic state of nitrous oxide have been reported by [99Mar1]. To derive integral cross sections from these differential measurements we have used a Molecular Phase Shift Analysis procedure, with these results being presented in Table 6.4.70 and plotted in Fig. 6.4.44.

The uncertainty on the cross sections is estimated to be ± 50 %.

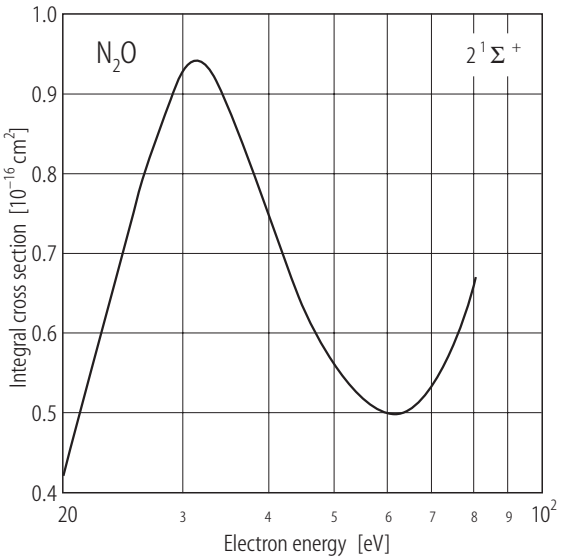

Fig. 6.4.44. Recommended integral cross section for $2^1\Sigma^+$ in N_2O.

Table 6.4.70. Preferred values of the integral cross section for the electron impact excitation of the $2^1\Sigma^+$ electronic state ($\sigma_{2^1\Sigma^+}$) of nitrous oxide.

Energy [eV]	$\sigma_{2^1\Sigma^+}$ [Å^2]
20	0.42
30	0.93
50	0.55
80	0.67

References for 6.4.5.7.4

99Mar1 Marinkovic, B., Panajotovic, R., R., Pesic, Z.D., Filipovic, D.M., Felfli, Z., Msezane, A.Z.: J. Phys. B: At. Mol. Opt. Phys. **32** (1999) 1949

6.4.5.7.5 $^1\Pi$

Absolute differential cross sections for electron impact excitation of the ($^2\Pi$) 3sσ $^1\Pi$ Rydberg electronic state of nitrous oxide have been reported by [99Mar1]. To derive integral cross sections from these differential measurements we have used a Molecular Phase Shift Analysis procedure, with these results being presented in Table 6.4.71 and plotted in Fig. 6.4.45.

The uncertainty on the cross sections is estimated to be ± 50 %.

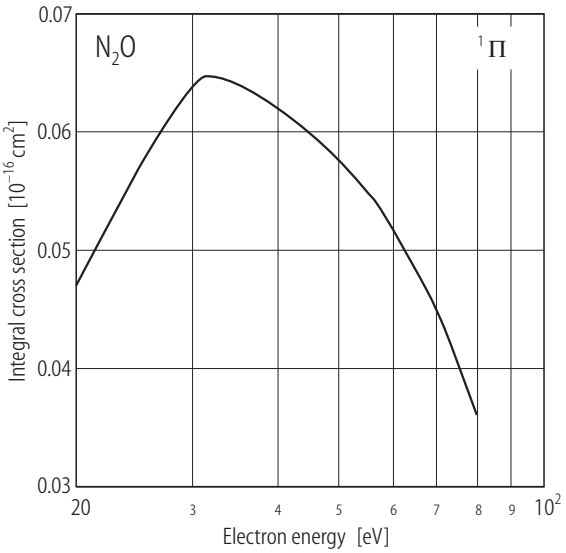

Fig. 6.4.45. Recommended integral cross section for $^1\Pi$ in N_2O.

Table 6.4.71. Preferred values of the integral cross section for the electron impact excitation of the $^1\Pi$ electronic state ($\sigma_{^1\Pi}$) of nitrous oxide.

Energy [eV]	($\sigma_{^1\Pi}$) [Å^2]
20	0.047
30	0.064
50	0.057
80	0.036

References for 6.4.5.7.5

99Mar1 Marinkovic, B., Panajotovic, R., Pesic, Z.D., Filipovic, D.M., Felfli, Z., Msezane, A.Z.: J. Phys. B: At. Mol. Opt. Phys. **32** (1999) 1949

6.4.5.8 Water (H_2O)

6.4.5.8.1 (000) → (010)

The available integral cross section data for electron impact excitation of the bending mode ((000) - (010)) of H_2O are due to [76Sen1, 88Shy1, 00Zei1]. There are some discrepancies between all three sets of results, and so our preferred cross section set was constructed from [76Sen1] for $\varepsilon < 6$ eV, from [00Zei1] for 6 eV $\leq \varepsilon \leq$ 10 eV and from [88Shy1] for ε = 15 and 20 eV where no other data exists. Our preferred set is tabulated in Table 6.4.72 and plotted in Fig. 6.4.46.

The uncertainty in the cross section is estimated to be ± 25 %.

