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Bibliography of Electron and Photon Cross Sections
with Atoms and Molecules
Published in the 20th Century
– Sulphur Hexafluoride –

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Bibliography of Electron and Photon Cross Sections With Atoms and Molecules Published in the 20th Century

—— Sulphur Hexafluoride ——*

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A bibliography of original and review reports of experiments or theories of electron and photon cross sections and also electron swarm data are presented for atomic or molecular species with specified targets. These works covered 17 atoms and 51 molecules. The present bibliography is only for sulphur hexafluoride (SF_6). About 920 papers were compiled. A comprehensive author index is included. The bibliography covers the period 1934 through 2000 for SF_6. Finally, author's comments for SF_6 electron collision cross section are given.

Keywords : SF_6 molecule, collision cross section, electron, elastic scattering, rotational, vibrational and electronic excitations, dissociation, ionization, photon, photoabsorption, photodissociation, photoexcitation, photoionization, electron swarm, drift velocity, diffusion coefficient, ionization coefficient, excitation and ionization energies, transition probabilities, lifetimes of excited states

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Introduction

History

This bibliography is the result of a continuing literature survey which was begun around 1970 and originally encompassed only electron collision cross section and electron swarm data. The organization responsible for continuing this survey is Nagoya Institute of Technology, Nagoya. From 1994, the work continued to Gaseous Electronics Insititute, Nagoya. In 1997, the collection of photon cross section references was begun. The search for references in both cases was retrospective and included all papers reporting measurements, theoretical calculations or reviews and data compilations of such cross sections and electron swarm data.

Scope

This bibliography contains references to original research papers which report experiments or theoretical calculations of cross sections for electron and photon collisions with sulphur hexafluoride SF_6. The review papers on this subject are also included. Some SF_6 molecule cluster papers are included. Some conference reports, company or agency reports and PhD thesis are included. SF_6 ion papers and positron collision papers are not included in principle.

Papers reporting the following data are included.

For electron collision cross section :

1) elastic scattering
2) rotational excitation
3) vibrational excitation
4) electronic excitation
5) dissociation
6) ionization
7) attachment
8) grand total scattering (sum of elastic and inelastic cross sections)
9) electron swarm parameters (drift velocity, diffusion coefficient)
10) excitation and ionization coefficients

For photon collision cross section :

1) photoabsorption
2) photoexcitation and fluorescence
3) photodissociation
4) photoionization

For some related data :

1) excitation and ionization energies
2) transition probabilities
3) lifetimes of excited states
4) others

The energy range for electron cross section data is usually 0 - 10 keV, but some higher electron energy papers are included. The wavelength range for photon cross section data is from microwave to X-ray. Most papers are concerned with infrared, visible and ultraviolet ray region.

The bibliography includes the papers published in the 20th century, from 1901 to 2000. Oldest papers in this list are given by A. Eucken (1934) and M. Yost (1934). So for this SF_6 bibliography, published papers from 1934 to 1999 are compiled by alphabetical order of the first author's surname of the paper. And the references published in 2000 and plus some old papers found very recently after compilation are added as "Addenda of References for SF_6 (1)". In total, about 920 papers are compiled in the sulphur hexafluoride SF_6 molecule bibliography.

Organization

This report consists of four parts : introduction, the bibliography and its addenda, author index, and some comments on electron collision cross sections.

Bibliography

In this section the complete citation for all references are given. At first following classifications are shown :

E : Elastic collision
R : Rotational excitation
V : Vibrational excitation
EX : electronic EXcitation
D : Dissociation
I : Ionization
A : Attachment
ME : MEtastable argon
S : electron Swarm
O : Others (photon cross sections and the others)

All authors' initials and surname, journal name, volume, inclusive pages and year of publication are given as well as the title, and some additional information in the square bracket [ ]. E and T in the square bracket mean experiment and theory.

Bibliography for SF_6 are divided into two parts :

Part 1.	1980 - 1999	p. 1 - 40	
Part 2.	1901 - 1979	p. 41 - 61	
Part 3.	Addenda of References (1)		published in 2000, plus some old papers
		p. 62 - 74	
Part 4.	Addenda of References (2)		some old papers
		p. 75 - 78	

Author Index

In this section all authors are listed alphabetically by surname. After each author's name is a list of page numbers indicating which references he or she authored or coauthored.

Part 1.	1901 - 1999	p. 1 - 12	
Part 2.	Addenda (1)	p. 13 - 16	

Some Comments on Electron Collision Cross Sections for SF_6

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References for SF_6 (1980 - 1999)

(Sulphur hexafluoride, Sulfur hexafluoride)

E	: Elastic collision,	R	: Rotational excitation,
V	: Vibrational excitation,	EX	: Electronic excitation,
D	: Dissociation,	I	: Ionization,
A	: Attachment, Detachment	QT	: Grand total cross section,
S	: Swarm,	α	: Ionization coefficient,
O	: The others,	[ ]	: Additional informations, E : Exp., T : Theory.

Some important papers published until 1979 are included in this part.

A N. G. Adams, D. Smith and E. Alge : 3rd Int. Swarm Seminar, Innsbruck 42-45 (1983)・
Electron attachment coefficients determined using a flowing afterglow/ Langmuir probe (FALP) apparatus.
[E, SF_6, CCl_4, CCl_3F, CCl_2F_2, $CHCl_3$, Cl_2; see D. Smith (1984)]

O B. M. Addison, K. H. Tan, G. M. Bancroft and F. Cerrina : Chem. Phys. Lett. 129, 468-474 (1986)
A comparison of shape resonant behaviour in the inner-shell photo-absorption and valence-level photoelectron spectra of SF_6, SF_5Cl and SeF_6.
[E, $h\nu$, SF_6, etc.; 21.2 - 215 eV]

O B. M. Addison-Jones, K. H. Tan, B. W. Yates, J. N. Cutler, G. M. Bancroft and J. S. Tse : J. Elect. Spectrosc. Relat. Phenom. 48, 155-178 (1989)・C47
A comparison of valence level photoelectron cross sections for SF_6, SeF_6 and "F_6" from 21 eV to 100 eV photon energy. [E, $h\nu$, SF_6, etc.]

