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Bibliography of Electron and Photon Cross Sections
with Atoms and Molecules
Published in the 20th Century
- Methane -

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

—— Methane ——*

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(Gaseous Electronics Institute)**

Bibliographies 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 methane (CH_4). About 1050 papers were compiled. A comprehensive author index is included. The bibliography covers the period 1924 through 2000 for CH_4. Finally, author's comments for CH_4 electron collision cross sections are given.

Keywords : CH_4 molecule, collision cross sections, 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 Institute, 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 methane molecules CH_4. The review papers on this subject are also included. Some methane molecule cluster papers are included. Some conference reports, company or agency reports and PhD thesis are included. Methane molecules 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 paper for CH_4 in this list is given by G. Glockler (1924) and A. L. Hughes (1924). So for this bibliography, published papers from 1924 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 CH_4". In total, about 1050 CH_4 papers are compiled in the methane 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 molecules
S : electron Swarm
O : Others (photon cross sections and the others)

QT : grand Total cross section (sum of elastic and inelastic electron cross sections). Q came from Querschnitt

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.

Bibliographies for CH_4 are divided into two parts :

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.

Some Comments on Electron Collision Cross Sections for CH_4

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References for CH_4, CH_3D, CH_2D_2, CHD_3, CD_4 (1900 - 1999)

(Methane, Methane-$D_{1,2,3,4}$, Duterated methane)

[n-Alkane, Linear alkane, Hydrocarbon]

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

The oldest paper in this list is given by G. Glockler (1924) and A. L. Hughes (1924).

EX J. F. M. Aarts : PhD Thesis, University of Leiden 1-132 (1970)・
Radiation from N_2, CO, CH_4 and C_2H_4 produced by electron impact.
[E, CH_4, N_2, CO, C_2H_4; 0 - 5 keV for CH_4 and C_2H_4]

EX J. F. M. Aarts, C. I. M. Beenakker and F. J. de Heer : Physica 53, 32-44 (1971)・
Radiation from CH_4 and C_2H_4 produced by electron impact. [E, CH_4, C_2H_4]

E N. Abusalbi, R. A. Eades, T. Nam, D. Thirumalai, D. A. Dixon, D. G. Truhlar and
R M. Dupuis : J. Chem. Phys. 78, 1213-1227 (1983)・K
Electron scattering by methane : Elastic scattering and rotational excitation cross sections calculated with ab initio interaction potentials. [T, CH_4; DCS, 10 eV]

E N. Abusalbi, D. W. Schwenke, C. A. Mead and D. G. Truhlar : Theor. Chim. Acta 71, 359-374
R (1987)
Application of fixed-nuclei scattering theory to electron methane elastic- and inelactic differential cross sections at 10 eV impact energy.
[T, CH_4]

I B. Adamczyk, A. J. H. Boerboom, B. L. Schram and J. Kistemaker : J. Chem. Phys. 44, 4640-4642 (1966)・K
Partial ionization cross sections of He, Ne, H_2 and CH_4 for electrons from 20 to 500 eV. [E, CH_4, He, Ne, H_2; 20 - 2000 eV]

S S. A. J. Al-Amin, H. N. Kücukarpaci and J. Lucas : J. Phys. D18, 1781-1794 (1985)・
Electron swarm parameters in oxygen and methane.
[E, CH_4, O_2; E/N = 0.28 - 848 Td for CH_4]

O M. I. Al-Joboury and D. W. Turner : J. Chem. Soc. 4434-4441 (1964)
Molecular photoelectrons spectroscopy. Part II. A summary of ionization potentials. [E, CH_4, C_2H_4, C_6H_6, NH_3, O_2, N_2O, etc. 48 compounds]

V S. C. Althorpe, F. A. Gianturco and N. Sanna : J. Phys. B28, 4165-4177 (1995)·
Calculation of integral cross sections for vibrationally inelastic electron-methane scattering. [T, CH_4; 0.17 - 12 eV]

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On the cross section of low-energy electron collision on CH_4 and CO_2.
[T, B.Eq., CH_4, CH_4 + Ar, CH_4 + Ar + CO_2, CO_2]

S S. R. Amendolia, M. Binder, et al. (about 30 persons) : Nucl. Instrum. Meth. A244, 516-520 (1986)
Dependence of the transverse diffusion of drifting electrons on magnetic field. [E, CH_4 + Ar]

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The polarizabilities of CH and CC bonds. [T, CH_4, C_2H_6, C_2H_4, C_2H_2]

O R. D. Amos : J. Chem. Soc. Faraday Trans. II 83, 1595-1607 (1987)
Geometrics, harmonic frequencies and infrared and Raman intensities for H_2O, NH_3, and CH_4. [T, $h\nu$, CH_4, NH_3, H_2O]

O J. Appell, J. Dunrup, F. C. Fehsenfeld and P. Fournier : J. Phys. B7, 406-414 (1974)·
Doubly ionized states of some polyatomic molecules studies by double charge transfer spectroscopy. [E, $h\nu$, CH_4, N_2O, etc.; not e^-]

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On the formation of energetic protons by electron impact on methane.
[E, CH_4; 26 - 43 eV]

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Ionization of gases by a pulsed electron beam as studied by self-focusing. II. Polyatomic gases. [E, CH_4, H_2, N_2, etc.]

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Energy losses of electrons passing through gases hydrogen, oxygen, air, carbon dioxide, methane and acetylene.
[, CH_4, C_2H_2, H_2, O_2, N_2 + O_2, CO_2]

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The dissociative ionisation of methane.
[E, CH_4 and CH_3D; isotope effects was observed at 14.5 - 16 eV]

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Ab initio study of the geometries, Jahn-Teller distortions, and electric charge distribution in the CH_4^+ ion. [T, CH_4]

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The absolute intensities of the infrared fundamentals of methane.
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The diffractions of electrons in gases.
[E, CH_4, He - Xe, H_2, CO; DCS, 30 - 410, 820 eV]

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The energy V_0 of the quasi-free electron in gases, liquid and solid methane. [E, CH_4]

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Pressure shifts and electron scattering lengths in atomic and molecular gases. [E and T, CH_4, N_2, H_2, C_2H_6, C_3H_8, CO_2, He - Xe]

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Vibrational structure and lifetime broadening in core-ionized methane. [E, CH_4; ESCA spectrum]

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Doubly charged molecular ions of methane. [E, CH_4, CD_4; 30.6 eV]

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The electron drift velocity in dense gases. [T, CH_4, He, Ar, N_2, H_2]

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The valence shell photoabsorption of the linear alkanes, C_nH_{2n+2} (n=1-8): Absolute oscillator strengths (7 - 220 eV). [E, $h\nu$, CH_4, C_2H_6 - C_8H_{18}]

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Far ultraviolet photolysis of alkanes. [review, $h\nu$, CH_4 - c-C_6H_{12}]

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Electron-electron coincidence measurements of CH_4. [E, CH_4]

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Electron-ion coincidence measurements of CH_4. [E, CH_4; 10 keV]

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Dipole excitation and fragmentation of H_2, HD, D_2, and CH_4. [E, CH_4, H_2, HD, D_2]

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Molecular photoelectron spectroscopy at 132.3 eV. The second-row hydrides. [E, $h\nu$, CH_4, NH_3, H_2O, HF, Ne]

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Low energy electron scattering from methane. [E, CH_4; 0.1 - 16 eV]

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A unified description of elastic, high energy electron-molecule scattering.
[T, CH_4, H_2O, C_2H_4, C_2H_6, CO, N_2, O_2, CO_2]

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Ionization cross-sections of atoms and molecules by electron impact.
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Excitation energies for the lowest triplets and singlet-triplet splittings in gas-phase methane including many-body effects. [T, CH_4]

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Dissociative excitation of some aliphatic hydrocarbons by electron impact. [E, CH_4, C_2H_2, C_2H_4, C_2H_6; 100 - 5000 eV]

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H_2^{++} loss from methane and ethane under electron impact : An experimental study of transition-state geometries. [E, CH_4, C_2H_6]

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Isotope effect in resonant vibrational excitation of H_2O(D_2O), NH_3(ND_3), CH_4(CD_4). [E, CH_4, CD_4, H_2O, D_2O, NH_3, ND_3]

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Spektren und Winkelverteilungen der Photoelektronen von Atomen und Molekulen. [E, $h\nu$, CH_4, C_2H_6 - n-C_4H_{10}, Kr, H_2, N_2, O_2, CO, NO]

