

AD A0 62 474

DDC FILE COPY

LEVEL III

DNA 1948H
Rev. 7

12

SPECIAL NOTICES TO ALL HANDBOOK USERS

100-4-62

1) The contents of Appendices A, E, F, and G, and of the Acknowledgments at the front of the Handbook are several years old and therefore outdated with respect to chapter revisions issued recently. Further such revisions will be issued in the near future. These will generate additional changes in the Appendices. It has therefore been determined that final revision of the Appendices will await completion of those chapter revisions now in progress.

2) The chemical kinetics data tabulated in Chapter 24 (transmitted herewith) supersedes much of the information in Chapters 10-21. Forthcoming revisions of some of these chapters may in turn supersede portions of Chapter 24. The user is therefore cautioned to do his own cross-checking within the Handbook, paying particular attention to the dates of issue of materials which appear to conflict with one another on any given datum.

3) In view of the above statements, if at any time you should require reference information which is inadequately covered in one of the outdated Appendices, or clarification as to the "latest" rate data where a rapidly advancing state of the art has left you in doubt on a given reaction, you may write or telephone either of the editors for assistance, as follows:

T. Baurer (215) 962-3125

M. H. Bortner (215) 962-3282

General Electric Company
Space Sciences Laboratory
P.O. Box 8555
Philadelphia, PA 19101

405 075

Space Div

ACCESSION BY	
DTIC	White Section ☒
DDC	Grey Section ☐
UNCLASSIFIED	☐
JUSTIFICATION	
BY _____	
DISTRIBUTION/AVAILABILITY CODES	
100	100, 101, 102, 103, 104
A	

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

DDC
RECEIVED
DEC 19 1978
REGISTERED

Q

1200

12 05 006

MEMORANDUM

To : All Recipients of the DNA Reaction Rate Handbook
(DNA 1948H)

From : The Editors

Subject: Revision Number 7

Enclosed is a copy of Revision Number 7 to the Handbook. It is a complete rewrite and recompilation of Chapter 24, "Summary of Suggested Rate Constants."

Please note especially the following two points regarding this particular revision:

(1) The revision effort, which began with an advisory group meeting at the University of Pittsburgh on March 30, 1976, has taken nearly two years, during which it has been necessary to cycle and recycle the recommendations of the attendees at that meeting back through the group and to consult with others concerning the validity and currency of many of the recommended data in the chapter. The result is considered to be the best possible one for DNA purposes as of March 1978. However, it should be borne in mind that this chapter, perhaps more than any other in the Handbook, represents only the interim status of a vigorously ongoing scientific effort.

(2) It is vital that all Handbook users now read the rewritten text of Chapter 24 because important changes have been made in the format of the data presentation in Table 24-1, and these are explained in detail at the beginning of the chapter. A thorough understanding of this material will enable the user to make the most effective possible use of the table. To repeat, PLEASE READ THESE NEW INTRODUCTORY PORTIONS OF THE CHAPTER, - NOW!!

As with previous revisions you should immediately discard the prior version of Chapter 24 and replace it with the enclosed material. You should also enter on page iii of your Handbook the following information: Revision Number 7, Date of Issue - June 1978; Date of Receipt - whatever day you receive this; and sign your name in the last column.

Revision Number 8 is expected to comprise a rewriting of Chapter 8 and an updating of Chapter 11, according to present plans. The anticipated issuance should take place in several months.

05 000

LEVEL III

Copy No.

Revision No. 7, March 1978

(18) (19)
DNA 1948H-REV-7
(Formerly DASA 1948)

(6) DEFENSE NUCLEAR AGENCY

REACTION RATE HANDBOOK.

SECOND EDITION. Revision N - V 7.

Editors-in-Chief:

Marlyn

(10) H. Bortner
J. Baurer

Theodore

(11) March 1978

(12) 1978

Project Officer: Dr. C.A. Blenk

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

Organized by General Electric Space Sciences Laboratory
for Defense Nuclear Agency under Contract

(15) DNA 001-78-C-0046
DNA 001-75-C-0023

This work sponsored by the Defense Nuclear Agency under
RDT&E RMSS Code B322078464 S99QAXH D02849 H2590D

Published by DASIAC
DoD Nuclear Information and Analysis Center
General Electric Company-TEMPO
Santa Barbara, California
Under Contract DNA 001-75-C-0023
NWED Subtask Code P99QAXD

DDC
RECEIVED
DEC 19 1978
D

(16) S99QAXH

(17) C008
D028

405 025 Jhu

24. SUMMARY OF SUGGESTED RATE CONSTANTS*

T. Baurer, General Electric Company
M.H. Bortner, General Electric Company
(Latest Revision 1 March 1978)

24.1 INTRODUCTION

This chapter presents a tabulated summary of reactions, with suggested rate coefficients, relevant to the problems of atmospheric chemical recovery following a perturbation. The present generation of computers permits the convenient handling of large numbers of reactions in the solution of such problems. Thus, one can now include in detailed calculations of this type hundreds of individual reactions and follow the complete histories of large numbers of individual species as atmospheric constituents. Many computer codes exist which have been designed for the study of atmospheric systems, and which are capable of carrying out the appropriate calculations. Such codes are in use at various institutes and laboratories throughout the country. In order to promote cooperation among these installations, it is desirable to have standard rate coefficients which are recognized universally as valid for all common purposes, e.g., the comparative solution of test problems, or the complementary solution of different aspects of a given large problem.

It is conceded at the outset that not all the reactions listed are universally important in all coded systems under all conditions. By the same token, some reactions which might not seem to have a direct bearing on a given system can be significant indirectly, either contributing to, or acting as precursors of, other processes which are influential within the given context. Furthermore, there probably are some important omissions from the table, since reactions not yet thought to play any significant role in atmospheric deionization mechanisms, or perhaps not yet even conceived of, might be found in the future to be quite significant in some context or scheme still to be considered or devised.

*The authors are pleased to acknowledge that Dr. R.H. Kummeler of Wayne State University was an active contributor to earlier versions of this chapter.

24.2 PRESENTATION OF REACTIONS AND RATE DATA

24.2.1 Listing of Reactions

The reactions are listed in Table 24-1 by type, in an order consistent with the listing of reaction types in Chapter 6 (Table 6-1). For each reaction type, i. e. , within each section of Table 24-1, reactions are usually listed according to the identity of the reactant species ranked according to the following "priority" order: oxygen, nitrogen, hydrogen, carbon, metals. This order is followed, respectively and in sequence, for monatomic, diatomic, triatomic, polyatomic, and complex or clustered species. Where one of the reactants is an ion, it is the atomic composition of the ionic reactant which will determine the order of listing; where two ions interact, it is the composition of the positive ion which will determine the order of listing.

For reactant or product species known to participate in a given reaction in an excited electronic state or vibrational mode, appropriate designations are appended to the appropriate species formula. Corresponding ground-state designations are sometimes noted for contrast, e. g. , where both ground and excited states of the same species are used or produced in essentially the same reaction. However, most reactions carry no state designations for any of the species involved. Species in these instances usually can be construed as being either in a Boltzmann distribution of states or in the ground state. The sources are usually indefinite on this point since modern investigative methods are not yet always keyed to the complete state analysis of all participating species in all reactions studied, and this summary can be no more definitive than its source material.

24.2.2 Data Format

In Table 24-1, the rate coefficients are presented in cgs units, i. e. , in sec^{-1} , $\text{cm}^3\text{sec}^{-1}$, and $\text{cm}^6\text{sec}^{-1}$ for one-, two-, and three-body processes, respectively. Species densities are in cm^{-3} and temperature is in K. The letter "M" is used to represent a collision partner; unless specifically noted otherwise, it represents any possible species present and acting as a catalyst. The numerical notation $[-x]$ signifies multiplication by 10^{-x} . Most rate functions "k" are represented by sets of numbers "a", "b", and "c", which refer in turn to the formulation:

$$k = a(T/300)^b \exp(-c/T),$$

where 300 in the first parenthesized term is the usual reference temperature (in K), unless another T_{ref} is designated in the "Notes" column of the table. A few rate functions found in Sections XXV, XXXII, XXXIV, and XXXV follow a more complex variation with temperature than that given above, or are dependent on other parameters as well, e.g., local species densities. These complex functions are presented in brackets and transcend the usual format of the table. For some reactions listed in Section XXV, the coefficient "a" is itself density-dependent rather than constant.

Wherever the authors of the various chapters (including revisions) of this Handbook have recommended specific values for the reaction rate constants or coefficients, those values are used in Table 24-1 unless they have been superseded by more recent work. In certain instances where the rate data are either uncertain or unavailable, the reactions might nevertheless be considered sufficiently important to be included. Values of these rate constants or coefficients have been estimated, either by an appropriate expert, e.g., a cognizant chapter author, or by a committee of knowledgeable workers. These cases are noted accordingly in the "Sources" column of the table as either a rather good estimate (Est.) or a somewhat shakier "guesstimate" (Gst.). IT IS STRESSED THAT SINCE A SIGNIFICANT NUMBER OF THE REACTIONS LISTED MIGHT BE CHARACTERIZED IN ONE OF THESE FASHIONS, ONE SHOULD BE EXTREMELY CAREFUL NOT TO CONSIDER THESE RATES AS FINAL.

In addition, it should be carefully noted that the listing of a zero (0) value for any rate parameter (viz., "a", "b", or "c") should be taken at face value as a true datum, i.e., the number in question is known to be zero. Where such a parameter is unknown, on the other hand, that fact is indicated by the use of a dash (-). Furthermore, wherever $c \neq 0$, it follows that the rate constant at 300 K, k_{300} , is unequal to the listed value of the "a" parameter; in all such cases k_{300} has been calculated and is listed in the "Notes" column. Such values are not to be construed as implying actual measurement at 300 K, unless specifically so stated in the table. Also, wherever the useful range of reaction temperatures is well beyond 300 K, a value of k_{300} would be meaningless and is, therefore, omitted.

In addition to such standard information items as T_{ref} and k_{300} just mentioned, and experimental temperature ranges (subsection 24.2.3),

the "Notes" column of the table contains explanatory and parametric facts covering a very broad scope. Certain items, which in prior versions of the table were given in footnotes, now have been relegated to a special listing at the end of the table. They are referred to by code letters ("Note a", "Note b", etc.) in the "Notes" column, where appropriate. This has been done to avoid repeating several rather lengthy footnotes, some of which appear more than once in the table.

24.2.3 Temperature Dependence

Temperature dependences designated by means of the "b" and "c" parameters refer in most instances to the ordinary gas-kinetic or translational temperature T or T_{gas} . However, certain reaction rates turn out to depend preferentially upon specialized temperatures, which are here designated accordingly, e.g., the kinetic temperature of interacting electrons (T_e) or ions (T_i), and the vibrational temperature of interacting molecules (T_v) or ions (T_{iv}). (N.B.: All temperatures and temperature dependences are expressed in kelvins (K).) In this connection, several types of special cases should be noted, as well as one or two other points on temperature dependence, viz.:

(1) Section IV of the table includes several instances where the temperature dependence changes, at some threshold in T_{iv} , from a variation in T_e to one in T_{iv} .

(2) Sections XIII and XIV include reactions for which the temperature dependence in T_i is characterized by a different set of kinetic parameters above some designated T_i than below it, i.e., the curve of rate constant as a function of T_i breaks sharply at the stated threshold value.

(3) Section XXVII lists some cases in which alternate sets of kinetic parameters must be used at temperatures in the hundreds of K (for which the mathematical treatment is the same as for any other reaction) or in the thousands of K (for which a T_{ref} different than 300 K — usually 3000 K — is the preferred form, and is so indicated).

(4) The literature reports many reactions for which temperature dependences may be equally well described mathematically as variations in "b" or in "c", but not both. In such cases, the "c"-variant form ordinarily reads like a negative activation energy. Therefore, the "b"-variant form usually has been reported in the table since it is less objectionable conceptually. Nevertheless,

some negative activation energies are also reported as such (in Sections XXVII and XXIX).

(5) Wherever possible, experimental temperature ranges defining the validity of a given set of rate parameters are listed in the "Notes" column. Where these are missing, it should be assumed that the values tabulated are valid at approximately room temperature (300 K) if both "b" and "c" are zero or unknown. Alternatively, if either "b" or "c" is listed as a known value other than zero, validity of the parameters given can be assumed roughly over the order of magnitude of several hundreds of K.

24.2.4 Uncertainties and Error Limits

The significance of the stated limits of uncertainty of most of the rate parameters in Table 24-1 is itself uncertain in that the tabulated limits could have been drawn from any of several different sources, e. g.:

(1) They might reflect experimental error as reported in the original literature citation from which the rate information was obtained.

(2) They might reflect a theoretician's uncertainty based upon the data or the treatment used to derive or estimate a given parameter.

(3) They might simply reflect a good guess or consensus accompanying an estimated rate parameter, and could have been arrived at by a knowledgeable individual or group who might have based the suggested uncertainties upon some handy rule of thumb derived from lengthy personal experience.

(4) If sufficient uncertainty exists, they might not even be listed.

(5) Where the uncertainty is so great that the parameter itself is considered to be unknown, values might not be listed at all and a dash (-) might be inserted at the appropriate location in the table.

24.3 OTHER SOURCES OF RATE DATA

Several more specialized compendia and services are available to the investigator of atmospheric chemical effects phenomenology.

24.3.1 Services of the National Bureau of Standards (NBS)

The National Standard Reference Data System (NSRDS) exists for the purpose of promoting the critical evaluation and dissemination of numerical data of the physical sciences in general. Although this program is coordinated by the Office of Standard Reference Data (OSRD) of NBS, it nevertheless involves the efforts of many groups in a variety of institutions. The primary aim of the program is to provide compilations of critically evaluated numerical data. These tables are published in the Journal of Physical and Chemical Reference Data, the NSRDS-NBS Publication Series of NBS, and through other appropriate channels. NSRDS communicates informally through its Reference Data Report, formerly known as NSRDS News, and subscriptions can be obtained by writing to: OSRD, NBS, Washington, D.C. 20234.

One of the more specialized data centers within the NSRDS system is the Chemical Kinetics Information Center (CKIC). This center maintains and routinely updates a data bank covering the kinetics of collisional and photochemical reactions involving neutral species, as reported in the open literature. In response to requests for current information in its areas of coverage, CKIC provides to the requestor either its own recommended value for a given rate parameter (if such a recommendation has been determined), or the latest and/or most pertinent literature citation available. For the fulfillment of requests of "substantial" magnitude, a charge might be levied for this service, at the discretion of CKIC. Requests should be directed to: Dr. Robert F. Hampson, Director, CKIC, NBS, Washington, D.C. 20234.

Another activity of NSRDS is the Radiation Chemistry Data Center (RCDC), Radiation Laboratory, University of Notre Dame, Notre Dame, Indiana 46556. RCDC publishes a Biweekly List of Papers on Radiation Chemistry which provides current bibliographical material in ten categories, selected for relevance to radiation chemistry, but often quite useful in atmospheric chemical kinetics as well. The material is derived from a scanning of about 50 journals as well as Chemical Abstracts and other publications which

list current references. A subscription, currently \$21 per year (domestic delivery) excluding the Annual Indexed Cumulation, is available by application to: NBS Accounting Division, Building 101, Room A836, NBS, Washington, D.C. 20234.

In addition, NSRDS published (1972) a translation (COM-72-10014) by L. J. Iloltschlag (edited by R. M. Fristrom) of V. N. Kondratiev's "Rate Constants of Gas Phase Reactions", a reference book of limited applicability to most DNA-oriented problems. It can be purchased through the National Technical Information Service, Springfield, Virginia 22151.

Finally, a summary listing entitled: "Chemical Kinetics Tables, Data Evaluations and Bibliographies. A Guide to the Literature" is available from NBS as NBS List of Publications #73 (revised Sept. 1976). Prepared by J. G. Koch of the CKIC Institute for Materials Research, the list is organized into six sections covering output of NSRDS, CKIC, and other organizations outside NBS. Disappointingly enough, the DNA Reaction Rate Handbook is not listed therein.

24.3.2 Services of the National Oceanic and Atmospheric Administration (NOAA)

The Environmental Research Laboratories (ERL) of NOAA at Boulder, Colorado, have recently announced the forthcoming publication of a compendium of rate parameters. The information provided will be limited to that determined experimentally at NOAA/ERL, and will pertain initially only to ion-neutral reactions, with planned future expansion to include information on ion mobilities and neutral-neutral reactions. Present indications are that the volume of intended coverage will be in excess of 550 ion-neutral reactions, approximately 100 zero-field ion mobilities, and more than 100 neutral-neutral reactions. The tabular format of the compendium will provide information, for each reaction reported, as follows: rate constant (as determined), percent experimental error, product branching ratio (if applicable), experimental energy range (K or eV), experimental method, and open literature citation (if applicable). No format as yet has been announced for the tabulation of ion mobility data. All information will be stored on tape for reproduction by magnetic-memory typewriter. The initial distribution is expected to take place in the near future, with updating planned on an annual basis. Requests for subscription to this service should be addressed to: Dr. Fred C. Fehsenfeld, U.S. Department of Commerce, NOAA, ERL, Boulder, Colorado 80302.

24.3.3 Other Services Available

The Department of Physical Chemistry, University of Leeds, Leeds 2, England, has compiled, analyzed, and reported its recommendations on "High Temperature Reaction Rate Data" in a series of reports prepared under the leadership of Professor D.L. Baulch, to whom any requests for further information should be addressed.

A "Bibliography of Chemical Kinetics and Collision Processes," edited by Adolf R. Hochstim, was published in 1969 by IFI/Plenum Data Corporation, 227 West 17th Street, New York, New York 10011. It provides a useful annotated list of approximately 20,000 literature citations covering the period 1900-1966, including data on reaction rates, cross-sections, and excited-state lifetimes.

