

Rate Coefficients for Ion-Molecule Reactions

Organic Ions Other than Those Containing Only C and H

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Foreword

The National Standard Reference Data System provides access to the quantitative data of physical science, critically evaluated and compiled for convenience and readily accessible through a variety of distribution channels. The System was established in 1963 by action of the President's Office of Science and Technology and the Federal Council for Science and Technology, and responsibility to administer it was assigned to the National Bureau of Standards.

NSRDS receives advice and planning assistance from a Review Committee of the National Research Council of the National Academy of Sciences-National Academy of Engineering. A number of Advisory Panels, each concerned with a single technical area, meet regularly to examine major portions of the program, assign relative priorities, and identify specific key problems in need of further attention. For selected specific topics, the Advisory Panels sponsor subpanels which make detailed studies of users' needs, the present state of knowledge, and existing data resources as a basis for recommending one or more data compilation activities. This assembly of advisory services contributes greatly to the guidance of NSRDS activities.

The System now includes a complex of data centers and other activities in academic institutions and other laboratories. Components of the NSRDS produce compilations of critically evaluated data, reviews of the state of quantitative knowledge in specialized areas, and computations of useful functions derived from standard reference data. The centers and projects also establish criteria for evaluation and compilation of data and recommend improvements in experimental techniques. They are normally associated with research in the relevant field.

The technical scope of NSRDS is indicated by the categories of projects active or being planned: nuclear properties, atomic and molecular properties, solid state properties, thermodynamic and transport properties, chemical kinetics, and colloid and surface properties.

Reliable data on the properties of matter and materials are a major foundation of scientific and technical progress. Such important activities as basic scientific research, industrial quality control, development of new materials for building and other technologies, measuring and correcting environmental pollution depend on quality reference data. In NSRDS, the Bureau's responsibility to support American science, industry, and commerce is vitally fulfilled.

A handwritten signature in black ink, reading "Ernest Ambler." The signature is written in a cursive, flowing style.

ERNEST AMBLER, *Director*

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Rate Coefficients for Ion-Molecule Reactions. Organic Ions Other Than Those Containing Only C and H

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A compilation is presented of all experimentally determined bimolecular and termolecular rate coefficients for the reactions of organic ions (other than those containing only C and H) with neutral molecules in the vapor phase. The literature covered is from 1960 to the present, and both positive and negative ions are considered. Five hundred and seventy-seven separate reaction-partners are tabulated, and experimental conditions are specified wherever possible. Preferred values are suggested for a number of these processes.

Key words: Chemical kinetics; data evaluation; gas phase ion-molecule reactions; mass spectrometry; organic molecules; rate coefficients.

1. Introduction

During the past decade, the detailed investigation of the dynamics, rates, and mechanisms associated with the interactions of ions with molecules in the vapor phase has been characterized by an almost exponential growth. The current widespread interest in these processes can be attributed to their recognized role in the upper atmosphere, combustion systems, in materials exposed to high energy radiation, and to their application in industrial chemical synthesis and trace analysis, especially in air and water pollution. This is the second in a series of compilations and evaluations of rate coefficients for ion-molecule reactions occurring at thermal or near thermal ion kinetic energies. The first segment, which dealt exclusively with the reactions of organic ions containing only C and H, was published in 1976 [1]¹. This portion deals with the reactivities of all other organic ions (other than those containing C and H only). Ions which constitute "borderline" organics, such as HCN⁺, CS₂⁺, CS₂⁻, and CO₃⁻, CO₄⁻, and CN⁻, as well as protonated CO and CO₂, will be considered in a subsequent article.

Our goal in preparing these articles is twofold. First, we wish to provide a comprehensive, up-to-date compilation of those bimolecular and termolecular ion-molecule reactions and the associated rate constants (coefficients) recorded under reasonably well-specified experimental conditions at ion kinetic energies ≤ 0.5 eV. We have restricted our entries to those data expressed in units of cm³/molecule-s or cm⁶/molecule²-s, which encompass more than 95 percent of the

recent measurements carried out at thermal or nearly thermal energies. Second, since rate coefficients have now been determined under a variety of experimental conditions it is possible, in individual cases, to subject the combined literature to critical evaluation and to suggest a preferred value. We feel that this objective is of prime importance since many investigators use reference reactions for instrumental calibration purposes. Unfortunately, depending upon the particular laboratory, different values have been assumed in many cases for the same calibration reaction, and in several instances the value chosen by a given laboratory has changed with time. One would hope that the assignment of a preferred value with appropriate error limits would provide a common reference base for use by the various research groups.

The following journals were searched for entries from 1960 to the cut-off date, approximately 1 January 1978.

Journal of Chemical Physics
Journal of Physical Chemistry
Journal of the American Chemical Society
Journal of Research of the National Bureau of Standards
The International Journal of Mass Spectrometry and Ion Physics
International Journal of Chemical Kinetics
Canadian Journal of Chemistry
Chemical Physics Letters
Transactions of the Faraday Society

Other pertinent entries were found by scanning Current Contents, Advances in Mass Spectrometry, and the published proceedings of various symposia and meet-

¹Figures in brackets indicate literature references at the end of this paper.

ings dealing with this subject. Unpublished results, as well as any which were not subjected to prior critical review via the normal scientific refereeing channels, are not included. In spite of the fact that every effort has been made to extract all of the relevant kinetic data from the literature it is possible, in an undertaking of this magnitude, that pertinent references may have been inadvertently overlooked. Any omissions which may have accidentally occurred are not intended to reflect the authors' judgments concerning the validity of individual rate measurements or the potential accuracy of the experimental technique used by any particular laboratory.

1.1. Evaluation of Data

With respect to error limits and the reliability of data, it is often difficult to make an objective judgment concerning the validity of a particular rate coefficient. However, it is our feeling that greater than 98 percent of the tabulated values for fast reactions are most certainly correct to within a factor of 2 of the true value at the stated temperature and/or kinetic energy. Difficulties often arise in assigning more stringent limits. For example, one of the perplexing aspects of the chemistry associated with complex ions is the fact that the reactivity of these species may depend critically upon the internal energy content of the reactant ion. Whenever specific reactions have been shown to exhibit such effects it is so stated in the compilation. Second, many of the older values reflect the reactivities of ions which were translationally excited due to the presence of electric fields within the reaction zone. Although this condition would not necessarily affect the total reactivity of any given ion, it is well established that resultant product distributions are often seriously affected. Moreover, in many cases the original authors did not properly state their experimental conditions, particularly with respect to the temperature of the bulk gas. Even when the temperature was stated it is unlikely that the neutral flow component had achieved equilibrium, especially in measurements carried out at reduced pressures. Taken together, these complications, as well as others discussed elsewhere [2,3], introduce a large and often undefinable uncertainty in a number of the tabulated values.

When the accuracy limits given by the original authors seem appropriate within the framework of the possible sources of error, the original error limits are cited. Otherwise, either a reasonable estimate is applied or limits are simply not stated. In general, the most

recent values tend to be the most accurate for any given reaction-pair.

2. Reaction Rate Tables

Two tables are presented, table 1 covering positive ion reactions and table 2, negative ion reactions. The entries in the various columns are described as follows:

2.1. Reaction

The reactions are listed sequentially according to the following format:

(a) Carbon number of the reactant ion; i.e., all of the C_1 's appear first.

(b) Increasing atomic number (Z) of the highest Z element. A C_1 ion containing only H and B (regardless of the number of boron atoms) would therefore appear before $CHNH^+$, $C_2F_6^+$ would be listed before $C_2H_4FBr^+$, and so forth.

(c) When the reactivity of any single ion towards two or more neutrals has been reported, the ordering sequence reflects the hierarchy of the neutral within the procedure outlined in (a) and (b).

Only the empirical formula of the reactant ion is given. The neutral from which the ion was derived, or the structure suggested by the original author, is given under the column entitled Comments (see below). The name or the structural formula of the neutral reactant is always given under the Reaction column. In order to conserve space, the abbreviations n (normal), i (iso), t (tertiary), and c (cyclo) are also sometimes used to define structural isomers. Due to the complexity of the product distributions associated with many of the reactions which are listed, as well as the fact that the branching ratios are often sensitive to changes in temperature, pressure, and internal energy, the reaction products are not specified. Moreover, in many cases only the total reactivity of a given ion towards a given neutral was reported, without specifying reaction products.

2.2. Rate Coefficient (k)

Rate coefficients are given in units of cm^3 molecule $^{-1}$ s $^{-1}$ for bimolecular reactions and cm^6 molecule $^{-2}$ s $^{-1}$ for third order processes. Unless otherwise stated, the error limits given are those imposed by the original authors (see Introduction for discussion). The most recent experimental determination is listed first, the other following in reverse chronological order. When a given laboratory has reported two or more values, or a corrected value, for a given reaction using the same

technique, then only the more recent or corrected value is reported.

2.3. Temperature (T)

When the system temperature was specified, then that value is given in degrees K. All ion cyclotron resonance measurements may be assumed to have been carried out at, or slightly above, ambient laboratory temperatures (295 + 15, -5 K).

2.4. Experimental Methods

The nomenclature used to describe the various measurements techniques is similar to that used by Ferguson [4].

Method	See below for short description
DT	Drift Tube
FA	Flowing Afterglow
ICR	Ion Cyclotron Resonance
MS	Mass Spectrometer Ion Source
B	Beam Apparatus
TI	Ion Trap

a. Drift Tube (DT)

This is a relatively new technique which yields rate coefficients from thermal to several electron volts kinetic energy. It has been mainly applied to the reactions of inorganic ions of aeronomic interest.

b. Flowing Afterglow (FA)

This versatile method, which utilizes a buffer gas at relatively high pressures, assures that the reactant ions are essentially always in thermodynamic equilibrium prior to reaction. The gas temperature is variable over a considerable range (up to 900 K). FA has been especially useful for the determination of equilibrium constants and other thermodynamic quantities pertinent to ionic association and particle transfer reactions as well as reactions of aeronomic importance.

c. Ion Cyclotron Resonance (ICR)

Ion Cyclotron Resonance mass spectrometry is a low pressure technique (10^{-7} to 10^{-3} Nm⁻²) in which the reaction time is usually the variable experimental parameter. Most of the rate data have been obtained at nearly thermal kinetic energies and at ambient room temperature.

d. Mass Spectrometer Ion Source (MS)

This is a catchall category used to denote measurements involving a single reaction chamber associated with a mass analysis system. The application of this technique varies considerably from laboratory to laboratory. Some groups work in the pressure range 10^{-3} to 10^{-1} Nm⁻², with or without pulsed chambers, while

others have extended the pressure range up to nearly one atmosphere. Both photoionization and electron impact have been utilized to produce reactant ions. Many of the earlier low pressure studies involved the application of a electric field across the reaction zone for the purposes of ion extraction. In these cases the reactant ions were continuously accelerated, giving an epithermal kinetic energy distribution.

e. Beam (B)

Beam experiments involve the generation of a mass and energy selected ion beam which is impacted on a neutral target in a collision chamber coupled with a second mass analyzer. The kinetic energy may be varied from nearly thermal values up to tens of kilovolts.

f. Ion Trap (TI)

This relatively new technique involves the trapping of ions for a variable period of time in the negative space charge of a continuous low energy electron beam. The reactant ions may have kinetic energies in excess of thermal values, in some cases up to several tenths of an electron volt.

In many cases characterization of an experiment as being of the Beam type, Mass Spectrometer ion source type, etc., is not sufficient for defining the exact measurement technique. The reader should always refer to the specific literature citation associated with the quoted rate coefficient for details of the variation used to generate any particular value.

2.5. Comments

This column is used to provide descriptive information pertinent to the measurement such as "*k* varies with temperature, photoionization," etc. When the quoted value of *k* for any particular reaction was determined relative to an assumed value for a calibration reaction, then the assumed value for the calibration reaction is given. For ions containing two or more C atoms, one or more structural isomers may be present in any given experiment. In every case where the identity of the reactant ion is not obvious, we have listed either the neutral from which the ion was derived or the probable structural formula. The following abbreviations are also used: KE = ion kinetic energy, IEE = ion exit energy, and V cm⁻¹ to denote the magnitude of the imposed potential within the reaction chamber. Several of the ICR values were determined by pressure variation. When such measurements are reported, the entry "Pressure varied" is included. Comments pertinent to our choice of a preferred value are also given in this column.