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The ionization potentials of CH_4 and CD_4.
[E, $h\nu$, CH_4, CD_4; 12.608 and 12.658 eV]

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Molecular electron ionization cross sections at 70 eV.
[E, CH_4, etc., 57 hydrocarbons, fluorocarbons and others]

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Transferability of local-density norm-conserving pseudopotentials to electron-molecule-collision calculations.
[T, CH_4, SiH_4, GeH_4, Si_2H_6, CH_2O; 1 - 10 eV]

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Calculation of elastic scattering cross sections of low-energy electrons by PbH_4 and SnH_4. [T, CH_4, SiH_4, GeH_4, PbH_4, SnH_4]

EX M. H. F. Bettega, A. P. P. Natalense, L. G. Ferreira and M. A. P. Lima : 20th ICPEAC, Vienna WE 102 (1997)
Electronic excitation of molecules by electron impact using the Schwinger multichannel method with norm-conserving pseudopotentials.
[T, CH_4, Na_2]

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Electronic excitation of XH_4 (X = C, Si, Ge, Sn, Pb) by electron impact.
[T, CH_4, SiH_4, GeH_4, SnH_4, PbH_4]

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A multiterm Boltzmann analysis of drift velocity, diffusion, gain and magnetic-field effects in argon-methane-water vapour mixtures.
[T, CH_4 + Ar + H_2O]

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30.4-nm He(II) photoelectron spectra of organic molecules. Part 1. Hydrocarbons. [E, CH_4, C_2H_2, C_2H_4, C_2H_6, C_3H_8, n-C_4H_{10}, C_6H_6, etc.]

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Vibrational contributions to molecular dipole polarizabilities.
[review, CH_4, CD_4, HF, HCl, DCl, HI, CO, NO, SF_6, C_6H_{12}, etc.]

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Static and dynamic polarizabilities and first hyperpolarizabilities for CH_4, CF_4, and CCl_4. [T, CH_4, CF_4, CCl_4]

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A continuum multiple scattering model for the treatment of elastic electron-molecule scattering. Total and DCS cross sections for argon and methane. [T, CH_4, Ar]

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O Molecular photoionization and electron impact ionization cross sections of polyatomic molecules.
[E, CH_4 - $C_{10}H_{22}$, C_2H_4 - $C_{10}H_{20}$, C_2H_2 - $C_{10}H_{18}$, etc.; 15 - 100 eV]

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Elastic DCS for e + CH_4 collisions, 1.5 - 100 eV. [E, CH_4; 10 - 130°]

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Virtual negative ion spectra of hydrocarbons. [E, CH_4, C_2H_4, C_6H_6]

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Drift velocities of electrons in some commonly used counting gases.
[E, CH_4, N_2, CO_2, C_2H_4, C_3H_6, etc.; E/N = 0.3 - 4.8 Td]

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Methane temporary negative ion resonances.
[E, CH_4; 6.53, 7.37 and 8.15 eV]

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On the bond distance in methane. [T, CH_4]

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Excitation of methane, ethane, ethylene, propylene, acetylene, propyne and i-butyne by low-energy electron beams.
[E, CH_4, C_2H_6, C_2H_4, C_3H_6, C_2H_2, i-C_4H_8; E/N = 0.03 - 30 Td, 229 - 370 K]

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Drift velocities of slow electrons in methane, ethane, ethylene, propylene, acetylene and i-butene.
[E, CH_4, C_2H_6, C_2H_4, C_3H_6, C_2H_2, i-C_4H_8; E/N = 0.03 - 30 Td, 229 - 370 K; q_m for 0.01 - 0.06 eV]

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Vibration-rotation bands of methane. [E, $h\nu$, CH_4; 3μ]

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Coriolis interaction between vibration-rotation bands of methane.
[T, $h\nu$, CH_4]

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Multiple scattering theory of electron mobility in dense gases.
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On the accuracy of the iterative method for swarm transport coefficients.
[T, CH_4]

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Multi-term solutions of Boltzmann's equation for electrons in the real gases Ar, CH_4 and CO_2. [T, CH_4, Ar, CO_2]

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Longitudinal- and transversal-diffusion coefficients for electrons in CH_4, Ar and CO_2. [T, CH_4, Ar, CO_2]

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Electron impact studies in CH_4, CH_3Cl, CH_3Br and CH_3I.
[E, CH_4, CH_3Cl, etc.; $D(CH_3\text{-}H) \leqq 4.2$ eV, $V_i(CH_4{}^+) = 13.1$ eV]

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Massenspektrometrische Untersuchung der Photoionisation von Molekulen.
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[E, $h\nu$, CH_4]

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Cross sections for rotational excitation of CH_4 by 3 - 20-eV electrons.
[T, CH_4]

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Cross sections for dissociative ionization of molecules by electron impact.
[E, CH_4, CO, H_2, D_2, N_2, NO, O_2, CO_2, N_2O]

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Continuum optical oscillator-strength measurements by electron spectroscopy in the gas phase.
[review, E and T, CH_4, Ne - Xe, H_2, N_2, CO, etc.]

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Compilation of valence shell molecular photoelectron branching ratios as a function of energy. [compilation, CH_4, HF, HCl, HBr, O_2, CO, NO, N_2, H_2O, NH_3, CO_2, CS_2, N_2O]

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

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The absorption coefficient for slow electrons in gases.
[E, CH_4, Ar, He, H_2, N_2, CO; 1.5 - 320 eV]

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Some Comments on Electron Collision Cross Sections for CH_4

We need more experimental studies of cross sections and other processes, especially grand total cross section, elastic scattering cross section, rotational, vibrational and electronic excitation cross sections, ionization cross section and electron swarm parameters, for the determination of tentative and approximate cross section set for CH_4.

We cannot determine the exact value of cross section set for molecules at low electron energies. The CH_4 molecules are always mixture of CH_4(r) and CH_4(v) at given experimental conditions. And cross section sets for CH_4(r) and CH_4(v) are different. Experimental study of the temperature dependence for all cross sections at low electron energies (lower than 10 eV) are required.

In 1998, some selected electron cross section data are compiled for methane. In the tables, many DCS values are shown here. Almost data are measured at room temperature, about 293 K. Very recently, some new data of grand total, elastic and ionization cross sections are reported, but not added in this compilation.

The compiled tables are as follows.

Table QT-1. Summary of the experimental study of grand total cross section Q_T for CH_4.

	Author	year	ε (eV)	error (%)
	Brode	1925	1.5 - 320	
	Bruche	1927	1 - 44	
	Bruche	1929	1 - 50	
	Ramsauer	1929	0.2 - 1.3	
	Ramsauer	1931		
	Barbarito	1979	0.1 - 16	
	Hasted	1979	(0.3 - 5)	
	Bonham	1980	(0.5 - 100)	
	Griffith	1982	5 - 400	
*	Ferch	1985	0.085 - 12	1 - 4
	Floeder	1985	5 - 400	
*	Jones	1985	1.3 - 50	3 - 8
*	Lohmann	1986	0.1 - 20	3 - 5
*	Sueoka	1986	1 - 400	4 - 5
*	Dababneh	1988	4.5 - 500	
*	Nishimura	1991	5 - 500	13
*	Zecca	1991	0.9 - 4000	6.5 - 8
*	Kanik	1992	4 - 300	
*	Garcia	1998	400 - 5000	3

( ) The data are not available.
* These data are shown in the tables.

Table QT-2. Summary of the theoretical study of grand total cross section Q_T for CH_4.

Author	year	ε (eV)	error (%)

Table QT-3. Grand total cross section Q_T measured by Ferch (1985).

ε (eV)	Q_T (A^2)	ε (eV)	Q_T (A^2)
0.085	5.08	0.8	1.86
0.09	4.79	0.85	1.97
0.096	4.52	0.9	2.09
0.10	4.27	0.95	2.21
0.11	3.82	1.0	2.34
0.12	3.53	1.1	2.59
0.13	3.30	1.2	2.83
0.14	3.07	1.3	3.12
0.15	2.90	1.4	3.39
0.16	2.76	1.5	3.67
0.17	2.61	1.6	4.00
0.18	2.48	1.7	4.33
0.19	2.37	1.8	4.65
0.20	2.27	1.9	4.97
0.25	1.87	2.0	5.31
0.30	1.58	3	9.25
0.35	1.42	4	14.0
0.40	1.36	5	19.0
0.45	1.39	6	22.4
0.50	1.43	7	24.2
0.55	1.49	8	24.7
0.60	1.54	9	24.4
0.65	1.58	10	24.0
0.70	1.66	12	22.7
0.75	1.75		

error 1 - 4 %.