Other sources of information can be found among the general references listed in Appendix H of this Handbook.

Table 24-1. Reactions and suggested rate constants.

$$k = a(T/300)^b e^{-c/T}$$

No.	Reaction	a	b	c	Notes	Sources
I. Radiative Recombination:						
1.	$O^+ + e \rightarrow O + h\nu$	$(3.5 \pm 1.0) \cdot 10^{-12}$	(-0.7 ± 0.1)	0		Chp. 16
2.	$N^+ + e \rightarrow N + h\nu$	$(3.5 \pm 1.0) \cdot 10^{-12}$	(-0.7 ± 0.1)	0		
3.	$H^+ + e \rightarrow H + h\nu$	$(3.5 \pm 1.0) \cdot 10^{-12}$	(-0.7 ± 0.1)	0		
4.	$O_2^+ + e \rightarrow O_2 + h\nu$	$(4) \cdot 10^{-12} \pm$	(-0.7 ± 0.5)	0	Note a	Est.
5.	$NO^+ + e \rightarrow NO + h\nu$	$(4) \cdot 10^{-12} \pm$	(-0.7 ± 0.5)	0	Note a	
6.	$N_2^+ + e \rightarrow N_2 + h\nu$	$(4) \cdot 10^{-12} \pm$	(-0.7 ± 0.5)	0	Note a	
II. Photoionization:						
1.a.	$O + h\nu \rightarrow O^+(^4S) + e$	$(2.83 \pm 0.57) \cdot 10^{-7}$	0	0	Note b	Ref. 24-1
b.	$-O^+(^2D) + e$		-	-	Note c	Chps. 12, 13
c.	$-O^+(^2P) + e$		-	-	Note b	Ref. 24-1
2.	$N + h\nu \rightarrow N^+ + e$	$(5.91 \pm 1.18) \cdot 10^{-7}$	0	0	Note b	Chps. 12, 13
3.a.	$O_2 + h\nu \rightarrow O_2^+ + e$		-	-	Note c	Ref. 24-1
b.	$-O^+ + e \rightarrow O$		-	-	Note b	Chps. 12, 13
c.	$-O^+ + e \rightarrow O(^1D)$		-	-	Note c	Ref. 24-1
4.	$O_2(^1A_g) + h\nu \rightarrow O_2^+ + e$	$(6.24 \pm 1.25) \cdot 10^{-7}$	0	0	Note b	Chps. 12, 13
5.	$NO + h\nu \rightarrow NO^+ + e$		-	-	Note c	Ref. 24-1

Table 24-1. (continued)

No.	Reaction	a	b	c	Notes	Sources	
II. Photoionization: (continued)							
6.a.	$N_2 + h\nu \rightarrow N_2^+ + e$	{ (4.22±0.84)·10 ⁻⁷ }	0	0	Note b	Ref. 24-1	
b.	$N^+ + e \rightarrow N$		0	0			
c.	$N^+ + e \rightarrow N(^2D)$		-	-	Note c	Chps. 12, 13	
7.	$NO_2 + h\nu \rightarrow NO_2^+ + e$	-	-	-			
III. Three-Body Recombination:							
1.	$X^+ + e + M \rightarrow \text{Products}$	{ (2)·10 ⁻²⁷ ±0.2·10 ⁻²⁷ (6)·10 ⁻²⁷ ±0.3·10 ⁻²⁷ (3)·10 ⁻²⁶ ±0.3·10 ⁻²⁷ (7±3)·10 ⁻²⁰ (6)·10 ⁻²⁷ ±0.3·10 ⁻²⁷ (3)·10 ⁻²⁶ ±0.3·10 ⁻²⁷ }	(-2.5)	0	X^+ = atomic ion and: M = atom M = molecule M = polar molecule	Chp. 16 + Est.	
2.	$X^+ + e + e \rightarrow \text{Products}$		(-2.5)	0	X^+ = any atomic or molecular ion		Chp. 16
3.	$XY^+ + e + M \rightarrow \text{Products}$		(-2.5)	0	0	XY^+ = molecular ion and: M = atom or molecule M = polar molecule	Chp. 16 + Est.
			(-2.5)	0	0		
IV. Dissociative Recombination:							
1.	$O_2^+ + e \rightarrow 1.0 O(^3P) + 0.9 O(^1D) + 0.1 O(^1S)$	(2.1±0.2)·10 ⁻⁷	(-0.62±0.07)	0	$T = T_e$; Notes d, e	Chp. 16 + Est.	
2.a.	$NO^+ + e \rightarrow N + O$	(4.0±0.3)·10 ⁻⁷	(-1.0±0.2)	0	T=200-300 K	Chp. 16	
b.		(4.0±0.3)·10 ⁻⁷	(-0.4±0.2) (-0.1)	0	$T = T_e \approx 300$ K; e Note f	Refs. 24-2 through 24-4; cf. Ref. 24-5	

Table 24-1. (continued)

No.	Reaction	a	b	c	Notes	Sources
IV. Dissociative Recombination: (continued)						
2.c.	$\text{NO}^+ + e \rightarrow \text{N}(\text{D}) + \text{O}(\text{P})$				Note g	Refs. 24-3, 24-6
3.a.	$\text{N}_2^+ + e \rightarrow 1.08 \text{N}(\text{D}) + 0.92 \text{N}(\text{S})$	$(1.8^{+0.4}_{-0.2}) [-7]$	(-0.39)	0	$T = T_e$; Notes h, i	Chp. 16 + Est.
b.		$(2.7 \pm 0.3) [-7]$	(-0.02)	0	$T = T_g = 200-480 \text{ K}$	Ref. 24-7 + Est.
4.	$\text{NO}_2^+ + e \rightarrow \text{NO} + \text{O}$	$(3 \pm 2) [-7]$	(-0.5 ± 0.2)	0	$T = T_e$	Gst.
5.	$\text{N}_3^+ + e \rightarrow \text{N} + \text{N}_2$	$(7 \pm 4) [-7]$	(-1.0 ± 0.5)	0		Est.
6.	$\text{O}_4^+ + e \rightarrow \text{O} + \text{O}_2$	$(2.0 \pm 0.5) [-6]$	(-1.0 ± 0.5)	0	Probable Products	Chp. 16
7.	$\text{NO}^+ \text{NO} + e \rightarrow \text{N} + \text{O} + \text{NO}$	$(1.7 \pm 0.5) [-6]$	(-1.0 ± 0.5)	0		
8.	$\text{NO}^+ \text{N}_2 + e \rightarrow \text{N} + \text{O} + \text{N}_2$	$(1.5 \pm 0.5) [-6]$	(-1.0 ± 0.5)	0		Gst.
9.	$\text{N}_4^+ + e \rightarrow \text{N}_2 + \text{N}_2$	$(2 \pm 1) [-6]$	(-1.0 ± 0.3)	0		Chp. 16
10.	$\text{O}_2^+ \text{H}_2\text{O} + e \rightarrow \text{O}_2 + \text{H}_2\text{O}$	$(1.5 \pm 0.5) [-6]$	(-0.2 ± 0.2)	0		Gst.
11.	$\text{NO}^+ \text{H}_2\text{O} + e \rightarrow \text{NO} + \text{H}_2\text{O}$	$(1.5 \pm 0.5) [-6]$	(-0.2 ± 0.2)	0		
12.	$\text{NO}^+ \text{CO}_2 + e \rightarrow \text{NO} + \text{CO}_2$	$(1.5 \pm 0.5) [-6]$	(-0.2 ± 0.2)	0		
13.	$\text{NO}^+ (\text{H}_2\text{O})_2 + e \rightarrow \text{NO} + 2\text{H}_2\text{O}$	$(2 \pm 1) [-6]$	(-0.2 ± 0.2)	0		
14.	$\text{NO}^+ (\text{H}_2\text{O})_3 + e \rightarrow \text{NO} + 3\text{H}_2\text{O}$	$(3 \pm 1) [-6]$	(-0.2 ± 0.2)	0	Probable Products	
15.	$\text{NO}^+ \text{H}_2\text{O} \cdot \text{N}_2 + e \rightarrow \text{NO} + \text{H}_2\text{O} + \text{N}_2$	$(2 \pm 1) [-6]$	(-0.2 ± 0.2)	0		
16.	$\text{NO}^+ \text{H}_2\text{O} \cdot \text{CO}_2 + e \rightarrow \text{NO} + \text{H}_2\text{O} + \text{CO}_2$	$(2 \pm 1) [-6]$	(-0.2 ± 0.2)	0		
17.	$\text{NO}^+ (\text{H}_2\text{O})_2 \text{N}_2 + e \rightarrow \text{NO} + 2\text{H}_2\text{O} + \text{N}_2$	$(3 \pm 1) [-6]$	(-0.2 ± 0.2)	0		
18.	$\text{NO}^+ (\text{H}_2\text{O})_2 \text{CO}_2 + e \rightarrow \text{NO} + 2\text{H}_2\text{O} + \text{CO}_2$	$(3 \pm 1) [-6]$	(-0.2 ± 0.2)	0		

Table 24-1. (continued)

No.	Reaction	a	b	c	Notes	Sources
IV. Dissociative Recombination: (continued)						
19.	$\text{NO}_2^+ \cdot \text{H}_2\text{O} + e \rightarrow \text{NO}_2 + \text{H}_2\text{O}$	$(1.5 \pm 0.5) [-6]$	(-0.2 ± 0.2)	0	Probable Products	Gst.
20.	$\text{NO}_2^+ (\text{H}_2\text{O})_2 + e \rightarrow \text{NO}_2 + 2\text{H}_2\text{O}$	$(2 \pm 1) [-6]$	(-0.2 ± 0.2)	0		
21.a.	$\text{H}_3\text{O}^+ + e \rightarrow \text{H}_2\text{O} + \text{H}$	$(1.3 \pm 0.3) [-6]$	$(-1.0^{+0.1}_{-0.2})$	0	300 K. $T_e = 10,000\text{K}$	Chp. 16 + Ref. 24-8
b.		$(1.3 \pm 0.3) [-6]$	$(-0.7^{+0.2}_{-0.3})$	0	100 K. $T_e = 300\text{K}$	
22.	$\text{H}_3\text{O}^+ \cdot \text{N}_2 + e \rightarrow \text{H} + \text{H}_2\text{O} + \text{N}_2$	$(1.5 \pm 0.5) [-6]$	(-0.2 ± 0.2)	0	Probable Products	Gst.
23.	$\text{H}_3\text{O}^+ \cdot \text{OH} + e \rightarrow \text{H}_2\text{O} + \text{H} + \text{OH}$	$(2 \pm 1) [-6]$	$(-0.2^{+0.1}_{-0.3})$	0		
24.	$\text{H}_3\text{O}^+ \cdot \text{H}_2\text{O} + e \rightarrow 2\text{H}_2\text{O} + \text{H}$	$(2.8 \pm 0.4) [-6]$	(-0.15 ± 0.15)	0	Probable Products; Notes j, k	
25.	$\text{H}_3\text{O}^+ (\text{H}_2\text{O})_2 + e \rightarrow 3\text{H}_2\text{O} + \text{H}$	$(5.1 \pm 0.7) [-6]$	$(-0.05^{+0.05}_{-0.10})$	0		
26.	$\text{H}_3\text{O}^+ (\text{H}_2\text{O})_3 + e \rightarrow 4\text{H}_2\text{O} + \text{H}$	$(6.1 \pm 1.2) [-6]$	(0.00 ± 0.05)	0	Probable Products; Notes j, l	Chp. 16
27.	$\text{H}_3\text{O}^+ (\text{H}_2\text{O})_4 + e \rightarrow 5\text{H}_2\text{O} + \text{H}$	$(7.4 \pm 1.5) [-6]$	(0.0 ± 0.2)	0	Probable Products; Note i	
28.	$\text{H}_3\text{O}^+ (\text{H}_2\text{O})_5 + e \rightarrow 6\text{H}_2\text{O} + \text{H}$	$(9.3 \pm 2.0) [-6]$	(0.0 ± 0.2)	0	Probable Products; Notes j, m	
V. Mutual Neutralization:						
1.	$\text{O}^+ + \text{O}^- \rightarrow \text{O} + \text{O}$	$(2.7 \pm 1.3) [-7]$	(-0.5)	0		Chp. 16
2.	$\text{N}^+ + \text{O}^- \rightarrow \text{N} + \text{O}$	$(2.6 \pm 0.8) [-7]$	(-0.5)	0		
3.	$\text{O}_2^+ + \text{O}^- \rightarrow \text{O}_2 + \text{O}$	$(1.0 \pm 0.3) [-7]$	(-0.5)	0		Chp. 16 + Ref. 24-11

Table 24-1. (continued)

No.	Reaction	a	b	c	Notes	Sources
V. Mutual Neutralization: (continued)						
4.	$O_2^+ + O_2^- - O_2 + O_2$	$(4.2 \pm 1.3) -7 $	(-0.5)	0		Chp. 16
5.	$O_2^+ + NO_2^- - O_2 + NO_2$	$(4.1 \pm 1.3) -7 $	(-0.5)	0		
6.	$O_2^+ + NO_3^- - O_2 + NO_3$	$(1.3 \pm 0.5) -7 $	(-0.5)	0		
7.	$NO^+ + O^- - NO + O$	$(4.9 \pm 1.5) -7 $	(-0.5)	0		
8.	$NO^+ + O_2^- - NO + O_2$	$(6 \pm 1) -7 $	(-0.5)	0	Note <u>n</u>	Ref. 24-11
9.	$NO^+ + NO_2^- - NO + NO_2$	$(1.0^{+0.8}_{-0.4}) -7 $	(-0.5)	0		Chp. 16 + Refs. 24-15, 24-16
10.	$NO^+ + NO_3^- - NO + NO_3$	$(9^{+9}_{-5}) -8 $	(-0.5)	0		
11.	$N_2^+ + O_2^- - N_2 + O_2$	$(1.6 \pm 0.5) -7 $	(-0.5)	0	Note <u>o</u>	Chp. 16
12.	$X^+ + Y^- - Products \text{ (probably } X+Y)$	$(1.0^{+4.0}_{-0.6}) -7 $	(-0.5)	0		Est.
VI. Three-Body Ion-Ion Recombination:						
1.	$X^+ + Y^- + M - Products$	$(3 \pm 1) -25 $	(-2.5)	0	Note <u>p</u> Note <u>q</u>	Chp. 16
2.	$X^+(cluster) + Y^- + M - Products$	$(1) -25.0 \pm 0.2 $	(-2.5)	0		Gst.
3.	$X^+ + Y^-(cluster) + M - Products$	$(1) -25.0 \pm 0.2 $	(-2.5)	0		
4.	$X^+(cluster) + Y^-(cluster) + M - Products$	$(1) -25.0 \pm 0.2 $	(-2.5)	0		
VII. Radiative Attachment:						
1.	$O + e - O^- + h\nu$	$(1.3 \pm 0.1) -15 $	0	0		Chp. 17

Table 24-1. (continued)

No.	Reaction	a	b	c	Notes	Sources
VII. Radiative Attachment: (continued)						
2.	$O_2 + e \rightarrow O_2^- + h\nu$	(2) -19±1	0	0	Note <u>1</u> Slow compared with reactions XI.2(a,b) } Est. See Reaction IX.7	Chp. 17
3.	$OH + e \rightarrow OH^- + h\nu$	(2.5±1.5) -15	(-0.25)	0		Ref. 24-17
4.	$O_3 + e \rightarrow O_3^- + h\nu$	(1) -17±3	0	0		
5.	$HO_2 + e \rightarrow NO_2^- + h\nu$	(1) -17±2	0	0		
VIII. Photodetachment: (See Note s)						
1.a.	$O^- + h\nu \rightarrow O + e$	(1.4±0.1) 0	0	0	Note <u>1</u>	Chp. 17; Ref. 24-18
b.	$-O(^1D) + e$	(7.6) -2.0±0.2	0	0		Ref. 24-19
2.	$O_2^- + h\nu \rightarrow O_2 + e$	(0.33±0.10) 0	0	0		Chp. 17; Ref. 24-18
3.	$OH^- + h\nu \rightarrow OH + e$	(1) 0±1	0	0	Note <u>u</u>	Chp. 17
4.	$O_3^- + h\nu \rightarrow O_3 + e$	(8±2) -2	0	0		Ref. 24-20
5.	$NO_2^- + h\nu \rightarrow NO_2 + e$	(5±3) -2	0	0	Est. (J.R. Peterson) from data of Ref. 24-21	
6.	$O_4^- + h\nu \rightarrow 2O_2 + e$	$\begin{pmatrix} 3 & +3 \\ -2 & -1 \end{pmatrix}$	0	0	See Reaction XXII.2; Probable Products	Ref. 24-18
7.	$NO_3^- + h\nu \rightarrow NO_3 + e$	(5) -3±2	0	0	} Probable Products	Ref. 24-22
8.	$CO_4^- + h\nu \rightarrow CO_2 + O_2 + e$	(3) -2±1	0	0		Ref. 24-20

Table 24-1. (continued)