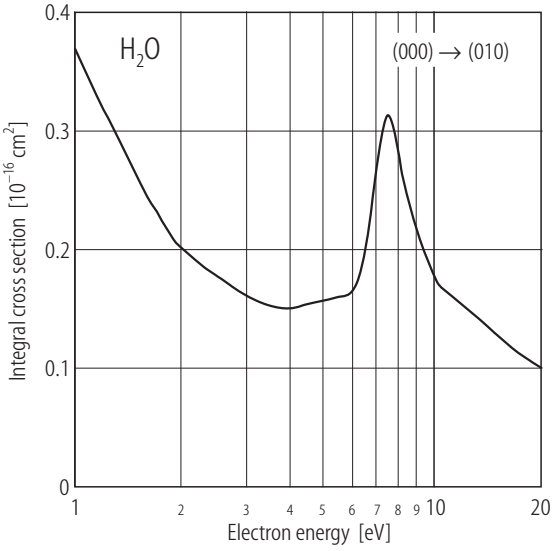

Fig. 6.4.46. Recommended integral cross section for (000) → (010) in H_2O.

Table 6.4.72. Preferred values of the integral (000) → (010) bending mode cross section (σ_{010}) for electron impact excitation in water.

Energy [eV]	σ_{010} [Å^2]	Energy [eV]	σ_{010} [Å^2]
1	0.370	6	0.163
2	0.200	7.5	0.317
2.2	0.190	8.75	0.227
3	0.160	10	0.180
4	0.150	15	0.130
5	0.157	20	0.100

References for 6.4.5.8.1

76Sen1 Seng, G., Linder, F.: J. Phys. B: At. Mol. Phys. **9** (1976) 2539
88Shy1 Shyn, T., Cho, S.Y., Cravens, T.E.: Phys. Rev. A **38** (1988) 678
00Zei1 El-Zein, A., Brunger, M.J., Newell, W.R.: Chem. Phys. Lett. **319** (2000) 701

6.4.5.8.2 (000) → (100 + 001)

The stretch modes of H_2O are essentially degenerate and so integral cross sections for their sum, (000) → (100 + 001) are usually reported in the literature. In this case the available electron impact integral cross sections are due to [76Sen1, 88Shy1, 00Zei1] and we note that in this case they are all in fair agreement with one another. Consequently all three data sets have been used to construct our preferred integral cross section. These data are tabulated in Table 6.4.73 and plotted in Fig. 6.4.47.

The uncertainty in the cross section is estimated to be ± 25 %.

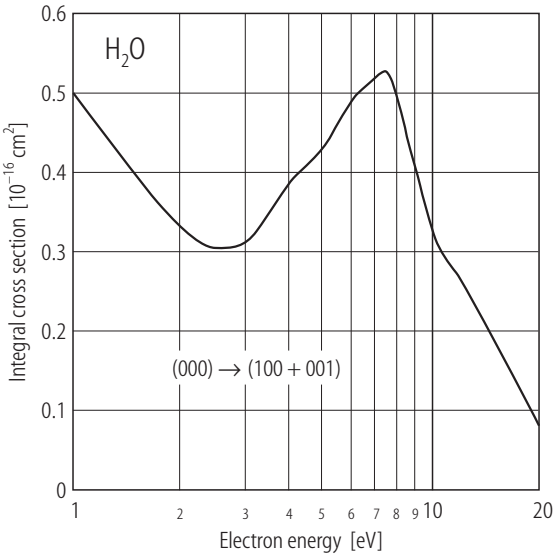

Fig. 6.4.47. Recommended integral cross section for (000) → (100 + 001) in H_2O.

Table 6.4.73. Preferred values of the integral (000) → (100 + 001) stretch mode cross section ($\sigma_{100+001}$) for electron impact excitation in water.

Energy [eV]	$\sigma_{100+001}$ [Å^2]	Energy [eV]	$\sigma_{100+001}$ [Å^2]
1	0.500	7.5	0.529
2.1	0.320	8	0.495
3	0.310	8.875	0.413
4	0.385	10	0.325
5	0.430	15	0.190
6	0.489	20	0.080
7	0.520		

References for 6.4.5.8.2

76Sen1 Seng, G., Linder, F.: J. Phys. B: At. Mol. Phys. **9** (1976) 2539
88Shy1 Shyn, T., Cho, S.Y., Cravens, T.E.: Phys. Rev. A **38** (1988) 678
00Zei1 El-Zein, A., Brunger, M.J., Newell, W.R.: Chem. Phys. Lett. **319** (2000) 701

6.4.5.9 Ammonia (NH_3)

6.4.5.9.1 $\nu_1 + \nu_3$ vibrational composite

Integral cross sections for electron impact excitation of the unresolved ν_1 symmetric stretch mode (ΔE = 414 meV) and ν_3 asymmetric stretch mode (ΔE = 427 meV) have been reported by [88Ben1] and [92Gul1]. The integral cross section of [88Ben1] was reported at ε = 7.3 eV, and that of [92Gul] at ε = 7.5 eV, with both values, allowing for the slight mismatch in energy near the peak of the ^{2}E shape resonance, being in good agreement with one another. We therefore report a single preferred integral cross section for $\nu_1 + \nu_3$ at ε = 7.5 eV, with this value being given in Table 6.4.74.