A J. M. Ajello and A. Chutjian : J. Chem. Phys. 71, 1079-1087 (1979) ○
Line shape for attachment of threshold electrons to SF_6 and $CFCl_3$: Threshold photoelectron (TPSA) studies of Xe, CO, and C_2H_2.
[E, SF_6, $CFCl_3$]

A N. L. Aleksandrov : Sov. Phys. Usp. 31, 101-118 (1988)・
Three-body electron attachment to a molecule.
[review, SF_6, O_2, SO_2, etc.]

I A. H. Al-Nasir, M. A. Chaudhry, A. J. Duncan, R. Hippler, D. M. Campbell and H. Kleinpoppen : J. Phys. B29, 1849-1859 (1996) C158 K
Doubly differential cross sections for the ionization of the SF_6 molecule by electron impact. [E, SF_6; 100, 200 eV]

O H. M. Anderson, J. A. Merson and R. W. Light : IEEE Trans. Plasma Sci. 14, 156-164 (1986)
A kinetic model for plasma etching silicon in a SF_6/O_2 RF discharge.
[T, SF_6, $SF_6 + O_2$]

O A. D. Appelhans, J. E. Delmore and D. A. Dahl : Anal. Chem. 59, 1685-1691 (1987)
Focused, rasterable, high energy neutral molecular beam probe for secondary ion mass spectrometry. [E, SF_6]

A A. D. Appelhans and J. E. Delmore : J. Chem. Phys. 88, 5561-5570 (1988)
Refinement of the autoneutralization lifetimes of short lived states of SF_6^-. [E, SF_6; $SF_6^- \rightarrow SF_6 + e$]

O H. Arai and H. Hotta : J. Chem. Phys. 75, 2723-2729 (1981)
Ionization of gases by a pulsed electron beam as studied by self-focusing. II. Polyatomic gases. [E, SF_6, CCl_2F_2, N_2O, etc.]

S Th. Aschwanden : in Gaseous Dielectrics IV, Pergamon Press, Knoxville 24-33
α (1984)○ C182
A Swarm parameters in SF_6 and SF_6/N_2-mixtures determined from a time resolved discharge study. [E, SF_6, $SF_6 + N_2$]

S Th. Aschwanden : PhD Thesis, Swiss Federal Institute of Technology, ETH, No. 7931 (1985)○
α Die Ermittlung physikalischer Entladungsparameter in Isoliergasen und
A Isoliergasgemischen mit einer verbesserten Swarm-Methode.
[E, SF_6, $SF_6 + N_2$, N_2, n-C_3F_6, 1,2-$C_2Cl_2F_4$]

S Th. Aschwanden : in Swarm Studies and Inelastic Electron-Molecule Collisions, Springer-Verlag, Lake Tahoe 97-97 (1987)
Measurements of electron and ion transport data in SF_6 and SF_6/N_2 mixtures. [E, SF_6, $SF_6 + N_2$]

O Th. Aschwanden, R. J. Van Brunt and M. E. Bieber : 18th ICPIG, Swansea 102-103 (1987a)
Analysis of dielectric strength data for binary electronegative gas mixtures. [T, $SF_6 + CO_2$, $SF_6 + Ar$, etc.]

S Th. Aschwanden, R. J. Van Brunt and A. V. Phelps : 40th GEC, Atlanta (1987b), Bull. Am. Phys. Soc. 33, 122-122 (1988)
Calculation of electron transport parameters and critical field strengths for the gas mixtures SF_6/CO_2, SF_6/Ar, SF_6/Ne, and SF_6/He.
[T, $SF_6 + CO_2$, $SF_6 + Ar$, $SF_6 + Ne$, $SF_6 + He$]

O J. P. Astruc, R. Barbe, A. Lagreze and J. P. Schermann : Chem. Phys. 75, 405-416 (1983)
Internal energy dependence of the autodetachment and dissociation times of the SF_6^- ion. [E, SF_6; 223 - 1073 K]

A J. A. Ayala, W. E. Wentworth and E. C. M. Chen : J. Phys. Chem. 85, 3989-3994 (1981)
Thermal electron attachment rate to CCl_4, $CHCl_3$, CH_2Cl_2, and SF_6.
[E, SF_6, CCl_4, $CHCl_3$, CH_2Cl_2; pulse sampling method]

O L. M. Babcock and G. E. Streit : J. Chem. Phys. 74, 5700-5706 (1981)
Ion-molecule reactions of SF_6 : Determination of I. P. (SF_5), A. P. (SF_5^+/SF_6), and D(SF_5 - F). [E, SF_6]

S M. G. Baeva and P. A. Atanasov : Nuovo Cimento 17D, 261-265 (1995)
Influence of SF_6 on HF laser plasma parameters.
[T, SF_6 + C_3H_8 + He; B. Eq.]