No.	Reaction	a	b	c	Notes	Sources
IX. Three-Body Attachment:						
1.	$O_2 + e + O \rightarrow O_2^- + O$	(1.1) -31 ± 2	0	0	Note v T = 195-600 K; $k_{300} = (1.9 \pm 0.3) \times 10^{-30}$	} } Chp. 17
2.	$O_2 + e + O_2 \rightarrow O_2^- + O_2$	(1.4 ± 0.2) -29	(-1)	600		
3.	$O_2 + e + N_2 \rightarrow O_2^- + N_2$	(1.0 ± 0.5) -31	0	0		
4.	$O_2 + e + H_2O \rightarrow O_2^- + H_2O$	(1.4 ± 0.2) -29	0	0	T = 300-400 K	
5.	$O_2 + e + CO_2 \rightarrow O_2^- + CO_2$	(3.3 ± 0.7) -30	0	0	T = 300-525 K	
6.	$NO + e + M \rightarrow \text{Products}$	(8) -31	0	0	M = NO	
7.	$NO_2 + e (+M) \rightarrow NO_2^- (+M)$	(4) -11	0	0	Note w; See Reaction VII.5	
X. Collisional Detachment:						
1.	$O^- + O_2 \rightarrow O + e + O_2$	(2.3 ± 1.0) -9	0	26,000-3000	} } T ₁ < 20,000 K; $k_{3000} = (4)^{-13} \pm 1^{-1}$	} } Chp. 17
2.	$O^- + N_2 \rightarrow O + e + N_2$	(2.3) -9, 0 ± 0.5	0	26,000-3000		
3.	$O_2^- + O \rightarrow O_2 + e + O$	(3.6) -11	0	5000	Note r; $k_{300} = (2.1) \times 10^{-18}$	Ref. 24-23
4.	$O_2^- + O_2 \rightarrow O_2 + e + O_2$	(2.7 ± 0.3) -10	(0.5)	5590	T = 375-600 K; $k_{300} = (2.2 \pm 0.3) \times 10^{-18}$	Chp. 17
5.	$O_2^- + O_2(a^1\Delta_g) \rightarrow O_2 + e + C_2$	(2.2) -10	-	-		Chps. 17, 20
6.	$O_2^- + N_2 \rightarrow O_2 + e + N_2$	(1.9 ± 0.4) -12	(1.5)	4990	T = 375-600 K; $k_{300} = (1.1 \pm 0.3) \times 10^{-18}$	Chp. 17

Table 24-1. (continued)

No.	Reaction	a	b	c	Notes	Sources
X. Collisional Detachment: (continued)						
7.	$O_2^- + H_2O \rightarrow O_2 + e + H_2O$	(5.0)[-9]	0	5000	Note r_i $k_{300} = (2.9)[-16]$	Ref. 24-23
8.	$O_2^- + CO_2 \rightarrow O_2 + e + CO_2$	(1.2)[-9]	0	5000	Note r_i $k_{300} = (6.9)[-17]$	
XI. Dissociative Attachment:						
1.	$O_2 + e \rightarrow O^- + O$	-	-	-	$k \propto (1)[-16]$ for $T > 2000$ K; Endothermic $c > (4)[4]$ at $T < 300$ K; Strong T_e dependence at high T_e .	Chps. 17, 20
2.a.	$O_3 + e \rightarrow O^- + O_2$	(9±2)[-12]	(1.5)	0	$T = 200-300$ K; See Reaction VII.4	Chp. 17
b.	$\rightarrow O_2^- + O$	(5.4)[-10.0±0.3]	(1.5)	13,200	$T = T_e$; No dependence on T for $T < 360$ K; $T_{ref} = 3000$ K; $k_{3000} = (6.6)[-12.0±0.3]$	Est. based on Ref. 24-24
3.	$HNO_3 + e \rightarrow NO_2^- + OH$	(5±3)[-8]	-	-		Ref. 24-25
XII. Associative Detachment:						
1.	$O^- + O \rightarrow O_2 + e$	(2)[-10.0±0.3]	-	-	$k < (5)[-15]$ at $T = 300$ K and $T_i = 300-10,000$ K; Endothermic $c \sim (5)[3]$	Ref. 24-26
2.	$O^- + N \rightarrow NO + e$	$\begin{pmatrix} 2 \\ -1 \end{pmatrix}[-10]$	-	-		
3.	$O^- + O_2 \rightarrow O_3 + e$	-	-	-		

Table 24-1. (continued)

No.	Reaction	a	b	c	Notes	Sources
XII. Associative Detachment: (continued)						
4.	$O^- + O_2(a^1\Delta_g) \rightarrow O_3 + e$	(3) -10.0±0.3	-	-	Cf. Reaction XV.1	Chps. 17, 20
5.	$O^- + NO \rightarrow NO_2 + e$	(2.5±0.6) -10	(-0.8)	0	$T_i = 300-2000$ K; Cf. Reaction XXII.2	Ref. 24-27
6.	$O^- + N_2 \rightarrow N_2O + e$	-	-	-	$k < (1) -14 $ at $T_i = 300$ K; Note x	Ref. 24-28
7.	$O^- + H_2 \rightarrow H_2O + e$	(6.0±1.0) -10	(-0.2)	0	$T = T_i < 3000$ K	} Ref. 24-27
8.	$O^- + CO \rightarrow CO_2 + e$	(6±1) -10	(-0.32)	0		
9.	$O^- + O_3 \rightarrow 2O_2 + e$	-	-	-	Slow compared with Reaction XV.3	Est.
10.	$O_2^- + O \rightarrow O_3 + e$	(1.5) -10.0±0.3	-	-	See Reaction XV.7	} Ref. 24-26
11.	$O_2^- + N \rightarrow NO_2 + e$	(3) -10.0±0.3	-	-		
12.	$OH^- + O \rightarrow HO_2 + e$	(2) -10.0±0.3	-	-		Ref. 24-29
13.	$OH^- + H \rightarrow H_2O + e$	(1.4) -9.0±0.3	-	-		Ref. 24-30
14.	$O_3^- + O \rightarrow 2O_2 + e$	(11)[-11 ⁺¹ ₋₂]	-	-	Note y	Est.
15.	$NO_2^- + H \rightarrow HNO_2 + e$	-	-	-	$k \sim (8) -11 $	} Ref. 24-31
16.	$NO_3^- + H \rightarrow HNO_3 + e$	-	-	-	$k \sim (5) -11 $	
17.	$CO_3^- + O \rightarrow CO_2 + O_2 + e$	-	-	-	Slow compared to Reaction XVI.42	Ref. 24-26

Table 24-1. (continued)

No.	Reaction	a	b	c	Notes	Sources
XIII. Positive-Ion Charge Transfer:						
1.	$O^+ + H \rightarrow O + H^+$	(6.8±3.0)[-10]	0	0		Chp. 18A
2.a.	$O^+ + O_2 \rightarrow O + O_2^+$	(2.0±0.2)[-11]	(-0.40±0.14)	0	$T = T_i$; 1800 K	} Ref. 24-27
b.		(1.3±0.2)[-12]	(1.20±0.13)	0	$T = T_i$; ~ 1800 K	
3.	$O^+(^2D) + O_2 \rightarrow O + O_2^+(^4\pi_u), (^4\Sigma_u^+)$	(3)[-10.0 ^{+0.5} _{-1.0}]	0	0		Chp. 20
4.a.	$O^+ + NO \rightarrow O + NO^+$ (see Note 2)	(8.0±1.2)[-13]	(-0.21)	0	$T = T_i$; ~ 1000 K; $T_v = 300$ K	} Ref. 24-32
b.		(7±1)[-14]	(1.66)	0	$T = T_i$; ~ 1000 K; $T_v = 300$ K	
5.	$O^+(^2D) + N_2 \rightarrow O + N_2^+$	(3)[-10-1]	0	0		Chp. 20
6.	$O^+ + NO_2 \rightarrow O + NO_2^+$	(1.6±0.3)[-9]	0	0	Data at 393 K	} Chp. 18A
7.	$O^+ + N_2O \rightarrow O + N_2O^+$	(2.2±1.0)[-10]	0	0	Cf. Reaction XIV.4	
8.	$O^+ + H_2O \rightarrow O + H_2O^+$	(2.3±0.3)[-9]	0	0		
9.	$N^+ + O \rightarrow N + O^+$	(1)[-12]	-	-		Est.
10.a.	$N^+ + O_2 \rightarrow N + O_2^+$ (see Notes 2, aa)	(2.8±1.0)[-10]	(0.00 ^{+0.80} _{-0.17})	0	$T = T_i$; < 4600 K	} Ref. 24-27
b.		(6±1)[-11]	(0.57±0.05)	0	$T = T_i$; ~ 4600 K	
11.	$N^+ + NO \rightarrow N + NO^+$	(8.0±2.4)[-10]	-	-		Chp. 18A
12.	$N^+ + CO \rightarrow N + CO^+$	(9±3)[-10]	-	-		Ref. 24-34
13.	$N^+ + H_2O \rightarrow N + H_2O^+$	(2.6±0.4)[-9]	-	-		Chp. 18A

Table 24-1. (continued)

No.	Reaction	a	b	c	Notes	Source
XIII. Positive-Ion Charge Transfer: (continued)						
14.	$N^+ + CO_2 \rightarrow N + CO_2^+$	$(1.3 \pm 0.4)[-9]$	-	-		Ref. 24-34
15.	$H^+ + O \rightarrow H + O^+$	$(3.8 \pm 2.0)[-10]$	-	-		} Chp. 18A
16.	$H^+ + NO \rightarrow H + NO^+$	$(1.9 \pm 0.5)[-9]$	-	-		
17.	$O_2^+(\sigma^4\Pi_u) + O \rightarrow O_2 + O^+$	$(5)[-10.0 \pm 0.3]$	-	-		Gst.
18.	$O_2^+ + Na \rightarrow O_2 + Na^+$	$(6.7)[-10 \pm 1]$	0	0	Cf. Reaction XIV.16	Chp. 18A
19.	$O_2^+(\sigma^4\Pi_u) + O_2 \rightarrow C_2 + O_2^+$				See Note ab	
20.	$O_2^+ + NO \rightarrow O_2 + NO^+$	$(4.5 \pm 1.0)[-10]$	0	0	$300\text{ K} \sim T \sim 900\text{ K}$	Chp. 18A + Ref. 24-35
21.	$O_2^+(\sigma^4\Pi_u) + NO \rightarrow O_2 + NO^+$	$(1.1 \pm 0.3)[-9]$	0	0	} $T = T_i < 2000\text{ K}$	Ref. 24-35
22.	$O_2^+(\sigma^4\Pi_u) + N_2 \rightarrow O_2 + N_2^+$	$(4.1 \pm 1.6)[-10]$	0	0		Ref. 24-36
23.	$O_2^+ + NO_2 \rightarrow O_2 + NO_2^+$	$(6.6 \pm 2.0)[-10]$	-	-		Chp. 18A
24.	$O_2^+ + H_2O_2 \rightarrow O_2 + H_2C_2^+$	$(1.5 \pm 0.4)[-9]$	0	0	$T = T_i \sim 700\text{ K}$	Ref. 24-37
25.	$NC^+ + Na \rightarrow NO + Na^+$	$(7.0 \pm 3.0)[-11]$	0	0		} Chp. 18A
26.	$OH^+ + O_2 \rightarrow OH + O_2^+$	$(2.0 \pm 0.5)[-10]$	-	-		
27.	$CC^+ + O \rightarrow CO + O^+$	$(1.4 \pm 0.8)[-10]$	-	-		
28.	$CO^+ + NO \rightarrow CO + NO^+$	$(3.3 \pm 1.0)[-10]$	-	-		

Table 24-1. (continued)

No.	Reaction	a	b	c	Notes	Sources
XIII. Positive-Ion Charge Transfer: (continued)						
29. a	$N_2^+ + O \rightarrow N_2 + O^+$ (Cf. Reaction XIV. 19)	(1.0±0.5)[-11]	(-0.23)	0	T = T _i ; 1500 K	Ref. 24-38
30.	$N_2^+ + N \rightarrow N_2 + N^+$	(3.6±1.4)[-12]	(0.41)	0	T = T _i ; ~ 1500 K	
31.	$N_2^+ + Na \rightarrow N_2 + Na^+$	-	-	-	k · (I) ⁻¹ [-11]	Chp. 18A
32. a	$N_2^+ + O_2 \rightarrow N_2 + O_2^+$ (Cf. Reaction XIV. 20)	(5.8±3.0)[-10]	0	0	T = T _i ; 3560 K	
b		(5.0±1.0)[-11]	(-0.8±0.2)	0	T = T _i ; ~ 3560 K	Chp. 18A + Ref. 24-27
33.	$N_2^+ + NO \rightarrow N_2 + NO^+$	(2.5±0.5)[-12]	(1.4±0.3)	0	Note <u>ac</u>	
34.	$N_2^+ + H_2O \rightarrow N_2 + H_2O^+$	(3.3±1.5)[-10]	-	-	Note <u>ad</u>	Chp. 18A
35.	$N_2^+ + CO_2 \rightarrow N_2 + CO_2^+$	-	-	-		
36.	$NO_2^+ + NO \rightarrow NO_2 + NO^+$	(9±3)[-10]	-	-		Ref. 24-34
37.	$H_2O^+ + O_2 \rightarrow H_2O + O_2^+$	(2.9±1.0)[-10]	-	-		
38.	$CO_2^+ + O \rightarrow CO_2 + O^+$	(2.0±0.5)[-10]	-	-		Chp. 18A
39.	$CO_2^+ + O_2 \rightarrow CO_2 + O_2^+$	(1.0±0.6)[-10]	-	-	Cf. Reaction XIV. 27	
40.	$CO_2^+ + NO \rightarrow CO_2 + NO^+$	(5±2)[-11]	-	-		
		(1.2±0.4)[-10]	-	-		

Table 24-1. (continued)

No.	Reaction	a	b	c	Notes	Sources
XIII. Positive-Ion Charge Transfer: (continued)						
41.	$O_4^+ + O_2(a^1\Delta_g) \rightarrow 2O_2 + O_2^+$	(1) [-10]	-	-		Gst.
42.	$O_4^+ + NO \rightarrow 2O_2 + NO^+$	(5) [-10]	-	-		Est.
43.	$O_4^+ + NO_2 \rightarrow 2O_2 + NO_2^+$	(5) [-10]	-	-		Est.
44.	$N_4^+ + O_2 \rightarrow 2N_2 + O_2^+$	(4±1) [-10]	-	-	Data at 200 K	Chp. 18A
45.	$H_2O_2^+ + NO \rightarrow H_2O_2 + NO^+$	(5.0±1.5) [-10]	0	0	$T = T_p < 700$ K	Ref. 24-37
46.	$O_2^+ + H_2O + O_2(a^1\Delta_g) \rightarrow O_2 + H_2O + O_2^+$	(1) [-10]	-	-		Gst.
47.	$O_2^+ + H_2O + NO \rightarrow O_2 + H_2O + NO^+$	(1) [-10]	-	-		Gst.
48.	$O_2^+ + H_2O + NO_2 \rightarrow O_2 + H_2O + NO_2^+$	(1) [-10]	-	-		Gst.
XIV. Positive-Ion-Atom Interchange:						
1.	$O^+ + NO \rightarrow O_2^+ + N$	-	-	-	$k < (1) \times 10^{-12}$; See Reaction XIII. 4	Est.
2. a.	$O^+ + N_2 \rightarrow NO^+ + N$	(1.2±0.1) [-12]	(-1.0±0.4)	0	$T < 750$ K	Chp. 18A +
b.	(See Note ae)	(8.0±2.0) [-14]	(2.0±0.2)	0	$T > 750$ K	Ref. 24-27
3.	$O^+ + H_2 \rightarrow OH^+ + H$	(2.6±0.5) [-9]	-	-		Chp. 18A
4.	$O^+ + N_2O \rightarrow NO^+ + NO$	(2.3±1.0) [-10]	-	-	See Reaction XIII. 7	Chp. 18A
5.	$O^+ + CO_2 \rightarrow O_2^+ + CO$	(1.1±0.3) [-9]	0	0		Chp. 18A

Table 24-1. (continued)

No.	Reaction	a	b	c	Notes	Sources
XIV. Positive-Ion-Atom Interchange: (continued)						
6.a.	$N^+ + O_2 \rightarrow NO^+ + O$ (See Note 2.)	$(2.8 \pm 1.0)[-10]$	$\begin{pmatrix} 0.00^{+0.80} \\ -0.17 \end{pmatrix}$	0	$T = 4600 \text{ K}$	Chp. 18A
b.		$(6 \pm 1)[-11]$	(0.57 ± 0.05)	0	$T = T_i \sim 4600 \text{ K}$	
7.	$N^+ + H_2 \rightarrow NH^+ + H$	$(5.6 \pm 2.0)[-10]$	0	0		
8.	$C^+ + O_2 \rightarrow CO^+ + O$	$(1.3 \pm 0.3)[-9]$	0	0		Ref. 24-41
9.	$C^+ + CO_2 \rightarrow CO^+ + CO$	$(1.8 \pm 0.6)[-9]$	0	0		
10.	$Fe^+ + O_3 \rightarrow FeO^+ + O_2$	$(1.5 \pm 0.8)[-10]$	0	0		Chp. 18A
11.	$S^+ + O_2 \rightarrow SO^+ + O$	$(1.6 \pm 0.3)[-11]$	0	0		
12.	$U^+ + O_2 \rightarrow UO^+ + O$	$\begin{pmatrix} 8.5^{+4.0} \\ -1.0 \end{pmatrix}[-10]$	0	0		
13.	$U^+ + NO \rightarrow UO^+ + N$	$(1)[-9^{+0}]{-1}$	0	0		Est.
14.	$U^+ + N_2 \rightarrow UN^+ + N$	-	-	-	$k < (10^{-11})$; see Note af	Chp. 18A
15.a.	$O_2^+ + N \rightarrow NO^+ + O$	$(1.2 \pm 0.4)[-10]$	0	0		Chp. 18A + Ref. 24-42
b.	$-O^+ + NO$	-	-	-	Note ag	Chp. 18A
16.	$O_2^+ + Na \rightarrow NaO^+ + O$	$(7.7 \pm 3.0)[-11]$	0	0	Cf. Reaction XIII. 18	
17.	$O_2^+ + N_2 \rightarrow NO^+ + NO$	$(1)[-16^{+1}]{-3}$	0	0	Note ah	Est.
18.	$O_2^+ + H_2 \rightarrow \text{Products}$	-	-	-	$k < (10^{-11})$	Chp. 18A

Table 24-1. (continued)

No.	Reaction	a	b	c	Notes	Sources
XIV. Positive-Ion-Atom Interchange: (continued)						
19. a.	$N_2^+ + O \rightarrow NO^+ + N$	(1.3±0.7)[-10]	(-0.46)	0	$T = T_1 < 1500 \text{ K}$	Chp. 18A + Ref. 24-38
b.	(Cf. Reaction XIII.29)	(4.8±2.0)[-11]	(0.18)	0	$T = T_1 > 1500 \text{ K};$ See Note <u>aj</u>	Chp. 18A
20.	$N_2^+ + O_2 \rightarrow NO^+ + NO$	(1)[-17±2]	0	0	Cf. Reaction XIII.32	Est.
21.	$N_2^+ + H_2 \rightarrow N_2H^+ + H$	(1.7±0.3)[-9]	0	0		Chp. 18A
22.	$N_2^+ + H_2O \rightarrow N_2H^+ + OH$	-	-	-	Note <u>ad</u>	
23.	$NO_2^+ + O \rightarrow NO^+ + O_2$	-	-	-	$k < 10^{10} \text{ l}^2 \text{ mol}^{-2} \text{ s}^{-1}$	Ref. 24-42
24.	$N_3^+ + O_2 \rightarrow \begin{cases} NO^+ + N_2 + O \\ NO_2^+ + N_2 \end{cases}$	(6.0±1.8)[-11]	(-0.52)	0	$T = T_1 < 900 \text{ K};$ Note <u>aj</u>	Ref. 24-43
25.	$N_3^+ + NO \rightarrow \begin{cases} NO^+ + N_2 + N \\ N_2O^+ + N_2 \end{cases}$	(1.4±0.4)[-10]	(-0.38)	0	$T = T_1 < 600 \text{ K};$ Note <u>aj</u>	
26.	$H_2O^+ + H_2O \rightarrow H_3O^+ + OH$	(1.8±0.3)[-9]	0	0		Chp. 18A
27.	$CO_2^+ + O \rightarrow O_2^+ + CO$	(1.6±0.8)[-10]	0	0	Cf. Reaction XIII.38	
28.	$O_4^+ + O \rightarrow O_2^+ + O_3$	(3±2)[-10]	-	-		
29.	$O_4^+ + H_2O \rightarrow O_2^+ + H_2O + O_2$	(1.5±0.5)[-9]	-	-		
30.	$O_2^+ + N_2 + O_2 \rightarrow O_4^+ + N_2$	(1.0±0.5)[-9]	-	-		Est.