The uncertainty on this cross section is estimated to be ± 20 %.

Table 6.4.74. Preferred values of the integral $\nu_1 + \nu_3$ stretch mode composite cross section ($\sigma_{\nu_1+\nu_3}$) for electron impact excitation in ammonia.

Energy [eV]	($\sigma_{\nu_1+\nu_3}$) [Å^2]
7.5	0.67

References for 6.4.5.9.1

88Ben1 Ben Arfa, M., Tronc, M.: J. Chim. Physique **85** (1988) 889
92Gul1 Gulley, R.J., Brunger, M.J., Buckman, S.J.: J. Phys. B: At. Mol. Opt. Phys. **25** (1992) 2433

6.4.5.10 Ozone (O_3)

6.4.5.10.1 Hartley band electronic-states

The only integral cross section for electron impact excitation of the Hartley band electronic states in ozone is due to [96Swe1]. It therefore forms the basis for our preferred cross section which is tabulated in Table 6.4.75 and plotted in Fig. 6.4.48.

The uncertainty on these cross sections is estimated to be ± 26 % at ε = 7 and 10 eV and ± 22 % at ε = 15 and 20 eV.

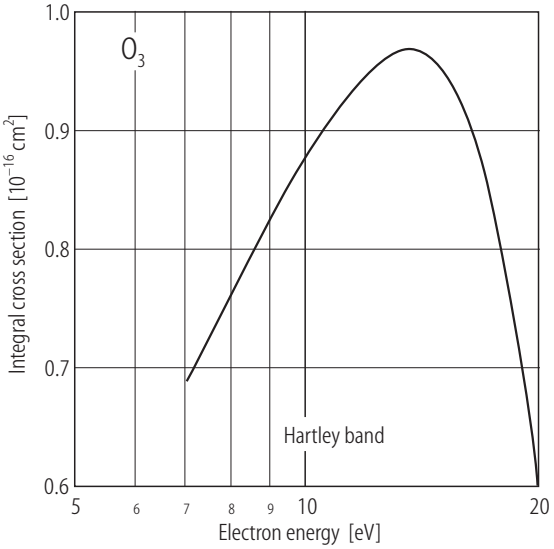

Fig. 6.4.48. Recommended integral cross section for the Hartley band in O_3.

Table 6.4.75. Preferred values of the integral cross section (σ_{HB}) for electron impact excitation of the Hartley band electronic-states of ozone.

Energy [eV]	σ_{HB} [Å^2]
7	0.69
10	0.88
15	0.95
20	0.60

References for 6.4.5.10.1

96Swe1 Sweeney, C.J., Shyn, T.W.: Phys. Rev. A **53** (1996) 1576

6.4.5.11 Carbonyl sulfide (OCS)

6.4.5.11.1 (000) → (010)

The only integral cross section measured for excitation of the bending mode in OCS ((000) → (010)) is due to [87Soh1]. Consequently our preferred cross section, as tabulated in Table 6.4.76 and plotted in Fig. 6.4.49, is taken directly from [87Soh1].

The uncertainty on these cross sections is estimated to be ± 20 %.

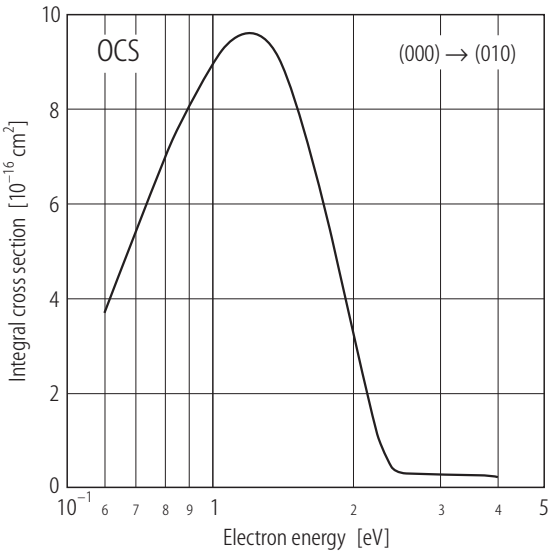

Fig. 6.4.49. Recommended integral cross section for (000) → (010) in OCS.

Table 6.4.76. Preferred values of the integral (000) → (010) bending mode cross section (σ_{010}) for electron impact excitation in carbonyl sulfide.

Energy [eV]	σ_{010} [Å^2]
0.6	3.65
1.15	9.6
2.5	0.3
3.0	0.27
3.5	0.28
4.0	0.25

References for 6.4.5.11.1

87Soh1 Sohn, W., Kochem, K-H., Scheuerlein, K.M., Jung, K., Ehrhardt, H.: J. Phys. B: At. Mol. Phys. **20** (1987) 3217

6.4.5.11.2 (000) → (100)

The only integral cross section measurement for excitation of the symmetric stretch mode in OCS ((000) → (100)) is also due to [87Soh1]. Thus our preferred cross section, as tabulated in Table 6.4.77 and plotted in Fig. 6.4.50, is taken directly from [87Soh1].