TABLE I. Rate coefficients^a for reactions of organic cations

Reaction	<i>T</i>	<i>k</i>	Method	Comments	Ref.		
CH ₂ N ⁺ + CH ₃ NH ₂ →	370	1.8(-9) ^b	MS	13eV e ⁻ , 3.4eV IEE	5		
	370	2.4(-9)	MS	15eV e ⁻ , 3.4eV IEE	5		
	370	1.6(-9)	MS	50eV e ⁻ , 3.4eV IEE	5		
		9±1(-10)	MS		6		
		5(-10)	MS		6		
		8.0±0.2(-10)	ICR		7		
CH ₂ N ⁺ + (CH ₃) ₂ NH →		5(-10)	MS		6		
		8.0±0.2(-10)	ICR		7		
		5(-10)	MS		6		
CH ₂ N ⁺ + c-C ₆ H ₅ NH ₂ →		5(-10)	MS		6		
		8.0±0.2(-10)	ICR		7		
		5(-10)	MS		6		
	CH ₂ N ⁺ + (CH ₃) ₂ N →	370	2.6(-9)	MS	13eV e ⁻ , 3.4eV IEE	5	
		370	2.6(-9)	MS	15eV e ⁻ , 3.4eV IEE	5	
		370	1.9(-9)	MS	50eV e ⁻ , 3.4eV IEE	5	
CH ₂ N ⁺ + CH ₃ NH ₂ →		9±1(-10)	MS		6		
	295	1.1±0.1(-9)	MS	Photoionization	8		
	370	1.8(-9)	MS	13eV e ⁻ , 3.4eV IEE	5		
	370	1.8(-9)	MS	15eV e ⁻ , 3.4eV IEE	5		
	370	1.2(-9)	MS	50eV e ⁻ , 3.4eV IEE	5		
		7±1(-10)	MS		6		
CH ₂ N ⁺ + (CH ₃) ₂ NH →		6±2(-10)	MS		6		
	CH ₂ N ⁺ + C ₂ H ₅ NH ₂ →	298	1.97±0.2(-9)	MS	Photoionization	9	
		298	1.56±0.2(-9)	MS	Photoionization	9	
	CH ₂ N ⁺ + n-C ₆ H ₅ NH ₂ →		4(-10)	MS		6	
		CH ₂ N ⁺ + (CH ₃) ₃ N →		1.64(-9)	ICR	Time varied	10
				2.06(-9)	ICR	Pressure varied	10
295			1.21±0.1(-9)	MS	Photoionization	8	
370			2.7(-9)	MS	13eV e ⁻ , 3.4eV IEE	5	
370			2.6(-9)	MS	15eV e ⁻ , 3.4eV IEE	5	
370	1.9(-9)		MS	50eV e ⁻ , 3.4eV IEE	5		
CH ₂ D ₂ N ⁺ + CD ₃ NH ₂ →		9±1(-10)	MS		6		
		1.85(-9)	ICR	From CD ₃ NH ₂	10		
	CH ₂ N ⁺ + 2CH ₃ NH ₂ →	250	3.0(-26)	MS	CH ₃ NH ₃ ⁺	11	
		350	1.6(-26)	MS	CH ₃ NH ₃ ⁺	11	
	CH ₂ DN ⁺ + CH ₃ NH ₂ →		6.4±0.2(-10)	TI	CH ₂ NH ₂ D ⁺	12	
	CH ₂ D ₁ N ⁺ + CD ₃ NH ₂ →		4.8(-10)	ICR	CD ₃ NH ₂ D ⁺	10	
		3.1(-10)	ICR	CD ₃ NH ₂ D ⁺	10		
CH ₂ N ₂ ⁺ + CH ₃ N ₂ CH ₃ →		7.8±1.0(-10)	ICR		13		
	CH ₂ O ⁺ + CH ₂ O →		1.3(-10)	ICR		14	
		1.77(-9)	ICR		15		
373		1.93±0.02(-9)	MS	3.4eV IEE	16		
373		2.00±0.01(-9)	MS	2.4eV IEE	16		
373		2.03±0.1(-9)	MS	Thermal ions	17		
373		1.40±0.2(-9)	MS	3.4eV IEE	17		
CH ₂ O ⁺ + (CH ₃) ₃ B →		2.2±0.4(-10)	ICR		18		
		6.7(-11)	ICR		14		
	CH ₂ O ⁺ + CH ₃ OH →	373	2.11±0.3(-9)	MS	11eV e ⁻ , Thermal	17	
		373	1.68±0.2(-9)	MS	50eV e ⁻ , Thermal	17	
		373	1.58±0.2(-9)	MS	11eV e ⁻ , 3.4eV IEE	17	
		373	8.0±2.0(-10)	MS	50eV e ⁻ , 3.4eV IEE	17	
		6.8(-10)	TI		19		
	CH ₂ O ⁺ + CH ₃ CHO →		1.80(-9)	ICR		15	
	CH ₂ O ⁺ + Ethylene oxide →		1.16±0.15(-9)	MS		20	
	CH ₂ O ⁺ + HCO ₂ CH ₃ →		2.0±0.2(-9)	MS		21	
	CH ₂ O ⁺ + Dimethylsulfoxide →	408	4.5±0.5(-9)	MS	0.71eV IEE	22	
		408	4.5±0.5(-9)	MS	1.07eV IEE	22	
CH ₂ DO ⁺ + DCO ₂ CH ₃ →		1.9±0.2(-9)	MS	2.4eV IEE	21		
CHD ₂ O ⁺ + CD ₃ OH →	373	1.44(-9)	MS	From CD ₃ OH, thermal	17		
	CH ₃ O ⁺ + CH ₃ OH →		2.17(-9)	ICR	Pressure varied, CH ₃ OH ⁺	10	
		2.08(-9)	ICR	Time varied, CH ₃ OH ⁺	10		
		1.86(-9)	ICR	CH ₃ OH ⁺	15		
		1.90(-9)	ICR	CH ₃ OH ⁺	23		

TABLE I. Rate coefficients^a for reactions of organic cations—Continued

Reaction	<i>T</i>	<i>k</i>	Method	Comments	Ref.
CH ₃ O ⁺ + CH ₃ OH →	373	2.53±0.2(−9)	MS	11eV e [−] , thermal, CH ₃ OH ⁺	17
	373	2.47±0.2(−9)	MS	50eV e [−] , thermal, CH ₃ OH ⁺	17
	373	2.56±0.4(−9)	MS	11eV e [−] , 3.4eV IEE, CH ₃ OH ⁺	17
	373	2.5±0.2(−9)	MS	50eV e [−] , 3.4eV IEE, CH ₃ OH ⁺	17
	450	2.0(−9)	MS	9.1 V cm ^{−1} , CH ₃ OH ⁺	24
	420	2.45(−9)	MS	0.86 V cm ^{−1} , CH ₃ OH ⁺	19
				See footnote c for further comment.	
+ HCO ₂ CH ₃ →	370	2.54±0.1(−9)	MS	2.4eV IEE, CH ₃ OH ⁺	21
		7.5(−10)	B	0.3eV KE, CH ₃ OH ⁺	25
+ 2-pentanone →					
CH ₃ DO ⁺ + CH ₃ OH →	450	2.0(−9)	MS	9.1 V cm ^{−1} , CH ₃ OD ⁺	24
	370	2.41±0.1(−9)	MS	2.4eV IEE, CH ₃ OD ⁺	21
CHD ₃ O ⁺ + CD ₃ OH →		2.56(−9)	ICR	CD ₃ OH ⁺	10
	373	2.19(−9)	MS	Thermal, CD ₃ OH ⁺	17
	450	2.0(−9)	MS	0.9eV IEE, CD ₃ OH ⁺	24
CH ₃ O ⁺ + CH ₃ OH →		1.1(−10)	ICR	Time varied, CH ₃ OH ₂ ⁺	10
		1.0(−10)	ICR	Pressure varied, CH ₃ OH ₂ ⁺	10
		8(−11)	ICR	CH ₃ OH ₂ ⁺	15
CH ₂ D ₂ O ⁺ + CD ₃ OH →		1.5(−10)	ICR	Pressure varied, CD ₃ OH ₂ ⁺	10
		1.3(−10)	ICR	Time varied, CD ₃ OH ₂ ⁺	10
CHD ₂ O ⁺ + CD ₃ OH →		4.4(−10)	ICR	Pressure varied, CD ₃ OHD ⁺	10
		4.2(−10)	ICR	Time varied, CD ₃ OHD ⁺	10
		4.0±0.5(−10)	TI	CD ₃ OHD ⁺	12
CDO ₂ ⁺ + DCO ₂ H →	370	1.72±0.1(−9)	MS	2.4eV IEE	21
CH ₂ O ₂ ⁺ + H ₂ O →	174	3(−10)	MS		26
	200	3(−10)	MS		26
	280	3(−10)	MS		26
	370	1.59±0.1(−9)	MS	2.4eV IEE	21
CHDO ₂ ⁺ + DCO ₂ H →					
CH ₃ NO ₂ ⁺ + 2 CH ₃ OH →		1.9±0.4(−27)	MS	(CH ₃ OH)NO ⁺	27
CF ⁺ + CH ₃ F →	373	4.7(−10)	MS	0.24eV IEE	28
	373	4.8(−10)	MS	0.65eV IEE	28
+ HFCO →		5(−11)	ICR		29
+ CH ₂ F ₂ →	320	1.12(−9)	MS		30
+ CF ₄ →	320	3.3(−10)	MS		30
+ CHCl ₂ F →		4(−10)	MS	0.2eV KE	31
+ CCl ₄ →		5.9(−10)	MS	0.2eV KE	31
+ C ₂ H ₂ F ₂ →	320	1.12(−9)	MS		30
+ C ₂ F ₆ →	295	1.9±0.4(−10)	MS	Photoionization	32
		3.9(−11)	B	0.3eV KE	33
+ C ₃ F ₈ →		7.1(−11)	B	0.3eV KE	34
+ 1,1,2,2,-c-C ₄ H ₄ F ₄ →		1.78(−10)	MS	Average of two methods	35
+ SiD ₄ →		1.1±0.1(−10)	B	1.0eV KE	36
CHF ⁺ + CH ₃ F →	373	1.21(−9)	MS	0.24eV KE	28
	373	1.10(−9)	MS	0.65eV KE	28
		1.6(−9)	MS	0.2eV IEE	37
+ CH ₂ F ₂ →	320	1.32(−9)	MS		30
	317	1.77(−9)	MS		38
+ CHCl ₂ F →		1.53(−9)	MS	0.2eV KE	31
+ CHClF ₂ →		3(−10)	MS	0.2eV KE	31
+ CHF ₃ →		1(−10)	MS	0.2eV KE	31
CH ₂ F ⁺ + 2 CH ₃ F →	320	2.8(−26)	MS	200eV e [−]	30
	320	3.45(−26)	MS	14.5eV e [−]	30
+ CH ₂ F ₂ →		1.30(−9)	ICR		39
		2.2(−10)	ICR		40
+ 2 CH ₂ F ₂ →	320	1.1(−26)	MS		30
+ CH ₂ FCI →		1.04±0.2(−9)	ICR		41
+ C ₂ H ₅ F →		1.9±0.1(−9)	MS		42
+ 2 CH ₂ CF ₂ →	317	7.8(−25)	MS		38