O R. T. Bailey, F. R. Cruickshank, R. Guthrie, D. Pugh and I. J. M. Weir : Chem. Phys. 114, 411-416 (1987)
Vibrational relaxation rate constants for SF_6 from thermal lensing studies. [E, $h\nu$, SF_6; TEA CO_2 laser pulse]

O L. S. Bartell, M. A. Kacner and S. R. Goates : J. Chem. Phys. 75, 2730-2735 (1981a)
Electron diffraction studies of laser-pumped molecules. I. Characterization of system and analysis of data. [E, $h\nu$, SF_6]

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Electron diffraction studies of laser-pumped molecules. II. Collisionally assisted absorption by SF_6. [E, $h\nu$, SF_6; pumped with CO_2 laser]

O L. S. Bartell and A. Jin : J. Chem. Phys. 78, 7159-7164 (1983)・
Intermolecular multiple scattering of electrons. I. Theory.
[T, SF_6; 40 keV]

O L. S. Bartell and J. F. Stanton : J. Chem. Phys. 81, 3792-3795 (1984)
Electron diffraction studies of hot molecules. IV. Asymmetries of nonbonded distribution functions of SF_6, SiF_4, and CF_4.
[E and T, SF_6, SiF_4, CF_4; see S. R. Goates (1982a) (1982b)]

O V. P. Bashurin, S. D. Velikanov, A. Ya. Dovgil, N. V. Ivanov, A. V. Pushkin, M. V. Sinitsyn and V. V. Shurov : Sov. Phys. Dokl. 31, 256-258 (1986)・
Transmission of an electron beam through an electronegative gas.
[E, SF_6]

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Two isomers of $SF_5^{\cdot}$ and SF_5^+ : Structures and energetics.
[T, SF_5; see Y.-S. Cheung (1994)]

EX K. H. Becker : in Nonequilibrium Processes in Partially Ionized Gases, Maratea, Edited by M. Capitelli and J. N. Bardsley, Plenum Press 283-290 (1990)・
Electron-molecule collision cross sections for etching gases.
[review, SF_6, CCl_2F_2, CF_4, NF_3; see K. A. Blanks ('87a, b), Z. J. Jabbour ('88)]

EX K. H. Becker : in Electron Collisions with Molecules, Clusters and Surfaces,
I Plenum Press, Royal Holloway 127-140 (1994a)・
Electron impact induced dissociative excitation and ionization of halogen-containing molecules. [review, SF_6, CF_4, CCl_2F_2, NF_3, BCl_3]

EX K. H. Becker : Comments At. Mol. Phys. 30, 261-284 (1994b)・
I Electron-impact ionization and dissociative excitation of halogen-containing molecules.
[comments, SF_6, CF_2Cl_2, CF_4, HCl, HBr, HF, CF_3H, CF_3Cl, CF_3Cl, etc.]

O M.T.Bernius and A.Chutjian : J.Appl.Phys.66, 2783-2788 (1989)・
Pulsed, high-current, in-line reversal electron attachment detector.
[E, SF_6, CCl_4, $CHCl_3$]

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Laser optogalvanic effects caused by formation of negative ions.
[E, SF_6, CCl_2F_2, I_2]

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Collisional chemionization of highly excited sodium atoms with electronegative molecule SF_6. [E, SF_6 + Na(nP)]

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Ionization of a highly excited (Rydberg) atoms and attachment of an ultraslow electron to an SF_6 molecule. [, SF_6]

O G.Bieri, L.Asbrink and W.von Niessen : J.Elect.Spectrosc.Relat.Phenom.27, 129-178 (1982) C55
30.4-nm He(II) photoelectron spectra of organic molecules. Part VII. Miscellaneous compounds. [E, $h\nu$, SF_6, H_2S, SiF_4, NH_3, I_2, etc.]

O D.M.Bishop and L.M.Cheung : J.Phys.Chem.Ref.Data 11, 119-133 (1982)・
Vibrational contributions to molecular dipole polarizabilities.
[compilation, SF_6, C_2F_6, C_2H_6, C_6F_6, C_6H_6, etc.]

EX K.A.Blanks, A.E.Tabor and K.Becker : J.Chem.Phys.86, 4871-4875 (1987a)・C153 K
Absolute cross sections for fluorine 3p → 3s line emissions following single electron impact on NF_3, CF_4, and SF_6. [E, SF_6, NF_3, CF_4]

EX K.A.Blanks and K.Becker : J.Phys.B20, 6157-6163 (1987b) C186 K
Optical emissions in the wavelength region 2000 - 6000 A produced by electron impact dissociation of NF_3, CF_4 and SF_6. [E, SF_6, NF_3, CF_4]

O P.Bletzinger : J.Appl.Phys.67, 130-138 (1990)
Experimental characteristics of rf parallel-plate discharges : Influence of attaching gases. [E, (SF_6, CF_4, C_2F_6) + Ar]

O J.E.Bloor and R.E.Sherrod : J.Am.Chem.Soc.102, 4333-4340 (1980)
Theoretical studies on the physical properties and bonding of the 5d metal hexafluorides using the multiple scattering Xα techniques.
[T, SF_6, WF_6, ReF_6, etc.]

O S.Bodeur and A.P.Hitchcock : Chem.Phys.111, 467-479 (1987)
Inner- and valence-shell excitation of SF_4 studied by photoabsorption and electron energy loss spectroscopy. [E, SF_6, SF_4; 2.5 keV for EELS]

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Calculations of transport parameters in SF_6 for a non-equilibrium medium by Monte-Carlo and Boltzmann methods. [T, SF_6]

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Monte Carlo simulation of electron swarm motion in SF_6. [T, SF_6]

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Sulphur hexafluoride : Introduction to material and dielectric.
[, SF_6]

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Intermolecular rearrangements and nature of barriers in SF_6 and SH_6.
[T, SF_6, SH_6]

O V. G. Bordo, V. A. Kravchenko, Yu. N. Petrov, S. P. Surov and V. A. Sychugov : Sov. Phys. Tech. Phys. 35, 186-189 (1990)・
Saturation of surface-electromagnetic-wave absorption at the interface of a metal with an absorbing gas. [E and T, SF_6 on the surface]

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Electron energy distribution function and electrical breakdown in SF_6.
[T, SF_6; B. Eq.]