Table QT-4. Grand total cross section Q_T measured by Jones (1985).

ε (eV)	Q_T (A^2)	ε (eV)	Q_T (A^2)
1.3	3.27	7.0	25.7
1.4	3.50	7.5	26.1
1.5	3.86	8	26.3
1.6	4.29	8.5	26.4
1.7	4.48	9	26.1
1.8	4.85	9.5	25.9
1.9	5.20	10	25.5
2.0	5.50	10.5	25.1
2.2	6.27	11	24.7
2.4	7.02	11.5	24.4
2.6	7.82	12	24.1
2.8	8.62	12.5	23.7
3.0	9.42	13	23.3
3.2	10.4	13.5	23.1
3.4	11.4	14	22.6
3.6	12.4	14.5	22.3
3.8	13.4	15	22.1
4.0	14.3	16	21.4
4.2	15.5	17	21.0
4.4	16.5	18	20.5
4.6	17.6	19	19.9
4.8	18.6	20	19.4
5.0	19.6	21	19.0
5.2	20.5	22	18.5
5.4	21.5	23	18.2
5.6	22.2	24	17.7
5.8	22.9	25	17.3
6.0	23.6	30	15.9
6.2	24.1	35	14.5
6.4	24.6	40	13.7
6.6	25.0	45	12.7
6.8	25.4	50	12.1

error 3 - 8 %

Table QT-5. Grand total cross section Q_T measured by Lohmann (1986).

ε (eV)	Q_T (A^2)	ε (eV)	Q_T (A^2)
0.1	4.18	0.7	1.62
0.11	3.47	0.75	1.71
0.12	3.31	0.8	1.79
0.13	3.11	0.85	1.86
0.18	2.25	0.9	1.94
0.2	2.05	0.95	2.01
0.25	1.75	1	2.13
0.28	1.53	1.2	2.54
0.3	1.46	1.5	3.54
0.32	1.41	2	5.24
0.34	1.36	3	9.06
0.36	1.31	4	14.1
0.38	1.33	5	18.8
0.4	1.34	6	22.4
0.42	1.37	7	24.6
0.44	1.39	8	25.3
0.46	1.40	9	25.2
0.48	1.40	10	24.7
0.5	1.40	12	23.3
0.52	1.42	14	21.9
0.55	1.45	16	20.8
0.6	1.49	18	19.9
0.65	1.56	20	19.0

error 3 - 5 %

Table QT-6. Grand total cross section Q_T measured by Sueoka (1986).

ε (eV)	Q_T (A^2)	ε (eV)	Q_T (A^2)
1.0	2.4	13	20.6
1.2	3.2	14	19.7
1.4	4.1	15	19.4
1.6	4.6	16	18.5
1.8	5.7	17	17.9
2.0	6.2	18	17.9
2.2	6.9	19	17.5
2.5	8.3	20	17.0
2.8	9.8	22	16.4
3.1	11.2	25	15.3
3.4	12.5	30	14.1
3.7	13.8	35	13.2
4.0	15.5	40	12.6
4.5	17.6	50	10.8
5.0	20.1	60	10.3
5.5	21.3	70	9.4
6.0	22.9	80	8.9
6.5	22.8	90	8.5
7.0	23.9	100	8.0
7.5	23.9	120	7.3
8.0	23.4	150	6.6
8.5	23.0	200	5.7
9.0	23.3	250	5.0
9.5	23.0	300	4.4
10	22.5	350	4.1
11	21.7	400	3.7
12	21.0		

error 4 - 5 %

Table QT-7. Grand total cross section Q_T measured by Dababneh (1988) and Kauppila (1983).

ε (eV)	Q_T (A^2)	ε (eV)	Q_T (A^2)
1.44	3.9	1.5	3.93
1.8	5.3	2.0	5.6
2.6	8.3	2.6	8.3
3.5	12.5	3.7	12.5
4.1	14.3	4.1	14.45
4.5	17.2	4.6	17.0
4.9	18.4	4.9	18.8
5.7	23.0	5.5	21.9
6.4	25.3	6.4	25.5
7.8	28.1	7.7	26.8
8.1	28.4	8.4	27.5
9.8	27.2	9.7	27.1
11.9	25.3	11.8	25.3
14.6	23.9	14.7	23.3
19.45	19.5	19.5	20.4
24.5	17.6	24.4	18.0
29.25	16.2	29.5	16.2
34.7	15.2	34.7	15.5
39.3	14.5	40	14.6
44.7	13.6	45	13.4
49.6	12.7	50	12.7
100	9.1	100	9.05
200	6.2	200	6.29
300	4.6	300	4.6
400	3.7	400	3.77
500	3.1	500	3.31

error %
Kauppila's values (right hand side) are given by private communication.

Table QT-8. Grand total cross section Q_T measured by Nishimura (1991).

ε (eV)	Q_T (A^2)	ε (eV)	Q_T (A^2)
5	20.9	60	11.9
6	23.8	70	10.7
7	26.5	80	10.3
8	26.5	90	9.48
9	27.1	100	9.01
10	25.7	110	8.59
12.5	24.2	125	7.92
15	22.4	150	7.05
17.5	21.0	175	6.42
20	19.4	200	5.84
25	17.4	250	4.98
30	15.9	300	4.31
35	14.8	350	3.76
40	13.8	400	3.37
45	13.4	450	3.02
50	13.0	500	2.75

error 13 %.

Table QT-9. Grand total cross section Q_T measured by Zecca (1991).

ε (eV)	Q_T (A^2)	ε (eV)	Q_T (A^2)
0.9	2.0	77.5	10.75
1.0	2.3	80	10.63
1.2	2.9	83	10.16
1.4	4.0	88	10.12
1.7	4.9	90	10.12
2.0	6.3	92.5	9.74
2.5	8.2	98	9.51
3.0	10.3	100	9.61
3.5	12.6	110	8.83
4.0	15.1	125	8.16
4.5	17.9	150	7.35
5.0	19.9	165	7.12
5.5	21.8	175	6.93
6.0	23.9	190	6.51
6.5	25.0	200	6.31
7.0	26.5	215	6.04
7.5	26.5	225	5.70
8.0	27.4	240	5.54
8.5	26.8	250	5.36
9.0	26.5	264	5.27
9.5	26.1	276	5.03
10	25.8	292	4.84
10.5	25.2	300	4.76
11	25.0	326	4.46
13	23.9	350	4.28
15	23.0	400	3.90
17	21.1	450	3.53
20	19.6	500	3.18
23	18.3	600	2.71
25	17.5	700	2.49
30	16.1	800	2.21
35	14.6	900	1.98
40	13.6	1000	1.78
45	12.8	1250	1.45
50	12.3	1500	1.21
60	11.7	1750	1.03
70	11.0	2000	0.894
75	10.8	2250	0.803
80	10.3	2500	0.717
90	9.6	2750	0.647
100	9.0	3000	0.588
		3250	0.554
		3500	0.517
Gdansk		4000	0.441 Treno

error 6.5 - 8 %

Table QT-10. Grand total cross section Q_T measured by Kanik (1992).

ε (eV)	Q_T (A^2)
4	13.9
5	18.9
6	23.5
8	26.4
10	25.9
12	24.5
14	22.8
16	21.7
18	20.7
20	20.0
25	17.9
30	16.5
40	14.6
50	13.3
60	12.2
70	11.4
80	10.7
90	10.1
100	9.56
125	8.48
150	7.61
200	6.42
250	5.58
300	4.97

error %

Table QT-11. Grand total cross sections Q_T measured by Garcia (1998) in unit of 10^{-16} cm^2.

ε (eV)	Q_T (A^2)
400	3.75
500	3.14
640	2.60
850	2.11
1000	1.85
1250	1.53
1500	1.34
1750	1.20
2000	1.07
2250	0.980
2600	0.877
3000	0.781
3500	0.695
4000	0.622
4500	0.571
5000	0.524

The values of Q_T lower than 10 eV have the temperature dependence, but no experimental data at present.