TABLE I. Rate coefficients^a for reactions of organic cations—Continued

Reaction	<i>T</i>	<i>k</i>	Method	Comments	Ref.	
CH ₃ F ⁺ + CH ₃ F →	320	1.86(−9)	MS	14.5eV e [−]	30	
	320	2.30(−9)	MS	200eV e [−]	30	
		1.73(−9)	ICR		39	
		1.37(−9)	ICR		43	
		1.38(−9)	ICR		44	
	373	1.53(−9)	MS	0.24eV IEE	28	
	373	2.27(−9)	MS	1.1eV IEE, Increases with increasing IEE	28	
		2.2(−9)	MS	0.2eV KE	37	
				See footnote d for further comment.		
CH ₂ F ⁺ + CH ₃ F →	320	1.36(−9)	MS	200eV e [−]	30	
	320	9.5(−10)	MS	14.5eV e [−]	30	
		9.9(−10)	ICR		39	
		7.1(−10)	ICR		44	
		9.0(−10)	MS		28	
		8.0(−10)	ICR		43	
CHOF ⁺ + HFCO →		2.5(−9)	ICR	HFCO ⁺	29	
CH ₂ FO ⁺ + HFCO →		1.2(−10)	ICR	(HFCO)H ⁺	29	
CF ₂ ⁺ + CHF ₃ →	320	9.3(−10)	MS		30	
		9.2(−10)	MS	0.2eV KE	31	
	320	2.7(−10)	MS		30	
		1.7(−10)	ICR		39	
		1.4(−10)	MS	0.2eV KE	31	
	390	4.0(−10)	MS	0.2eV KE	31	
	390	4.0(−10)	MS	0.2eV KE	31	
	317	2.15(−9)	MS		38	
	295	1.45±0.3(−10)	MS	Photoionization	32	
		6.7(−11)	B	0.3eV KE	33	
		2.8(−10)	B	0.3eV KE	34	
		1.1±0.1(−9)	B	1.0eV KE	36	
	CHF ₂ ⁺ +	<i>i</i> -C ₄ H ₁₀ →		1.24±0.08(−9)	ICR	45
		<i>neo</i> -C ₄ H ₁₂ →		1.22±0.06(−9)	ICR	45
		CH ₃ OH →		1.41(−9)	ICR	46
		HCOOH →		1.16(−9)	ICR	46
		CH ₃ CHO →		9.6(−10)	ICR	46
C ₂ H ₅ OH →			1.11(−9)	ICR	46	
CH ₃ OCH ₃ →			1.0(−9)	ICR	46	
CH ₃ COOH →			1.9(−9)	ICR	46	
HCOOCH ₃ →			1.53(−9)	ICR	46	
CH ₃ COCH ₃ →			1.84(−9)	ICR	46	
HCOOC ₂ H ₅ →			1.86(−9)	ICR	46	
CH ₃ COOC ₂ H ₅ →			1.51(−9)	ICR	46	
CH ₃ COC ₂ H ₅ →			1.27(−9)	ICR	46	
(CH ₃) ₂ CHCHO →			2.05(−9)	ICR	46	
HCOOC ₄ H ₉ →			1.56(−9)	ICR	46	
320		6.0(−10)	MS		30	
		1.9(−10)	ICR		39	
		2.2(−10)	ICR		39	
		1.4(−10)	ICR		40	
		1.4(−10)	ICR		39	
+ CHF ₃ →			9.7±1.4(−10)	ICR		41
+ CF ₂ Cl ₂ →			1.35±0.20(−9)	ICR		41
+ CCl ₃ H →			1.21±0.18(−9)	ICR		41
+ CFCl ₃ →		1.28±0.19(−9)	ICR		41	
+ CCl ₄ →		1.0(−9)	ICR		46	
+ NH ₃ →		1.0(−9)	ICR		46	
CH ₂ F ₂ ⁺ + CH ₂ F ₂ →	320	1.77(−9)	MS	200eV e [−]	30	
	320	1.13(−9)	MS	14.5eV e [−]	30	

TABLE I. Rate coefficients* for reactions of organic cations—Continued

Reaction	<i>T</i>	<i>k</i>	Method	Comments	Ref.
CH ₂ F ₂ ⁺ + CH ₂ F ₂ →		1.30(−9)	ICR		39
CH ₃ F ₂ ⁺ + CH ₂ F ₂ →		1.40(−9)	ICR		39
CF ₃ ⁺ + C ₂ H ₆ →	323	3.6±0.4(−10)	MS	15 V cm ^{−1}	47
+ <i>i</i> -C ₆ H ₁₀ →		5.5±0.5(−10)	ICR		45
+ <i>i</i> -C ₈ H ₁₈ →		7.3±0.5(−10)	ICR		45
+ <i>neo</i> -C ₈ H ₁₈ →		4.9±0.4(−10)	ICR		45
+ CH ₃ F →		2.7±0.7(−10)	ICR		41
+ CHF ₃ →	320	6.4(−10)	MS		30
		2.1(−10)	ICR		39
		5.9(−10)	MS	0.2eV KE	31
+ CH ₂ FCI →		7.3±1.1(−10)	ICR		41
+ CF ₂ Cl ₂ →		5.8±0.9(−10)	ICR		41
+ CHCl ₃ →		9.1±1.4(−10)	ICR		41
+ CFCl ₃ →		7.7±1.2(−10)	ICR		41
+ CCl ₄ →		9.1±1.4(−10)	ICR		41
+ C ₂ F ₆ →	295	4±1(−11)	MS	Photoionization	32
		3.4(−11)	B	0.3eV KE	33
		2.9(−11)	B	0.3eV KE	34
+ SiH ₄ →		6.5±0.7(−10)	B	1.0eV KE	36
CH ₂ F ₃ ⁺ + CHF ₃ →		8.2(−11)	ICR	(CHF ₃) ⁺ H ⁺	39
CHSi ⁺ + CH ₃ SiH ₃ →		1.9±0.3(−10)	MS		48
CH ₂ Si ⁺ + CH ₃ SiH ₃ →		1.7±0.4(−10)	MS		48
CH ₃ Si ⁺ + CH ₃ SiH ₃ →		1.26±0.33(−9)	MS		48
+ (CH ₃) ₄ Si →		1.6±0.4(−9)	MS	11.7 V cm ^{−1}	49
CH ₄ Si ⁺ + CH ₃ SiH ₃ →		2.45±0.6(−9)	MS	(CH ₃ SiH) ⁺	48
+ (CH ₃) ₂ SiH ₂ →		1.3(−9)	MS	(CH ₃ SiH) ⁺	50
CH ₅ Si ⁺ + CH ₃ SiH ₃ →		3.2±0.8(−10)	MS	(CH ₃ SiH ₂) ⁺	48
+ (CH ₃) ₄ SiH ₄ →		7.5(−10)	MS	(CH ₃ SiH ₂) ⁺	50
CH ₂ SiF ₂ ⁺ + CH ₃ SiF ₃ →		6.1(−11)	ICR		51
CH ₃ SiF ₂ ⁺ + CH ₃ SiF ₃ →		1.3(−11)	ICR		51
+ (CH ₃) ₂ SiF ₂ →		3.2(−10)	ICR		51
CH ₃ SiF ₃ ⁺ + CH ₃ SiF ₃ →		6.7(−11)	ICR		51
CH ₃ P ⁺ + CH ₃ PH ₂ →		9.5±2.0(−10)	ICR	CH ₃ PH ₂ ⁺	52
CS ⁺ + H ₂ →		7.3±1.1(−10)	ICR		53
+ CH ₄ →		9.5±1.4(−10)	ICR		53
CHS ⁺ + CH ₃ SH →		8.0±1.0(−10)	MS	10.7 V cm ^{−1}	54
		7(−10)	MS	3.4eV IEE	55
+ (CH ₃) ₂ SH →		1.0±0.2(−9)	MS	10.7 V cm ^{−1}	54
CDS ⁺ + CD ₃ SH →		3.5±0.2(−10)	TI	0.4eV KE	56
CH ₂ S ⁺ + CH ₃ SH →		8±1(−10)	TI	0.4eV KE	56
+ (CH ₃) ₂ S →		2.0±0.3(−9)	MS	10 V cm ^{−1}	54
+ dimethylsulfoxide →	408	3.2±0.3(−9)	MS	≥0.7eV KE	22
CHDS ⁺ + CD ₃ SH →		7.9±1.5(−10)	TI	0.4eV KE	56
CD ₂ S ⁺ + CD ₃ SH →		4.7±0.3(−10)	TI	0.4eV KE	56
CH ₃ S ⁺ + CH ₃ SH →		6.3±1.6(−10)	TI	0.4eV KE	56
		1.6±0.2(−9)	MS	10.7 V cm ^{−1}	54
		1.04±0.03(−9)	MS	3.4eV IEE	55
+ (CH ₃) ₂ S →		1.5±0.2(−9)	MS	10.7 V cm ^{−1}	54
+ dimethylsulfoxide →	408	2.7±0.3(−9)	MS	0.7eV IEE	22
	408	2.6±0.3(−9)	MS	1.1eV IEE	22
CHD ₂ S ⁺ + CD ₃ SH →		6.7±0.2(−10)	TI	0.4eV KE	56
		8.0±0.6(−10)	MS	3.4eV IEE	55
CD ₃ S ⁺ + CD ₃ SH →		7.2±0.6(−10)	TI	0.4eV KE	56
		1.00±0.04(−9)	MS	3.4eV IEE	55
CH ₄ S ⁺ + CH ₃ SH →		1.41±0.07(−9)	MS	Photoionization	57
		7.7±0.2(−10)	TI	0.4V KE	56
		1.19±0.06(−10)	MS	3.4eV IEE	55
+ C ₂ H ₅ CHO →		1.8±0.1(−9)	MS		58

TABLE I. Rate coefficients^a for reactions of organic cations—Continued

Reaction		<i>T</i>	<i>k</i>	Method	Comments	Ref.	
CHD ₃ S ⁺	+ CH ₃ CHO →		1.2±0.2(-9)	MS	(CD ₃ SH) ⁺	58	
	+ CD ₃ SH →		8.2±0.2(-10)	TI	0.4eV KE, (CD ₃ SH) ⁺	56	
CH ₃ S ⁺	+ CH ₃ OCH ₃ →		1.21±0.03(-9)	MS	(CD ₃ SH) ⁺	55	
	+ CH ₃ SH →		1.51±0.36(-9)	MS	(CD ₃ SH) ⁺	58	
	+ C ₆ H ₅ CHO →		7.6(-12)	TI	0.4eV KE, CH ₃ SH ₂ ⁺	56	
	+ (CH ₃) ₂ S →		5.3±0.8(-10)	MS	10 V cm ⁻¹ , CH ₃ SH ₂ ⁺	54	
	+ CH ₃ COCH ₃ →		5.6±0.3(-10)	MS	CH ₃ SH ₂ ⁺	58	
	+ CH ₃ S →		1.74±0.05(-9)	MS	CH ₃ SH ₂ ⁺	58	
CH ₃ DS ⁺	+ CH ₃ S →		2.30±0.21(-9)	MS	CH ₃ SH ₂ ⁺	58	
CH ₃ D ₃ S ⁺	+ CH ₃ OCH ₃ →		4.4±0.6(-10)	TI	CH ₃ SHD ⁺	12	
CHD ₂ S ⁺	+ CHD ₃ S →		1.24±0.10(-9)	MS	CD ₃ SH ₂ ⁺	58	
	+ CHD ₂ S →		1.3±0.2(-10)	TI	<i>k</i> reflects sources of CD ₃ SHD ⁺	56	
			2.6±0.3(-10)	TI	<i>k</i> reflects source CD ₃ SHD ⁺	56	
CH ₃ SO ⁺	+ CH ₃ CHO →		7.3±0.9(-10)	MS	CD ₃ SHD ⁺	58	
	+ dimethylsulfoxide →	408	3.4±0.3(-9)	MS	1.07eV IEE	22	
		408	3.4±0.3(-9)	MS	0.71 IEE	22	
		408	3.2±0.3(-9)	MS	Thermal	22	
CCl ⁺	+ CH ₃ Cl →	373	1.2(-10)	MS	0.21eV IEE	28	
		373	1.7(-10)	MS	0.46eV IEE	28	
	+ CH ₃ Cl →	373	2.1(-10)	MS	0.65eV IEE	28	
		373	1.4(-10)	MS	1.1eV IEE	28	
	+ CHClF ₂ →		2.0(-10)	MS	0.2eV IEE	31	
	+ CHFCl ₂ →		4.0(-10)	MS	0.2eV IEE	31	
	+ CHCl ₃ →		7.0(-10)	MS	0.2eV IEE	31	
	+ CCl ₄ →		4.0(-10)	MS	0.2eV IEE	31	
	CHCl ⁺	+ CH ₃ Cl →	373	6.1(-10)	MS	0.2eV IEE	28
			373	4.4(-10)	MS	0.46eV IEE	28
		373	3.3(-10)	MS	0.65eV IEE	28	
		373	3.2(-10)	MS	1.1eV IEE	28	
+ CHFCl ₂ →			7.6(-10)	MS	0.2eV KE	31	
CH ₂ Cl ⁺	+ CHCl ₃ →		7(-10)	MS	0.2eV KE	31	
	+ CH ₃ Cl →	373	4.6(-10)	MS		17	
	+ CHF ₂ Cl →		1.5±0.5(-10)	ICR		41	
	+ CH ₂ Cl ₂ →		<1.0(-11)	ICR		41	
	+ C ₂ H ₅ Cl →	320	1.15±0.08(-9)	MS		42	
CH ₃ Cl ⁺	+ CH ₃ Cl →		1.25(-9)	ICR		44	
		373	1.54±0.08(-9)	MS	Value over range 0.21 to 1.1eV IEE	28	
			1.66(-9)	MS	0.2eV KE	59	
		373	1.70(-9)	MS		17	
CH ₄ Cl ⁺	+ CH ₃ Cl →	373	1.4(-10)	ICR		44	
		373	1.0(-10)	MS	0.45eV IEE	28	
CNCl ⁺	+ CNCl →		1.2(-9)	MS		60	
CFCl ⁺	+ CHClF ₂ →		4.2(-10)	MS	0.2eV KE	31	
	+ CHFCl ₂ →		5.0(-10)	MS	0.2eV KE	31	
	+ CF ₂ Cl ₂ →		6.1(-10)	MS	0.2eV KE	31	
	+ CHFCl ₂ →		3.0±0.5(-11)	ICR		41	
CF ₂ Cl ⁺	+ CHFCl ₂ →		2.2±0.3(-10)	ICR		41	
	+ CFCl ₃ →		4.0±0.6(-10)	ICR		41	
	+ CCl ₄ →		5.0±0.8(-10)	ICR		41	
	+ <i>i</i> -C ₄ H ₁₀ →		3.3(-10)	MS	0.2eV KE	31	
	+ CHFCl ₂ →		2.4±0.1(-10)	ICR		45	
CCl ₂ ⁺	+ CHCl ₃ →		3.6(-10)	MS	0.2eV KE	31	
	+ CCl ₄ →		5.9(-10)	MS	0.2eV KE	31	
	+ CH ₃ OH →		7.5(-11)	ICR		46	
CHCl ₂ ⁺	+ HCOOH →		5.7(-11)	ICR		46	