O R. W. Boswell and D. Henry : Appl. Phys. Lett. 47, 1095-1097 (1985)
Pulsed high rate plasma etching with variable Si/SiO_2 selectivity and variable Si etch profiles. [E, SF_6]

O K. P. Brand and H. Jungblut : J. Chem. Phys. 78, 1999-2007 (1983) C322
The interaction potentials of SF_6 ions in SF_6 parent gas determined from mobility data. [review, E, SF_6; not e^-]

O W. W. Brandt : Plasma Chem. Plasma Process. 3, 329-336 (1983)
Kinetic studies of SF_6 plasmas during etching of Si. [, SF_6]

A G. Brincourt, S. Rajab Pacha, R. Catella, Y. Zerega and J. Andre : Chem. Phys. Lett. 156, 573-577 (1989)
Collision of SF_6 molecules with Xe(nf) Rydberg atoms in a quadrupole trap. Dependence of the SF_6^- ion lifetime on n. [, SF_6]

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Compilation of dipole oscillator strengths (cross sections) for the photoabsorption, photoionization and ionic fragmentation of molecules.
[compilation, $h\nu$, SF_6, H_2, CO, N_2, O_2, NO, HF, HCl, HBr, H_2O, NH_3, CH_4, N_2O, CO_2, COS, CS_2]

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Infrared spectral absorption intensities in the ν_3 and ν_4 regions of SF_6. [E, $h\nu$, SF_6]

E P. D. Burrow : in The Physics of Electronic and Atomic Collisions, 19th ICPEAC, Whistler 257-266 (1995)○
Electron scattering from vibrationally excited molecules.
[review, SF_6, N_2; CO_2]

A H. S. Carman, Jr., C. E. Klots and R. N. Compton : J. Chem. Phys. 90, 2580-2584 (1989) C240
Observation of l-dependent rate constants for ion production in Rydberg electron transfer reactions. [E, SF_6, CCl_4; $Cs^{**} + SF_6 \rightarrow Cs^+ + SF_6^-$]

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Relaxation in pure and seeded supersonic jets of SF_6.
[E, SF_6, SF_6 + (Ar, He, N_2)]

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Electron detachment processes. [review]

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Collisional electron detachment in dielectric gases. [,

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Negative ion formation in gas lasers.
[review, SF_6, F_2, NF_3, HCl, $HgBr_2$, CO_2, Cl_2, CCl_4, I_2]

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Infrared absorption of SF_6 from 32 to 3000 cm^{-1} in the gaseous and liquid states. [E, $h\nu$, SF_6]

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JANAF thermochemical tables, third edition.

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Photo-enhanced dissociative electron attachment in SF_6 and its isotopic selectivity. [E, SF_6; 300 - 880 K]

EX C. L. Chen, P. J. Chantry and D. K. Davies : 33rd GEC, Oklahoma AA-5, 16-16 (1980)
The electronic excitation spectrum of SF_6. [E, SF_6]

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The negative ion states of sulfur hexafluoride.
[E, SF_6; SF_6^-, temp. dependence]

O E. C. M. Chen, J. R. Wiley, C. F. Batten and W. E. Wentworth : J. Phys. Chem. 98, 88-94 (1994) C105
Determination of the electron affinities of molecules using negative ion mass spectrometry. [E, SF_6, C_6F_6]

O Y.-S. Cheung, W.-K. Li, S.-W. Chiu and C. Y. Ng : J. Chem. Phys. 101, 3412-3413 (1994)
Comment on "Two isomers of SF_5^- and SF_5^+ : Structures and energetics" [see J. Chem. Phys. 100, 1759 (1994)].

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Combining theory with experiment : Assessment of the thermochemistry of SF_n, SF_n^+, and SF_n^-, n = 1 - 6. [E and T, SF_6, SF_5 - SF, etc.]

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Role of binding energies in $A^- \cdot B$ and $A \cdot B^-$ complexes in the kinetics of gas phase electron transfer reactions : $A^- + B = A + B^-$ involving perfluoro compounds : SF_6, $C_6F_{11}CF_3$, C_6F_6. [E, SF_6, C_6F_6, etc.]

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Electron affinities of atoms, molecules, and radicals.
[review and compilation, SF_6, etc.]

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Negative ions of polyatomic molecules.
[review, SF_6, CH_4, CF_4, n-C_3F_8, 2-C_4F_6, c-C_4F_8, 2-C_4F_8, CCl_4, CH_3Br, etc.]

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On the role of electron attachment in the breakdown strength of gaseous dielectrics. [E, SF_6, CCl_4, CCl_2F_2, C_4F_8, etc.]

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Gas breakdown and high voltage insulating gases.
[review, SF_6, c-C_4F_8, 2-C_4F_8, etc.]

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Electron attachment processes. [review]

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From basic research to applications. [review]

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Electron attachment and detachment processes in electronegative gases.
[review, SF_6, F_2, Cl_2, CF_4, C_2F_6, C_3F_8, n-C_4F_{10}, etc.]