Table QT-12. Comparison of Q_T for CH_4 at selected electron energies.

ε (eV)	Ferch	Lohmann	Jones	Kanik	Sueoka		Nishimura	Zecca
					Dababneh			
0.1	4.27	4.18						
0.2	2.27	2.05						
0.3	1.58	1.46						
0.5	1.43	1.40						
1	2.34	2.13			2.4			2.3
2	5.31	5.24	5.50		6.2			6.3
3	9.25	9.06	9.42					10.3
5	19.0	18.8	19.6	18.9	20.1		20.9	19.9
10	24.0	24.7	25.5	25.9	22.5		25.7	25.8
20		19.0	19.4	20.0	17.0		19.4	19.6
30			15.9	16.5	14.1		15.9	16.1
50			12.1	13.3	10.8		13.0	12.3
100				9.56	8.0	9.1	9.01	9.61
200	Zecca	Garcia		6.42	5.7	6.2	5.84	6.31
300				4.97	4.4	4.6	4.31	4.76
500	3.18	3.14				3.1	2.75	3.18
1000	1.78	1.85						
2000	0.894	1.07						
3000	0.588	0.781						

Table E-1. Summary of the experiments on DCS of elastic electron scattering for CH_4.

	Author	year	ε (eV)	θ (deg)
	Kollath	1928	1.5 - 30	90
	Arnot	1931	30-410, 820	10-120, 10-50
	Bullard	1931	4 - 30	20 - 120
	Mohr	1932	30 - 84	20 - 160
	Hugher	1933	10-625, 800	10-150, 10-50
	Newell	1979	10	20 - 130
	Rohr	1979	2	10 - 120
*	Rohr	1980	0.1 - 10	10 - 120
*	Sohn	1983	0.1 - 1.3	35 - 110
	Tanaka	1982	3 - 20	30 - 140
*	Vuskovic	1983	20 - 200	8 - 130
	Curry	1985	7.5 - 20	30 - 140
*	Sohn	1986	0.2 - 5	15 - 138
	Mapstone I.	1987		
*	Sakae	1989	75 - 700	
	Boesten	1991	1.5 - 100	
*	Shyn	1990 1	5 - 50	12 - 156
*	Mapstone B.	1992 4	3 - 15	30 - 140
*	Bundschu	1997	0.6 - 5.4	
*	Molte-Tollet	1997	15, 30	8 - 95
	Maji	1997	200 - 1500	30 - 120
	Muller T.	1997	0.1 - 12	
	Przybyla	1997	15 - 200	

Table E-2. Elastic scattering DCS measured by Rohr (1980) (1986) in unit of 10^{-16} cm^2/sr.

angle (deg)	electron energy (eV) 1	2	5
10	0.25 *	0.325*	-
20	0.051	0.169	2.51
30	0.026	0.092	1.46
40	0.046	0.144	1.05
50	0.072	0.266	0.923
60	0.108	0.436	1.08
70	0.154	0.564	1.28
80	0.195	0.625	1.26
90	0.205	0.564	1.15
100	0.205	0.462	0.769
110	0.169	0.282	0.462
120	0.154	0.128	0.256

* These two data came from Rohr (1980).

These data are shown in Sohn (1986).

Table E-3. Elastic scattering DCS measured by Sohn (1983) in unit of 10^{-16} cm^2/sr.

energy (eV)	angle (deg) 35	55	90	110
0.1	0.054	0.051	0.033	0.019
0.15	0.046	0.039	0.012	0.021
0.2	0.040	0.029	0.005	0.032
0.25	0.034	0.017	0.004	0.052
0.3	0.029	0.009	0.008	0.072
0.4	0.018	0.003	0.028	0.111
0.5	0.010	0.004	0.048	0.138
0.6	0.005	0.012	0.069	0.156
0.7	0.004	0.025	0.092	0.169
0.8	0.005	0.040	0.116	0.179
0.9	0.009	0.063	0.142	0.184
1.0	0.015	0.092	0.17	0.188
1.2	0.032	0.157	-	0.195

Table E-4. Elastic scattering DCS measured by Vuskovic (1983) in unit of 10^{-16} cm^2/sr.

angle (deg)	electron energy (eV) 20	30	200
8			
10	(13.1)	14.2	11.1
15	(11.2)	10.7	5.1
20	9.4	8.0	2.05
25	7.8	5.5	1.04
30	6.2	3.5	0.65
35	4.5	2.17	0.435
40	3.05	1.36	0.29
45	2.05	0.94	0.192
50	1.46	0.68	0.136
55	1.10	0.53	0.099
60	0.89	0.44	0.075
65	0.75	0.38	0.0615
70	0.63	0.323	0.051
75	0.535	0.272	0.045
80	0.475	0.231	0.040
85	0.416	0.196	0.037
90	0.365	0.168	0.0341
95	0.317	0.146	0.0312
100	0.283	0.133	0.0288
105	0.265	0.129	0.0268
110	0.271	0.137	0.025
115	0.301	0.162	0.0235
120	0.362	0.192	0.0221
125	0.440	0.237	0.0218
130	0.52	0.295	0.0212
150	(0.71)	(0.58)	(0.0283
180	(0.86)	(1.00)	(0.038)

Table E-5. Elastic scattering DCS measured by Curry (1985) in unit of 10^{-16} cm^2/sr.

angle (deg)	electron energy (eV) 7.5	10	12.5	15	17.5	20
30	3.40	3.41	4.20	4.26	4.02	3.91
40	2.40	3.19	2.99	2.54	2.16	2.26
50	1.78	2.10	1.84	1.66	1.22	1.21
60	1.52	1.45	1.11	0.98	0.81	0.81
70	1.64	1.05	0.89	0.74	0.55	0.59
80	1.47	0.93	0.75	0.59	0.46	0.46
90	1.20	0.80	0.60	0.41	0.38	0.35
100	0.73	0.61	0.41	0.34	0.27	0.32
110	0.25	0.28	0.29	0.30	0.24	0.29
120	0.19	0.24	0.29	0.32	0.31	0.37
130	0.55	0.43	0.42	0.48	0.43	0.52
140	1.30	1.05	0.72	0.64	0.54	0.61

Table E-6. Elastic scattering DCS measured by Sohn (1986) in unit of 10^{-16} cm^2/sr.

angle (deg)	electron energy (eV) 0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
15	-	-	-	-	0.626	0.266	0.199	0.138
20	-	-	-	0.424	0.242	0.177	0.131	0.084
25	-	0.749	0.560	0.339	0.237	0.097	0.068	0.04
30	0.749	0.564	-	0.233	0.130	0.068	0.046	0.023
35	0.634	0.498	0.362	-	0.109	0.042	0.024	0.020
40	0.469	0.359	-	0.10	0.048	0.014	0.018	0.016
45	0.418	0.282	0.194	-	0.032	0.017	0.015	0.04
50	0.403	0.208	-	0.028	0.009	0.009	0.014	0.050
55	0.283	0.146	0.089	0.011	0.002	0.017	0.042	0.079
60	0.256	0.109	-	0.0029	0.005	0.032	0.052	0.095
65	0.189	0.068	0.031	-	0.0125	0.052	0.081	0.126
70	0.167	0.045	-	0.017	0.020	0.066	0.096	0.146
75	0.112	0.026	0.007	-	0.0353	0.077	0.111	0.156
80	0.107	0.0145	-	0.032	0.051	0.095	0.132	0.177
85	0.062	0.0078	0.0038	-	0.0574	0.100	0.138	0.182
90	0.056	0.0022	0.0036	0.059	0.065	0.108	0.149	0.193
95	0.036	0.0018	0.0062	-	0.0665	0.113	0.150	0.181
100	0.038	0.0002	-	0.080	0.081	0.11	0.143	0.165
105	0.021	0.0043	0.019	-	0.082	0.110	0.140	0.166
110	0.023	0.0028	-	0.093	0.081	0.105	0.125	0.148
115	0.010	0.0086	0.0265	-	0.075	0.099	0.119	0.133
120	0.014	0.0065	-	0.099	0.079	0.089	0.1	0.115
125	0.006	0.0132	0.034	-	0.070	0.089	0.099	0.101
130	0.0088	0.0158	-	0.10	0.061	0.074	0.069	0.081
135	0.0048	0.0178	0.044	-	0.058	0.069	0.069	0.075
138	0.0051	0.0088	0.037	0.098	-	0.063	-	0.063