TABLE I. Rate coefficients^a for reactions of organic cations—Continued

	Reaction	<i>T</i>	<i>k</i>	Method	Comments	Ref.	
CHCl ₂ ⁺	+ CH ₃ CHO →		5.6(-10)	ICR		46	
	+ C ₂ H ₅ OH →		5.2(-10)	ICR		46	
	+ CH ₃ OCH ₃ →		4.0(-10)	ICR		46	
	+ HCOOCH ₃ →		3.9(-10)	ICR		46	
	+ CH ₃ COCH ₃ →		5.7(-10)	ICR		46	
	+ HCOOC ₂ H ₅ →		8.3(-10)	ICR		46	
	+ CH ₃ COOCH ₃ →		9.8(-10)	ICR		46	
	+ <i>i</i> -C ₄ H ₁₀ →		6.7±0.3(-10)	ICR		45	
	+ CH ₃ COC ₂ H ₅ →		7.2(-10)	ICR		46	
	+ (CH ₃) ₃ CHCHO →		1.33(-9)	ICR		46	
	+ C ₂ H ₅ OC ₂ H ₅ →		9.0(-10)	ICR		46	
	+ <i>i</i> -C ₆ H ₁₂ →		8.4±0.3(-10)	ICR		45	
	+ <i>neo</i> -C ₆ H ₁₂ →		3.5±0.3(-10)	ICR		45	
	+ HCOOC ₄ H ₉ →		1.01(-9)	ICR		46	
	+ CCl ₄ →		8.0±1.2(-11)	ICR		41	
	CDCl ₂ ⁺	+ NH ₃ →		7.8(-10)	ICR		46
		+ (CH ₃) ₃ N →		1.37(-9)	ICR		46
CFCl ₂ ⁺	+ CHCl ₃ →		<4(-12)	ICR		41	
	+ CCl ₃ F →		1.3±0.2(-11)	ICR		41	
	+ CCl ₄ →		<4(-12)	ICR		41	
	+ <i>i</i> -C ₄ H ₁₀ →		7.4±1.0(-11)	ICR		45	
	+ 2,2-dimethylpentane →		1.2±0.2(-10)	ICR		45	
	+ 3,3-dimethylpentane →		1.8±0.1(-10)	ICR		45	
	+ 2-methylheptane →		7.3±0.4(-10)	ICR		45	
	+ 2,3-dimethylhexane →		5.8±0.3(-10)	ICR		45	
	+ 2,4-dimethylhexane →		3.7±0.3(-10)	ICR		45	
	+ 2,5-dimethylhexane →		4.5±0.1(-10)	ICR		45	
	+ 2,3,4-trimethylpentane →		3.4±0.2(-10)	ICR		45	
	CCl ₃ ⁺	+ 2-methylheptane →		6.0±0.4(-11)	ICR		45
		+ 3-methylheptane →		6.8±0.4(-11)	ICR		45
		+ 2,3-dimethylhexane →		6.2±0.5(-11)	ICR		45
		+ 2,4-dimethylhexane →		4.6±0.6(-11)	ICR		45
+ 2,5-dimethylhexane →			1.1±0.1(-10)	ICR		45	
+ 2,3,4-trimethylpentane →			4.9±0.7(-11)	ICR		45	
CH ₃ Br ⁺	+ CH ₃ Br →	295	5.8±0.4(-11)	MS	Photoionization at 10.0eV	61	
		295	3.8±0.3(-11)	MS	Photoionization at 11.7eV	61	
			5.5(-11)	ICR		44	
CH ₃ I ⁺	+ CH ₃ I →	220	2.46±0.25(-11)	MS	Photoionization	62	
		295	2.37±0.12(-11)	MS	Photoionization	62	
		320	2.37±0.05(-11)	MS	Photoionization	62	
	+ CH ₃ I →	295	1.2±0.5(-11)	MS	Photoionization	61	
			5.5(-12)	ICR		44	
	+ 2CH ₃ I →	295	3.3±0.1(-25)	MS	Photoionization	62	
CD ₃ I ⁺	+ CD ₃ I →	220	2.04±0.12(-11)	MS	Photoionization	62	
		295	2.23±0.05(-11)	MS	Photoionization	62	
		320	2.16±0.12(-11)	MS	Photoionization	62	
	+ 2CD ₃ I →	295	9.4±3.0(-25)	MS	Photoionization	62	
CH ₃ Hg ⁺	+ C ₂ H ₄ →		2.7±0.4(-10)	ICR		63	
	+ C ₃ H ₆ →		2.9±0.3(-10)	ICR		63	
	+ Allene →		1.5±0.5(-10)	ICR		63	
	+ 1,3-butadiene →		3.9±1.3(-10)	ICR		63	
	+ 1-C ₄ H ₈ →		1.6±0.1(-10)	ICR		63	
	+ <i>iso</i> -C ₄ H ₈ →		3.7±0.9(-10)	ICR		63	
	+ <i>trans</i> -2-C ₄ H ₈ →		5.2(-10)	ICR		63	
	+ 2-methyl-2-butene →		5.2(-10)	ICR		63	
	C ₂ H ₅ B ⁺	+ (CH ₃) ₃ B →		2.6±0.4(-10)	ICR	(CH ₃) ₂ B ⁺	18
C ₂ N ⁺	+ CH ₃ CN →	300	2.6(-9)	MS	Pressure varied	64	
	+ C ₂ H ₅ CN →		2.1(-9)	MS	Pressure varied	64	
			2.0(-9)	MS	Time varied	64	

TABLE I. Rate coefficients^a for reactions of organic cations—Continued

Reaction	<i>T</i>	<i>k</i>	Method	Comments	Ref.
C ₂ HN ⁺ + CH ₃ CN →		3.54(−9)	ICR	CHCN ⁺	15
	300	3.0(−9)	MS	Pressure varied, CHCN ⁺	64
C ₂ DN ⁺ + CD ₃ CN →	300	2.5(−9)	MS	Pressure varied, CDCN ⁺	64
	300	6.7(−9)	MS	Time varied, CDCN ⁺	64
C ₂ H ₂ N ⁺ + CH ₃ CN →	300	1.78(−9)	MS	Pressure varied, CH ₂ CN ⁺	64
		2.09(−9)	ICR	CH ₂ CN ⁺	15
+ C ₂ H ₅ CN →	300	9(−10)	MS	Pressure varied, CH ₂ CN ⁺	64
	300	1(−9)	MS	Time varied, CH ₂ CN ⁺	64
C ₂ D ₂ N ⁺ + CD ₃ CN →	300	1.15(−9)	MS	Pressure varied, CD ₂ CN ⁺	64
	300	1.08(−9)	MS	Time varied, CD ₂ CN ⁺	64
C ₂ H ₃ N ⁺ + D ₂ →		1.0(−10)	MS	3.4eV IEE, CH ₃ CN ⁺	65
+ CH ₃ CN →		2.09(−9)	ICR	CH ₃ CN ⁺	15
	373	1.96(−9)	MS	Thermal, CH ₃ CN ⁺	17
	300	2.01(−9)	MS	Pressure varied, CH ₃ CN ⁺	64
	300	2.38(−9)	MS	Time varied, CH ₃ CN ⁺	64
		2.15±0.21(−9)	MS	3.7eV IEE, CH ₃ CN ⁺ See footnote e for further information	65
C ₂ D ₃ N ⁺ + CD ₃ CN →	300	2.45(−9)	MS	Pressure varied, CD ₃ CN ⁺	64
	300	1.98(−9)	MS	Time varied, CD ₃ CN ⁺	64
C ₂ H ₄ N ⁺ + (CH ₃) ₂ NH →		4(−10)	MS	From (CH ₃) ₂ NH	6
C ₂ H ₅ N ⁺ + (CH ₃) ₂ NH →		5(−10)	MS	From (CH ₃) ₂ NH	6
C ₂ H ₆ N ⁺ + (CH ₃) ₂ NH →		1.00±0.13(−9)	MS	CH ₃ NHCH ₂ ⁺	8
	373	8(−10)	MS	3.4eV IEE, (CH ₃) ₂ NH ⁺	5
		4±1(−10)	MS	CH ₃ NHCH ₂ ⁺	6
C ₂ H ₇ N ⁺ + (CH ₃) ₂ NH →		1.28(−9)	ICR	Pressure varied, (CH ₃) ₂ NH ⁺	10
		1.49(−9)	ICR	Time varied, (CH ₃) ₂ NH ⁺	10
	295	1.16±0.08(−9)	MS	Photoionization at 8.4eV	8
	295	1.02±0.08(−9)	MS	Photoionization at 10.0, 11.7eV	8
	373	1.2(−9)	MS	3.4 eV IEE, (CH ₃) ₂ NH ⁺	5
		6±1(−10)	MS	(CH ₃) ₂ NH ⁺	6
	298	1.83±0.09(−9)	MS	Photoionization, C ₂ H ₅ NH ₂ ⁺	9
C ₂ HD ₆ N ⁺ + (CD ₃) ₂ NH →		1.4(−9)	ICR	(CD ₃) ₂ NH ⁺	10
C ₂ H ₈ N ⁺ + 2(CH ₃) ₂ NH →	350	2.6(−26)	MS	(CH ₃) ₂ NH ₂ ⁺	11
		3.5(−10)	MS	From (CH ₃) ₂ N	6
C ₂ H ₇ DN ⁺ + (CH ₃) ₂ NH →		3.1±0.2(−10)	TI	(CH ₃) ₂ NHD ⁺	12
C ₂ HD ₇ N ⁺ + (CD ₃) ₂ NH →		3.4(−10)	ICR	Pressure varied, (CD ₃) ₂ NHD ⁺	10
		2.8(−10)	ICR	Time varied, (CD ₃) ₂ NHD ⁺	10
C ₂ H ₃ O ⁺ + CH ₃ CHO →	373	1.3±1.0(−10)	MS	2.4eV IEE, CH ₃ CO ⁺	16
+ CH ₃ COCH ₃ →		2.0(−10)	ICR	CH ₃ CO ⁺	66
		2.33±0.10(−10)	ICR	CH ₃ CO ⁺ from acetone	67
		2.30±0.10(−10)	ICR	CH ₃ CO ⁺ from protonated ketene	67
		2.2±0.2(−10)	TI	CH ₃ CO ⁺	20
	295	4.6±0.6(−10)	MS	CH ₃ CO ⁺ , Photoionization	68
		4.3±0.3(−10)	ICR	CH ₃ CO ⁺	69
	473	3.0(−10)	MS	CH ₃ CO ⁺	69
		7.0(−10)	ICR	CH ₃ CO ⁺	66
+ CH ₃ COC ₂ H ₅ →		1.4(−9)	MS	2.4eV IEE	16
+ vinyl formate →		7.1±2.1(−10)	ICR	CH ₃ CO ⁺	7
+ C ₆ H ₅ COCH ₃ →		1.2(−10)	ICR	CH ₃ CO ⁺	70
+ C ₆ H ₅ CHO →		2.3(−10)	ICR	CH ₃ CO ⁺	70
+ C ₆ H ₅ OC ₂ H ₅ →		2(−10)	ICR	CH ₃ CO ⁺ from acetone	71
+ <i>o</i> -methylanisole →		1.9±0.4(−9)	ICR	CH ₃ CO ⁺ from biacetyl	71
+ <i>m</i> -methylanisole →		1.8±0.4(−10)	ICR	CH ₃ CO ⁺ from biacetyl	71
+ <i>p</i> -methylanisole →		3.5±0.7(−10)	ICR	CH ₃ CO ⁺ from biacetyl	71
+ <i>o</i> -cresol →		5.6±0.6(−10)	ICR	CH ₃ CO ⁺ from biacetyl	72