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Gas/liquid transition : Interphase physics. [review]

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Electron attachment to excited molecules. [review]

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Effect of temperature on the formation and autodestruction of parent anions. [E, SF_6, c-C_4F_6, C_6F_6; 300 - 600 K]

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[, SF_6]

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(Sulphur hexafluoride, Sulfur hexafluoride)

E : Elastic collision,
V : Vibrational excitation,
D : Dissociation,
A : Attachment, Detachment
S : Swarm,
O : The others,

R : Rotational excitation,
EX : Electronic excitation,
I : Ionization,
QT : Grand total cross section,
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Some Comments on Electron Collision Cross Sections for SF_6

The pioneer work on electron collision cross section set for SF_6 is given by L.E.Kline in 1979. After that, many cross section sets for SF_6 are proposed by T.Yoshizawa (1979), H.Itoh (1980, 1990), J.P.Novak (1982, 1984), M.Yousfi (1982, 1985, 1987, 1994), M.S.Dincer (1983), M.Hayashi (1984, 1991) Th.Vassiliadis (1985) and A.V.Phelps (1988). The authors' conference preprint M.Hayashi (1991) is included at the end of this report. In this preprint, the author presented the improved cross section set using new experimental data. Recently, L.G.Christophorou (2000) reviewed the new data and recommended cross section set for SF_6 are shown in Fig.47 of their paper.

Now author do not like these all cross section sets. In 1999, author discussed that SF_6 molecules used in the beam and swarm experiments are always mixture of $SF_6(r)$ and $SF_6(v)$. r and v mean rotationally and vibrationally excited one. At 300 K, the concentration of ground state $SF_6(g)$ molecules are negligible small, $SF_6(r_J)$ = 30.1 %, $SF_6(v_6)$ = 17.2 %, $SF_6(v_5)$ = 7.4 %, $SF_6(2v_6)$ = 6.5 % and $SF_6(v_4, v_2, v_1, v_3,$ etc.) = 38.8 %. The cross section sets for $SF_6(r_J)$ and $SF_6(v_1)$ are different each other. At least, we have to determine these many cross section sets for the exact calculations.

All molecules have the same component M(g), M(r), M(v) and M_n (n = 2), depend on the pressure and temperature conditions of the experiment. Most interesting experimental results occur in the triatomic molecules. The change from linear mode combination of three atoms to bend mode combination of three atoms, or vice versa, occur very easy by vibrational excitation. SF_6 molecule is an octahedral molecule belonging to the O_h group, with very high symmetry. So the difference of cross section sets for $SF_6(r)$ and $SF_6(v)$ are not so large compared with the difference of triatomic molecules. Then cross section sets given by many authors, assuming all SF_6 molecules are in the $SF_6(g)$ or $SF_6(r)$ or $SF_6(v)$ state, can use for approximate calculations for SF_6.

Author would like to present our recent two conference preprints at the end of this report.

M.Hayashi and S.Hara : Joint Symposium on Electron and Ion Swarms and Low Energy Electron Scattering, Bond University, Australia 109-111 (1991)

M.Hayashi and Y.Nakamura : International Symposium on Electron-Molecule Collisions and Swarms, EMS-99, Tokyo 175-176 (1999)

ELECTRON COLLISION CROSS SECTIONS FOR SF_6

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We have determined a new set of elastic and inelastic electron collision cross sections for SF_6 using the data obtained by beam experiments mainly and electron swarm experiments a little.

There are many cross section sets for SF_6. We have the sets given by Kline(1979), Yoshizawa(1979), Dincer(1983), Novak(1982, 1984), Hayashi [1](1984), and Yousfi(1985). In 1988, Phelps [2] and Itoh [3] reported the new sets, but these two cross sections are different each other. Last year we have discussed again the all cross sections, including the new experimental data. Important beam experiments after 1988 are as follows: for elastic scattering, Sakae [4], 20-700 eV, and Johnstone [5], 5-75 eV; for attachment, Fenzlaff [6], 0-19 eV, and Hunter [7], 0-10 eV; for grand total cross section Q_T, Dababneh [8], 2.8-500 eV, and Zecca [9], 92.5-4000 eV.

Present tentative conclusion is given in Figure 1. Present final values of momentum transfer cross sections q_m are compared with reference values as shown in Figure 2. White triangle points in Fig-