The uncertainty on these cross sections is estimated to be ± 20 %.

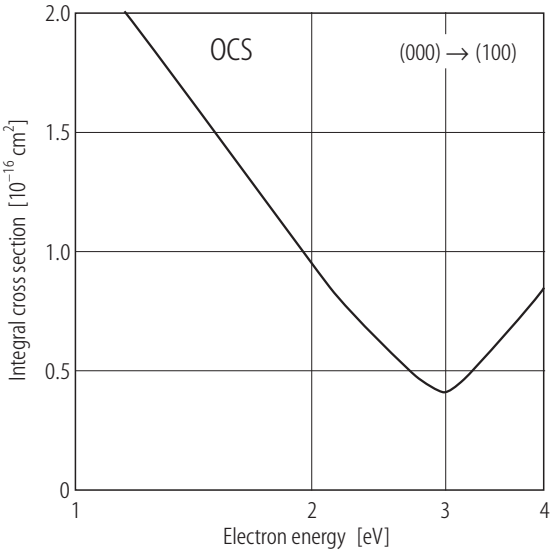

Fig. 6.4.50. Recommended integral cross section for (000) → (100) in OCS.

Table 6.4.77. Preferred values of the integral (000) → (100) symmetric stretch mode cross section (σ_{100}) for electron impact excitation in carbonyl sulfide.

Energy [eV]	σ_{100} [Å^2]
1.15	2.0
2.5	0.6
3.0	0.4
3.5	0.6
4.0	0.84

References for 6.4.5.11.2

87Soh1 Sohn, W., Kochem, K-H., Scheuerlein, K.M., Jung, K., Ehrhardt, H.: J. Phys. B: At. Mol. Phys. **20** (1987) 3217

6.4.5.11.3 (000) → (001)

Once again, the only integral cross section measurement for excitation of the asymmetric stretch mode in OCS ((000) → (001)) is also due to [87Soh1]. Thus our preferred cross section, as tabulated in Table 6.4.78 and plotted in Fig. 6.4.51, is taken directly from [87Soh1].

The uncertainty on these cross sections is estimated to be ± 20 %.

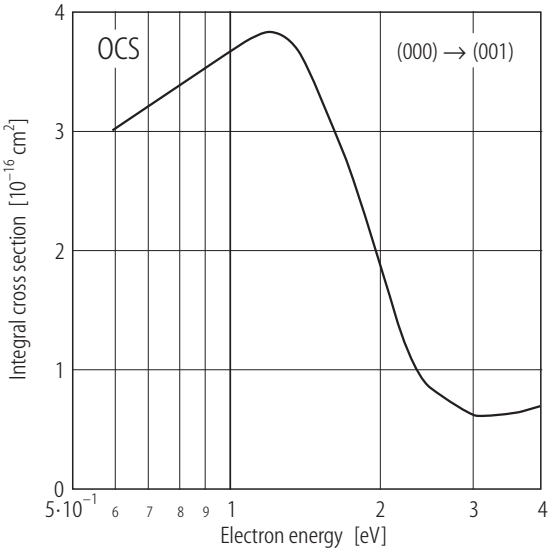

Fig. 6.4.51. Recommended integral cross section for (000) → (001) in OCS.

Table 6.4.78. Preferred values of the integral (000) → (001) asymmetric stretch mode cross section (σ_{001}) for electron impact excitation in carbonyl sulfide.

Energy [eV]	σ_{001} [Å^2]
0.6	3
1.15	3.8
2.5	0.82
3.0	0.62
3.5	0.63
4.0	0.69

References for 6.4.5.11.3

87Soh1 Sohn, W., Kochem, K-H., Scheuerlein, K.M., Jung, K., Ehrhardt, H.: J. Phys. B: At. Mol. Phys. **20** (1987) 3217

6.4.5.12 Methane (CH_4)

6.4.5.12.1 $\nu_{1,3}$ vibrational composite

Integral cross sections for excitation of the hybrid (unresolved) $\nu_{1,3}$ modes in CH_4 have been reported by [83Tan1, 91Shy1, 97Bun1]. The data of [83Tan1], for $\varepsilon \leq 7.5$ eV, tends to be somewhat systematically lower in magnitude than either [91Shy1] or [97Bun1]. Nonetheless, in our polynomial least squares fitting procedure we have used all three data sets to determine our preferred integral cross section for the $\nu_{1,3}$ modes. This cross section is tabulated in Table 6.4.79 and plotted in Fig. 6.4.52.

The uncertainty on these cross sections is estimated to be ± 25 %.