TABLE I. Rate coefficients^a for reactions of organic cations—Continued

Reaction	<i>T</i>	<i>k</i>	Method	Comments	Ref.
C ₂ D ₃ O ⁺ + CD ₃ COCD ₃ →	295	4.6±0.6(−10)	MS	Photoionization, CD ₃ CO ⁺	69
C ₂ H ₃ O ⁺ + CH ₃ CHO →		1.99(−9)	ICR	CH ₃ CHO ⁺	15
		2.49±0.10(−9)	TI	CH ₃ CHO ⁺	20
	373	1.91±0.20(−9)	MS	Thermal, CH ₃ CHO ⁺	16
+ ethylene oxide →		1.9±0.2(−10)	ICR	From ethylene oxide	73
		1.5±0.3(−10)	TI	From ethylene oxide	20
	373	2±1(−10)	MS	2.4eV IEE	16
C ₂ D ₁ O ⁺ + CD ₃ CDO →		2.46(−9)	TI	CD ₃ CDO ⁺	20
+ ethylene oxide (<i>d</i> ₄) →		1.9±0.2(−10)	TI	From deuterated ethylene oxide	20
C ₂ H ₅ O ⁺ + 2CH ₃ CHO →		1.25(−25)	TI	CH ₃ CHOH ⁺	20
+ C ₂ H ₅ OH →		1.12(−9)	ICR	From C ₂ H ₅ OH	10
	473	1.2±0.6(−9)	MS	From C ₂ H ₅ OH	74
+ (CH ₃) ₂ O →		1.3±0.9(−11)	TI	CH ₃ COCH ₂ ⁺	20
+ (CD ₃) ₂ O →		1.88±0.05(−9)	TI	CH ₃ CHOH ⁺	20
+ (CH ₃) ₂ CO →		3.3±1.0(−11)	TI	CH ₃ OCH ₂ ⁺	20
		2.25(−9)	TI	CH ₃ CHOH ⁺	20
+ <i>i</i> -C ₃ H ₇ OH →	295	1.1±0.1(−9)	MS	Photoionization, CH ₃ CHOH ⁺	75
		1.5±0.3(−9)	ICR	CH ₃ CHOH ⁺	76
C ₂ H ₂ D ₃ O ⁺ + CD ₃ OC ₂ H ₅ →		1.75±0.05(−10)	TI	CD ₃ OCH ₂ ⁺	20
C ₂ HD ₂ O ⁺ + C ₂ D ₅ OH →		1.04(−9)	ICR	CD ₃ CDOH ⁺	10
C ₂ H ₆ O ⁺ + (CH ₃) ₂ O ⁺ →		1.58±0.15(−9)	TI	(CH ₃) ₂ O ⁺	20
+ (CH ₃) ₂ O ⁺ →	373	1.45±0.1(−9)	MS	2.4eV IEE, (CH ₃) ₂ O ⁺	16
	373	1.93(−9)	MS	Thermal, (CH ₃) ₂ O ⁺	17
+ C ₂ H ₅ OII →		1.78(−10)	ICR	C ₂ H ₅ OII ⁺	10
		3.03(−9)	MS	10 V cm ^{−1} , C ₂ H ₅ OH ⁺	77
C ₂ H ₃ D ₃ O ⁺ + CH ₃ OCD ₃ →	373	2.09(−9)	MS	Thermal, CH ₃ OCD ₃ ⁺	17
C ₂ D ₆ O ⁺ + CD ₃ OCD ₃ →		1.58(−9)	TI	(CD ₃) ₂ O ⁺	20
C ₂ H ₇ O ⁺ + C ₂ H ₅ OH →		2.2(−9)	ICR	Pressure varied, C ₂ H ₅ OH ₂ ⁺	10
		2.4(−9)	ICR	Time varied, C ₂ H ₅ OH ₂ ⁺	10
+ 2(CH ₃) ₂ O →		1.0±0.2(−25)	TI	(CH ₃) ₂ OH ⁺	20
+ (CH ₃) ₂ CO →		1.0±0.1(−9)	TI	(CH ₃) ₂ OH ⁺	20
C ₂ H ₂ D ₅ O ⁺ + C ₂ D ₅ OH →		1.7(−10)	ICR	Pressure varied, C ₂ D ₅ OH ₂ ⁺	10
		1.4(−10)	ICR	Time varied, C ₂ D ₅ OH ₂ ⁺	10
C ₂ HD ₆ O ⁺ + C ₂ D ₅ OH →		3.7(−10)	ICR	Pressure varied, C ₂ D ₅ OHD ⁺	10
		2.8(−10)	ICR	Time varied, C ₂ D ₅ OHD ⁺	10
C ₂ H ₄ O ₂ ⁺ + HCO ₂ CH ₃ →	370	1.57±0.10(−9)	MS	2.4eV IEE, HCO ₂ CH ₃ ⁺	21
C ₂ H ₃ DO ₂ ⁺ + DCO ₂ CH ₃ →	370	1.65±0.10(−9)	MS	2.4eV IEE, DCO ₂ CH ₃ ⁺	21
C ₂ H ₃ NO ₃ ⁺ + 2CH ₃ OH →		2(−27)	MS	(CH ₃ OH) ₂ NO ⁺	27
C ₂ F ⁺ + CH ₂ CF ₂ →	317	1.91(−9)	MS		38
C ₂ HF ⁺ + C ₂ H ₃ F →		1.93±0.12(−9)	MS		78
	370	1.95(−9)	MS		79
+ CH ₂ CF ₂ →	317	1.84(−9)	MS		38
C ₂ H ₂ F ⁺ + C ₂ H ₃ F →		1.03±0.06(−9)	MS		78
	370	7.5±1.0(−10)	MS		79
+ C ₂ H ₃ F →		1.75±0.19(−9)	MS		42
C ₂ H ₃ F ⁺ + C ₂ H ₄ →		5.9±1.8(−10)	ICR		80
+ C ₂ D ₄ →		5.1(−10)	ICR		81
+ C ₂ H ₃ F →	300	2.9(−10)	ICR	<i>k</i> varies with internal energy	82
C ₂ H ₃ F ⁺ + C ₂ H ₃ F →		2.1(−10)	ICR		81
	295	3.2±0.2(−10)	MS	Photoionization	83
		2.1(−10)	ICR		84
		1.34(−10)	ICR		85
		2.2±0.4(−10)	TI		86
	370	3.0(−11)	MS	19eV e [−]	79
	370	2.3(−11)	MS	11eV e [−]	79
+ 2C ₂ H ₃ F →		1.61(−25)	MS		78
+ C ₂ H ₆ F →	320	5.9(−10)	MS	From C ₂ H ₃ F	42
+ CH ₂ CF ₂ →		1.02(−9)	ICR		81

TABLE 1. Rate coefficients^a for reactions of organic cations—Continued

Reaction	<i>T</i>	<i>k</i>	Method	Comments	Ref.				
$C_2H_3F^+$		+ <i>cis</i> -CHFCHF →		1.4(−9)	ICR	81			
		+ <i>trans</i> -CHFCHF →		1.3(−9)	ICR	81			
		+ C_2HF_3 →		1.3(−9)	ICR	81			
		+ C_2F_4 →		8.8(−10)	ICR	81			
		+ 2-fluoropropane →		1.3±0.2(−9)	ICR	From 2-fluoropropane	87		
$C_2H_4F^+$	320	+ C_2H_3F →		4.2±0.7(−10)	MS	78			
		+ C_2H_5F →		1.06±0.10(−9)	MS	42			
		+ 2-fluoropropane →		1.4±0.2(−9)	ICR	From 2-fluoropropane	87		
$C_2H_5F^+$	320	+ C_2H_5F →		1.53±0.12(−9)	MS	200eV e^-	42		
	320			1.18±0.20(−9)	MS	14eV e^-	42		
$C_2H_6F^+$	320	+ $2CH_3F$ →		1.50(−9)	ICR	44			
				1.5(−27)	MS	200eV e^- , $(CH_3)_3F^+$	30		
				2.3(−27)	MS	14.5eV e^- , $(CH_3)_2F^+$	30		
		+ $2CH_2F_2$ →		5.88(−28)	MS		30		
		+ C_2H_5F →		1.33±0.14(−9)	MS		42		
$C_3F_5^+$		+ C_3F_6 →		1.4(−9)	ICR	44			
				1.2(−10)	B	0.3eV KE	34		
$C_2H_3F_2^+$		+ C_2H_4 →		3.4±0.5(−10)	ICR	CHFCHF ⁺	80		
				2.5±0.5(−10)	ICR	$CH_2CF_2^+$	80		
				1.6(−10)	ICR	From <i>cis</i> -CHFCHF	81		
				8.5(−11)	ICR	From <i>trans</i> -CHFCHF	81		
				1.7(−10)	ICR	$CH_2CF_2^+$	81		
				2.9(−10)	ICR	$CH_2CF_2^+$	81		
				5.1(−10)	ICR	$CH_2CF_2^+$	81		
				1.9(−10)	ICR	From <i>trans</i> -CHFCHF	81		
				3.5(−10)	ICR	From <i>cis</i> -CHFCHF	81		
				2.2(−10)	ICR	From <i>trans</i> -CHFCHF	81		
				8.9(−10)	ICR	$CH_2CF_2^+$	81		
				6.3(−12)	ICR	From <i>cis</i> -CHFCHF, Charge transfer only	88		
				8.3(−11)	ICR	From <i>trans</i> -CHFCHF, charge transfer only	88		
				6(−12)	ICR	From <i>cis</i> -CHFCHF, condensation only	81		
				2.6(−10)	ICR	From <i>trans</i> -CHFCHF	81		
				5.7(−10)	ICR	From <i>cis</i> -CHFCHF	81		
				3(−12)	ICR	From <i>trans</i> -CHFCHF, condensation only	81		
				2.4(−10)	ICR	From <i>cis</i> -CHFCHF, charge transfer only	88		
				3(−12)	ICR	From <i>trans</i> -CHFCHF, charge transfer only	88		
			320	+ $2CH_2CF_2$ →		5.98(−26)	MS	$CH_2CF_2^+$	38
						1.1±0.2(−24)	ICR	$CH_2CF_2^+$	89
				+ C_2HF_3 →		8.9(−10)	ICR	$CH_2CF_2^+$	81
				7.8(−10)	ICR	From <i>cis</i> -CHFCHF	81		
				5.4(−10)	ICR	From <i>trans</i> -CHFCHF	81		
		+ C_2F_4 →		6.4(−10)	ICR	$CH_2CF_2^+$	81		
				5.7(−10)	ICR	From <i>cis</i> -CHFCHF	81		
				3.9(−10)	ICR	From <i>trans</i> -CHFCHF	81		
$C_2D_2F_2^+$		+ C_2H_3F →		3.5(−10)	ICR	From <i>cis</i> -CDFCDF	81		
				1.9±0.4(−10)	MS		78		
$C_2F_3^+$		+ C_3F_8 →		8.3(−11)	B	0.3eV KE	34		
$C_2HF_3^+$		+ C_2H_4 →		1.7(−10)	ICR		81		
				6.7±0.7(−10)	ICR		80		
		+ CH_2CF_2 →		1.8(−10)	ICR	$CHF_2CF_2^+$	81		
		+ <i>cis</i> -CHFCHF →		2.7(−10)	ICR	$CHF_2CF_2^+$	81		
		+ <i>trans</i> -CHFCHF →		2.8(−10)	ICR	$CHF_2CF_2^+$	81		
		+ C_2HF_3 →		5(−11)	ICR	Condensation only	81		