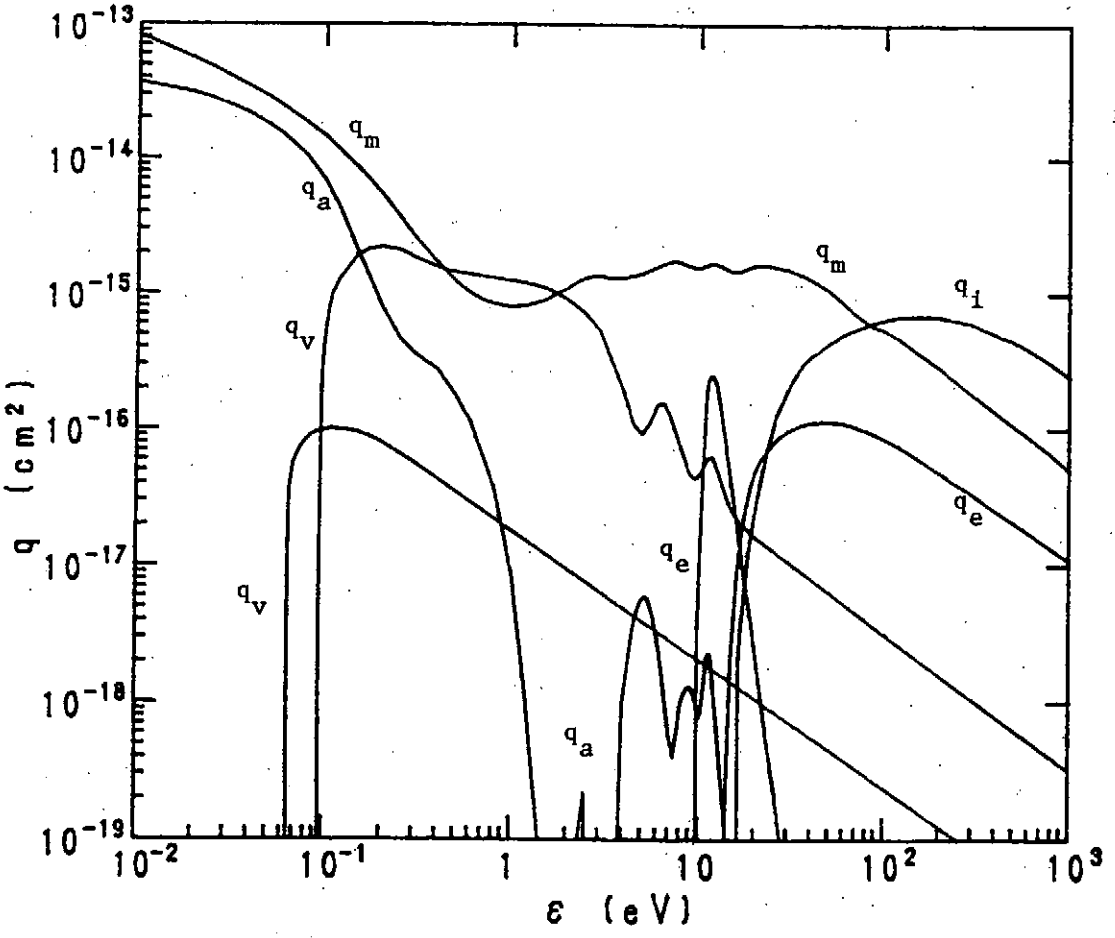

Figure 1. Electron collision cross sections for SF_6.

ure 2 are calculated from Rohr's DCS values. But we had to reduce the values of q_m for the electron energies from 1 to 5 eV by electron swarm data, as shown in Figure 2. The DCS values measured by Sakae [4] are much larger than Trajmar's one, especially at small scattering angles. We have used Sakae's data under some improvements by "smoothing method" [10]. It was concluded that Johnstone's [5] new values at around 10 eV is good and have interesting structure, but the values at around 50 eV are smaller than true values. Then more exact DCS experiments are needed for the electron energies from 1 to 100 eV, especially 2, 3, 4, 30 and 50 eV of wide scattering angles.

In our old paper [1], we have pointed out that the values of very small attachment cross sections q_a of F^- formation are important for the determination of electron swarm data, and also there is a large contradiction between measured Q_T and sum of all cross sections. Nobody discuss this latter problem in the literatures. From this study, we have found a solution of this problem approximately, for the first time, as shown in figure 3.

Electron swarm parameters have been calculated from the cross sections shown in Figure 1, using two term approximation of Boltzmann equation solution. Calculated electron drift velosities are almost coincide with Aschwanden's and Nakamura's [11] values, and characteristic energies also almost fit with Naidu's and Maller's data. Ionization coefficients agree with Aschwanden's and our data below about