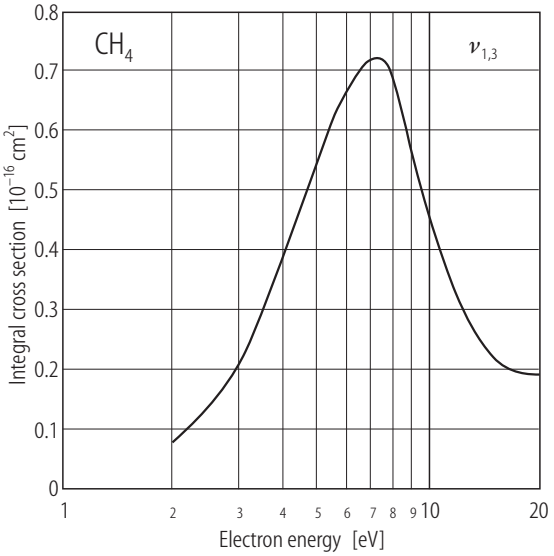

Fig. 6.4.52. Recommended integral cross section for the $\nu_{1,3}$ mode in CH_4.

Table 6.4.79. Preferred values of the integral $\nu_{1,3}$ hybrid vibrational mode cross section ($\sigma_{\nu_{1,3}}$) for electron impact excitation in methane.

Energy [eV]	$\sigma_{\nu_{1,3}}$ [Å^2]	Energy [eV]	$\sigma_{\nu_{1,3}}$ [Å^2]
2.0	0.080	10.0	0.450
3.0	0.204	12.5	0.291
4.0	0.384	15.0	0.220
5.0	0.558	20.0	0.190
7.5	0.716		

References for 6.4.5.12.1

83Tan1 Tanaka, H., Kubo, M., Onodera, N., Suzuki, A.: J. Phys. B: At. Mol. Phys. **16** (1983) 2861
91Shy1 Shyn, T.W.: J. Phys. B: At. Mol. Opt. Phys. **24** (1991) 5169
97Bun1 Bundschu, C.T., Gibson, J.C., Gulley, R.J., Brunger, M.J., Buckman, S.J., Sanna, N., Gianturco, F.A.: J. Phys. B: At. Mol. Opt. Phys. **30** (1997) 2239

6.4.5.12.2 $\nu_{2,4}$ vibrational composite

Integral cross sections for excitation of the hybrid (unresolved) $\nu_{2,4}$ modes in CH_4 have been reported by [83Tan1, 91Shy1, 97Bun1]. At 3 eV the data of [83Tan1] is significantly smaller in magnitude than that of [97Bun1], while at 5 eV the cross sections of [83Tan1] and [91Shy1] are also smaller in magnitude than that of [97Bun1]. Whilst we believe the more recent measurement [97Bun1] is the most reliable, we have nonetheless incorporated all three cross section sets in our polynomial least squares fit to determine the preferred integral cross section for the $\nu_{2,4}$ modes. This cross section is tabulated in Table 6.4.80 and plotted in Fig. 6.4.53.

The uncertainty on these cross sections is estimated to be ± 25 %.

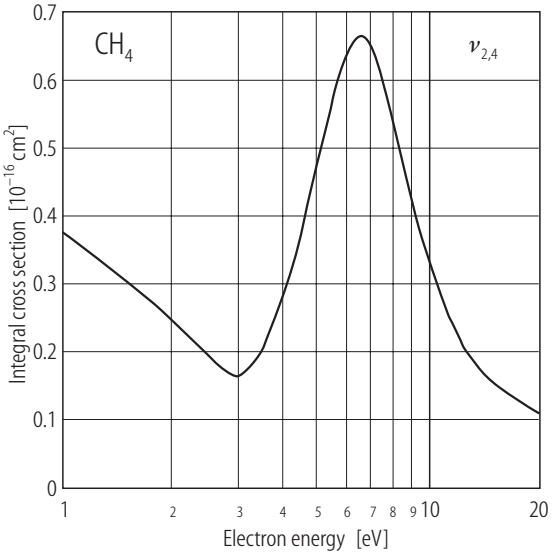

Fig. 6.4.53. Recommended integral cross section for the $\nu_{2,4}$ mode in CH_4.

Table 6.4.80. Preferred values of the integral $\nu_{2,4}$ hybrid vibrational mode cross section ($\sigma_{\nu_{2,4}}$) for electron impact excitation in methane.

Energy [eV]	$\sigma_{\nu_{2,4}}$ [Å^2]	Energy [eV]	$\sigma_{\nu_{2,4}}$ [Å^2]	Energy [eV]	$\sigma_{\nu_{2,4}}$ [Å^2]
1.0	0.377	6.0	0.644	10.0	0.333
2.0	0.242	7.0	0.647	12.5	0.203
3.0	0.163	7.5	0.591	15.0	0.153
4.0	0.284	8.0	0.527	17.5	0.128
5.0	0.495	9.0	0.418	20.0	0.109

References for 6.4.5.12.2

83Tan1 Tanaka, H., Kubo, M., Onodera, N., Suzuki, A.: J. Phys. B: At. Mol. Phys. **16** (1983) 2861
91Shy1 Shyn, T.W.: J. Phys. B: At. Mol. Opt. Phys. **24** (1991) 5169
97Bun1 Bundschu, C.T., Gibson, J.C., Gulley, R.J., Brunger, M.J., Buckman, S.J., Sanna, N., Gianturco, F.A.: J. Phys. B: At. Mol. Opt. Phys. **30** (1997) 2239

6.4.5.13 Ethane (C_2H_6)

6.4.5.13.1 ν_b bending vibrational composite

The only integral cross section measurement for electron impact excitation of the bending composite vibrational modes in C_2H_6 (ν_b) is due to [90Boe1]. Consequently our preferred cross section, as tabulated in Table 6.4.81 and plotted in Fig. 6.4.54, is taken directly from [90Boe1].