TABLE I. Rate coefficients^a for reactions of organic cations—Continued

Reaction	<i>T</i>	<i>k</i>	Method	Comments	Ref.	
$C_2HF_3^+$ + $C_2HF_3 \rightarrow$		5.6(-11)	ICR	CHF ₂ CF ₂ ⁺	90	
		4.8(-11)	ICR	CHF ₂ CF ₂ ⁺	85	
	+ $C_2F_4 \rightarrow$	2.2(-10)	ICR	CHF ₂ CF ₂ ⁺	81	
		5.7(-11)	ICR	CHF ₂ CF ₂ ⁺	90	
$C_2DF_3^+$ + $C_2H_2F \rightarrow$		1.4(-10)	ICR	CDF ₂ CF ₂ ⁺	81	
$C_2H_4F_3^+$ + $2CH_2F_2 \rightarrow$		5.16(-28)	MS		30	
$C_2F_4^+$ + $C_2H_4 \rightarrow$		1.7(-10)	ICR		81	
		1.07±0.30(-10)	ICR		80	
	+ $C_2H_6F \rightarrow$		1.6(-10)	ICR		81
	+ $C_2F_2 \rightarrow$		1.0(-11)	ICR		90
	+ $CH_2CF_2 \rightarrow$		1.5(-10)	ICR		81
	+ <i>cis</i> -CHFCHF \rightarrow		1.9(-10)	ICR		81
	+ <i>trans</i> -CHFCHF \rightarrow		2.0(-10)	ICR		81
	+ $C_2HF_3 \rightarrow$		2.1(-10)	ICR		81
			1.06(-10)	ICR		90
	+ $C_2F_4 \rightarrow$		1.5(-11)	ICR	Condensation only	81
			1.0(-11)	ICR	Condensation only	85
$C_2F_5^+$ + $C_2F_6 \rightarrow$		7.1(-11)	B	0.3eV KE	34	
	+ $C_3F_8 \rightarrow$		8.6(-12)	B	0.3eV KE	34
$C_2H_6Si^+$ + $(CH_3)_2SiH_2 \rightarrow$		7.0(-10)	MS	(CH ₃) ₂ Si ⁺	50	
$C_2H_6FSi^+$ + $(CH_3)_2SiF_2 \rightarrow$		5(-10)	ICR	(CH ₃) ₂ SiF ⁺	51	
	+ $(CH_3)_3SiF \rightarrow$		7.4(-10)	ICR	(CH ₃) ₂ SiF ⁺	51
$C_2H_6F_2Si^+$ + $(CH_3)_2SiF_2 \rightarrow$		2.0(-10)	ICR	(CH ₃) ₂ SiF ⁺	51	
$C_2H_5P^+$ + $(CH_3)_2PH \rightarrow$		6.3±1.2(-10)	ICR	(CH ₃) ₂ PH ⁺	52	
$C_2H_5S^+$ + $CH_3SH \rightarrow$		1.5±0.2(-10)	MS	10.7 V cm ⁻¹	54	
	+ $(CH_3)_2S \rightarrow$		3.5±0.5(-10)	MS	10.7 V cm ⁻¹	54
$C_2H_6S^+$ + $C_2H_5SH \rightarrow$		1.25±0.06(-9)	MS	Photoionization, C ₂ H ₅ SH ⁺	57	
	+ $(CH_3)_2SH \rightarrow$		3.2(-12)	MS	(CH ₃) ₂ S ⁺	58
$C_2H_7S^+$ + $(CH_3)_2S \rightarrow$		2.8±0.4(-10)	MS		54	
$C_2H_6OS^+$ + dimethylsulfoxide \rightarrow	408	1.9±0.2(-9)	MS	From dimethylsulfoxide	22	
$C_2H_5Cl^+$ + $C_2H_5Cl \rightarrow$		295	1.78±0.09(-10)	MS	Photoionization	83
			9.6(-11)	ICR		84
			5.2(-11)	ICR		85
		370	1.81±0.06(-11)	MS	20eV e ⁻	91
		370	1.35(-11)	MS	15eV e ⁻	91
		370	1.03(-11)	MS	10.5eV e ⁻	91
		320	1.78±0.09(-9)	MS		42
			1.50(-9)	ICR		44
		320	1.36(-9)	MS	C ₂ H ₅ ClH ⁺	42
			5.5(-10)	ICR	C ₂ H ₅ ClH ⁺	44
$C_2H_3Br^+$ + $C_2H_3Br \rightarrow$		295	1.25(-10)	MS	Photoionization	83
		370	6.5±0.2(-12)	MS	2.4eV IEE	91
	+ $2C_2H_3Br \rightarrow$	370	5.5±0.2(-26)	MS		91
	$C_2H_5Br^+$ + $C_2H_3Br \rightarrow$	295	6.7±0.5(-11)	MS	Photoionization	61
		5.6(-11)	ICR		44	
$C_2H_6Br^+$ + $C_2H_3Br \rightarrow$		5(-11)	ICR	C ₂ H ₅ BrH ⁺	44	
$C_2H_5I^+$ + $C_2H_5I \rightarrow$		295	2.0±0.1(-11)	MS	Photoionization	62
			1.6(-11)	ICR		44
	+ $2C_2H_5I \rightarrow$	295	4.1(-24)	MS	Photoionization	62
	$C_2H_5D_2I^+$ + $CH_3CD_2I \rightarrow$	295	2.0±0.1(-11)	MS	Photoionization, CH ₃ CD ₂ I ⁺	62
$C_2H_3D_3I^+$ + $2CH_3CD_2I \rightarrow$	295	5.3(-24)	MS	Photoionization, CH ₃ CD ₂ I ⁺	62	
$C_2H_2D_3I^+$ + $CD_3CH_2I \rightarrow$	295	2.0±0.1(-11)	MS	Photoionization, CD ₃ CH ₂ I ⁺	62	
	295	7.4(-24)	MS	Photoionization, CD ₃ CH ₂ I ⁺	62	
$C_2D_5I^+$ + $C_2D_5I \rightarrow$		295	2.0±0.1(-11)	MS	Photoionization	62
	+ $2C_2D_5I \rightarrow$	295	1.01(-23)	MS	Photoionization	62
C_3HN^+ + $C_2H_5CN \rightarrow$	300	3.7(-9)	MS	From C ₂ H ₅ CN	64	
$C_3H_2N^+$ + $C_2H_5CN \rightarrow$	300	1.9(-9)	MS	From C ₂ H ₅ CN	64	
$C_3H_4N^+$ + $C_2H_5CN \rightarrow$	300	1.2(-9)	MS	Pressure varied, C ₂ H ₅ CN ⁺	64	

TABLE I. Rate coefficients^a for reactions of organic cations—Continued

Reaction	T	k	Method	Comments	Ref.
C ₃ H ₄ N ⁺ + C ₂ H ₂ CN →		0.6(−9)	MS	Time varied, C ₂ H ₄ CN ⁺	64
C ₃ D ₄ N ⁺ + C ₂ D ₂ CN →	300	1.7(−9)	MS	Pressure varied, C ₂ D ₄ CN ⁺	64
	300	0.5(−9)	MS	Time varied, C ₂ D ₄ CN ⁺	64
C ₃ H ₆ N ⁺ + <i>cyclo</i> -C ₃ H ₅ NH ₂ →		1.3±0.4(−10)	ICR	From <i>cyclo</i> -C ₃ H ₅ NH ₂	7
C ₃ H ₇ N ⁺ + <i>cyclo</i> -C ₃ H ₅ NH ₂ →		1.9(−10)	ICR	From <i>cyclo</i> -C ₃ H ₅ NH ₂	7
		1.0(−10)	MS	From (CH ₃) ₃ N	6
C ₃ H ₈ N ⁺ + diethylamine →	298	1.36±0.14(−9)	MS	From diethylamine	9
		5.3(−10)	ICR	(CH ₃) ₂ NH ₂ ⁺	92
C ₃ H ₉ N ⁺ + <i>n</i> -C ₃ H ₇ NH ₂ →	298	1.56±0.08(−9)	MS	From <i>n</i> -C ₃ H ₇ NH ₂	9
	295	8.2±0.3(−10)	MS	Photoionization at 8.4eV, (CH ₃) ₃ N ⁺	8
	295	5.5±0.5(−10)	MS	Photoionization at 10.0eV, (CH ₃) ₃ N ⁺	8
	295	4.9±0.3(−10)	MS	Photoionization at 11.7eV, (CH ₃) ₃ N ⁺	8
		3.3(−10)	MS	(CH ₃) ₃ N ⁺	6
C ₃ H ₁₀ N ⁺ + 4-methylpyridine →		2.6(−10)	ICR	(CH ₃) ₃ NH ⁺	92
C ₆ H ₁₂ B ₃ N ₃ ⁺ + (CH ₃) ₃ B ₃ N ₃ H ₃ →		7.0±0.4(−10)	MS	(CH ₃) ₃ B ₃ N ₃ H ₃ ⁺	93
C ₃ H ₅ O ⁺ + <i>cyclo</i> -C ₃ H ₅ OH →		2.0±0.6(−10)	ICR	From <i>cyclo</i> -C ₃ H ₅ OH	7
		6.0(−11)	ICR	C ₂ H ₅ CO ⁺	66
C ₃ H ₆ O ⁺ + <i>cyclo</i> -C ₃ H ₅ OH →		1.5±0.5(−10)	ICR	From <i>cyclo</i> -C ₃ H ₅ OH	7
		6.0(−10)	ICR	CH ₃ COCH ₃ ⁺	66
		2.0(−10)	ICR	Condensation only	72
		6.5±0.3(−10)	TI	CH ₃ COCH ₃ ⁺	20
		5.4±0.4(−10)	ICR	CH ₃ COCH ₃ ⁺	69
	473	5.1(−10)	MS	CH ₃ COCH ₃ ⁺	69
	300	8.5±0.3(−10)	MS	Photoionization at 10.0eV, CH ₃ COCH ₃ ⁺	68
	300	7.6±0.3(−10)	MS	Photoionization at 11.7eV, CH ₃ COCH ₃ ⁺	68
C ₃ D ₅ O ⁺ + CD ₃ COCD ₃ →	300	7.0±0.3(−10)	MS	Photoionization at 10.0eV, CD ₃ COCD ₃ ⁺	68
	300	6.8±0.3(−10)	MS	Photoionization at 11.7eV, CD ₃ COCD ₃ ⁺	68
C ₃ H ₇ O ⁺ + CH ₂ CO →		2.98±0.10(−10)	ICR	(CH ₃) ₂ COH ⁺	67
		4.0(−11)	ICR	(CH ₃) ₂ COH ⁺	66
	473	4.3(−10)	MS	12 V cm ^{−1} , (CH ₃) ₂ COH ⁺	69
		6.5±0.5(−25)	TI	(CH ₃) ₂ COH ⁺	20
		7.1(−11)	ICR	(CH ₃) ₂ COH ⁺	92
		1.1(−9)	ICR	(CH ₃) ₂ COH ⁺	94
		3.7±0.5(−10)	ICR	(CH ₃) ₂ COH ⁺	95
C ₃ H ₅ D ₃ O ⁺ + CD ₃ OC ₂ H ₅ →		1.43±0.05(−9)	TI	CD ₃ OC ₂ H ₅ ⁺	20
C ₃ H ₄ O ₂ ⁺ + vinyl formate →	373	1.4(−9)	MS	From vinyl formate	16
C ₃ H ₆ O ₂ ⁺ + <i>t</i> -C ₄ H ₉ OH →		6.8(−10)	ICR	(CH ₃) ₂ COHOH ₂ ⁺	94
C ₃ H ₄ F ⁺ + C ₃ H ₃ F →		2.2±0.7(−10)	MS		78
	320	3.49(−10)	MS		38
C ₃ H ₆ F ⁺ + 2-fluoropropane →		4.4±0.6(−10)	ICR	(CH ₃) ₂ CF ⁺	87
C ₃ H ₂ F ₂ ⁺ + C ₃ H ₃ F →		5(−11)	MS		78
	320	1.24(−10)	MS		38
C ₃ H ₂ F ₃ ⁺ + CH ₂ CF ₂ →	320	6.6(−11)	MS		38
		3.0(−11)	ICR		90
C ₃ H ₁₀ Si ⁺ + (CH ₃) ₃ SiH →		7(−11)	MS	(CH ₃) ₃ SiH ⁺	50
C ₃ H ₈ FSi ⁺ + (CH ₃) ₃ SiF →		6.5(−10)	ICR	(CH ₃) ₃ SiF ⁺	51
C ₃ H ₅ P ⁺ + (CH ₃) ₃ P →		5.9±1.2(−10)	ICR	(CH ₃) ₃ P ⁺	52
C ₃ H ₄ S ⁺ + C ₃ H ₇ SH →		1.13±0.56(−9)	MS	Photoionization, C ₃ H ₇ SH ⁺	57
C ₃ H ₆ S ₂ ⁺ + (CH ₃) ₂ S →		1.6±0.2(−11)	MS	10.7 V cm ^{−1}	54
C ₄ H ₅ N ⁺ + C ₃ H ₅ CN →		1.78±0.54(−9)	ICR	C ₃ H ₅ CN ⁺	7
C ₄ H ₁₁ N ⁺ + diethylamine →	298	1.25±0.06(−9)	MS	From diethylamine	9