Table 24-1. (continued)

No.	Reaction	σ	b	c	Notes	Sources
XIV. Positive-Ion-Atom Interchange: (continued)						
31.	$O_2^+ \cdot N_2 + H_2O \rightarrow O_2^+ \cdot H_2O \cdot N_2$	$(4 \pm 2) \times 10^{-9}$	-	-		Chp. 18A
32.	$NO^+ \cdot NO + H_2O \rightarrow NO^+ \cdot H_2O \cdot NO$	$(1.4 \pm 0.3) \times 10^{-9}$	-	-		Ref. 24-37
33.	$H_2O_2^+ + H_2O \rightarrow H_3O^+ + HO_2$	$(1.7 \pm 0.5) \times 10^{-9}$	0	0	$T = 700 \text{ K}$	Ref. 24-25
34.	$H_3O^+ + HNO_3 \rightarrow NO_2^+ \cdot H_2C + H_2O$	$(1.6 \pm 0.6) \times 10^{-9}$	0	0		Est.
35.	$O_2^+ \cdot H_2O + O_2 \rightarrow O_4^+ + H_2O$	$(2) \times 10^{-10}$	0	2300	$k_{300} = (9.4 \pm 1.4) \times 10^{-11}$	Chp. 18A
36.	$O_2^+ \cdot H_2O + H_2O \rightarrow H_3O^+ + OH \cdot O_2$	$(2.0 \pm 1.0) \times 10^{-10}$	-	-		Chp. 18A
b.	$-H_3O^+ \cdot OH \cdot O_2$	$(1.0 \pm 0.4) \times 10^{-9}$	-	-		Chp. 18A
37.	$NO^+ \cdot N_2 + H_2O \rightarrow NO^+ \cdot H_2O \cdot N_2$	$(1.0) \times 10^{-9}$	-	-		Gst.
38.	$NO^+ \cdot N_2 + CO_2 \rightarrow NO^+ \cdot CC_2 \cdot N_2$	$(1.0) \times 10^{-9}$	-	-		Gst.
39.	$NO^+ \cdot H_2O + O \rightarrow NO_2^+ \cdot H_2O$	-	-	-	$k < (1) \times 10^{-11}$	Ref. 24-42
40.	$NO^+ \cdot H_2O + H \rightarrow H_3O^+ + NO$	-	-	-	$k < (7) \times 10^{-12}$	Ref. 24-28
41.	$NO^+ \cdot H_2O + NO \rightarrow NO^+ \cdot NO \cdot H_2O$	$(2.0 \pm 0.4) \times 10^{-10}$	0	2300	$k_{300} = (9.4 \pm 1.9) \times 10^{-14}$	Ref. 24-44
42.	$NO^+ \cdot H_2O + OH \rightarrow H_3O^+ + NO_2$	-	-	-	$k \leq (6.0) \times 10^{-11}$	Ref. 24-45
43.	$NO^+ \cdot H_2O + HC_2 \rightarrow H_3O^+ + NO \cdot O_2$	$(5.0) \times 10^{-10}$	-	-		Est.

Table 24-1. (continued)

No.	Reaction	a	b	c	Notes	Sources
XIV. Positive-Ion-Atom Interchange: (continued)						
44. a.	$\text{NO}^+ \cdot \text{H}_2\text{O} \cdot \text{H}_2\text{O}_2 \cdot \text{H}_3\text{O}^+ \cdot \text{NO}_2 \cdot \text{OH}$	(3.0) [-11]	-	-	Note ok	Ref. 24-28
b.	$\text{NO}_2^+ + 2\text{H}_2\text{O}$	(3.0) [-11]	-	-		
c.	$\text{NO}_2^+ \cdot \text{H}_2\text{O} \cdot \text{H}_2\text{O}$	(3.0) [-11]	-	-		
45.	$\text{NO}^+ \cdot \text{CO}_2 \cdot \text{NO} \cdot \text{NO}^+ \cdot \text{NC} \cdot \text{CO}_2$	(1.0) [-9]	-	-		Gst.
46.	$\text{NO}^+ \cdot \text{CO}_2 \cdot \text{H}_2\text{O} \cdot \text{NO}^+ \cdot \text{H}_2\text{O} \cdot \text{CO}_2$	(1.0 ± 0.3) [-9]	-	-		Chp. 18A
47.	$\text{NO}^+ (\text{H}_2\text{O})_3 \cdot \text{H}_2\text{O} \cdot \text{H}_3\text{O}^+ (\text{H}_2\text{O})_2 \cdot \text{HNO}_2$	(7-2) [-11]	-	-		
48.	$\text{NO}^+ \cdot \text{H}_2\text{O} \cdot \text{N}_2 + \text{CO}_2 \cdot \text{NO}^+ \cdot \text{H}_2\text{O} \cdot \text{CO}_2 \cdot \text{N}_2$	(1.0) [-9]	-	-		Est.
49.	$\text{NO}^+ \cdot \text{H}_2\text{O} \cdot \text{CO}_2 \cdot \text{H}_2\text{O} \cdot \text{NO}^+ (\text{H}_2\text{O})_2 \cdot \text{CO}_2$	(1.0) [-9]	-	-		
50.	$\text{NO}^+ (\text{H}_2\text{O})_2 \cdot \text{N}_2 \cdot \text{CO}_2 \cdot \text{NO}^+ (\text{H}_2\text{O})_2 \cdot \text{CO}_2 \cdot \text{N}_2$	(1.0) [-9]	-	-		
51.	$\text{NO}^+ (\text{H}_2\text{O})_2 \cdot \text{CO}_2 \cdot \text{H}_2\text{O} \cdot \text{NO}^+ (\text{H}_2\text{O})_3 \cdot \text{CO}_2$	(1.0) [-9]	-	-		Ref. 24-25
52.	$\text{NO}_2^+ \cdot \text{H}_2\text{O} \cdot \text{NO} \cdot \text{NO}^+ \cdot \text{H}_2\text{O} \cdot \text{NO}_2$	(3.1-0.9) [-11]	0	0		

Table 24-1. (continued)

No.	Reaction	a	b	c	Notes	Sources
XIV. Positive-Ion-Atom Interchange: (continued)						
53.	$\text{NO}_2^+(\text{H}_2\text{O})_2 + \text{H}_2\text{O} \rightarrow \text{H}_3\text{O}^+ \cdot \text{H}_2\text{O} + \text{HNO}_3$	-	-	-	$k \sim (1.0) \times 10^7$	Ref. 24-25
54.	$\text{H}_3\text{O}^+ \cdot \text{N}_2 + \text{H}_2\text{O} \rightarrow \text{H}_3\text{O}^+ \cdot \text{H}_2\text{O} + \text{N}_2$	(1.0) [-9]	-	-		Est.
55.	$\text{H}_3\text{O}^+ \cdot \text{OH} + \text{H}_2\text{O} \rightarrow \text{H}_3\text{O}^+ \cdot \text{H}_2\text{O} + \text{OH}$	(1.4 ± 0.5) [-9]	0	0		Chp. 18A
XV. Negative-Ion Charge Transfer:						
1.	$\text{O}^- + \text{O}_2(\alpha^1\Delta_g) \rightarrow \text{O} + \text{O}_2^-$	-	-	-	$k_{300} \sim (1) \times 10^7$; Cf. Reaction XII. 4	Est.
2.	$\text{O}^- + \text{OH} \rightarrow \text{O} + \text{OH}^-$	(5.0) [-10]	-	-		Gst.
3.	$\text{O}^- + \text{O}_3 \rightarrow \text{O} + \text{O}_3^-$	(5.3 ± 2.0) [-10]	0	0	See Reaction XII. 9	} Chp. 18A
4.	$\text{O}^- + \text{NO}_2 \rightarrow \text{O} + \text{NO}_2^-$	(1.2 ± 0.4) [-9]	-	-		
5.	$\text{O}^- + \text{NO}_3 \rightarrow \text{O} + \text{NO}_3^-$	(5.0) [-10]	-	-		Gst.
6.	$\text{H}^- + \text{NO}_2 \rightarrow \text{H} + \text{NO}_2^-$	(2.9 ± 1.0) [-9]	0	0		Chp. 18A
7.	$\text{O}_2^- + \text{O} \rightarrow \text{O}_2 + \text{O}^-$	(1.5) [-10.0 ± 0.3]	-	-	See Reaction XII. 10	Ref. 24-26
8.	$\text{O}_2^- + \text{OH} \rightarrow \text{O}_2 + \text{OH}^-$	(5) [-10]	-	-		Est.
9.	$\text{O}_2^- + \text{O}_3 \rightarrow \text{O}_2 + \text{O}_3^-$	(4.0 ± 1.3) [-10]	0	0		Chp. 18A
10.	$\text{O}_2^- + \text{NO}_2 \rightarrow \text{O}_2 + \text{NO}_2^-$	(1.2 ± 0.5) [-9]	0	0		Chp. 18A + Ref. 24-46

Table 24-1. (continued)

No.	Reaction	a	b	c	Notes	Sources
XV. Negative-Ion Charge Transfer: (continued)						
11.	$\text{O}_2^- + \text{NO}_3^- \rightarrow \text{O}_2 + \text{NO}_3^-$	(5)[-10]	-	-		Est.
12.	$\text{NO}^- + \text{O}_2 \rightarrow \text{NO} + \text{O}_2^-$	(5±2)[-10]	0	0		Chp. 18A
13.	$\text{OH}^- + \text{O}_3 \rightarrow \text{OH} + \text{O}_3^-$	(5)[-10]	-	-		Est.
14.	$\text{OH}^- + \text{NO}_2 \rightarrow \text{OH} + \text{NO}_2^-$	(1.0±0.3)[-9]	0	0		Chp. 18A
15.	$\text{OH}^- + \text{NO}_3 \rightarrow \text{OH} + \text{NO}_3^-$	(1)[-9]	-	-		Est.
16.	$\text{O}_3^- + \text{NO}_2 \rightarrow \text{O}_3 + \text{NO}_2^-$	(2.8±1.0)[-10]	0	0	$T = T_i < 2000 \text{ K};$ See Note a ²	Ref. 24-47
17.	$\text{O}_3^- + \text{NO}_3 \rightarrow \text{O}_3 + \text{NO}_3^-$	(5)[-10]	-	-		Est.
18.	$\text{NO}_2^- + \text{NO}_3 \rightarrow \text{NO}_2 + \text{NO}_3^-$	(5)[-10]	-	-		
19.	$\text{O}_4^- + \text{OH} \rightarrow 2\text{O}_2 + \text{OH}^-$	(5)[-10]	-	-		
20.	$\text{O}_4^- + \text{O}_3 \rightarrow 2\text{O}_2 + \text{O}_3^-$	(3)[-10]	-	-		
21.	$\text{O}_4^- + \text{NO}_2 \rightarrow 2\text{O}_2 + \text{NO}_2^-$	(5)[-10]	-	-		
22.	$\text{O}_4^- + \text{NO}_3 \rightarrow 2\text{O}_2 + \text{NO}_3^-$	(5)[-10]	-	-		
23.	$\text{OONO}^- + \text{NO}_3 \rightarrow \text{NO} + \text{O}_2 + \text{NO}_3^-$	(5)[-10]	-	-		
24.	$\text{CO}_3^- + \text{NO}_3 \rightarrow \text{CO}_2 + \text{O} + \text{NC}_3^-$	(5)[-10]	-	-		

Table 24-1. (continued)

No.	Reaction	a	b	c	Notes	Sources
XV. Negative-Ion Charge Transfer: (continued)						
25.	$\text{CO}_4^- + \text{OH} \rightarrow \text{CO}_2 + \text{O}_2 + \text{OH}^-$	(5) -10	-	-	} <u>Note am</u>	Est.
26.	$\text{CO}_4^- + \text{O}_3 \rightarrow \text{CO}_2 + \text{O}_2 + \text{O}_3^-$	(1, 3) -10, 0+0, 3	-	-		Ref. 24-46
27.	$\text{CO}_4^- + \text{NO}_3 \rightarrow \text{CO}_2 + \text{O}_2 + \text{NO}_3^-$	(5) -10	-	-		Est.
28.	$\text{O}_2^-\cdot\text{H}_2\text{O} + \text{O}_3 \rightarrow \text{O}_2 + \text{H}_2\text{O} + \text{O}_3^-$	(2, 3) -10, 0+0, 3	-	-		Chp. 18A + Ref. 24-46
29.	$\text{O}_2^-(\text{H}_2\text{O})_2 + \text{O}_3 \rightarrow \text{O}_2 + 2\text{H}_2\text{O} + \text{O}_3^-$	(3, 4+1, 0) -10	0	0		Chp. 18A
XVI. Negative-Ion-Atom Interchange:						
1.	$\text{O}^- + \text{N}_2\text{O} \rightarrow \text{NO}^- + \text{NO}$	(2, 3+0, 5) -10	(-0, 23)	-	T = T _f = 2000 K	Ref. 24-48
2.	$\text{O}^- + \text{HNO}_2 \rightarrow \text{NO}_2^- + \text{OH}$	(1) -9	-	-		Est.
3.	$\text{O}^- + \text{HNO}_3 \rightarrow \text{NO}_3^- + \text{OH}^-$	(3, 0+1, 2) -9	-	-		Ref. 24-25
4.	$\text{O}^- + \text{CH}_4 \rightarrow \text{OH}^- + \text{CH}_3$	(8+2) -11	(-0, 12)	-	T = T _f = 600 K	Ref. 24-48
5.	$\text{O}_2^- + \text{N} \rightarrow \text{O}^- + \text{NO}$	(1) -10, 0+0, 3	-	-		Ref. 24-48
6.	$\text{O}_2^- + \text{N}_2\text{O} \rightarrow \text{O}_3^- + \text{N}_2$	-	-	-	k (2) -14	Ref. 24-49
7.	$\text{O}_2^- + \text{HNO}_2 \rightarrow \text{NO}_2^- + \text{HO}_2$	(1) -9	-	-		Est.
8.	$\text{O}_2^- + \text{HNO}_3 \rightarrow \text{NO}_3^- + \text{HO}_2$	(2, 8+1, 2) -9	-	-		Ref. 24-25
9.	$\text{OH}^- + \text{HNO}_2 \rightarrow \text{NO}_2^- + \text{H}_2\text{O}$	(1) -9	-	-		Est.