The uncertainty on these cross sections is estimated to be ± 25 %.

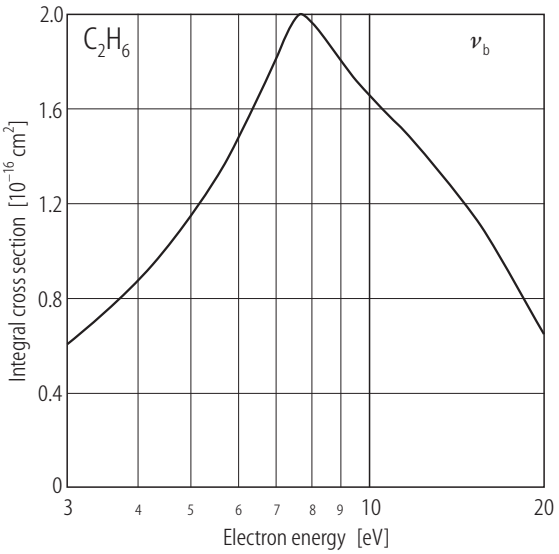

Fig. 6.4.54. Recommended integral cross section for the ν_b mode in C_2H_6.

Table 6.4.81. Preferred values of the integral ν_b bending composite mode cross section (σ_{ν_b}) for electron impact excitation in ethane.

Energy [eV]	σ_{ν_b} [Å^2]
3	0.604
5	1.185
7.5	2.012
10	1.651
15	1.158
20	0.648

References for 6.4.5.13.1

90Boe1 Boesten, L., Tanaka, H., Kubo, M., Sato, H., Kimura, M., Dillon, M.A., Spence, D.: J. Phys. B: At. Mol. Opt. Phys. **23** (1990) 1905

6.4.5.13.2 ν_s stretching vibrational composite

The only integral cross section measurement for electron impact excitation of the stretching composite vibrational modes in C_2H_6 (ν_s) is also due to [90Boe1]. Thus our preferred cross section, as tabulated in Table 6.4.82 and plotted in Fig. 6.4.55, is taken directly from [90Boe1].

The uncertainty on these cross sections is estimated to be ± 27 %.

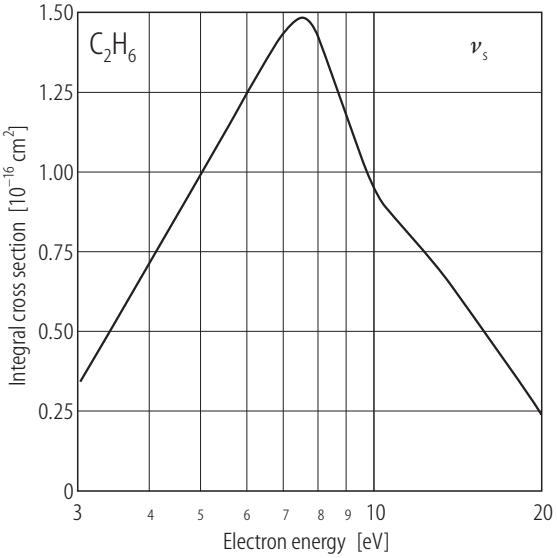

Fig. 6.4.55. Recommended integral cross section for the ν_s mode in C_2H_6.

Table 6.4.82. Preferred values of the integral ν_s stetching composite mode cross section (σ_{ν_s}) for electron impact excitation in ethane.

Energy [eV]	σ_{ν_a} [Å^2]
3	0.344
5	1.022
7.5	1.483
10	0.952
15	0.552
20	0.234

References for 6.4.5.13.2

90Boe1 Boesten, L., Tanaka, H., Kubo, M., Sato, H., Kimura, M., Dillon, M.A., Spence, D.: J. Phys. B: At. Mol. Opt. Phys. **23** (1990) 1905

6.4.5.14 Ethyne (C_2H_2)

6.4.5.14.1 $\nu_{1,3}$ vibrational composite

Integral cross sections for excitation of the composite (unresolved) $\nu_{1,3}$ modes in C_2H_2 have been reported by [85Koc1] and [93Kha1]. These data sets do not overlap in energy and so we have employed them both in constructing our preferred cross section. This preferred integral cross section is tabulated in Table 6.4.83 and plotted in Fig. 6.4.56.

The uncertainty on these cross sections is estimated to be ± 35 %.