Sohn (1986), continued.

angle (deg)	electron energy (eV) 1	1.5	1.8	2.5	3	3.5	5
15	-	-	-	0.517	0.802	0.898	3.84
20	0.109	0.051	0.161	0.31	0.505	0.719	2.82
25	0.049	0.075	-	-	0.294	0.545	-
30	0.011	0.042	0.088	0.164	0.299	0.512	1.72
35	-	0.028	0.178	-	0.317	0.626	-
40	0.015	0.031	0.210	0.239	0.415	0.664	1.18
45	-	0.077	0.351	-	0.507	0.924	-
50	0.063	0.109	0.332	0.449	0.696	0.897	1.14
55	-	0.183	0.426	-	0.841	1.23	-
60	0.112	0.228	0.572	0.682	0.954	1.35	1.37
65	-	0.294	0.549	-	1.08	1.41	-
70	0.158	0.335	0.623	0.869	1.06	1.44	1.58
75	-	0.368	0.610	-	1.13	1.41	-
80	0.187	0.384	0.591	0.910	1.05	1.38	1.64
85	-	0.378	0.573	-	0.968	1.22	-
90	0.198	0.397	0.485	0.823	0.858	1.07	1.42
95	-	0.383	0.453	-	0.727	0.845	-
100	0.195	0.339	0.361	0.617	0.59	0.707	1.03
105	-	0.315	0.311	-	0.423	0.484	-
110	0.181	0.264	0.219	0.411	0.313	0.376	0.550
115	-	0.233	0.184	-	0.194	0.259	-
120	0.148	0.169	0.172	0.223	0.146	0.194	0.278
125	-	0.153	0.122	-	0.083	0.245	-
130	0.111	0.095	0.095	0.095	0.091	0.215	0.321
135	-	0.067	0.07	-	-	0.415	-
138	-	0.059	0.062	0.077	0.152	0.358	0.752

Table E-7. Elastic scattering DCS measured by Sakae (1989) in unit of 10^{-16} cm^2/sr.

angle (deg)	electron energy (eV) 75	100	150	200	300	500	700
0	(31.6)	(40.5)	(26.4)	(20.9)	(14.0)	(15.2)	(13.4)
5	(26.1)	25.6	17.7	14.7	9.74	9.95	8.13
10	13.5	8.77	6.52	5.99	3.78	3.24	2.09
12.5		6.71					
15	7.41	4.94	2.75	2.50	1.41	1.01	0.666
20	2.86	2.06	1.05	0.908	0.586	0.470	0.323
25	1.46	0.929	0.542	0.482	0.337	0.258	0.168
30	0.750	0.510	0.376	0.314	0.223	0.153	0.109
35	0.448	0.366	0.259	0.220	0.142	0.0953	0.0634
40	0.319	0.270	0.194	0.147	0.102	0.0613	0.0410
45	0.270	0.224	0.139	0.101	0.0732	0.0414	0.0266
50	0.218	0.166	0.0969	0.0752	0.0555	0.0300	0.0189
55	0.177	0.121	0.0719	0.0595	0.0426	0.0217	0.0136
60	0.135	0.0854	0.0542	0.0489	0.0357	0.0169	0.00989
65	0.104	0.0626	0.0476	0.0415	0.0289	0.0129	0.00817
70	0.0761	0.0497	0.0432	0.0363	0.0239	0.0104	0.00630
75	0.0557	0.0379	0.0397	0.0336	0.0214	0.00846	0.00511
80	0.0471	0.0388	0.0366	0.0317	0.0169	0.00702	0.00416
85	0.0437	0.0381	0.0359	0.0287	0.0142		
90	0.0427	0.0385	0.0372	0.0265	0.0125	0.00547	0.00310
95	0.0439	0.0391					
100	0.0499	0.0419	0.0337	0.0208	0.0109	0.00409	0.00238
110	0.0569	0.0484	0.0316	0.0182	0.0101	0.00347	0.00199
120	0.0740	0.0534	0.0298	0.0174	0.00919	0.00316	0.00169
130	0.0851	0.0522	0.0292	0.0183	0.00816	0.00298	0.00168
135	0.0874	0.0525	0.0285	0.0196	0.00903	0.00316	0.00160
140	(0.0890)	(0.0510)	(0.0285)	(0.0209)	(0.0092)	(0.00319)	(0.00165)
160	(0.0865)	(0.0418)	(0.0283)	(0.0275)	(0.0110)	(0.00369)	(0.00184)
180	(0.0834)	(0.0376)	(0.0284)	(0.0308)	(0.0120)	(0.00398)	(0.00196)

Sakae measured the DCS values at 20, 30, 40 and 60 eV.

Table E-8a. Elastic scattering DCS measured by Boesten (1991) in unit of 10^{-16} cm^2/sr.

angle (deg)	electron energy (eV) 1.5	2	3	4	5	6	7.5	8
10						5.10	7.36	8.13
15		0.250	0.562	1.75	2.81	4.91	6.86	7.52
20	0.150	0.194	0.419	1.60	2.53	4.39	6.00	6.43
25	0.102	0.152	0.368	1.16	2.25	3.77	4.94	5.41
30	0.064	0.136	0.347	1.01	1.73	3.01	4.08	4.43
35	0.070	0.147	0.364	0.948	1.38	2.55	3.40	3.62
40	0.089	0.195	0.480	0.895	1.26	2.14	2.86	3.02
45	0.126	0.266	0.635	0.992	1.23	1.89	2.32	2.47
50	0.181	0.367	0.722	1.10	1.28	1.66	1.88	2.08
55		0.465	0.953	1.22	1.42		1.71	1.77
60	0.312	0.555	1.09	1.36	1.54	1.65	1.61	1.64
65		0.645					1.59	1.52
70	0.412	0.718	1.31	1.60	1.59	1.73	1.57	1.41
75		0.758					1.48	1.38
80	0.471	0.771	1.25	1.67	1.74	1.73	1.53	1.40
85		0.748					1.39	1.27
90	0.505	0.722	1.08	1.31	1.53	1.42	1.26	1.15
95		0.677				1.19	1.05	0.879
100	0.458	0.625	0.804	1.02	1.00	0.945	0.816	0.773
105		0.528	0.640	0.738	0.743	0.680	0.612	0.568
110	0.363	0.451	0.492	0.543	0.444	0.419	0.435	0.387
115		0.380	0.332	0.323	0.282	0.257	0.262	0.273
120	0.272	0.302	0.206	0.183	0.153	0.189	0.209	0.227
125		0.239	0.126	0.160	0.192	0.249	0.245	0.303
130	0.175	0.167	0.115	0.179	0.281	0.356	0.414	0.474

Table E-8b. Elastic scattering DCS measured by Boesten (1991) in unit of 10^{-16} cm^2/sr.

angle (deg)	electron energy (eV) 9	10	12	15	20	30	50	100
10	8.99	7.24	9.29	8.14	8.61	9.86	11.05	6.32
15	8.23	6.49	8.31					
20	6.86	5.65	6.76	6.66	6.91	5.60	4.02	1.62
25	5.85	4.89	5.79					
30	4.71	4.11	4.78	4.56	3.96	2.60	1.27	0.439
35	3.79	3.36	3.94					
40	3.05	2.74	3.12	2.87	2.21	1.15	0.492	0.205
45	2.61	2.21	2.40					0.166
50	2.13	2.14	2.02	1.80	1.21	0.606	0.290	0.130
55	1.77							0.0967
60	1.57	1.57	1.36	1.18	0.768	0.415	0.217	0.0623
65	1.43						0.170	0.0460
70	1.31	1.25	1.03	0.879	0.586	0.317	0.139	0.0386
75	1.27	1.20					0.114	0.0305
80	1.21	1.09	0.862	0.704	0.462	0.246	0.0818	0.0301
85	1.09	0.986					0.0685	0.0268
90	0.972	0.852	0.656	0.525	0.351	0.183	0.0528	0.0269
95	0.843	0.736					0.0480	0.0280
100	0.658	0.588	0.472	0.389	0.263	0.130	0.0464	0.0332
105	0.516	0.441					0.0484	0.0369
110	0.348	0.336	0.313	0.306	0.231	0.131	0.0623	0.0393
115	0.272	0.271					0.0722	0.0428
120	0.228	0.268	0.294	0.329	0.274	0.162	0.0860	0.0429
125	0.293	0.347					0.1032	0.0430
130	0.456	0.502	0.475	0.465	0.355	0.215	0.1164	0.0488