TABLE I. Rate coefficients^a for reactions of organic cations—Continued

Reaction	<i>T</i>	<i>k</i>	Method	Comments	Ref.
C ₄ H ₄ O ⁺ + toluene →		1.28±0.19(−9)	ICR	From furan	96
C ₄ H ₇ O ⁺ + diisopropyl ketone →		1.1(−10)	ICR	(CH ₃) ₂ CHCO ⁺	66
C ₄ H ₉ O ⁺ + 2-butanone →		9(−11)	ICR	CH ₃ COC ₂ H ₅ ⁺	66
C ₄ H ₉ O ⁺ + 2-butanone →		9.0(−11)	ICR	(CH ₃ COC ₂ H ₅)H ⁺	66
C ₄ H ₁₁ O ⁺ + <i>t</i> -butanol →		7.2(−10)	ICR	(CH ₃) ₃ COH ₂ ⁺	94
C ₄ H ₉ O ₂ ⁺ + biacetyl →		7.5±1.0(−10)	ICR	(CH ₃ CO) ₂ ⁺	97
+ pyrrole →		4.3(−10)	ICR	(CH ₃ CO) ₂ ⁺	97
C ₄ H ₁₃ O ₂ ⁺ + <i>t</i> -butanol →		2.3(−10)	ICR	(CH ₃) ₃ COH ₂ OH ₂ ⁺	94
C ₄ H ₁₀ S ⁺ + (CH ₃) ₃ CSH →		5.7(−10)	MS	(CH ₃) ₃ CSH ⁺	57
C ₅ H ₆ N ⁺ + (CH ₃) ₂ NH →		3.3(−10)	ICR	Protonated pyridine	92
C ₅ H ₁₂ N ⁺ + triethylamine →	298	1.28±0.13(−10)	MS	(C ₂ H ₅) ₂ NCH ₂ ⁺	9
C ₅ H ₈ O ⁺ + <i>cyclo</i> -C ₅ H ₅ COCH ₃ →		2.0±0.6(−10)	ICR	From <i>cyclo</i> -C ₅ H ₅ COCH ₃	7
C ₅ H ₁₀ O ⁺ + 3-pentanone →		8(−11)	ICR	From 3-pentanone	66
C ₅ H ₁₁ O ⁺ + 3-pentanone →		5(−11)	ICR	Protonated 3-pentanone	66
C ₅ H ₉ O ₂ ⁺ + CH ₃ COCH ₃ →		8(−11)	ICR	(CH ₃ COCH ₃)CH ₂ CO ⁺	66
	473	5.4±0.4(−10)	ICR	(CH ₃ COCH ₃)CH ₂ CO ⁺	69
		5.1(−10)	MS	(CH ₃ COCH ₃)CH ₂ CO ⁺	69
+ C ₆ H ₅ NH ₂ →		1.5(−10)	ICR	CH ₃ CO(COCH ₃)CH ₃ ⁺	98
+ C ₆ H ₅ NO ₂ →		4(−11)	ICR	CH ₃ CO(COCH ₃)CH ₃ ⁺	71
+ anisole (H-substituted) →		2.9±0.6(−10)	ICR	CH ₃ CO(COCH ₃)CH ₃ ⁺	71
+ anisole (<i>o</i> -methyl substituted) →		4.0±0.8(−10)	ICR	CH ₃ CO(COCH ₃)CH ₃ ⁺	71
+ anisole (<i>m</i> -methyl substituted) →		5.4±1.1(−10)	ICR	CH ₃ CO(COCH ₃)CH ₃ ⁺	71
+ anisole (<i>p</i> -methyl substituted) →		3.0±0.6(−10)	ICR	CH ₃ CO(COCH ₃)CH ₃ ⁺	71
+ anisole (<i>p</i> -ethyl substituted) →		3.7±0.7(−10)	ICR	CH ₃ CO(COCH ₃)CH ₃ ⁺	71
+ <i>o</i> -cresol →		5.8±0.6(−10)	ICR	CH ₃ CO(COCH ₃)CH ₃ ⁺	72
+ <i>m</i> -cresol →		6.1±0.6(−10)	ICR	CH ₃ CO(COCH ₃)CH ₃ ⁺	72
+ <i>p</i> -cresol →		4.6±0.5(−10)	ICR	CH ₃ CO(COCH ₃)CH ₃ ⁺	72
+ C ₆ H ₅ OH →		4.3(−10)	ICR	CH ₃ CO(COCH ₃)CH ₃ ⁺	70
+ C ₆ H ₅ CHO →		8.5(−10)	ICR	CH ₃ CO(COCH ₃)CH ₃ ⁺	70
+ C ₆ H ₅ OCH ₃ →		2.9(−10)	ICR	CH ₃ CO(COCH ₃)CH ₃ ⁺	70
+ C ₆ H ₅ OCD ₃ →		2.9(−10)	ICR	CH ₃ CO(COCH ₃)CH ₃ ⁺	70
+ C ₆ H ₅ COCH ₃ →		6.3(−10)	ICR	CH ₃ CO(COCH ₃)CH ₃ ⁺	70
+ C ₆ H ₅ OC ₂ H ₅ →		4.8(−10)	ICR	CH ₃ CO(COCH ₃)CH ₃ ⁺	70
C ₅ H ₅ Fe ⁺ + Fe(C ₅ H ₅) ₂ →		2.4±0.5(−9)	MS	From cyclopentyl iron	99
		7.9±0.7(−10)	ICR	From cyclopentyl iron	100
C ₅ H ₅ Ni ⁺ + CH ₃ CHO →		8.0±1.6(−10)	ICR	from cyclopentyl nickel	101
C ₆ H ₅ N ⁺ + (CH ₃) ₃ N →		6.5(−10)	ICR	Protonated 4-methyl pyridine	92
C ₆ H ₁₅ N ⁺ + (C ₂ H ₅) ₃ N →	298	7.05±0.35(−10)	MS	(C ₂ H ₅) ₃ N ⁺	9
C ₆ H ₁₆ N ⁺ + quinuclidine →		5.6(−10)	ICR	(C ₂ H ₅) ₃ NH ⁺	92
C ₆ H ₁₃ O ₂ ⁺ + 2-butanone →		9.0(−11)	ICR	(CH ₃ COC ₂ H ₅)CH ₂ CO ⁺	66
C ₆ H ₉ O ₃ ⁺ + C ₆ H ₅ NH ₂ →		1.8(−9)	ICR	CH ₃ CO(COCH ₃)COCH ₃ ⁺	98
+ <i>o</i> -cresol →		4.8±0.5(−10)	ICR	CH ₃ COCO(COCH ₃)CH ₃ ⁺	72
C ₆ H ₉ O ₃ ⁺ + <i>m</i> -cresol →		4.9±0.5(−10)	ICR	CH ₃ COCO(COCH ₃)CH ₃ ⁺	72
+ <i>p</i> -cresol →		4.9±0.5(−10)	ICR	CH ₃ COCO(COCH ₃)CH ₃ ⁺	72
+ anisole (H-substituted) →		1.4±0.2(−9)	ICR	CH ₃ COCO(COCH ₃)CH ₃ ⁺	71
+ anisole (<i>o</i> -methyl substituted) →		9.5±1.9(−10)	ICR	CH ₃ COCO(COCH ₃)CH ₃ ⁺	71
+ anisole (<i>m</i> -methyl substituted) →		1.6±0.3(−9)	ICR	CH ₃ COCO(COCH ₃)CH ₃ ⁺	71
+ anisole (<i>p</i> -methyl substituted) →		1.6±0.3(−9)	ICR	CH ₃ COCO(COCH ₃)CH ₃ ⁺	71
+ anisole (<i>p</i> -ethyl substituted) →		2.5±0.5(−9)	ICR	CH ₃ COCO(COCH ₃)CH ₃ ⁺	71
+ pyrrole →		1.1(−9)	ICR	(CH ₃ CO) ₃ ⁺	97
+ C ₆ H ₅ OH →		4.2(−9)	ICR	(CH ₃ CO) ₃ ⁺	70
+ C ₆ H ₅ NO ₂ →		1.7(−9)	ICR	CH ₃ CO(COCH ₃)COCH ₃ ⁺	98
+ C ₆ H ₅ CN →		3.0(−9)	ICR	CH ₃ CO(COCH ₃)COCH ₃ ⁺	98
+ C ₆ H ₅ CHO →		1.5(−9)	ICR	(CH ₃ CO) ₃ ⁺	70
+ C ₆ H ₅ OCH ₃ →		1.4(−9)	ICR	(CH ₃ CO) ₃ ⁺	70
+ C ₆ H ₅ OCD ₃ →		1.4(−9)	ICR	(CH ₃ CO) ₃ ⁺	70
+ C ₆ H ₅ COCH ₃ →		6.8(−9)	ICR	(CH ₃ CO) ₃ ⁺	70
+ C ₆ H ₅ OC ₂ H ₅ →		1.2(−9)	ICR	(CH ₃ CO) ₃ ⁺	70

TABLE 1. Rate coefficients* for reactions of organic cations—Continued

Reaction	<i>T</i>	<i>k</i>	Method	Comments	Ref.
C ₆ H ₅ O ₃ ⁺ + <i>o</i> -methyl nitrobenzene →		9.0(−10)	ICR	CH ₃ CO(COCH ₃)COCH ₃ ⁺	98
+ <i>m</i> -methyl nitrobenzene →		<3.0(−11)	ICR	CH ₃ CO(COCH ₃)COCH ₃ ⁺	98
C ₆ H ₅ F ⁺ + <i>p</i> -difluorobenzene →		1.02±0.15(−9)	ICR	From fluorobenzene	96
+ 2-C ₆ H ₄ F →	295	4±1(−26)	MS	From fluorobenzene	102
C ₆ H ₄ F ₂ ⁺ + C ₆ H ₅ F →		2.4±0.4(−10)	ICR	From <i>p</i> -difluorobenzene	96
C ₆ H ₅ Cl ⁺ + 2C ₆ H ₅ Cl →	295	5.3±1.0(−26)	MS	From chlorobenzene	102
+ C ₆ H ₅ Br →	530	1.1(−9)	MS	From chlorobenzene	103
	570	1.4(−9)	MS	From chlorobenzene	103
C ₆ H ₅ N ⁺ + C ₆ H ₅ →	500	1.3(−9)	MS	C ₆ H ₅ CN ⁺	103
C ₇ H ₁₄ N ⁺ + (C ₂ H ₅) ₃ N →		3.3(−10)	ICR	Protonated quinulidine	92
C ₇ H ₁₄ O ⁺ + (<i>i</i> -C ₃ H ₇) ₂ CO →		2(−11)	ICR	(<i>i</i> -C ₃ H ₇) ₂ CO ⁺	66
C ₇ H ₁₅ O ⁺ + (<i>i</i> -C ₃ H ₇) ₂ CO →		2(−11)	ICR	(<i>i</i> -C ₃ H ₇) ₂ COH ⁺	66
C ₇ H ₇ F ⁺ + toluene →		2.8±0.4(−10)	ICR	From <i>p</i> -fluoro toluene	96
C ₇ H ₅ F ₃ ⁺ + C ₆ F ₅ H →		1.16±0.17(−9)	ICR	C ₆ H ₅ CF ₃ ⁺	96
C ₈ H ₁₅ O ₂ ⁺ + (C ₂ H ₅) ₂ CO →		3(−11)	ICR	(C ₂ H ₅) ₂ COC ₂ H ₅ CO ⁺	66
C ₉ H ₁₁ O ₂ ⁺ + CH ₃ COOC ₇ H ₇ →	360	2.8(−9)	MS	(CH ₃ COOC ₇ H ₇)H ⁺	104
C ₁₁ H ₂₁ O ₂ ⁺ + (<i>i</i> -C ₃ H ₇) ₂ CO →		2(−11)	ICR	(<i>i</i> -C ₃ H ₇) ₂ COC ₃ H ₇ CO ⁺	66

*Rate coefficients are in units of cm³ molecule^{−1} s^{−1} for bimolecular reactions and cm⁶ molecule^{−2} s^{−1} for termolecular reactions.

^bThe numbers in parenthesis should be read as the power 10 of the number. Thus (−9) is 10^{−9}.