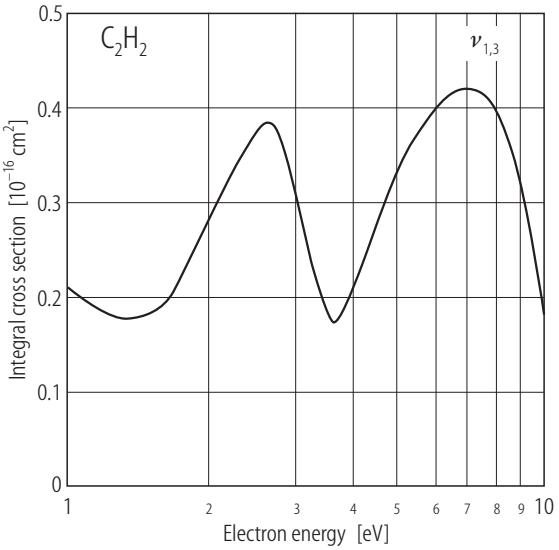

Fig. 6.4.56. Recommended integral cross section for the $\nu_{1,3}$ mode in C_2H_2.

Table 6.4.83. Preferred values of the integral $\nu_{1,3}$ composite mode cross section ($\sigma_{\nu_{1,3}}$) for electron impact excitation in ethyne.

Energy [eV]	$\sigma_{\nu_{1,3}}$ [Å^2]
1.0	0.21
1.6	0.192
2.0	0.287
2.6	0.383
3.6	0.172
5.0	0.340
10.0	0.180

References for 6.4.5.14.1

85Koc1 Kochem, K-H., Sohn, W., Jung, K., Ehrhardt, H., Chang, E.S.: J. Phys. B: At. Mol. Phys. **18** (1985) 1253

93Kha1 Khakoo, M.A., Jayaweera, T., Wang, S., Trajmar, S.: J. Phys. B: At. Mol. Opt. Phys. **26** (1993) 4845

6.4.5.14.2 ν_2 vibrational mode

Integral cross sections for excitation of the ν_2 normal vibrational mode in C_2H_2 have also been reported by [85Koc1] and [93Kha1]. These data sets do not overlap in energy and so once again we have employed them both when constructing our preferred cross section. This preferred integral cross section is tabulated in Table 6.4.84 and plotted in Fig. 6.4.57.

The uncertainty on these cross sections is estimated to be ± 35 %.

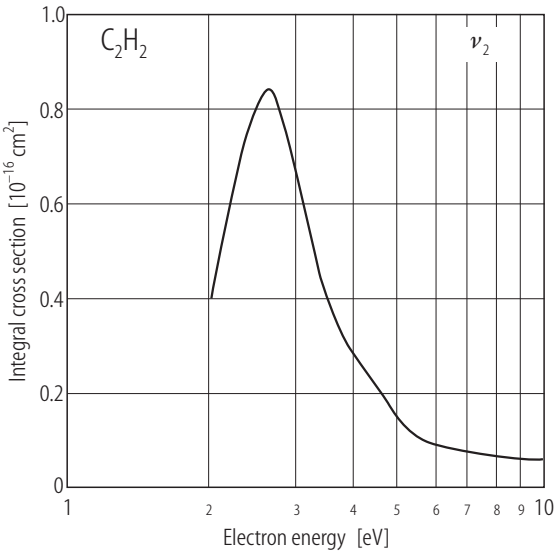

Fig. 6.4.57. Recommended integral cross section for the ν_2 mode in C_2H_2.

Table 6.4.84. Preferred values of the integral ν_2 normal vibrational mode cross section (σ_{ν_2}) for electron impact excitation in ethyne.

Energy [eV]	σ_{ν_2} [Å^2]
2.0	0.400
2.6	0.840
3.6	0.370
5.0	0.140
10.0	0.059

References for 6.4.5.14.2

85Koc1 Kochem, K-H., Sohn, W., Jung, K., Ehrhardt, H., Chang, E.S.: J. Phys. B: At. Mol. Phys. **18** (1985) 1253

93Kha1 Khakoo, M.A., Jayaweera, T., Wang, S., Trajmar, S.: J. Phys. B: At. Mol. Opt. Phys. **26** (1993) 4845

6.4.5.14.3 $\nu_{4,5}$ vibrational composite

Once again, integral cross sections for excitation of the composite (unresolved) $\nu_{4,5}$ modes in C_2H_2 have been reported by [85Koc1] and [93Kha1]. These data sets have both been used in determining our preferred cross section, which is tabulated in Table 6.4.85 and plotted in Fig. 6.4.58.

The uncertainty on these cross sections is estimated to be ± 35 %.

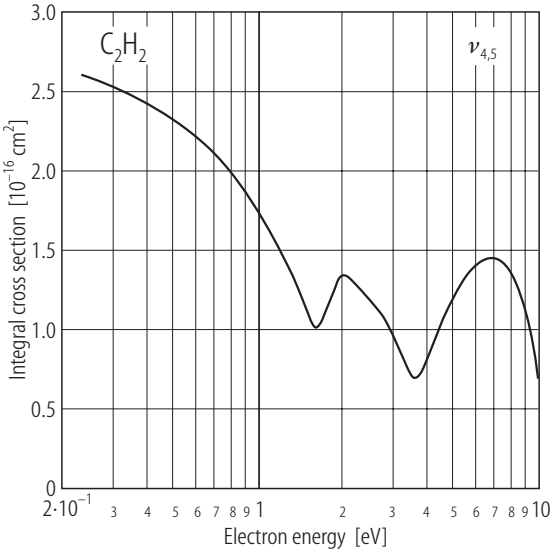

Fig. 6.4.58. Recommended integral cross section for the $\nu_{4,5}$ mode in C_2H_2.