Table E-9. Elastic scattering DCS measured by Shyn (1990) in unit of 10^{-16} cm^2/sr.

angle (deg)	electron energy (eV) 5	10	15	20	30	50
12	44.2	115	155	169	165	82.3
24	27.5	66.7	74.3	73.3	52.3	18.0
36	16.1	38.1	30.4	24.6	13.4	4.4
48	13.3	25.4	19.9	13.2	6.7	3.0
60	12.3	14.6	10.3	6.7	3.8	1.6
72	13.5	9.4	6.0	4.2	2.5	0.85
74	15.0	7.3	3.4	2.8	1.7	0.49
96	13.3	5.2	2.9	1.8	1.1	0.48
108	9.2	2.9	1.9	1.6	1.2	0.62
120	3.6	2.1	2.3	2.2	1.7	1.2
132	2.3	3.5	4.5	3.3	2.5	1.8
144	4.2	8.0	6.9	4.9	3.2	1.9
156	6.7	14.0	9.2	5.7	3.7	2.1
168	(10.5)	(29.5)	(12.4)	(7.2)	(4.8)	(2.3)

The figures in parentheses represent the extrapolated by Shyn. Error of DCS %.

Table E-10. Elastic scattering DCS measured by Mapstone (1992) in unit of 10^{-16} cm^2/sr.

angle (deg)	electron energy (eV) 3.2	4.2	4.9	6.0	7.9	15.4
30	0.40	0.78	1.45	1.81	3.48	3.57
40	0.46	0.85	1.14	1.35	2.20	2.21
50	0.54	1.11	1.16	1.42	1.80	1.75
60	0.94	1.19	1.25	1.30	1.43	1.08
70	0.81	1.19	1.36	1.42	1.39	0.65
80	0.85	1.14	1.30	1.38	1.32	0.50
90	0.83	1.01	1.02	1.18	0.98	0.40
100	0.62	0.86	0.86	0.81	0.62	0.29
110	0.34	0.73	0.46	0.41	0.27	0.27
120	0.22	0.42	0.26	0.22	0.17	0.32
130	0.20	0.25	0.40	0.45	0.46	0.43
140	0.27	0.53	0.73	0.80	0.94	0.57

Table E-11. Elastic scattering DCS measured by Bundschu (1997) in unit of 10^{-16} cm^2/sr.

angle (deg)	electron energy (eV) 0.6	1.0	1.5	1.7	2	3	5	5.7
12							3.91	4.88
15					(0.22)	0.556	3.39	4.24
20			0.085	0.103	(0.147)	0.380	2.60	3.34
25				0.057	(0.115)	0.354	2.05	2.58
30		0.020	0.043	0.052	(0.136)	0.356	1.64	2.05
35	0.068			0.066	(0.19)	0.441	1.36	1.69
40	0.040	0.026	0.104	0.128	(0.27)	0.558	1.26	1.50
45					(0.37)		1.28	1.42
50	0.035	0.081	0.234	0.274	(0.47)	0.845	1.33	1.45
55					(0.58)		1.47	1.53
60	0.038	0.158	0.374	0.444	(0.70)	1.12	1.59	1.63
65				0.519	(0.79)	1.24	1.71	1.72
70	0.040	0.227	0.475	0.557	(0.84)	1.30	1.82	1.81
75				0.592		1.32	1.83	1.81
80	0.068	0.275	0.524	0.611	(0.85)	1.25	1.79	1.75
85				0.615			1.64	1.62
90	0.100	0.272	0.484	0.588	(0.76)	1.03	1.47	1.44
95							1.19	1.17
100	0.112	0.263	0.424	0.490	(0.60)	0.758	0.962	0.935
105							0.681	0.658
110	0.100	0.221	0.329	0.375	(0.39)	0.431	0.452	0.427
115							0.266	0.246
120	0.127	0.180	0.216	0.241	(0.215)	0.194	0.160	0.153
125						0.111	0.148	0.161
130	0.128	0.131	0.138	0.140	(0.102)	0.109	0.236	0.280
error	12-47	8-41	7-35	7-21	7-19	7-11	7-9	6-8 %

The figures in parentheses at 2 eV represent the interpolated values.

Original data of Bundschu (1997) at 2 eV.

angle (deg)	2 eV	angle (deg)	2 eV
17.5	0.177	77.5	0.850
22.5	0.124	82.5	0.847
27.5	0.122	87.5	0.806
32.5	0.154	92.5	0.705
42.5	0.321	102.5	0.569
52.5	0.551	112.5	0.343
62.5	0.752	122.5	0.178
67.5	0.820	132.5	0.084
72.5	0.850		

Table E-12. Elastic scattering DCS measured by Motte-Tollet (1997).

angle (deg)	ε (eV) 15	30
8	9.01	14.5
10	8.6	12.4
15	7.3	9.6
20	6.0	6.8
30	4.6	2.8
40	3.0	1.1
50	1.5	0.57
60	0.92	0.37
70	0.73	0.26
80	0.58	0.22
95	0.50	0.14

error of DCS 18 %.

Table V-1. Summary of the experiments on DCS of vibrational excitation electron scattering for CH_4.

Author	year	ε (eV)	θ (deg)
Rohr	1979	th. - 4	60
Rohr	1980		
Kubo	1981	3 - 20	30 - 140
Sohn	1983	0.17 - 1.8	35 - 105
Tanaka	1983	3 - 20	30 - 140
* Curry	1985	7.5 - 20	32 - 142
Muller R.	1985		
Mapstone I.	1987	2.81	
Boesten	1991	7.5	20 - 130
Shyn	1991	5 - 15	12 - 168
Mapstone B.	1994	3 - 15	30 - 140
* Bundschu	1997	1 - 5.4	
* Motte-Tollet	1997	15, 30	8-95 or 10-40
Muller T.	1997	0.1 - 12	

Table V-2a. Experimental values of vibrational excitation DCS of ν_{24} measured by Curry (1985) at 7.5 to 20 eV in unit of 10^{-18} cm^2/sr.

angle	electron energy (eV)					
(deg)	7.5	10	12.5	15	17.5	20
32.8	5.83	3.82	3.23	3.22	2.06	1.18
43.8	4.35	3.35	2.71	2.49	1.92	1.32
54.7	4.20	2.67	2.22	2.02	1.91	1.65
65.6	3.32	2.62	1.80	1.76	1.53	1.51
76.6	3.59	3.33	1.91	1.39	1.16	1.37
87.5	3.80	3.30	2.02	1.83	1.63	0.95
98.4	4.21	4.18	3.08	2.36	1.97	1.57
109.4	6.38	5.30	3.56	2.83	2.52	1.96
120.3	9.73	5.38	4.03	2.98	2.46	2.17
131.3	6.85	4.64	3.75	2.72	2.18	2.02
142.2	4.41	3.51	3.31	2.03	2.01	1.98

Table V-2b. Experimental values of vibrational excitation DCS of ν_{13} measured by Curry (1985) at 7.5 to 20 eV in unit of 10^{-18} cm^2/sr.

angle	electron energy (eV)					
(deg)	7.5	10	12.5	15	17.5	20
32.8	6.88	3.45	2.14	1.39	0.93	0.55
43.8	5.72	3.60	2.08	1.38	0.97	0.49
54.7	3.99	3.23	1.83	1.13	0.94	0.67
65.6	3.98	3.19	1.76	1.15	0.86	0.53
76.6	4.73	3.01	1.47	1.14	0.68	0.50
87.5	4.88	2.44	1.52	1.08	0.77	0.44
98.4	5.95	2.64	1.46	1.06	0.91	0.73
109.4	6.70	3.55	2.21	1.33	1.15	1.26
120.3	8.29	3.67	2.73	1.60	1.42	1.33
131.3	5.78	3.70	2.66	1.61	1.41	1.31
142.2	2.86	3.25	2.35	1.24	1.36	1.30

Table V-3. Experimental values of vibrational excitation DCS of ν_{24} mode measured by Bundshu (1997) in unit of 10^{-18} cm^2/sr.