Table 24-1. (continued)

No.	Reaction	σ	δ	ϵ	Notes	Sources
XVI. Negative-Ion-Atom Interchange: (continued)						
10.	$\text{OH}^- + \text{HNO}_3 \rightarrow \text{NO}_3^- + \text{H}_2\text{O}$	(1) [-9]	-	-		Est.
11.	$\text{O}_3^- + \text{O} \rightarrow \text{O}_2^- + \text{O}_2$	(3.2) [-10.0 ± 0.3]	-	-		Ref. 24-26
12.	$\text{O}_3^- + \text{H} \rightarrow \text{OH}^- + \text{O}_2$	(8.4) [-10.0 ± 0.3]	-	-		Ref. 24-31
13.	$\text{O}_3^- + \text{NO} \rightarrow \text{NO}_2^- + \text{O}_2$	(2.8 ± 0.8) [-12]	(-1.8)	0	$T = T_1$; 600 K; Note <u>an</u>	Ref. 24-47
14.	$\text{O}_3^- + \text{N}_2 \rightarrow \text{N}_2\text{O}^- + \text{O}_2$	-	-	-	$k < (1) [-15]$	Chp. 18A
15.	$\text{O}_3^- + \text{NO}_2 \rightarrow \text{NO}_3^- + \text{O}_2$	-	-	-	Note <u>af</u>	
16.	$\text{O}_3^- + \text{N}_2\text{O} \rightarrow \text{O}_4^- + \text{N}_2$	-	-	-	$k < (2) [-14]$	Ref. 24-49
17.	$\text{O}_3^- + \text{CO}_2 \rightarrow \text{CO}_3^- + \text{O}_2$	(5.5 ± 1.7) [-10]	(-0.49)	0	$T = T_1$; < 600 K; Note <u>ap</u>	Ref. 24-47
18.	$\text{O}_3^- + \text{HNO}_2 \rightarrow \text{NO}_2^- + \text{OH}^- + \text{O}_2$	(1) [-9]	-	-		Est.
19.	$\text{O}_3^- + \text{HNO}_3 \rightarrow \text{NO}_3^- + \text{OH}^- + \text{O}_2$	(1) [-9]	-	-		Est.
20.	$\text{NO}_2^- + \text{O} \rightarrow \text{Products}$	-	-	-		Chp. 18A
21.	$\text{NO}_2^- + \text{N} \rightarrow \text{Products}$	-	-	-	$k < (1) [-11]$	Chp. 18A
22.	$\text{NO}_2^- + \text{H} \cdot \text{OH}^- \rightarrow \text{NO}$	(3.7) [-10.0 ± 0.3]	-	-		Ref. 24-31
23.	$\text{NO}_2^- + \text{O}_3 \rightarrow \text{NO}_3^- + \text{O}_2$	(1.8 ± 0.6) [-11]	-	-		Chp. 18A
24.	$\text{NO}_2^- + \text{NO}_2 \rightarrow \text{NO}_3^- \cdot \text{NO}$	-	-	-	$k < 2.0 [-13]$; Note <u>ap</u>	Chp. 18A + Ref. 24-25

Table 24-1. (continued)

No.	Reaction	a	b	c	Notes	Sources
XVI. Negative-Ion-Atom Interchange: (continued)						
25.	$\text{NO}_2^- + \text{N}_2\text{O} \rightarrow \text{NO}_3^- + \text{N}_2$	-	-	-	k (1)-12]	Ref. 24-49
26.	$\text{N}_2\text{O} + \text{HNO}_3 \rightarrow \text{NO}_3^- + \text{HNO}_2$	(1.6±0.6)-9]	-	-		Ref. 24-25
27.	$\text{O}_4^- + \text{O} \rightarrow \text{O}_3^- + \text{O}_2$	(4-2)-10]	-	-	Note aq	Chp. 18A
28.	$\text{O}_4^- + \text{NO} \rightarrow \text{OONO}^- + \text{O}_2$	(2.5±0.8)-10]	-	-		
29.	$\text{O}_4^- + \text{H}_2\text{O} \rightarrow \text{O}_2^- + \text{H}_2\text{O} + \text{O}_2$	(1.4±0.4)-9]	-	-		
30.	$\text{O}_4^- + \text{CO}_2 \rightarrow \text{CO}_3^- + \text{O}_2$	(4.3±1.3)-10]	-	-		Est.
31.	$\text{O}_4^- + \text{HNO}_2 \rightarrow \text{NO}_2^- + \text{HO}_2 + \text{O}_2$	(1)-9]	-	-		
32.	$\text{O}_4^- + \text{HNO}_3 \rightarrow \text{NO}_3^- + \text{HO}_2 + \text{O}_2$	(1)-9]	-	-		
33.	$\text{NO}_3^- + \text{O} \rightarrow \text{Products}$	-	-	-	k < (1)-11]	Chp. 18A
34.	$\text{NO}_3^- + \text{N} \rightarrow \text{NO}_2^- + \text{NO}$	-	-	-		
35.	$\text{NO}_3^- + \text{H} \rightarrow \text{NO}_2^- + \text{OH}$	-	-	-	k (5)-10]	
36.	$\text{NO}_3^- + \text{NO} \rightarrow \text{NO}_2^- + \text{NO}_2$	-	-	-	k < (1)-12; Note ap	Chp. 18A
37.	$\text{NO}_3^- + \text{O}_3 \rightarrow \text{NO}_2^- + 2\text{O}_2$	-	-	-	k < (1)-13]	Ref. 24-28
38.	$\text{OONO}^- + \text{H} \rightarrow \begin{cases} \text{NO}_2^- + \text{OH} \\ \text{OH}^- + \text{NO}_2 \end{cases}$	(7.2)-10.0±0.3]	-	-		Ref. 24-31

Table 24-1. (continued)

No.	Reaction	a	b	c	Notes	Sources
XVI. Negative-Ion-Atom Interchange: (continued)						
39.	$\text{OONO}^- + \text{NO} \rightarrow \text{NO}_2^- + \text{NO}_2$	(1.5)[-11-11]	-	-	Note <u>ap</u>	Chp. 18A
40.	$\text{OONO}^- + \text{HNO}_2 \rightarrow \text{NO}_2^- + \text{NO} + \text{HO}_2$	(1)[-9]	-	-	}	Est.
41.	$\text{OONO}^- + \text{HNO}_3 \rightarrow \text{NO}_3^- + \text{NO} + \text{HO}_2$	(1)[-9]	-	-		
42.	$\text{CO}_3^- + \text{O} \rightarrow \text{O}_2^- + \text{CO}_2$	(1.1)[-10.0-0.3]	-	-		Chp. 18A
43.	$\text{CO}_3^- + \text{H} \rightarrow \text{OH}^- + \text{CO}_2$	(1.7)[-10.0-0.3]	-	-	See Reaction XII. 17	Ref. 24-31
44.	$\text{CO}_3^- + \text{NO} \rightarrow \text{NO}_2^- + \text{CO}_2$	(1.1±0.3)[-11]	(-1, 1)	0	T = 600 K	Chp. 18A + Ref. 24-47
45.	$\text{CO}_3^- + \text{NO}_2 \rightarrow \text{NO}_3^- + \text{CO}_2$	(2.0±1.0)[-10]	0	0		Ref. 24-46
46.	$\text{CO}_3^- + \text{N}_2\text{O} \rightarrow \text{CO}_4^- + \text{N}_2$	-	-	-	k < (5)[-13]	Ref. 24-49
47.	$\text{CO}_3^- + \text{HNO}_2 \rightarrow \text{NO}_2^- + \text{CO}_2 + \text{OH}$	(1)[-9]	-	-		Est.
48.	$\text{CO}_3^- + \text{HNO}_3 \rightarrow \text{NO}_3^- + \text{CO}_2 + \text{OH}$	(8.0±3.0)[-10]	-	-		Ref. 24-25
49.	$\text{CO}_4^- + \text{O} \rightarrow \text{CO}_3^- + \text{O}_2$	(1.5±0.8)[-10]	-	-	Note <u>ap</u>	Chp. 18A
50.	$\text{CO}_4^- + \text{H} \rightarrow \text{CO}_3^- + \text{OH}$	(2.2)[-10.0-0.3]	-	-		Ref. 24-31
51.	$\text{CO}_4^- + \text{O}_2 \rightarrow \text{O}_4^- + \text{CO}_2$	(4.3)[-10]	0	3000	k ₃₀₀ (2.0)[-14]; Note <u>ap</u>	Est.
52.	$\text{CO}_4^- + \text{NO} \rightarrow \text{OONO}^- + \text{CO}_2$	(4.8±2.0)[-11]	-	-		Chp. 18A

Table 24-1. (continued)

No.	Reaction	a	b	c	Notes	Sources
XVI. Negative-Ion-Atom Interchange: (continued)						
53.	$\text{CO}_4^- + \text{HNO}_2 \rightarrow \text{NO}_2^- + \text{CO}_2 + \text{HO}_2$	(1) [-9]	-	-	}	Est.
54.	$\text{CO}_4^- + \text{HNO}_3 \rightarrow \text{NO}_3^- + \text{CO}_2 + \text{HO}_2$	(1) [-9]	-	-		
55.	$\text{O}_2^- \cdot \text{H}_2\text{O} + \text{NO} \rightarrow \text{OONO}^- + \text{H}_2\text{O}$	(3.1 ± 1.0) [-10]	-	-		
56.	$\text{O}_2^- \cdot \text{H}_2\text{O} + \text{CO}_2 \rightarrow \text{CO}_4^- + \text{H}_2\text{O}$	(5.8 ± 1.0) [-10]	-	-		
57.	$\text{NO}_2^- \cdot \text{H}_2\text{O} + \text{O}_3 \rightarrow \text{NO}_3^- \cdot \text{H}_2\text{O} + \text{O}_2$	(1) [-11]	-	-	}	Gst.
58.	$\text{NO}_3^- \cdot \text{H}_2\text{O} + \text{HNO}_3 \rightarrow$ $\text{NO}_3^- \cdot \text{HNO}_3 \cdot \text{H}_2\text{O}$	-	-	-		
59.	$\text{CO}_3^- \cdot \text{H}_2\text{O} + \text{NO} \rightarrow \text{NO}_2^- \cdot \text{H}_2\text{O} + \text{CO}_2$	(7.0 ± 2.5) [-12]	0	0		
60.	$\text{CO}_4^- \cdot \text{H}_2\text{O} + \text{NO} \rightarrow \text{NO}_3^- \cdot \text{H}_2\text{O} + \text{CO}_2$	(1) [-11]	-	-	}	Gst.
XVII. Radiation-Stabilized Positive-Ion-Neutral Association:						
1.	$\text{X}^+ + \text{Y} \xrightarrow{f} (\text{XY})^+ \rightarrow \text{XY}^+ + h\nu$	(1) [-19.0 ± 0.5] (1) [-15.0 ± 0.5] (1) [-13.0 ± 0.5]	0 0 0	0 0 0	Monatomic reactants Diatomic reactants Polyatomic and complex reactants	}

Table 24-1. (continued)

No.	Reaction	a	b	c	Notes	Sources
XVIII. Positive-Ion Photodissociation:						
1.	$O_4^+ \cdot h\nu \rightarrow O_2^+ + O_2$	$(3.2 \pm 1.3) \times 10^{-11}$	0	0	Note at <u>Ref. 24-31</u>	Ref. 24-31
2.	$O_2^+ \cdot H_2O \cdot h\nu \rightarrow O_2^+ \cdot H_2O$	$(4.2 \pm 2.1) \times 10^{-11}$	0	0		
3.	$NO^+ \cdot H_2O \cdot h\nu \rightarrow NO^+ \cdot H_2O$	$(2.0) \times 10^{-12}$	0	0		
XIX. Three-Body Positive-Ion-Neutral Association:						
1.	$O^+ + N_2 + M \rightarrow NO^+ + N + M$	$(6.0) \times 10^{-29}$	(-2.0 ± 1.0)	0	Notes at, <u>av</u> ; See Reaction XIV. 2	Chp. 18A
2.	$N^+ + N_2 + M \rightarrow N_3^+ + M$	$(1.8 \pm 0.2) \times 10^{-29}$	$(-1.0^{+0.5}_{-1.0})$	0	M: N ₂ ; Note at <u>Ref. 24-53, 24-54</u>	Refs. 24-53, 24-54
3.	$O_2^+ + O_2 + M \rightarrow O_4^+ + M$	$(3.9) \times 10^{-30}$	(-3.2 ± 0.5)	0	Notes <u>av</u> , <u>av</u>	Ref. 24-55
4.	$O_2^+ + N_2 + M \rightarrow O_2^+ \cdot N_2 + M$	$(9.0) \times 10^{-31}$	(-2.0 ± 1.0)	0	Notes at, <u>av</u>	Chp. 18A
5.	$O_2^+ + O_3 + M \rightarrow O_5^+ + M$	$(1.0^{+3.0}_{-0.7}) \times 10^{-28}$	-	-	M: He	Ref. 24-56
6.	$O_2^+ \cdot H_2O + M \rightarrow O_2^+ \cdot H_2O + M$	$(2.8) \times 10^{-28}$	(-2.0 ± 0.3)	0	M: N ₂ ; Note <u>av</u>	Ref. 24-57
7.	$NO^+ \cdot NO + M \rightarrow NO^+ \cdot NO + M$	$(5.0) \times 10^{-30}$	(-2.0 ± 1.0)	0	M: NO; Note at <u>Ref. 24-58</u>	Chp. 18A
8.	$NO^+ \cdot N_2 + M \rightarrow NO^+ \cdot N_2 + M$	$(2) \times 10^{-31} \pm 0.2$	(-4.4 ± 0.5)	0	M: N ₂	Chp. 18A
9.	$NO^+ \cdot O_3 + M \rightarrow NO^+ \cdot O_3 + M$	$(1.0^{+3.0}_{-0.7}) \times 10^{-29}$	-	-	M: He	Ref. 24-56
10.	$NO^+ \cdot H_2O + M \rightarrow NO^+ \cdot H_2O + M$	$(1.5) \times 10^{-28}$	(-2.0 ± 1.0)	0	M: N ₂ ; Note at <u>Ref. 24-58</u>	Chp. 18A

Table 24-1. (continued)

No.	Reaction	a	b	c	Notes	Sources
XIX. Three-Body Positive-Ion-Neutral Association: (continued)						
11. a	$\text{NO}^+ + \text{CO}_2 + \text{M} - \text{NO}^+ \cdot \text{CO}_2 + \text{M}$	(3) -29	(-2.0 ± 1.0)	0	Data at 200 K; M = N ₂ ; Note at	Chp. 18A
b		(2) -29	(-2.3 ± 1.5)	0	M CO ₂ ; Note at	
12.	$\text{N}_2^+ + \text{N}_2 + \text{M} - \text{N}_4^+ + \text{M}$	(5.0) -29	(-1.0 ^{+0.5} -1.0)	0	M N ₂ ; Note at	
13.	$\text{NO}_2^+ + \text{H}_2\text{O} + \text{M} - \text{NO}_2^+ \cdot \text{H}_2\text{O} + \text{M}$	(5.0) -28	(-2.0 ± 1.0)	0	M = N ₂ ; Note at	Ref. 24-25
14.	$\text{H}_3\text{O}^+ + \text{N}_2 + \text{M} - \text{H}_3\text{O}^+ \cdot \text{N}_2 + \text{M}$	(1.4) -30	(-2.0 ± 1.0)	0	Est.	Chp. 18A
15. a	$\text{H}_3\text{O}^+ + \text{H}_2\text{O} + \text{M} - \text{H}_3\text{O}^+ \cdot \text{H}_2\text{O} + \text{M}$	(3.7) -27	(-2.0 ± 1.0)	0	Data at 307 K; M = O ₂ ; Note at	
b		(3.4) -27	(-4.0 ± 2.0)	0	M N ₂ ; Note at	
16.	$\text{NO}^+ \cdot \text{H}_2\text{O} + \text{N}_2 + \text{M} - \text{NO}^+ \cdot \text{H}_2\text{O} \cdot \text{N}_2 + \text{M}$	(2.0) -31	(-4.4 ± 0.5)	0	Est.	Chp. 18A
17.	$\text{NO}^+ \cdot \text{H}_2\text{O} + \text{H}_2\text{O} + \text{M} - \text{NO}^+ (\text{H}_2\text{O})_2 + \text{M}$	(1.1) -27	(-4.7 ± 1.0)	0	M = N ₂ ; Note at	
18.	$\text{NO}^+ \cdot \text{H}_2\text{C} + \text{CO}_2 + \text{M} - \text{NO}^+ \cdot \text{H}_2\text{O} \cdot \text{CO}_2 + \text{M}$	(2.0) -29	(-2.0 ± 1.0)	0	Est.	
19.	$\text{NO}^+ (\text{H}_2\text{O})_2 + \text{N}_2 + \text{M} - \text{NO}^+ (\text{H}_2\text{O})_2 \cdot \text{N}_2 + \text{M}$	(2.0) -31 ± 1	(-4.4 ± 1.0)	0	Gst.	