Table 6.4.85. Preferred values of the integral $\nu_{4,5}$ composite mode cross section ($\sigma_{\nu_{4,5}}$) for electron impact excitation in ethyne.

Energy [eV]	$\sigma_{\nu_{4,5}}$ [Å^2]
0.235	2.600
1.0	1.740
1.6	1.000
2.0	1.340
2.6	1.150
3.6	0.690
5.0	1.220
10.0	0.690

References for 6.4.5.14.3

85Koc1 Kochem, K-H., Sohn, W., Jung, K., Ehrhardt, H., Chang, E.S.: J. Phys. B: At. Mol. Phys. **18** (1985) 1253

93Kha1 Khakoo, M.A., Jayaweera, T., Wang, S., Trajmar, S.: J. Phys. B: At. Mol. Opt. Phys. **26** (1993) 4845

6.4.5.15 Carbon tetrafluoride (CF_4)

6.4.5.15.1 $\nu_1 + \nu_2 + \nu_3 + \nu_4$ vibrational excitation

Differential cross sections for electron impact excitation of the ν_1, ν_2, ν_3 and ν_4 fundamental modes of vibration for CF_4 have been reported by [92Man1] and [92Boe1]. However, they did not report integral cross sections in these studies. Nonetheless, [94Bon1] derived integral cross sections, for energies in the range ε = 1.5 - 20 eV, from the work of [92Man1] and [94Boe1] and reported them as an integral cross section for the sum $\nu_1 + \nu_2 + \nu_3 + \nu_4$ of the fundamental modes. We have taken this experimentally-based integral cross section (for $\nu_1 + \nu_2 + \nu_3 + \nu_4$) as our preferred integral cross section. It is tabulated in Table 6.4.86 and plotted in Fig. 6.4.59.

The uncertainty on these cross sections is estimated to be ± 35 %.

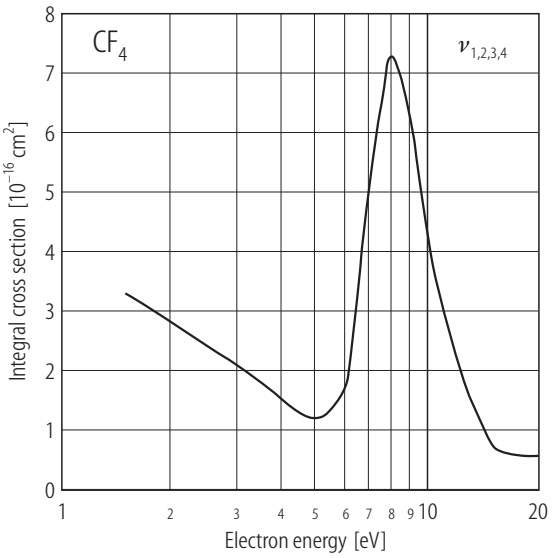

Fig. 6.4.59. Recommended integral cross section for the $\nu_{1,2,3,4}$ mode in CF_4.

Table 6.4.86. Preferred values of the integral $\nu_1 + \nu_2 + \nu_3 + \nu_4$ composite mode cross section ($\sigma_{\nu_1+\nu_2+\nu_3+\nu_4}$) for electron impact excitation in carbon tetrafloride.

Energy [eV]	$\sigma_{\nu_1+\nu_2+\nu_3+\nu_4}$ [Å^2]	Energy [eV]	$\sigma_{\nu_1+\nu_2+\nu_3+\nu_4}$ [Å^2]
1.5	3.30	8.0	7.30
2.0	2.80	9.0	6.30
3.0	2.10	10.0	4.30
5.0	1.20	15.0	0.76
6.0	1.70	20.0	0.55
7.0	5.30		

References for 6.4.5.15.1

92Man1 Mann, A., Linder, F.: J. Phys. B: At. Mol. Opt. Phys. **25** (1992) 545
92Boe1 Boesten, L., Tanaka, H., Kobayashi, A., Dillon, M.A., Kimura, M.: J. Phys. B: At. Mol. Opt. Phys. **25** (1992) 1607
94Bon1 Bonham, R.A.: Jpn. J. Appl. Phys. **33** (1994) 4157

6.4.6 Concluding remarks

After an extensive and critical search of the literature we have presented recommended inelastic cross sections for 15 important molecules. Great care was taken when applying our procedure for deriving each of the recommended cross section sets presented in this paper. In spite of this attention to detail we feel it important to note that there is no guarantee that our recommended cross section sets, when subjected to a Boltzmann or Monte Carlo analysis, will exactly reproduce the relevant transport parameters. We would hope, however, that when subjected to such an analysis our recommended sets would be largely consistent with the transport data, to within the uncertainties we quote.