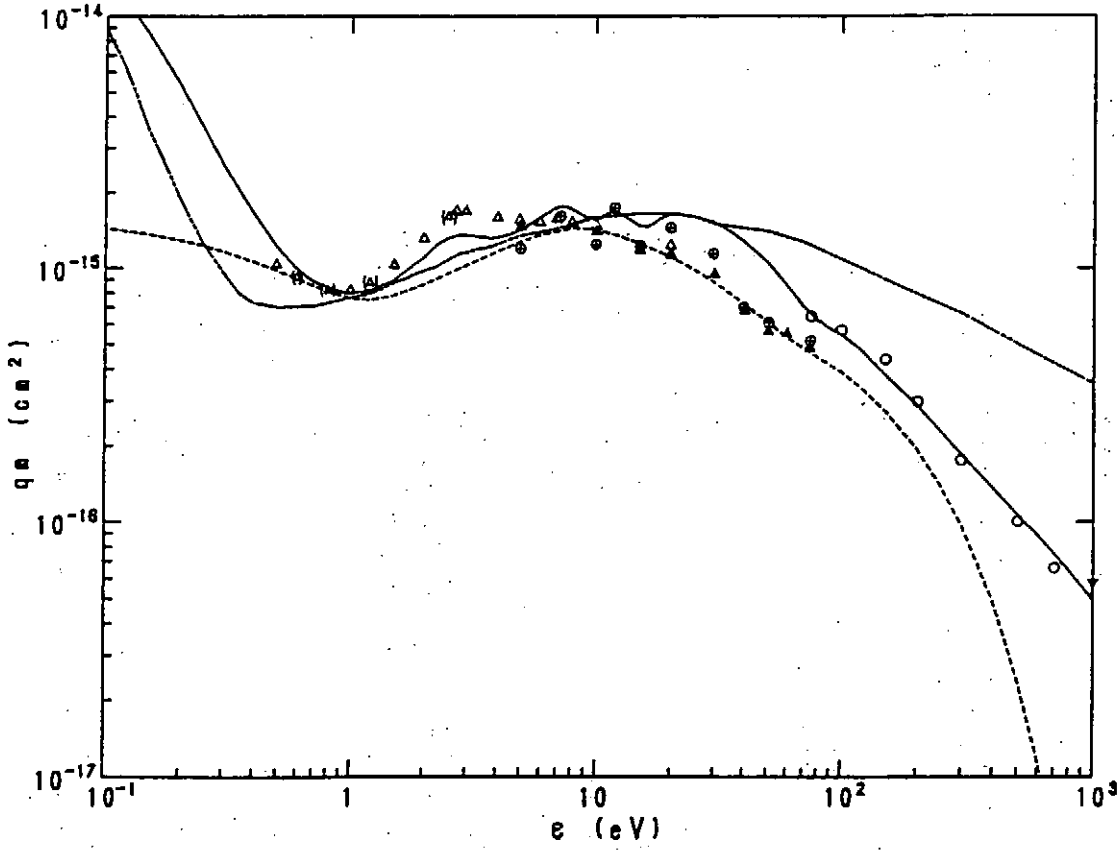

Figure 2. Momentum transfer cross sections q_m for SF_6. Solid line is the present value. Dotts and line is Phelps' and dotted line is Itoh's value. Δ : Rohr, Θ : Johnstone, ▲ : Trajmar, and o : Sakae. These values are integrated values from DCS experiments.

600 Td. More exact approximation is needed for the calculations, and slight improvements of cross section values are needed from the exact calculations of swarm parameters.

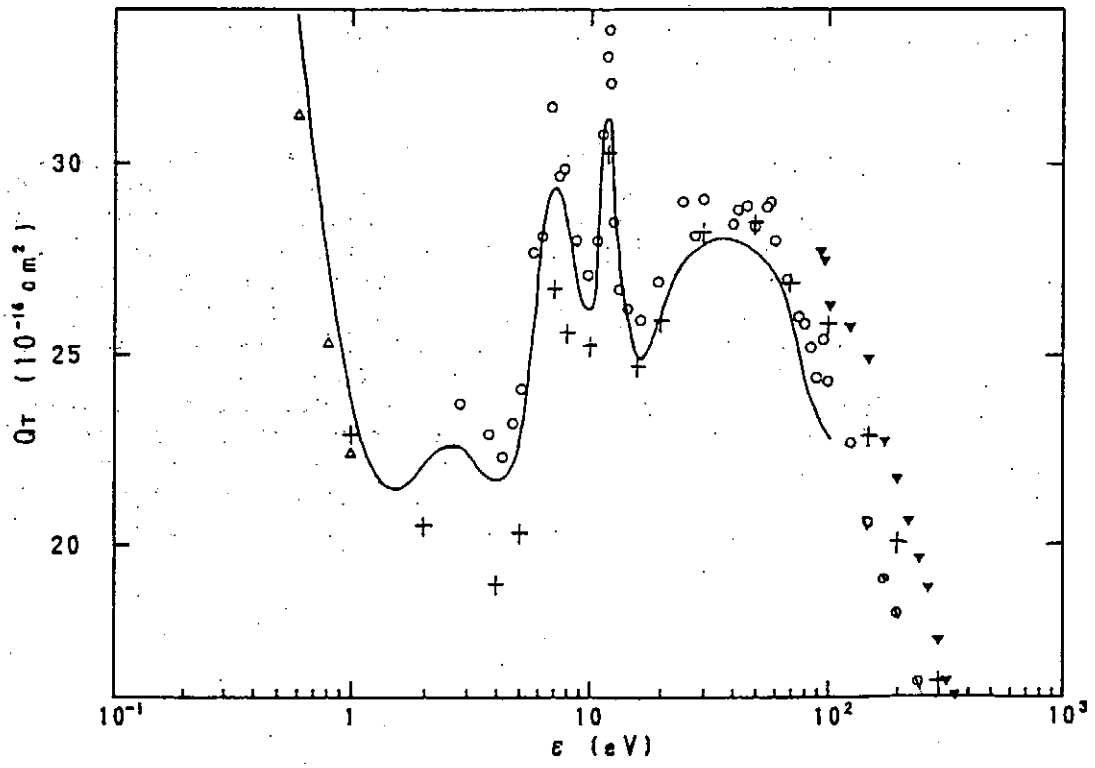

Figure 3. Grand total cross sections Q_T for SF_6. + : sum of all cross sections given in Figure 1, but for elastic scattering, the values of integral elastic cross section q_t, insted of q_m, are summed. Solid line : Kennery, Δ : Ferch, o : Dababneh, and ▼ : Zecca.

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May We Measure the Exact Values of Electron Collision Cross Sections for Molecules by Beam and Swarm Experiments ?

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We cannot measure the exact values of DCS for molecules intrinsically. Of course, we can measure the approximate values of DCS for molecules, but can measure the exact values of DCS for atoms. The reason is very simple.

Target molecule M in both beam and swarm experiments consists of the mixture of different states :

$$M = M(g) + M(r_J) + M(v_1) + M_N$$

where $M(g)$, $M(r_J)$, $M(v_1)$ and M_N represent the completely ground state molecules, the rotationally excited molecules, the vibrationally excited molecules and the van der Waals clusters consisting of N molecules ($N \geqq 2$), respectively. Usually beam and swarm experiments are carried out at about 300 K. The concentration of $M(g)$ is small compared to $M(r_J)$ (except H_2 molecules) at 300 K. Then the molecule M is always mixture of $M(r_J)$ and $M(v_1)$, and the concentration of $M(r_J)$ and $M(v_1)$ changes with temperature. And electron collision cross section sets from elastic to inelastic collision processes for $M(r)$ and $M(v)$ are different each other. The target molecules M in the beam and swarm experiments are always mixtures of different molecules $M(r_J)$ and $M(v_1)$. In the case of H_2, the target gas consists of $M(g)$ and $M(r_J)$, especially $M(g)$ and $M(r_1)$ at 78 K.