Table 24-1. (continued)

No.	Reaction	a	b	c	Notes	Sources
XIX. Three-Body Positive-Ion-Neutral Association: (continued)						
20.	$\text{NO}^+(\text{H}_2\text{O})_2 + \text{H}_2\text{O} + \text{M} -$ $\text{NO}^+(\text{H}_2\text{O})_3 + \text{M}$	(1.6) [-27]	(-4.7 ± 1.0)	0	M N_2 ; Note at	Chp. 18A
21.	$\text{NO}^+(\text{H}_2\text{O})_2 + \text{CO}_2 + \text{M} -$ $\text{NO}^+(\text{H}_2\text{O})_2\text{CO}_2 + \text{M}$	(2.0) [-29 ± 1]	(-2.0 ± 1.0)	0		Gas.
22.	$\text{NO}_2^+\text{H}_2\text{O} + \text{H}_2\text{O} + \text{M} -$ $\text{NO}_2^+(\text{H}_2\text{O})_2 + \text{M}$	(2.0) [-27]	(-2.0 ± 1.0)	0	M N_2 ; Note at	Ref. 24-25
23. a.	$\text{H}_3\text{O}^+\text{H}_2\text{O} + \text{H}_2\text{O} + \text{M} -$ $\text{H}_3\text{O}^+(\text{H}_2\text{O})_2 + \text{M}$	(2.0) [-27]	(-4.0 ± 2.0)	0	Data at 307 K; M = O_2 ; Note at	Chp. 18A
b.		(2.3) [-27]	(-2.0 ± 1.0)	0	M N_2 ; Note at	
24. a.	$\text{H}_3\text{O}^+(\text{H}_2\text{O})_2 + \text{H}_2\text{O} + \text{M} -$ $\text{H}_3\text{O}^+(\text{H}_2\text{O})_3 + \text{M}$	(2.0) [-27]	(-4.0 ± 2.0)	0	Data at 307 K; M = O_2 ; Note at	
b.		(2.4) [-27]	(-2.0 ± 1.0)	0	M N_2 ; Note at	
25.	$\text{H}_3\text{O}^+(\text{H}_2\text{O})_3 + \text{H}_2\text{O} + \text{M} -$ $\text{H}_3\text{O}^+(\text{H}_2\text{O})_4 + \text{M}$	(9.0) [-28]	(-4.0 ± 2.0)	0	Data at 307 K; M = O_2 ; Note at	

Table 24-1. (continued)

No.	Reaction	σ	b	c	Notes	Sources
XX. Positive-Ion Collisional Dissociation: (See Note ay)						
1.	$O_4^+ + M \rightarrow O_2^+ + O_2 + M$	(1) $[-5 \pm 1]$	(-4.2 ± 0.2)	5400 ± 300	Notes az, bz; $k_{300} = [3.9 \pm 2.0] \times 10^{-13}$; or $(2.8 \pm 1.4) \times 10^{-13}$ for $M = N_2$ or O_2 , respectively	Ref. 24-59
2.	$NO^+ \cdot NO + M \rightarrow NO^+ + NO + M$	$(3.3 \pm 2.3) \times 10^{-5}$	(-1)	7300 ± 1000	$k_{300} = (9 \pm 2) \times 10^{-16}$; $M = NO$	Refs. 24-44, 24-60
3.	$NO^+ \cdot N_2 + M \rightarrow NO^+ + N_2 + M$	(1) $[-8 \pm 1]$	(-5.4 ± 0.5)	2100 ± 300	$k_{300} = (9 \pm 8) \times 10^{-12}$; $M = N_2$	Ref. 24-59
4.	$NO^+ \cdot H_2O + M \rightarrow NO^+ + H_2O + M$	(2) $[-5]$	(-1)	9300	Estimated value; $k_{300} = (7) \times 10^{-19}$	Ref. 24-61
5.	$NO^+ \cdot CO_2 + M \rightarrow NO^+ + CO_2 + M$	(2) $[-5 \pm 2]$	(-3.3 ± 1.5)	5500 ± 1300	Note bb; $k_{300} = [2.4 \pm 1.0] \times 10^{-13}$ or $(4.0 \pm 1.6) \times 10^{-13}$ for $M = N_2$ or CO_2 , respectively	Ref. 24-59
6.	$NO^+ \cdot (H_2O)_2 + M \rightarrow NO^+ \cdot H_2O + H_2O + M$	(1) $[-2 \pm 1]$	(-5.7 ± 1.0)	8100 ± 500	$k_{300} = (1.7 \pm 0.5) \times 10^{-14}$; $M = N_2$; Note az	
7.	$NO^+ \cdot (H_2O)_3 + M \rightarrow NO^+ \cdot (H_2O)_2 + H_2O + M$	(1) $[-2.0 \pm 1.3]$	(-5.7 ± 1.0)	6800 ± 800	$k_{300} = (1.4 \pm 0.3) \times 10^{-12}$ $M = N_2$; Notes az, bz	
8.	$NO^+ \cdot H_2O \cdot N_2 + M \rightarrow NO^+ \cdot H_2O + N_2 + M$	(5) $[-8]$	(-5.4)	2100	Estimated value; $k_{300} = (5) \times 10^{-11}$	Ref. 24-59
9.	$NO^+ \cdot H_2O \cdot CO_2 + M \rightarrow NO^+ \cdot H_2O + CO_2 + M$	(2) $[-4]$	(-3.3)	5500	Estimated value; $k_{300} = (2) \times 10^{-12}$	

Table 24-1. (continued)

No.	Reaction	a	b	c	Notes	Sources
XX. Positive-Ion Collisional Dissociation: (continued) (See Note ay)						
10.	$\text{NO}^+(\text{H}_2\text{O})_2\text{N}_2 + \text{M} \rightarrow \text{NO}^+(\text{H}_2\text{O})_2 + \text{N}_2 + \text{M}$	(5) -7	(-5.4)	2100	Estimated value; $k_{300} = (5) -10$	Ref. 24-59
11.	$\text{NO}^+(\text{H}_2\text{O})_2\text{CO}_2 + \text{M} \rightarrow \text{NO}^+(\text{H}_2\text{O})_2 + \text{CO}_2 + \text{M}$	(2) -3	(-3.3)	5500	Estimated value; $k_{300} = (2) -11$	
12.	$\text{H}_3\text{O}^+\text{N}_2 + \text{M} \rightarrow \text{H}_3\text{O}^+ + \text{N}_2 + \text{M}$	(2) -6	(-5)	4500	Estimated value; $k_{300} = (6) -13$	
13.	$\text{H}_3\text{O}^+\text{OH} + \text{M} \rightarrow \text{H}_3\text{O}^+ + \text{OH} + \text{M}$	(5) -1	(-5 ± 2)	13,000-4000	$k_{300} < (7) -18$; M N ₂ ; Note bd	
14.	$\text{H}_3\text{O}^+\text{H}_2\text{O} + \text{M} \rightarrow \text{H}_3\text{O}^+ + \text{H}_2\text{O} + \text{M}$	(1) -2.0 ± 1.5	(-5 ± 2)	16,000-1000	$k_{300} = (7) -26$; M N ₂ ; Note az	
15.	$\text{H}_3\text{O}^+(\text{H}_2\text{O})_2 + \text{M} \rightarrow \text{H}_3\text{O}^+\text{H}_2\text{O} + \text{H}_2\text{O} + \text{M}$	(2) -3 ± 1	(-5 ± 2)	10,000-600	$k_{300} = (7.0 \pm 2.8) -18$; M N ₂ ; Notes az, be	
16.	$\text{H}_3\text{O}^+(\text{H}_2\text{O})_3 + \text{M} \rightarrow \text{H}_3\text{O}^+(\text{H}_2\text{O})_2 + \text{H}_2\text{O} + \text{M}$	(1) -1.0 ± 1.5	(-5 ± 2)	8800-500	$k_{300} = (4.0 \pm 3.3) -14$; M N ₂ ; Note be	
17.	$\text{H}_3\text{O}^+(\text{H}_2\text{O})_4 + \text{M} \rightarrow \text{H}_3\text{O}^+(\text{H}_2\text{O})_3 + \text{H}_2\text{O} + \text{M}$	(1) 0.0 ± 1.3	(-5 ± 2)	7700-700	Notes ba, be; $k_{300} = (8.4 \pm 3.6) -12$ or $(6.0 \pm 2.6) -12$; for M N ₂ or O ₂ , respectively	

Table 24-1. (continued)

No.	Reaction	a	b	c	Notes	Sources
XXI. Radiation-Stabilized Negative-Ion-Neutral Association:						
1.	$O^- + O_2 \rightarrow O_3^- + h\nu$	(1) 17 ± 2	0	0		Est.
XXII. Negative-Ion Photodissociation:						
1.	$O_3^- + h\nu \rightarrow O^- + O_2$	(5) 21 ± 1	-	-		Ref. 24-62
2.	$O_4^- + h\nu \rightarrow O_2^- + O_2$	(3) 3 ± 1	-	-	Cf. Reaction VIII. 5	Ref. 24-18
3.	$OONO^- + h\nu \rightarrow O_2^- + NO$	(7) 21 ± 2	-	-	Estimated value	Ref. 24-63
4.	$CO_3^- + h\nu \rightarrow O^- + CO_2$	(2) 2 ± 1	-	-		Ref. 24-62
5.	$CO_4^- + h\nu \rightarrow O_2^- + CO_2$	(1, 4) 2.0 ± 0.3	-	-		Ref. 24-64
6.	$O_2^- \cdot H_2O + h\nu \rightarrow O_2^- + H_2O$	(1, 1) 1.0 ± 0.3	-	-		Ref. 24-18
7.	$NO_2^- \cdot H_2O + h\nu \rightarrow NO_2^- + H_2O$	(2) 1.0 ± 0.7	-	-		} Ref. 24-64
8.	$NO_3^- \cdot H_2O + h\nu \rightarrow NO_3^- + H_2O$	(7) 2.0 ± 0.7	-	-		
9.	$NO_3^- \cdot HNO_3 + h\nu \rightarrow NO_3^- + HNO_3$	(2) 1.0 ± 0.7	-	-		
10.	$CO_3^- \cdot H_2O + h\nu \rightarrow CO_3^- + H_2O$	(1, 0) 0.5 ± 0.1	-	-		Ref. 24-62
11.	$CO_4^- \cdot H_2O + h\nu \rightarrow CO_4^- + H_2O$	(2) 1.0 ± 0.7	-	-		Ref. 24-64

Table 24-1. (continued)

No.	Reaction	a	b	c	Notes	Sources
XXIII. Three-Body Negative-Ion-Neutral Association:						
1.	$O^- + O_2 + M \rightarrow O_3^- + M$	(1.1 ± 0.1) -30	$\begin{pmatrix} -1.0 & -0.5 \\ -1.0 & -1.0 \end{pmatrix}$	0	M = O ₂ ; Note at	Chc. 18A
2.	$O^- + NO + M \rightarrow NO_2^- + M$	{11} -29 ± 2	$\begin{pmatrix} -1.0 & -0.5 \\ -1.0 & -1.0 \end{pmatrix}$	0	Notes at, bf	Est.
3.	$O^- + N_2 + M \rightarrow N_2O^- + M$	(31) -31	$\begin{pmatrix} -1.0 & -0.5 \\ -1.0 & -1.0 \end{pmatrix}$	0	Data at 200 K; M = He; Note at	} Crc. 18A
4.	$O^- + H_2O + M \rightarrow H_2O_2^- + M$	(1.0) -28	$\begin{pmatrix} -1.0 & -0.5 \\ -1.0 & -1.0 \end{pmatrix}$	0	} M = O ₂ ; Note at	
5.	$O^- + CO_2 + M \rightarrow CO_3^- + M$	(3.1) -28	$\begin{pmatrix} -1.0 & -0.5 \\ -1.0 & -1.0 \end{pmatrix}$	0		Ref. 24-46
6.	$O_2^- + O_2 + M \rightarrow O_4^- + M$	(3.5 ± 0.5) -31	$\begin{pmatrix} -1.0 & -0.5 \\ -1.0 & -1.0 \end{pmatrix}$	0	Data at 200 K; M = He; Note at	} Chc. 18A
7.	$O_2^- + N_2 + M \rightarrow O_2^- \cdot N_2 + M$	(31) -32	$\begin{pmatrix} -1.0 & -0.5 \\ -1.0 & -1.0 \end{pmatrix}$	0	} M = O ₂ ; Note at	
8.	$O_2^- + H_2O + M \rightarrow O_2^- \cdot H_2O + M$	(31) -28	$\begin{pmatrix} -1.0 & -0.5 \\ -1.0 & -1.0 \end{pmatrix}$	0		M = NO; Note at
9.	$O_2^- + CO_2 + M \rightarrow CO_4^- + M$	(2.0) -29	$\begin{pmatrix} -1.0 & -0.5 \\ -1.0 & -1.0 \end{pmatrix}$	0	Note at	Ref. 24-65
10.	$O_3^- + H_2O + M \rightarrow O_3^- \cdot H_2O + M$	(2.1) -28	$\begin{pmatrix} -1.0 & -0.5 \\ -1.0 & -1.0 \end{pmatrix}$	0	M = O ₂ ; Note at	Ref. 24-46
11.	$NO_2^- + H_2O + M \rightarrow NO_2^- \cdot H_2O + M$	(1.3) -28	$\begin{pmatrix} -1.0 & -0.5 \\ -1.0 & -1.0 \end{pmatrix}$	0	Estimated value; Note at	Ref. 24-64
12.	$NO_3^- + H_2O + M \rightarrow NO_3^- \cdot H_2O + M$	(7.5) -29	$\begin{pmatrix} -1.0 & -0.5 \\ -1.0 & -1.0 \end{pmatrix}$	0		
13.	$CO_3^- + H_2O + M \rightarrow CO_3^- \cdot H_2O + M$	(1.0) -28	$\begin{pmatrix} -1.0 & -0.5 \\ -1.0 & -1.0 \end{pmatrix}$	0		
14.	$CO_4^- + H_2O + M \rightarrow CO_4^- \cdot H_2O + M$	(5.0) -29	$\begin{pmatrix} -1.0 & -0.5 \\ -1.0 & -1.0 \end{pmatrix}$	0		

Table 24-1. (continued)

No.	Reaction	a	b	c	Notes	Sources
XXIII. Three-Body Negative-Ion-Neutral Association: (continued)						
15.	$O_2^- + H_2O + M \rightarrow O_2^-(H_2O)_2 + M$	(4) -28	$(-1.0^{+0.5})$ $(-1.0^{-1.0})$	0	$M = O_2$; Note at	Chp. 18A
XXIV. Negative-Ion Collisional Dissociation: (See Note ay)						
1.	$O_4^- + M \rightarrow O_2^- + O_2 + M$	$(2.2 \pm 1.3) \times 10^{-5}$	(-1)	6300	$k_{300} = (1.7 \pm 1.0) \times 10^{-14}$; $M = O_2$	Refs. 24-66 through 24-69
XXV. Radiation-Stabilized Neutral Recombination:						
1.a.	$O + O \rightarrow O_2(A^3\Sigma_u^+) \rightarrow O_2 + h\nu$ (Herzberg)	(2.4 ± 0.1) -21	0	0		Refs. 24-70, 24-71
b.	$O_2(b^1\Sigma_g^+) \rightarrow O_2 + h\nu$ (Atmospheric)	$(1.7 \pm 0.2) \times 10^{-37} \cdot n_{N_2}$	0	0		Ref. 24-71
c.	$O_2(b^3\Sigma_u^-) \rightarrow O_2 + h\nu$ (Schumann-Runge)	(2) -17	0	$12,000 \pm 1100$	$k_{3000} = (3.7 \pm 1.5) \times 10^{-19}$	Ref. 24-72
2.a.	$O + N \rightarrow NO(A^2\Sigma^+) \rightarrow NO + h\nu$ (Gamma)	$\left\{ \begin{array}{l} 1.2 \times 10^{-17} \\ 1.2 \times 10^{-17} \end{array} \right\} \left(\frac{T}{300} \right)^{-0.35} + 2.1 \times 10^{-34} \left(\frac{T}{300} \right)^{-1.24}$				Ref. 24-73
b.	$NO(b^2\Pi) \rightarrow NO + h\nu$ (Beta)	$(3.1 \pm 0.1) \times 10^{-34} \cdot n_{N_2}$	(-1.4)	0		
c.	$NO(c^2\Pi) \rightarrow NO + h\nu$ (Delta)	$(6.8 \pm 3.0) \times 10^{-18}$	(-0.35)	0		
3.a.	$O + NO \rightarrow NO_2 + h\nu$	(8 ± 2) -17	(-2.0 ± 0.5)	0	$p \geq 0.3$ torr	Chp. 19
b.		(7 ± 2) -18	(-2.0 ± 0.5)	0	$p \leq 10^{-3}$ torr	
4.	$N + N \rightarrow N_2 + h\nu$	$(1.0 \pm 0.5) \times 10^{-17}$	(-0.90 ± 0.05)	0		Ref. 24-74

Table 24-1. (continued)

No.	Reaction	a	b	c	Notes	Sources
XXVI. Neutral Photodissociation: (See Notes and bq)						
1. a.	$O_2 + h\nu \rightarrow O + O$	(8.4 ± 2.5) [-8]	0	0	Schumann-Runge	Ref. 24-75
b.	$\cdot O + O(^1D)$	(2.2 ± 0.7) [-6]	0	0		
2.	$NO + h\nu \rightarrow N + O$	(6.1 ± 1.8) [-6]	0	0		
3. a.	$O_3 + h\nu \rightarrow O + O_2$	(4.5 ± 0.9) [-4]	0	0		
b.	$\rightarrow O + O_2(^1\Delta_g)$	(1.1 ± 0.2) [-4]	0	0		
c.	$\rightarrow O(^1D) + O_2(^1\Delta_g)$	(8.7 ± 1.3) [-3]	0	0		
d.	$\rightarrow O(^1D) + O_2(^1\Sigma_g^+)$	(4.8 ± 1.2) [-4]	0	0		
4.	$NO_2 + h\nu \rightarrow NO + O$	(1.2 ± 0.2) [-2]	0	0		
5.	$N_2O + h\nu \rightarrow N_2 + O(^1D)$	(2.0 ± 0.4) [-6]	0	0		
6.	$HO_2 + h\nu \rightarrow OH + O$	(9.6 ± 2.9) [-4]	0	0		
7.	$H_2O + h\nu \rightarrow H + OH$	(8.3 ± 2.5) [-6]	0	0		
8. a.	$CO_2 + h\nu \rightarrow CO + O$	(1.1 ± 0.6) [-8]	0	0		
b.	$\rightarrow CO + O(^1D)$	(9.4 ± 4.7) [-8]	0	0		
9.	$OCS + h\nu \rightarrow CO + S$	(4.5 ± 1.1) [-5]	0	0		
10.	$SO_2 + h\nu \rightarrow SO + O$	(1.0 ± 0.4) [-4]	0	0		

Table 24-1. (continued)