^cThe reaction CH₃OH⁺ + CH₃OH → products has been investigated in five different laboratories. The most recent determinations (refs. 10, 15, and 23) of the overall conversion coefficient were obtained by the ICR technique, and suggest an average value of 2.00 ± 0.17 (−9) for this process. All earlier values were obtained by single source mass spectrometry (refs. 17, 19, and 24). In each of those studies the rate coefficient for the reaction CH₄⁺ + CH₄ → products was independently determined and reported. Taking the reference value which we suggested earlier [1.14 (−9), ref. 1] for the methane reaction together with the methanol values given in refs. 17, 19, and 24, and appropriately correcting the individual values given for methanol, an average value of 2.47 ± 0.16 (−9) is obtained for the MS studies. Although one is tempted to suggest that the recent ICR values are more accurate, it is disconcerting to note that ref. 10 (the most recent ICR study) also reports a value of 2.56 ± 0.17 (−9) for the reaction CD₃OH⁺ + CD₃OH → products, which is essentially equivalent to the MS value for the unlabeled analogue. Taking all factors into consideration, and recognizing that the methanol reaction will exhibit a negative temperature and ion kinetic dependence due to ion-dipole interactions (ref. 23), it would seem that the actual value of the thermal rate coefficient (300 K) for the reaction CH₃OH⁺ + CH₃OII → products other than CH₃OII⁺ (resonance electron or hydrogen exchange also gives CH₃OII⁺, and would be undetected) should fall within the limits 2.2 ± 0.3 (−9). Additional careful measurements involving this reaction pair are encouraged since it appears to represent a model highly reactive oxygenated organic system.

^dTaking the most recent value from Beauchamp's laboratory (ref. 39), the lowest kinetic energy value from ref. 28, the lowest electron impact energy value of ref. 30, and the earlier ICR value of ref. 43, the current thermal value for this fast reaction falls within the limits 1.64 ± 0.22 (−9), which is essentially equivalent to a collision efficiency of unity for conversion to products. Contributions from resonant electron or atom exchange cannot be evaluated.

^eThe rate coefficients reported for this very fast reaction have remained remarkably consistent over the years, and a value of 2.12 ± 0.20 (−9) is suggested at moderate temperatures (~300 K) for thermal ions.

TABLE 2. Rate coefficients^a for reactions of organic anions

Reaction	T	k	Method	Comments	Ref.
CH ₃ N ⁻ + CH ₃ F →	297	5(-11) ^b	FA	CH ₃ NH ⁻	105
+ CH ₂ Cl →	297	1.7±0.1(-9)	FA	CH ₃ NH ⁻	105
+ C ₂ H ₂ →	297	1.33±0.33(-9)	FA	CH ₃ NH ⁻	106
CH ₃ O ⁻ + CH ₃ OH →		1.2±0.3(-9)	ICR		107
+ CH ₃ F →	297	1.4±0.2(-11)	FA		105
+ CH ₂ Cl →	297	1.3±0.1(-9)	FA		105
+ C ₂ H ₂ →	297	1.64±0.41(-9)	FA		106
	300	1.3(-9)	FA		108
+ CH ₃ CN →	297	3.5±0.3(-9)	FA		109
+ C ₂ H ₅ OH →	300	≥5(-11)	FA		110
+ allene →	300	~5(-12)	FA		110
+ propylene →	300	<5(-12)	FA		110
+ <i>t</i> -C ₄ H ₉ OH →	300	≥5(-11)	FA		110
+ C ₆ H ₅ CH ₃ →		2.0±0.2(-10)	ICR		107
	300	≥5(-12)	FA		110
+ C ₆ H ₅ CH(CH ₃) ₂ →	300	≤5(-12)	FA		110
CD ₃ O ⁻ + CH ₃ CH ₂ F →		1.3(-10)	ICR		111
+ CH ₃ CHF ₂ →		1.26(-9)	ICR		111
+ CH ₂ FCHF ₂ →		1.68(-9)	ICR		111
+ CH ₂ CF ₃ →		1.55(-10)	ICR		111
+ CHF ₂ CHF ₂ →		1.69(-9)	ICR		111
+ CH ₂ FCF ₃ →		8.8(-10)	ICR		111
+ CHF ₂ CF ₃ →		1.9(-9)	ICR		111
+ (CH ₃) ₃ B →		3.85±0.77(-10)	ICR		18
CH ₂ NO ₂ ⁻ + CHCl ₃ →	300	≤5(-12)	FA		110
+ <i>n</i> -C ₄ H ₉ SH →	300	>1.6(-10)	FA		110
+ C ₆ H ₆ →	300	<1(-11)	FA		110
CHF ⁻ + CH ₃ F →	297	≥4.1(-10)	FA		105
CF ₃ ⁻ + NO ₂ →		3.7(-10)	B	0.3 eV KE	112
+ Xe →		3(-12)	B	0.3 eV KE	113
CH ₃ S ⁻ + CH ₃ F →	297	≤1(-12)	FA		105
+ CH ₃ Cl →	297	1.1±0.1(-10)	FA		105
		7.8±1.2(-11)	ICR		114
+ CH ₃ Br →		1.4±0.2(-10)	ICR		114
CHCl ₂ ⁻ + CH ₃ Cl →	297	5.1±0.4(-10)	FA		105
+ C ₂ H ₂ →	300	~3(-11)	FA		110
+ CH ₃ CN →	300	≥2(-10)	FA		110
+ C ₂ H ₅ OH →	300	≤1(-11)	FA		110
+ CH ₃ SOCH ₃ →	300	≥1(-11)	FA		110
CCl ₃ ⁻ + CH ₃ NO ₂ →	300	≥1(-10)	FA		110
+ CH ₃ CN →	300	<5(-12)	FA		110
+ CH ₃ COCH ₃ →	300	<1(-12)	FA		110
+ C ₆ H ₆ →	300	~2(-11)	FA		110
C ₂ H ₂ N ⁻ + CHCl ₃ →	300	≥1(-10)	FA	CH ₂ CN ⁻	110
+ CH ₃ SOCH ₃ →	300	<1(-11)	FA	CH ₂ CN ⁻	110
+ CH ₃ COCH ₃ →	300	≥1(-10)	FA	CH ₂ CN ⁻	110
C ₂ H ₅ N ⁻ + C ₂ H ₂ →	297	1.04±0.26(-9)	FA	(CH ₂) ₂ N ⁻	106
	297	1.18±0.30(-9)	FA	C ₂ H ₅ NH ⁻	106
C ₂ H ₇ N ⁻ + H ₂ O →		2.4(-9)	FA	C ₂ H ₅ NH ₂ ⁻	115
C ₂ H ₅ O ⁻ + CH ₃ OH →	300	≥5(-11)	FA		110
+ CH ₂ Cl ₂ →	300	≥5(-11)	FA		110
C ₂ H ₅ O ⁻ + C ₂ H ₂ →	297	1.41±0.35(-9)	FA		106
	300	1.1(-9)	FA		108
+ (CH ₃) ₃ B →		4.6±0.9(-10)	ICR		18
+ <i>i</i> -C ₃ H ₇ OH →	300	≥5(-11)	FA		110
+ <i>t</i> -C ₄ H ₉ OH →	300	≥5(-11)	FA		110
+ C ₆ H ₅ CH ₃ →	300	<5(-11)	FA		110
+ C ₆ H ₅ CH(CH ₃) ₂ →	300	≤1(-11)	FA		110

TABLE 2. Rate coefficients^a for reactions of organic cations—Continued

Reaction	<i>T</i>	<i>k</i>	Method	Comments	Ref.
C ₂ H ₃ F ₂ ⁻ + CH ₃ CHF ₂ →		1.5±0.4(-10)	ICR	CHF ₂ CH ₂ ⁻	111
C ₂ H ₂ F ₃ ⁻ + CHF ₂ CH ₂ F →		1.5±0.2(-10)	ICR	CHF ₂ CHF ⁻	111
		7.9±0.9(-10)	ICR	CF ₃ CH ₂ ⁻	111
C ₂ HF ₄ ⁻ + CHF ₂ CHF ₂ →		1.07±0.10(-9)	ICR	CHF ₂ CF ₂ ⁻	111
		1.5±0.3(-10)	ICR	CF ₃ CFH ⁻	111
C ₂ F ₅ ⁻ + NO ₂ →		3.2(-10)	B	0.3 eV KE	112
		8(-12)	B	0.3 eV KE	113
C ₂ H ₅ OS ⁻ + CH ₂ Cl ₂ →	300	≥2(-10)	FA	CH ₃ SOCH ₂ ⁻	110
	300	≤1(-11)	FA	CH ₃ SOCH ₂ ⁻	110
	300	≥2(-10)	FA	CH ₃ SOCH ₂ ⁻	110
	300	≤1(-12)	FA	CH ₃ SOCH ₂ ⁻	110
C ₃ H ₅ O ⁻ + CHCl ₃ →	300	>2(-10)	FA	CH ₃ COCH ₂ ⁻	110
	300	≤3(-11)	FA	CH ₃ COCH ₂ ⁻	110
		3.2±1.9(-12)	ICR	CH ₃ COCH ₂ ⁻	116
		8±4(-12)	ICR	CH ₃ COCH ₂ ⁻	116
		3.6±0.3(-10)	ICR	CH ₃ COCH ₂ ⁻	116
C ₃ D ₅ O ⁻ + CH ₃ COC ₂ H ₅ →		6.4±4.0(-12)	ICR	CD ₃ COCD ₂ ⁻	116
C ₃ H ₇ O ⁻ + C ₂ H ₂ →	297	≥8.9±2.3(-10)	FA	(CH ₃) ₂ CHO ⁻	106
	300	5.2(-10)	FA	<i>i</i> -C ₃ H ₇ O ⁻	108
	300	≥5(-11)	FA	<i>i</i> -C ₃ H ₇ O ⁻	110
	300	≥5(-11)	FA	<i>i</i> -C ₃ H ₇ O ⁻	110
C ₃ H ₅ DO ⁻ + CH ₃ COC ₂ CH ₃ →		1.8±1.5(-12)	ICR	CH ₃ COC ₂ CD ₂ ⁻	116
C ₃ H ₅ D ₂ O ⁻ + CH ₃ COC ₂ CH ₃ →		2.7±2.2(-12)	ICR	CH ₃ COC ₂ CD ₂ ⁻	116
C ₃ H ₅ O ⁻ + CH ₃ OH →	300	≥5(-11)	FA	<i>t</i> -C ₃ H ₅ O ⁻	110
	300	≥1(-10)	FA	<i>t</i> -C ₃ H ₅ O ⁻	110
	300	1.6(-10)	FA	<i>t</i> -C ₃ H ₅ O ⁻	108
	300	≥5(-11)	FA	<i>t</i> -C ₃ H ₅ O ⁻	110
	300	≥5(-11)	FA	<i>t</i> -C ₃ H ₅ O ⁻	110
C ₄ F ₉ ⁻ + NO ₂ →		1.0(-10)	B	0.3 eV KE	117
	300	<1(-10)	FA		118
C ₄ H ₉ S ⁻ + CH ₃ NO ₂ →	300	≤2.6(-11)	FA	<i>n</i> -C ₄ H ₉ S ⁻	110
C ₅ H ₉ O ⁻ + CH ₃ CD ₂ COC ₂ CH ₃ →		3.8±3.0(-12)	ICR	CH ₃ CH ₂ COCH ₂ CD ₂ ⁻	116
C ₆ H ₇ O ₂ ⁻ + C ₆ H ₅ SH →		3.0±0.3(-10)	ICR	From CH ₃ COCHCOHCH ₃	116
		1.5±0.4(-10)	ICR	From CH ₃ COCHCOHCH ₃	116
C ₆ H ₅ DO ₂ ⁻ + CD ₃ COC ₂ COCD ₂ CH ₃ →		1.2±0.3(-11)	ICR	CH ₃ COC ₂ COCH ₂ ⁻	116
C ₆ H ₅ D ₂ O ₂ ⁻ + CH ₃ COC ₂ COCD ₂ CH ₃ →		3.0±0.5(-11)	ICR	CH ₃ COC ₂ COCD ₂ CH ₃ ⁻	116
C ₆ H ₅ O ⁻ + parahydroxytoluene →		6.2±2.0(-11)	ICR	Phenoxy anion	116
C ₆ H ₅ NO ₂ ⁻ + NO ₂ →		3.6(-10)	B	0.3 eV KE	117
C ₆ F ₅ ⁻ + NO ₂ →		2.0(-10)	B	0.3 eV KE	117
C ₆ F ₁₀ ⁻ + NO ₂ →		1.3(-11)	B	0.3 eV KE	117
C ₇ H ₇ O ⁻ + phenol →		1.8±0.3(-10)	ICR	From parahydroxytoluene	116
C ₇ F ₉ ⁻ + NO ₂ →		7.0(-11)	B	0.3 eV KE	117

^aRate coefficients are in units of cm³ molecule⁻¹ s⁻¹ for bimolecular reactions and cm⁶ molecule⁻² s⁻¹ for termolecular reactions.

^bThe numbers in parenthesis should be read as the power 10 of the number. This (-9) is 10⁻⁹.

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