Most clear change of cross sections of $M(r_J)$ and $M(v_1)$ will occur for triatomic molecules. CO_2, N_2O and so on. Triatomic molecules can change from linear to bend, or vice versa easily. The authors [1] have presented the different elastic momentum transfer cross sections q_{mr} and q_{mv} for $CO_2(r)$ and $CO_2(v)$, where they assumed that all other inelastic cross sections of $CO_2(r)$ and $CO_2(v)$ are practically the same. Then they have calculated the electron drift velocity W as a function of gas temperature T. When T increas, concentrations of $CO_2(v)$ increases, then W decreases with T at the same E/N, the electric field over the gas number density, around 50 Td.

We have a comment to the interesting and important paper of W. Johnstone, et al. [2]. They have measured the temperature dependence of elastic DCS for CO_2 at 4.0 eV. Unfortunitly, q_{mv} for $CO_2(v)$ at 4 eV is almost equal to q_{mr} for $CO_2(r)$ [1]. Then we propose the same experiments at about 3.4 eV for CO_2, because the temperature dependence of DCS seems to be very large there.

Winstead and McKoy [3] calculated the elastic DCS for $N_2O(g)$ at low electron energies and compare the experimental DCS data for $N_2O(r) + N_2O(v)$ mixture at 300 K. We can see large discrepancy between them at lower than about 10 eV. We urge Winstead and Mckoy to calculate the DCS

for $N_2O(v)$ and also $N_2O(r)$ for comparison. We can see the same discrepancy of DCS for CO_2 [4] [5] at low electron energies..

H_2 molecules have the famous long standing controversy in the vibrational excitation cross section [6]. A possible way to solve the problem may be as follows. At first, theoreticians calculate the q_{mg}, q_{mr}, q_{mv}, q_{rg}, q_{rr}, q_{rv}, q_{vg}, q_{vr}, and q_{vv} for $H_2(g)$, $H_2(r_1)$ and $H_2(v_1)$, as a function of electron energies. Using these data, we calculate the electron swarm parameters. From beam experiments, we cannot determine the values of q_{mg}, q_{mr}, q_{rg}, q_{rr} for $H_2(g)$ and $H_2(r_1)$ at the same time. It is clear that the threshold energies of q_r and q_v for $H_2(g)$ and $H_2(r_1)$ are different. Bhattacharyya, et al. [7] have shown that elastic integral cross sections q_{tr} are larger than q_{tg} for 20 to 200 eV for $H_2(g)$ and $H_2(r_1)$. We want the elastic DCS values for $H_2(g)$ and $H_2(r_1)$ at low electron energies lower than 10 eV. Swarm experiments also carried out in the mixtures of $H_2(g)$ and $H_2(r_1)$, except for para-$H_2(g)$ at 78 K (concentration of $H_2(g)$ is 99.3 %). We compare the experimental and calculated swarm parameters at given conditions.

Usually, theoreticians calculate the DCS for M(g), not for $M(r_J)$ and $M(v_1)$, for most molecules. Theoretical studies involving the rotationally and vibrationally excited species are urgently required for many molecules. There is a interesting paper given by A. Jain [8].

If we have the cross section sets for excited inert gas clusters, we can calculate the electron swarm parameters of inert gases at high pressure and low temperature conditions. The concentration of the clusters for atoms and molecules are important at low temperature and high pressure conditions.

Most interesting temperature dependence occur for attachment cross sections q_a [9]-[13]. The values of non-dissociative q_{an} and dissociative q_{ad} are quite different for M(r) and M(v), and M(r) and M(v) have the definit and individual cross sections, independ on the temperature. Apparent temperature dependence of attachment cross section is caused through different concentration of the excited components M(r) and M(v) at different temperatures.

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2003. 4. 26.

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on Electron and Photon Collisions with Atoms and Molecules published in the 20th Century

Atoms (17)

A + e,	A + hν
He 2	2170 *
Ne 10	1140 *
Ar 18	1960
Kr 36	900
Xe 54	1040
Li 3	450
Na 11	800
K 19	370
Rb 37	220
Cs 55	370
O 8	390
F 9	90
Cl 17	130
Cu 29	180
Cd 48	210
Ba 56	320
Hg 80	600

not final, but finished mostly

include electron swarm papers

include review papers

Molecules (51)

	M + e,		M + hν,	
2	H_2, D_2	1870	5	CH_4	780
	N_2	2240			
	O_2	1700		CF_4	390
	CO	1190		CCl_4	210
	NO	880		CCl_2F_2	250
				CH_3Cl	90
	F_2	190		SiH_4	230
	Cl_2	360		SiF_4	140
	Br_2	140		GeH_4	50
	I_2	240			
			6	C_2H_4	370
	HF	260		CH_3OH	240
	HCl	320			
	HBr	190			
	HI	130	7	SF_6	920
3	CO_2	1240			
			8	C_2H_6	260
	H_2O	850		C_2F_6	150
	O_3	480		Si_2H_6	70
	N_2O	450			
	NO_2	300	9	C_3H_6	120
	H_2S	270		C_2H_5OH	60
	SO_2	260			
	CS_2	260			
	OCS	240	11	C_3H_8	190
				C_3F_8	100
4	C_2H_2	390			
			12	C_4F_8	100
	NH_3	400		C_6H_6	240
	NF_3	110		C_6F_6	100
	BF_3	110			
	BCl_3	90	60	C_{60}	300
	PH_3	80			
	H_2CO	180		$M_r + M_v$	850

* He(Ne) + e only. Not include He(Ne) + hν papers.

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