No.	Reaction	a	b	c	Notes	Sources
XXVI. Neutral Photodissociation: (continued) (See Notes 5 and 6a)						
11.	$H_2S + h\nu \rightarrow H + SH$	(3.7±1.1)[-4]	0	0	Ref. 24-75	
12.	$HNO_2 + h\nu \rightarrow OH + NO$	(8.9±2.7)[-4]	0	0		
13.	$H_2O_2 + h\nu \rightarrow OH + OH$	(7.1±2.1)[-5]	0	0		
14. a.	$HCHO + h\nu \rightarrow H + CHO$	(1.1±0.4)[-4]	0	0		
b.	$-H_2 + CO$	(1.5±0.6)[-4]	0	0		
15.	$HNO_3 + h\nu \rightarrow OH + NO_2$	(1.6±0.3)[-4]	0	0		
16.	$CH_4 + h\nu \rightarrow \begin{cases} H + CH_3 \\ H_2 + CH_2 \end{cases}$	(4.0±2.0)[-6]	0	0		
17.	$N_2O_5 + h\nu \rightarrow \text{Products}$	(6.6±1.7)[-4]	0	0		
XXVII. Three-Body Neutral Recombination:						
1.	$O + O + O \rightarrow O_2 + O(^1S)$	(1.4)[-30.0±0.3]	0	650:300	$k_{300} = (1.6)^{-31.0 \pm 0.8}$; $T = 200 - 400$ K	Ref. 24-76
2.	$O + O + O_2 \rightarrow O_2(A^3\Sigma_u^-) + O_2$	(3)[-33.0±0.3]	0	0	$T = 1000$ K	Chp. 20
3. a.	$O + O + N_2 \rightarrow O_2 + N_2$	(4.80±0.36)[-33]	(-2.0)	0	$T = 200 - 300$ K	Ref. 24-77
b.		(1.3)[-33.0±0.3]	(-1.0)	170	$T > 1000$ K; $T_{ref} = 3000$ K; $k_{3000} = (1.2)^{-33.0 \pm 0.3}$	Ref. 24-78
c.	$-O_2(A^3\Sigma_u^-) + N_2$	(2.1)[-37±1]	0	0		Chp. 20

Table 24-1. (continued)

No.	Reaction	a	b	c	Notes	Sources
XXVII. Three-Body Neutral Recombination: (continued)						
3.d	$C + O + N_2 - O_2(b^1\pi_g^+) + N_2$	(1.7)[-37±1]	0	0		Chp. 20
4.	$O + N + O - NO + O(^1S)$	(3)[-33±1]	0	0		Ref. 24-78
5.a	$O + N + N_2 - NO + N_2$	(1.0)[-32.0±0.2]	(-0.5)	0		Chp. 20
b	$-NO(8^2\Pi_r) + N_2$	(1)[-34±1]	0	0		Ref. 24-78
6.	$O + H + Ar - OH + Ar$	(2.0)[-32±1]	0	0	$T = 1000-3000\text{ K}$	Chp. 19
7.a	$N + N + N_2 - N_2 + N_2$	(8.3)[-34.0±0.2]	0	-500	$k_{300} = (4.4)[-33.0±0.2]$	Chp. 20
b		(4.6±0.2)[-33]	(-1.7)	0	$T_{ref} = 3000\text{ K}$	Ref. 24-79
c	$-N_2(8^3\Pi_g^-) + N_2$	(1.4)[-33±1]	0	0		Chp. 19 - Ref. 24-78
8.	$H + H + H_2 - H_2 + H_2$	(8.3)[-33.0±0.5]	(-0.6±0.2)	0	$k_{300} = (6 \pm 1)[-34^+]$ $M=N_2\text{ or }O_2$	Ref. 24-80
9.	$O + O_2 + M - O_3 + M$	(1.1)[-34.00±0.07]	0	-510	$T = 217 - 500\text{ K}$ $k_{300} = (1.09±0.30)[-31]$	Ref. 24-61
10.	$O + NO + N_2 - NO_2 + N_2$	(1.55±0.20)[-32]	0	-584±35	Estimated value	Ref. 24-81
11.	$O + OH + M - HO_2 + M$	(1.0)[-31]	0	0		Est.
12.	$O + CO + N_2 - CO_2 + N_2$	(1.4±0.3)[-35]	0	0		
13.	$O + N_2 + M - N_2O + M$	(1)[-34±2]	0	7500	$k_{3000} = (8)[-36 \pm 2]$	

Table 24-1. (continued)

No.	Reaction	a	b	c	Notes	Sources
XXVII. Three-Body Neutral Recombination: (continued)						
14.	$O(^1D) + N_2 + M \rightarrow N_2O + M$	$(2.8 \pm 1.4)[-36]$	0	0	$T = 200 - 400 \text{ K};$ $M = N_2 \text{ or } O_2;$ $k_{300} = (5.5 \pm 1.0)[-32]$	Ref. 24-82
15.	$H + O_2 + M \rightarrow HO_2 + M$	$(2.1)[-32.00 \pm 0.07]$	0	-290		Chp. 19 + Ref. 24-78
16.	$H + NO + M \rightarrow HNO + M$	$(2.1)[-32.0 \pm 0.2]$	0	-300	$T = 220 - 400 \text{ K};$ $k_{300} = (5.7)[-32.0 \pm 0.2]$	Ref. 24-78
17.	$H + OH + M \rightarrow H_2O + M$	$(6.8)[-33.0 \pm 0.3]$	(-2.0)	0	$T = 1000 - 3000 \text{ K};$ $T_{ref} = 3000 \text{ K}$	Ref. 24-61, 24-78
18.	$O + NO_2 + M \rightarrow NO_3 + M$	$(1.0)[-31.0 \pm 0.2]$	(-2.0)	0	Note ^{bh}	
19.	$H + NO_2 + M \rightarrow HNO_2 + M$	$(5.0)[-31]$	(-2.4)	0	Estimated value	Ref. 24-61
20.	$NO + O_2 + M \rightarrow NO_3 + M$	$(1.0)[-40]$	0	0		
21.	$NO + OH + N_2 \rightarrow HNO_2 + N_2$	$(5.8 \pm 1.2)[-31]$	(-2.4)	0		Ref. 24-83
22.	$OH + OH + N_2 \rightarrow H_2O_2 + N_2$	$(2.5 \pm 0.3)[-31]$	(-2)	0	Note ^{bi}	Refs. 24-84, 24-85
23.	$OH + NO_2 + N_2 \rightarrow HNO_3 + N_2$	$(2.2 \pm 0.5)[-30]$	(-2.5)	0		Ref. 24-83
XXVIII. Neutral Collisional Dissociation:						
1.	$O_2 + O_2 \rightarrow O + O + O_2$	$(6.6 \pm 3.1)[-9]$	(-1.5 ± 0.5)	59,000	$T = 3000 - 5000 \text{ K};$ $T_{ref} = 3000 \text{ K};$ $k_{3000} = (1.9 \pm 0.9)[-17]$	Ref. 24-72
2.	$NO + M \rightarrow N + O + M$	$(4.1 \pm 1.9)[-9]$	(-1.5 ± 0.5)	75,000	$T = 3000 - 8000 \text{ K};$ $M = O_2, N_2, Ar;$ $T_{ref} = 3000 \text{ K};$ $k_{3000} = (5.7 \pm 2.6)[-20]$	Ref. 24-86

Table 24-1. (continued)

No.	Reaction	a	b	c	Notes	Sources
XXVIII. Neutral Collisional Dissociation: (continued)						
3.	$N_2 + N_2 \rightarrow N + N + N_2$	$(3.5 \pm 0.9) \cdot 10^{-9}$	(-1.6 ± 0.5)	113,000	$T = 8000 - 15,000 \text{ K};$ $T_{\text{ref}} = 8000 \text{ K};$ $k_{8000} = (2.6 \pm 0.7) \cdot 10^{-15}$	Ref. 24-87
4.	$N_2 + Ar \rightarrow N + N + Ar$	$(1.3 \pm 0.2) \cdot 10^{-9}$	(-1.6 ± 0.5)	113,000	$T = 8000 - 15,000 \text{ K};$ $T_{\text{ref}} = 8000 \text{ K};$ $k_{8000} = (9.5 \pm 1.5) \cdot 10^{-16}$	
5.	$O_3 + O_2(^1\Delta_g) \rightarrow O + O_2 + O_2$	$(4.5) \cdot 10^{-11}$	0	2800 ± 200	$T = 283 - 321 \text{ K};$ $k_{300} = (4.0) \cdot 10^{-15.0 \pm 0.3}$	Ref. 24-88
6.	$O_3 + O_2(^1\Sigma_g^+) \rightarrow O + O_2 + O_2$	$(2.5 \pm 0.5) \cdot 10^{-11}$	0	0		Ref. 24-89
7.	$O_3 + N_2 \rightarrow O + O_2 + N_2$	$(6.4 \pm 1.6) \cdot 10^{-10}$	0	11,400	$T = 200 - 1000 \text{ K};$ $k_{300} = (2.0 \pm 0.5) \cdot 10^{-26}$	Ref. 24-90
8.	$NO_3 + M \rightarrow NO + O_2 + M$	$(9.0) \cdot 10^{-14}$	(-1)	2100	Estimated value; $k_{300} = (8.2) \cdot 10^{-17}$	Ref. 24-61
XXIX. Neutral Rearrangement:						
1.	$O + NO \rightarrow N + O_2$	$(7.5) \cdot 10^{-12.00 \pm 0.11}$	(1)	19,500	$T = 1000 - 3000 \text{ K};$ $T_{\text{ref}} = 3000 \text{ K};$ $k_{3000} = (1.1 \pm 0.3) \cdot 10^{-14}$	Ref. 24-78
2.	$O + OH \rightarrow H + O_2$	$(4.2 \pm 1.7) \cdot 10^{-11.0 \pm 0.3}$	0	0	$T = 300 - 2000 \text{ K}$	
3.	$O + N_2 \rightarrow N + NO$	$(1.3) \cdot 10^{-10.0 \pm 0.3}$	0	38,000	$T = 2000 - 5000 \text{ K};$ $k_{3000} = (4.1) \cdot 10^{-16.0 \pm 0.3}$	Ref. 24-91 Ref. 24-78
4.	$O(^1D) + H_2 \rightarrow H + OH$	$(1.30 \pm 0.05) \cdot 10^{-10}$	-	-		
5.	$O + O_3 \rightarrow O_2 + O_2$	$(1.9) \cdot 10^{-11.0 \pm 0.1}$	0	2300	$T = 220 - 1000 \text{ K};$ $k_{300} = (9 \pm 2) \cdot 10^{-15}$	

Table 24-1. (continued)

No.	Reaction	a	b	c	Notes	Sources
XXIX.	Neutral Rearrangement: (continued)					
6.	$O(^1D) + O_3 \rightarrow O_2 + O_2$	$(2.4 \pm 0.1) \cdot 10^{-12}$	-	-		Ref. 24-91
7.	$O + NO_2 \rightarrow O_2 + NO$	$(9.1 \pm 2.0) \cdot 10^{-12}$	0	0		Chp. 19
8.	$O(^1D) + NO_2 \rightarrow O_2 + NO$	$(1.8 \pm 0.1) \cdot 10^{-10}$	-	-	Note b _j	Ref. 24-92
9.a.	$O + N_2O \rightarrow NO + NO$	$(1.5 \pm 0.5) \cdot 10^{-10}$	0	$14,000 \pm 2000$	$k_{3000} = (1.4) \cdot 10^{-12.0 \pm 0.4}$	Chp. 19
b.	$- O_2 + N_2$	$(5 \pm 2) \cdot 10^{-11}$	0	$14,000 \pm 2000$	$k_{3000} = (4.7) \cdot 10^{-13.0 \pm 0.5}$	
10.	$O(^1D) + N_2O \rightarrow \begin{cases} NO + NO \\ O_2 + N_2 \end{cases}$	$(1.4 \pm 0.1) \cdot 10^{-10}$	-	-		Ref. 24-91
11.	$O + HO_2 \rightarrow O_2 + OH$	$(8.0) \cdot 10^{-11}$	0	500	Estimated value; $k_{300} = (1.5) \cdot 10^{-11}$	Ref. 24-78
12.	$O(^1D) + H_2O \rightarrow OH + OH$	$(2.1 \pm 1.0) \cdot 10^{-10}$	-	-		Ref. 24-91
13.	$O + NO_3 \rightarrow O_2 + NO_2$	$(1.0) \cdot 10^{-12}$	0	1500	Estimated value; $k_{300} = (6.7) \cdot 10^{-15}$	Ref. 24-61
14.	$O + H_2O_2 \rightarrow \begin{cases} OH + HO_2 \\ O_2 + H_2O \end{cases}$	$(2.75) \cdot 10^{-12.00 \pm 0.07}$	0	2125	$k_{300} = (2.3 \pm 0.4) \cdot 10^{-15}$	Ref. 24-78
15.	$O(^1D) + H_2O_2 \rightarrow \begin{cases} OH + HO_2 \\ O_2 + H_2O \end{cases}$	$\sim (5) \cdot 10^{-10}$	0	0	Estimated value	
16.	$O + HNO_3 \rightarrow OH + NO_3$	-	-	-	Products uncertain; $k < (3) \cdot 10^{-17}$	Ref. 24-94

Table 24-1. (continued)

No.	Reaction	a	b	c	Notes	Sources
XXIX.	Neutral Rearrangement: (continued)					
17.	$N + O_2 \rightarrow O + NO$	$(3.3) \pm 12.00 \pm 0.12$	(1)	3150	$T = 300 - 1500 \text{ K};$ $k_{300} = (9 \pm 3) \cdot 10^{-17}$	Ref. 24-78
18.	$N(^2D) + O_2 \rightarrow O + NO$	$(7.5 \pm 0.5) \cdot 10^{-12}$	(0.5)	0		Ref. 24-95
19.	$N + O_2(^1\Delta_g) \rightarrow O + NO$	$(2.0 \pm 0.8) \cdot 10^{-14}$	0	600	Products uncertain; $k_{300} = (2.7 \pm 1.1) \cdot 10^{-15}$	Ref. 24-96
20.	$N + NO \rightarrow O + N_2(^3\Sigma^-)$	$(8.2 \pm 1.4) \cdot 10^{-11}$	0	410 ± 120	$k_{300} = (2.1) \cdot 10^{-11.00 \pm 0.25}$	Ref. 24-97
21.	$N(^2D) + NO \rightarrow O + N_2$	$(6.0) \cdot 10^{-11}$	0	0	Estimated value	Ref. 24-61
22.	$N + OH \rightarrow H + NO$	$(5.3) \cdot 10^{-11.0 \pm 0.3}$	0	0		Ref. 24-78
23.	$N(^2D) + OH \rightarrow H + NO$	$(5.0) \cdot 10^{-11}$	0	0	Estimated value	Ref. 24-61
24.	$N + O_3 \rightarrow O_2 + NO$	$(5.7) \cdot 10^{-13.0 \pm 0.2}$	0	0		Ref. 24-78
25.	$N + NO_2 \rightarrow O + N_2O$	$(2.0 \pm 0.2) \cdot 10^{-11}$	0	800	Note bk; $k_{300} = (1.4 \pm 0.1) \cdot 10^{-12}$	Refs. 24-85, 24-97
26.a.	$N(^2D) + NO_2 \rightarrow O + N_2O$	$(1.0) \cdot 10^{-10}$	0	0		} Ref. 24-61
b.	$- NO + NO$	$(1.0) \cdot 10^{-10}$	0	0	Estimated value	
27.	$N + HO_2 \rightarrow NO + OH$	$(2.0) \cdot 10^{-11}$	0	0		
28.	$N(^2D) + HO_2 \rightarrow NO + OH$	$(2.0) \cdot 10^{-11}$	0	0		
29.	$H + O_2 \rightarrow O + OH$	$(3.7) \cdot 10^{-10.0 \pm 0.1}$	0	8450	$T = 700 - 2500 \text{ K};$ $k_{3000} = (2.2 \pm 0.6) \cdot 10^{-11}$	} Ref. 24-78
30.	$H + OH \rightarrow O + H_2$	$(4.2) \cdot 10^{-12.00 \pm 0.15}$	(1)	3500	$T = 400 - 2000 \text{ K};$ $k_{300} = (3.6) \cdot 10^{-17.00 \pm 0.15}$	

Table 24-1. (continued)

No.	Reaction	a	b	c	Notes	Sources
XXIX.	Neutral Rearrangement: (continued)					
31.	$H + O_3 \rightarrow O_2 + OH$	(1.23) -10°	0	562±144	$k_{300} = (1.9) \cdot 10^{-11.0 \pm 0.2}$	Ref. 24-98
32.	$H + NO_2 \rightarrow NO + OH$	(4.9) -10°	0	412±115	$k_{300} = (1.2) \cdot 10^{-10.0 \pm 0.2}$	
33.	$H + N_2O \rightarrow OH + N_2$	(1.26) -10.0±0.2°	0	7600	T = 700 - 2500 K; $k_{3000} = (1.0) \cdot 10^{-11.0 \pm 0.2}$	Ref. 24-78
34.a.	$H + HO_2 \rightarrow OH + OH$	(4.2) -10.0±0.3°	0	950	T = 290 - 800 K; $k_{300} = (1.8) \cdot 10^{-11.0 \pm 0.3}$	Ref. 24-99
b.	$- O_2 + H_2$	(4.2) -11.0±0.4°	0	350	T = 290 - 800 K; $k_{300} = (1.3) \cdot 10^{-11.0 \pm 0.4}$	
c.	$- O + H_2O$	(8.3) -11.0±0.5°	0	500	T = 300 - 1000 K; $k_{300} = (1.6) \cdot 10^{-11.0 \pm 0.5}$	Ref. 24-78
35.a.	$H + H_2O_2 \rightarrow H_2 + HO_2$	(2.3±1.3) -12°	0	1400±140	T = 283 - 353 K; $k_{300} = (2.2) \cdot 10^{-14.0 \pm 0.5}$	Refs. 24-100, 24-101
b.	$- OH + H_2O$ (See Note bf)	(2.9±1.3) -12°	0	1400±140	T = 283 - 353 K; $k_{300} = (2.7) \cdot 10^{-14.0 \pm 0.5}$	
36.	$O_2 + 2 NO \rightarrow NO_2 + NO_2$	(3.3) -39.0±0.2°	0	-530	$k_{300} = (1.9) \cdot 10^{-38.0 \pm 0.2}$	Ref. 24-78
37.	$NO + O_3 \rightarrow O_2 + NO_2$	(2.1) -12.00±0.16°	0	1450	T = 203 - 361 K; $k_{300} = (1.7) \cdot 10^{-14.00 \pm 0.16}$	Ref. 24-102
38.	$NO + HO_2 \rightarrow OH + NO_2$	(8±3) -12°	-	-	Note bm	Refs. 24-103, 24-104
39.	$NO + NO_3 \rightarrow NO_2 + NO_2$	(2.0) -11°	0	0	Estimated value	Ref. 24-61