angle (deg)	electron energy (eV) 1	2	3	5	5.4
12				8.6	9.0
15			4.8	7.5	7.8
20			4.1	6.9	6.9
25			4.0	5.8	6.2
30	5.7		3.8	5.4	5.7
35			3.0	4.9	5.3
40	3.7		2.5	4.7	5.1
45				4.8	4.9
50	3.2		3.1	4.8	5.3
55				4.7	5.1
60	2.5		2.5	5.2	4.9
65			2.7	5.0	5.0
70	2.9		3.1	5.3	5.2
75			2.7	5.3	5.2
80	2.5		3.0	5.6	5.4
85				5.5	5.5
90	2.8		3.1	5.6	5.5
95				5.4	5.6
100	2.9		2.8	5.6	5.7
105				5.5	5.5
110	2.5		3.1	5.2	5.5
115				5.3	5.5
120	2.9		2.8	5.2	5.4
125			2.4	5.2	5.4
130	2.3		2.6	5.2	5.5

angle (deg)	ε (eV) 2
17.5	5.4
22.5	3.5
27.5	3.1
32.5	3.9
42.5	2.4
52.5	2.7
62.5	2.6
67.5	2.4
72.5	2.4
77.5	2.6
82.5	2.7
87.5	2.6
92.5	2.3
102.5	2.5
112.5	2.6
122.5	2.1
132.5	1.8

Table V-4. Experimental values of vibrational excitation DCS of ν_{13} mode measured by Bundshu (1997) in unit of 10^{-18} cm^2/sr.

angle (deg)	ε (eV) 2
17.5	4.7
22.5	3.5
27.5	2.5
32.5	1.6
42.5	1.7
52.5	1.1
62.5	0.67
67.5	0.70
72.5	0.77
77.5	1.19
82.5	0.57
87.5	0.88
92.5	0.93
102.5	1.03
112.5	0.83
122.5	0.93
132.5	0.98

angle (deg)	electron energy (eV) 2	3	5	5.4
12			12.3	12.9
15		4.7	10.7	11.8
20		2.9	9.0	10.2
25		3.1	8.1	8.9
30		2.5	7.1	7.9
35		1.5	6.5	7.1
40		1.5	5.6	6.4
45			5.9	6.0
50		1.7	5.3	6.1
55			5.3	5.9
60		2.2	5.3	5.7
65		1.5	5.5	5.8
70		1.9	5.7	6.1
75		2.0	6.0	6.2
80		2.2	6.1	6.3
85			6.0	6.3
90		2.1	6.0	6.3
95			5.5	6.0
100		1.9	5.6	5.8
105			5.0	5.2
110		1.8	4.7	4.8
115			4.0	4.4
120		2.2	3.8	3.9
125		1.4	3.3	3.7
130		1.5	3.3	3.5

Table V-5. Experimental values of vibrational excitation DCS measured by Motte-Tollet (1997) at 15 and 30 eV in unit of 10^{-18} cm^2/sr.

angle (deg)	15 ν_{24}	15 ν_{13}	30 ν_{24}	30 ν_{13}
8	5.3	2.9	2.8	1.8
10	4.6	2.3	2.6	1.3
15	4.1	1.8	2.4	0.63
20	3.9	1.6	2.2	0.44
30	3.9	2.0	1.8	0.48
40	3.6	2.2	1.4	0.45
50	2.6	1.8	1.1	0.36
60	2.1	1.5	0.99	0.31
70	2.2	1.5	0.70	0.14
80	2.5	1.4	0.77	0.13
95	3.4	1.8	0.92	0.17

measured at Liege. error of DCS 20 %.

(deg)	15 ν_{24}	15 ν_{13}	30 ν_{24}	30 ν_{13}
10	4.3	2.3		
15	3.5	2.0	2.0	0.52
20	3.2	1.5	1.7	0.48
25	3.2	1.8	1.6	0.48
30	3.2	2.2	1.4	0.54
35	3.0	2.4	1.1	0.50
40	2.5	2.3	0.90	0.44

measured in London.
error of DCS 20 %

Table EX-1. Dissociation cross section q_d for CH_4 measured by Winters (1975), Perrin (1982) and Nakano (1991).

(eV)	Melton	Winters	Perrin	Nakano	
10				CH_3	CH_2
12.5		0.68	0.70		
15		1.38	1.25		
17.5		2.06	1.85		
20		2.75	2.45		
25		3.22	3.00		
30			3.35		
35			3.50		
40			3.70		
45			3.80		
50		3.86	3.90		
60			4.05		
70			4.15		
80			4.20		
90			4.20		
100	4.7	4.01	4.15		
110			4.05		
120			3.95		
150		3.62			
200		3.31			
250		2.98			
300		2.76			
350		2.60			
400		2.48			
450		2.38			
500		2.27			

Table I-1. Summary of the experimental studies of ionization cross section for CH_4.

	Author	year	ε (eV)		
	Tozer	1958			
	Kebarie	1962	100 - 10000		
	Briglia	1965			
*	Rapp	1965	13.5 - 1000	total	8 %
*	Adamczyk	1966	20 - 500	partial	
*	Schram	1966	600 - 12000		
*	Chatham	1984	15 - 400	partial	
*	Orient	B 1987	10 - 510	partial	
*	Duric	1991	14 - 240	total	
*	Nishimura	1994	15 - 3000	total	8 %
	Tarnovsky	1996	th. - 200	CD_4	
*	Straub	C 1997	th. - 1000	partial	
	Tian	1997	th. - 100		
	Vallance	B 1997	th. - 200	total	

Table I-2. Total q_t for CH_4 measured by Rapp (1965), Catham ('84), Orient ('87), Duric ('91), Nishimura ('94), Straub ('97) and Tian ('98).

ε (eV)	Rapp	Catham	Orient	Duric	Nishimura	Straub	Tian	recommend
14	0.074			0.09				
15	0.198	0.20	0.13	0.33	0.209	0.235		
16	0.361			0.55				
17	0.531			0.76				
17.5	0.610					0.763	0.41	
18	0.706			0.95				
19	0.880			1.12				
20	(1.10)	1.07	0.94	1.28	1.22	1.42	0.78	
22	1.42			1.57				
22.5	1.50					1.88		
24	1.72			1.82				
25	(1.85)					2.28	1.77	
26	1.97			2.04				
28	2.20			2.24				
30	2.38	2.30	2.70	2.41	2.56	2.79	2.71	
32	2.54			2.56				
34	2.68			2.69				
35	(2.75)					3.09	3.12	
36	2.79			2.81				
38	2.91			2.92				
40	3.02		3.32	3.02	3.23	3.34	3.48	
45	3.21			3.21	3.49	3.59	3.64	
50	3.36	3.30	3.69	3.36	3.60	3.72	3.84	
55	3.48			3.40				
60	3.56		3.92	3.56	3.86	3.90	4.03	
65	3.62			3.59				
70	3.66		4.04	3.64	3.93	4.01	4.17	
75	3.68			3.65				
80	3.70		4.08	3.66	3.98	4.01	4.24	
85	3.70			3.65				
90	3.70		4.08	3.64	3.98	3.99	4.27	
95	3.68			3.62				
100	3.66	3.55	4.04	3.60	3.92	3.94	4.18	
110	3.62					3.89		
120	3.55		3.93	3.47				
125	3.52					3.74	3.94	
140	3.41		3.81	3.35				
150	3.33					3.52	3.69	
160	3.25		3.68	3.15				
175						3.32	3.53	
180	3.11		3.56	2.99				
200	3.01	3.02	3.40	2.85	3.17	3.15	3.34	
240				2.58				
250	2.72					2.77	3.02	
300	2.49	2.37	2.76		2.55	2.51	2.71	2.49
400	2.09	2.01	2.36		2.17	2.08	2.22	2.08
500	1.83		2.10		1.85	1.80	1.91	1.79

Table I-3. Total ionization cross sections qi for CH_4 measured by Rapp (1965), Adamczyk (1966), Schram (1966), Nishimura (1994), Straub (1997) and Tian (1998).

ε (eV)	Rapp	Adamczyk	Schram	Nishimura	Straub	Tian	recommend
225						3.22	
275						2.82	
350	2.27					2.42	
450	1.94					2.03	
550	1.72					1.70	
600	1.63		1.38	1.62	1.57	1.56	1.58
650	1.54						
700	1.47			1.44	1.40		1.42
750	1.40						
800	1.34			1.33	1.24		1.29
850	1.28						
900	1.24			1.22	1.15		1.19
950	1.21						
1000	1.18	0.839	0.937	1.13	1.05		1.10
1250				0.937			0.936
1500				0.818			0.815
1750				0.747			0.724
2000			0.538	0.666			0.653
2500				0.552			0.549
3000				0.435			0.476
4000			0.305				0.378
7000			0.193				
12000			0.124				

Table I-4. Total ionization cross sections q_i measured by many authours at 70, 75 and 100 eV.

Authour	year	70	75	100
Hughes	1924			2.21
Otvos	1956			
Lampe	1957		3.63	
Tozer	1958	3.24	3.23	3.15
de Maria	1962	3.04		
Kebarle	1962			2.7
Rapp	1965	3.66	3.68	3.66
Glick	1966			4.5
Adamczyk	1966			3.18
Melton	1967			3.81
Beran	1969			
Chatham	1984			3.55
Orient	1987	4.04		4.04
Duric	1991	3.64	3.65	3.60
Nishimura	1994	3.93		3.92
Straub	1997			
Vallance	1997			

Table I-5. Partial ionization cross sections for CH_4 measured by Straub (1997) in unit of 10^{-16} cm^2.

ε (eV)	CH_4^+	CH_3^+	CH_2^+	CH^+	C^+	H_2^+	H^+
15	0.197	0.038					
17.5	0.519	0.238	0.0055				
20	0.892	0.512	0.0169				
22.5	1.11	0.740	0.0285				
25	1.29	0.923	0.0559	0.0045		0.00065	0.0074
30	1.46	1.12	0.141	0.0314	0.00323	0.00113	0.0308
35	1.51	1.19	0.218	0.0800	0.0151	0.00646	0.0750
40	1.55	1.22	0.265	0.119	0.0293	0.0160	0.139
45	1.61	1.27	0.297	0.143	0.0367	0.0238	0.210
50	1.63	1.29	0.307	0.150	0.0449	0.0286	0.266
60	1.65	1.33	0.318	0.169	0.0509	0.0341	0.350
70	1.66	1.35	0.321	0.178	0.0571	0.0373	0.403
80	1.64	1.34	0.323	0.175	0.0608	0.0385	0.434
90	1.62	1.33	0.314	0.178	0.0602	0.0392	0.452
100	1.60	1.31	0.312	0.170	0.0600	0.0389	0.453
110	1.56	1.29	0.305	0.166	0.0601	0.0378	0.452
125	1.52	1.25	0.290	0.155	0.0591	0.0362	0.433
150	1.44	1.18	0.270	0.140	0.0530	0.0337	0.399
175	1.37	1.13	0.248	0.128	0.0478	0.0197	0.369
200	1.31	1.08	0.234	0.116	0.0443	0.0264	0.342
250	1.17	0.970	0.201	0.0978	0.0353	0.0223	0.278
300	1.07	0.886	0.178	0.0839	0.0305	0.0195	0.239
400	0.918	0.742	0.140	0.0634	0.0210	0.0142	0.183
500	0.799	0.655	0.119	0.0518	0.0166	0.0114	0.147
600	0.703	0.574	0.102	0.0428	0.0140	0.0101	0.123
700	0.636	0.518	0.0892	0.0372	0.0122	0.00852	0.103
800	0.562	0.463	0.0796	0.0322	0.00951	0.00735	0.0888
900	0.524	0.427	0.0725	0.0299	0.00908	0.00598	0.0787
1000	0.483	0.391	0.0656	0.0270	0.00817	0.00550	0.0699

Table I-6. Partial ionization cross sections for CH_4 measured by Tian (1998) in unit of 10^{-16} cm^2.

ε (eV)	CH_4^+	CH_3^+	CH_2^+	CH^+	C^+	H_2^+	H^+
17.5	0.26	0.14	0.010				
20	0.47	0.28	0.030				
25	1.00	0.69	0.056	0.015	0.0009		0.010
30	1.41	1.08	0.132	0.034	0.0064	0.0020	0.048
35	1.53	1.21	0.208	0.071	0.0142	0.0061	0.080
40	1.62	1.29	0.267	0.120	0.0272	0.0120	0.141
45	1.63	1.31	0.294	0.137	0.0368	0.0230	0.205
50	1.68	1.36	0.312	0.157	0.0426	0.0281	0.258
60	1.69	1.39	0.339	0.174	0.0515	0.0348	0.346
70	1.71	1.42	0.354	0.181	0.0572	0.0378	0.410
80	1.72	1.43	0.362	0.187	0.0644	0.0385	0.442
90	1.71	1.43	0.363	0.189	0.0679	0.0377	0.471
100	1.67	1.40	0.348	0.184	0.0687	0.0384	0.471
125	1.58	1.32	0.326	0.165	0.0620	0.0352	0.448
150	1.50	1.24	0.298	0.148	0.0566	0.0335	0.417
175	1.45	1.20	0.279	0.136	0.0535	0.0299	0.379
200	1.38	1.14	0.263	0.123	0.0485	0.0278	0.358
225	1.34	1.12	0.247	0.117	0.0444	0.0259	0.330
250	1.26	1.06	0.231	0.106	0.0411	0.0228	0.304
275	1.18	1.00	0.215	0.095	0.0357	0.0215	0.275
300	1.14	0.96	0.207	0.090	0.0333	0.0195	0.257
350	1.03	0.87	0.176	0.077	0.0278	0.0173	0.221
400	0.96	0.80	0.163	0.067	0.0239	0.0149	0.195
450	0.89	0.73	0.146	0.058	0.0202	0.0130	0.173
500	0.84	0.70	0.134	0.052	0.0190	0.0120	0.156
550	0.79	0.66	0.128	0.049	0.0163	0.0114	0.042
600	0.74	0.62	0.119	0.042	0.0147	0.0099	0.029

Table A-1. Summary of experimental study on attachment cross section q_a for CH_4.

	Author	year	ε (eV)
	Trepka	1963	
	Bouby	1965	
*	Sharp	1967	
	Christophorou	1980	
*	Rutkowsky	1980	7.5 - 14
	Tanaka	1991	7 - 15

Table A-2. Attachment cross section q_a measured by Sharp (1967), Rutkowsky (1980).

(eV)	q_a (10^{-3} A^2) Sharp	Rutkowsky
7.5	0.01	0.18
8	0.1	0.54
8.5		1.44
9	0.75	2.64
9.5	0.83	4.00
10	0.95	5.89
10.5		5.25
11	0.72	3.20
11.5	0.5	2.10
12	0.28	1.26
12.5	0.13	0.86
13	0.06	0.70
13.5	0.025	0.65
14	0.01	0.68

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A + e,	A + hν			M + e,		M + hν,	
He 2	2170 *		2	H_2, D_2	2200 ○	5	CH_4 1050 ○
Ne 10	1140 *			N_2	2240 ○		
Ar 18	1960 ○			O_2	1700		CF_4 400
Kr 36	1000			CO	1190		CCl_4 210
Xe 54	1180 ○			NO	880		CCl_2F_2 250
							CH_3Cl 90
Li 3	450			F_2	190 ○		
Na 11	800			Cl_2	360 ○		SiH_4 230
				Br_2	140 ○		SiF_4 140
K 19	370			I_2	240 ○		GeH_4 50
Rb 37	220						
Cs 55	370			HF	330 ○	6	C_2H_4 370
				HCl	420 ○		CH_3OH 350
O 8	390			HBr	220 ○		
				HI	150 ○	7	SF_6 920 ○
F 9	90						
Cl 17	130		3	CO_2	1240 ○		
				H_2O	1200 ○	8	C_2H_6 260
Cu 29	180						C_2F_6 150
Cd 48	210			O_3	490		Si_2H_6 70
Ba 56	340			N_2O	460		
				NO_2	360	9	C_3H_6 120
Hg 80	600			H_2S	270		C_2H_5OH 60
				SO_2	290		
				CS_2	260		
				OCS	280	11	C_3H_8 190
not final, but							C_3F_8 100
finished mostly			4	NH_3	820 ○		
				PH_3	190 ○	12	C_4F_8 100
include electron							C_6H_6 240
swarm papers				C_2H_2	390		C_6F_6 100
				NF_3	110		
include				BF_3	110	60	C_{60} 300
review papers				BCl_3	90		
				H_2CO	180		$M_r + M_v$ 850

* He(Ne) + e only. Not include He(Ne) + hν papers.
○ The bibliography was published already.

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