Table 24-1. (continued)

No.	Reaction	a	b	c	Notes	Sources
XXIX.	Neutral Rearrangement: (continued)					
40.	$\text{OH} + \text{OH} \rightarrow \text{O} + \text{H}_2\text{O}$	(1.0) $\pm$ 11.0 $\pm$ 0.2	0	550	T = 300 - 2000 K; $k_{300} = (1.6) \pm 12.0 \pm 0.2$	Ref. 24-78
41.	$\text{OH} + \text{CO} \rightarrow \text{H} + \text{CO}_2$	(1.4) $\pm$ 13.0 $\pm$ 0.1	0	0	T = 200 - 400 K	
42.	$\text{OH} + \text{H}_2 \rightarrow \text{H} + \text{H}_2\text{O}$	(3.6) $\pm$ 11.00 $\pm$ 0.08	0	2590	T = 300 - 2500 K; $k_{300} = (6.4 \pm 1.3) \pm 15$	Ref. 24-78
43.	$\text{OH} + \text{O}_3 \rightarrow \text{O}_2 + \text{HO}_2$	(1.5) $\pm$ 12.0 $\pm$ 0.3	0	1000	T = 220 - 450 K; $k_{300} = (5.4) \pm 14.0 \pm 0.3$	Ref. 24-102
44.	$\text{OH} + \text{HO}_2 \rightarrow \text{O}_2 + \text{H}_2\text{O}$	(3) $\pm$ 11.0 $\pm$ 0.5	-	-		
45.	$\text{OH} + \text{HNO}_2 \rightarrow \text{NO}_2 + \text{H}_2\text{O}$	(2.1 $\pm$ 0.2) $\pm$ 12	0	0		Ref. 24-78
46.	$\text{OH} + \text{H}_2\text{O}_2 \rightarrow \text{HO}_2 + \text{H}_2\text{O}$	(1) $\pm$ 11.0 $\pm$ 0.3	0	750	T = 300 - 670 K; $k_{300} = (8.2) \pm 13.0 \pm 0.3$	Ref. 24-102
47.	$\text{OH} + \text{HNO}_3 \rightarrow \text{H}_2\text{O} + \text{NO}_3$	(8.9 $\pm$ 1.3) $\pm$ 14	0	0		Ref. 24-110
48.	$\text{O}_3 + \text{NO}_2 \rightarrow \text{O}_2 + \text{NO}_3$	(1.2) $\pm$ 13.0 $\pm$ 0.1	0	2450	T = 220 - 340 K; $k_{300} = (3.4 \pm 0.9) \pm 17$	Ref. 24-78
49.	$\text{O}_3 + \text{HO}_2 \rightarrow 2\text{O}_2 + \text{OH}$	(1.0) $\pm$ 13.0 $\pm$ 0.3	0	1250	T = 225 - 298 K; $k_{300} = (1.6) \pm 15.0 \pm 0.3$	
50.	$\text{NO}_2 + \text{HO}_2 \rightarrow \text{O}_2 + \text{HNO}_2$	(3.0) $\pm$ 14	-	-		Ref. 24-102
51.	$\text{HO}_2 + \text{HO}_2 \rightarrow \text{O}_2 + \text{H}_2\text{O}_2$	(7.5) $\pm$ 12.0 $\pm$ 0.6	0	500	T = 300 - 1000 K; $k_{300} = (1.4) \pm 12.0 \pm 0.6$	
52.	$\text{NO}_3 + \text{NO}_3 \rightarrow \text{O}_2 + 2\text{NO}_2$	(5.0) $\pm$ 12.0 $\pm$ 0.5	0	3000	T = 293 - 309 K; $k_{300} = (2.3) \pm 16.0 \pm 0.5$	Ref. 24-78

Table 24-1. (continued)

No.	Reaction	a	b	c	Notes	Sources
XXX. Radiative Electronic-State Deexcitation:						
1.	$O(^1D) - O + h\nu$	(6.8±2.0)[-3]	0	0	Note bn	Chp. 20
2.	$O(^1S) - O + h\nu$	(1.35±0.40)[0]	0	0		
3.a.	$O(^2D)_{5/2} - O^+ + h\nu$	(4.8)[-5.0±0.3]	0	0		
b.	$O(^2D)_{3/2} - O^+ + h\nu$	(1.7)[-4.0±0.3]	0	0		
4.a.	$O(^2P)_{3/2} - O^+ + h\nu$	(2.4)[-1.0±0.3]	0	0	Note bn	
b.	$O(^2P)_{1/2} - O^+ + h\nu$	(1.9)[-1.0±0.3]	0	0		
5.a.	$N(^2D)_{3/2} - N + h\nu$	(1.6)[-5.0±0.3]	0	0		
b.	$N(^2D)_{1/2} - N + h\nu$	(7.1)[-6.0±0.3]	0	0		
6.	$N(^2P) - N + h\nu$	(7.7)[-2.0±0.3]	0	0		
7.	$N(^1D) - N^+ + h\nu$	(4.0)[-3.0±0.3]	0	0		
8.	$N(^1S) - N^+ + h\nu$	(1.1)[0.0±0.3]	0	0		
9.	$O_2(^1\Delta_g) - O_2 + h\nu$	(2.6±1.0)[-4]	0	0		
10.	$O_2(^1\Sigma_g^+) - O_2 + h\nu$	(8.3)[-2.0±0.3]	0	0		
11.a.	$N_2(A^3\Sigma_u^+)(F_2) - N_2 + h\nu$	(7.7)[-1.0±0.3]	0	0		
b.	$N_2(A^3\Sigma_u^+)(F_1, F_3) - N_2 + h\nu$	(3.7)[-1.0±0.3]	0	0		

Table 24-1. (continued)

No.	Reaction	a	b	c	Notes	Sources
XXX. Radiative Electronic-State Deexcitation: (continued)						
12.	$\text{NO}(a^4\pi_1) \rightarrow \text{NO} + h\nu$	$(6.3)^{+0.0 \pm 0.3}$	0	0		} Chp. 20
13.	$\text{NO}_2(^2B_1) \rightarrow \text{NO}_2 + h\nu$	$(1.4 \pm 0.2)^{+4}$	0	0		
XXXI. Electronic-State Photoexcitation:						
1.a.	$\text{O}_2 + h\nu \rightarrow \text{O}_2(a^1\Delta_g)$				} Note c	
b.	$\rightarrow \text{O}_2(b^1\Sigma_g^+)$					
XXXII. Collisional Electronic-State Quenching:						
1.	$\text{O}(^1D) + e \rightarrow \text{O}(^3P) + e$	$(7.80 \pm 1.36)^{-9}$	(-0.083 ± 0.085)	3993 ± 1649	Notes bo, bq; $T = T_e = 160-232,000 \text{ K};$ $T_{\text{ref}} = 3000 \text{ K};$ $k_{3000} = (2.1)^{-9.0 \pm 0.3}$	} Ref. 24-111 + Calc. (Note bp)
2.	$\text{O}(^1D) + \text{O}_2 \rightarrow \text{O} + \text{O}_2(^1\Sigma_g^+)$	$(4.1 \pm 0.5)^{-11}$	-	-	} Note bo	
3.	$\text{O}(^1D) + \text{N}_2 \rightarrow \text{O} + \text{N}_2$	$(3.0 \pm 0.1)^{-11}$	-	-		} Ref. 24-91
4.	$\text{O}(^1D) + \text{CO}_2 \rightarrow \text{O} + \text{CO}_2$	$(1.20 \pm 0.09)^{-10}$	-	-	Note bq; $T = T_e = 160-232,000 \text{ K};$ $T_{\text{ref}} = 3000 \text{ K};$ $k_{3000} = (2.1)^{-9.0 \pm 0.2}$	
5.a.	$\text{O}(^1S) + e \rightarrow \text{O}(^3P) + e$	$(3.16 \pm 0.33)^{-9}$	(0.087 ± 0.052)	1299 ± 987		
b.	$\rightarrow \text{O}(^1D) + e$	$(9.40 \pm 0.40)^{-9}$	(-0.206 ± 0.032)	12840 ± 352	Note bq; $T = T_e = 160-232,000 \text{ K};$ $T_{\text{ref}} = 3000 \text{ K};$ $k_{3000} = (1.3 \pm 0.2)^{-10}$	

Table 24-1. (continued)

No.	Reaction	a	b	c	Notes	Sources
XXXII. Collisional Electronic-State Quenching: (continued)						
6.	$O(^1S) + O(^3P) \rightarrow \begin{cases} O(^1D) + O(^1D) \\ O(^1D) + O(^3P) \end{cases}$	$(7.5) \pm 12.0 \pm 0.2^{\circ}$	-	-		Chp. 20 + Ref. 24-79
7.	$O(^1S) + O_2 \rightarrow O + O_2$	$(4.3) \pm 12.00 \pm 0.15^{\circ}$	0	850	$T = 200 - 377$ K; $k_{300} = (2.5) \pm 13.00 \pm 0.15^{\circ}$	Ref. 24-78
8.	$O(^1S) + N_2 \rightarrow O + N_2$	-	-	-	$k < (1) \pm 17^{\circ}$	Ref. 24-71
9.	$O(^1S) + H_2O \rightarrow O + H_2O$	$(3 \pm 2) \pm 10^{\circ}$	0	0		Refs. 24-113, 24-114
10.	$O(^1S) + CO_2 \rightarrow O + CO_2$	$(3.1) \pm 11.00 \pm 0.15^{\circ}$	0	1320	$T = 200 - 450$ K; $k_{300} = (3.8) \pm 13.00 \pm 0.15^{\circ}$	Ref. 24-78
11.	$O(^+2D) + e \rightarrow O^+ + e$	$(6.75 \pm 3.38) \times 10^{-12} \left(\frac{T_e}{300} \right)^{-0.5}$	-	-		Ref. 24-111
12.	$N(^2D) + e \rightarrow N(^4S) + e$	$(4.32 \pm 0.25) \pm 9^{\circ}$	(-0.116 ± 0.041)	3551 ± 93	$T = T_e = 1160 - 232,000$ K; $T_{ref} = 3000$ K; $k_{3000} = (1.3 \pm 0.1) \pm 9^{\circ}$	Ref. 24-111 + Calc. (Note bp)
13.	$N(^2D) + N_2 \rightarrow N + N_2$	-	-	-	$k < (6) \pm 15^{\circ}$	Ref. 24-115
14.a.	$N(^2P) + e \rightarrow N(^4S) + e$	$(4.23 \pm 0.72) \pm 9^{\circ}$	(-0.164 ± 0.065)	4461 ± 1816	$T = T_e = 1160 - 232,000$ K; $T_{ref} = 3000$ K; $k_{3000} = (9.6) \pm 10.0 \pm 0.3^{\circ}$	Ref. 24-111 + Calc. (Note bp)
b.	$\rightarrow N(^2D) + e$	$(1.47 \pm 0.05) \pm 8^{\circ}$	(-0.069 ± 0.035)	1481 ± 307	$T = T_e = 1160 - 232,000$ K; $T_{ref} = 3000$ K; $k_{3000} = (9.0 \pm 1.3) \pm 9^{\circ}$	
15.	$O_2(a^1\Delta_g) + e \rightarrow O_2 + e$	$(1) \pm 11 \pm 1^{\circ}$	0	0	Notes r, br	Ref. 24-116 + Chp. 20 (fig. 20-8) + Est.

Table 24-1. (continued)

No.	Reaction	a	b	c	Notes	Sources
XXXII. Collisional Electronic-State Quenching: (continued)						
16.	$O_2(a^1\Delta_g) + O \rightarrow O_2 + O$	-	-	-	$k < (1) \cdot 10^{-16}$; Note <u>br</u>	Chp. 20
17.	$O_2(a^1\Delta_g) + O_2 \rightarrow O_2 + O_2$	(2.2) $\cdot 10^{-18} \pm 0.1$	(0.8)	0	Note <u>br</u>	Ref. 24-78
18.	$O_2(a^1\Delta_g) + O_2(a^1\Delta_g) \rightarrow O_2 + O_2(b^1\Sigma_g^+)$	(2) $\cdot 10^{-18} \pm 1$	0	0		Ref. 24-117
19.	$O_2(a^1\Delta_g) + N_2 \rightarrow O_2 + N_2$	-	-	-	$k < (2) \cdot 10^{-20}$; Note <u>br</u>	Ref. 24-78
20.	$O_2(a^1\Delta_g) + O_3 \rightarrow O_2 + O + O_2$	(4.5) $\cdot 10^{-11} \pm 0.1$	0	2830	$T = 283 - 321$ K; $k_{300} = (3.6 \pm 1.0) \cdot 10^{-15}$; Note <u>br</u>	
21.	$O_2(b^1\Sigma_g^+) + O_2 \rightarrow O_2 + O_2$	(1.5) $\cdot 10^{-16} \pm 0.12$	0	0	Ref. 24-78	Ref. 24-78
22.	$O_2(b^1\Sigma_g^+) + N_2 \rightarrow O_2 + N_2$	(2.0) $\cdot 10^{-15} \pm 0.1$	0	0		
23.	$O_2(a^4\Pi_u) + O_2 \rightarrow O_2^+ + O_2$	(3.1 ± 1.5) $\cdot 10^{-10}$	0	0	$T = T_0 < 2000$ K; See Reaction XIII, 19.	Ref. 24-36
24.	$N_2(A^3\Sigma_u^+) + O \rightarrow \begin{cases} N_2 + O \\ NO + N \end{cases}$	$(5) \cdot 10^{-11} \pm 1$	-	-	$k \leq (3) \cdot 10^{-11}$; Note <u>bs</u>	Chp. 20 Table 20-4
25.	$N_2(A^3\Sigma_u^+) + N \rightarrow N_2 + N$		0	0		
26.	$N_2(A^3\Sigma_u^+) + O_2 \rightarrow N_2 + O_2$	(3.8 ± 2.0) $\cdot 10^{-12}$	0	0		
27.	$N_2(A^3\Sigma_u^+) + NO \rightarrow N_2 + NO$	(7 ± 4) $\cdot 10^{-11}$	0	0		
28.	$N_2^+(A^2\Pi_u) + N_2 \rightarrow N_2^+ + N_2$	(1) $\cdot 10^{-9} \pm 1$	0	0		
29.	$N_2^+(B^2\Sigma_u^+) + O_2 \rightarrow N_2^+ + O_2$	(2) $\cdot 10^{-9} \pm 1$	0	0		Chp. 20

Table 24-1. (continued)

No.	Reaction	a	b	c	Notes	Sources
XXXII. Collisional Electronic-State Quenching: (continued)						
30.	$N_2^+(\text{B } ^2\Sigma_u^+) + N_2 \rightarrow N_2^+ + N_2$	$(6) \cdot 10^{-12}$	0	0		Chp. 20
XXXIII. Radiative Vibrational-State Deexcitation:						
1.	$CO(v=1) \rightarrow CO(v=0) + h\nu$	$(3.3 \pm 0.3) \cdot 10^{-12}$	0	0		Chp. 11
2.	$CO_2(001) \rightarrow CO_2(000) + h\nu$	$(4.00 \pm 0.20) \cdot 10^{-12}$	0	0		
XXXIV. Collisional Vibrational-State Quenching:						
1.	$O_2(v=1) + M \rightarrow O_2(v=0) + M$	$\left\{ \frac{2.5 \times 10^{-12} T \exp(-2.95 \times 10^6/T)}{1 - \exp(-2270/T)} \right\}$			$M = N_2 \text{ or } O_2$ $T = 800 - 3200 \text{ K};$ $k_{3000} = (6.78) \cdot 10^{-13}$	Chp. 20 (Table 20-5)
2.a.	$O_2(v=1) + O \rightarrow O_2(v=0) + O$	$(5.7 \pm 3.0) \cdot 10^{-12}$	(-0.5)	483	$T = 300 - 1700 \text{ K};$ $k_{300} = (1.1 \pm 0.6) \cdot 10^{-12}$	
b.		$(1.7 \pm 0.5) \cdot 10^{-12}$	0	4000	$T = 2000 - 4000 \text{ K};$ $k_{3000} = (4.5 \pm 1.3) \cdot 10^{-12}$	Chp. 20 (Table 20-5)
3.	$N_2(v=1) + O \rightarrow N_2(v=0) + O$	$\left\{ \frac{6.21 \times 10^{-14} T \exp(-1.37 \times 10^5/T)}{1 - \exp(-3390/T)} \right\}$ or $\left\{ \frac{3.43 \times 10^{-12} T \exp(-3.74 \times 10^6/T)}{1 - \exp(-3390/T)} \right\}$			$T = 3000 - 4500 \text{ K};$ $k_{3000} = (7.71) \cdot 10^{-12}$	
4.	$N_2(v=1) + N_2 \rightarrow N_2(v=0) + N_2$	$\left\{ 1.3 \times 10^{-11} T \exp(-1.06 \times 10^7/T) \right\}$			$T = 300 - 5000 \text{ K};$ $k_{300} = (2.2) \cdot 10^{-23};$ $k_{3000} = (9.5) \cdot 10^{-15}$	Chp. 20 (Table 20-2)

Table 24-1. (continued)

No.	Reaction	a	b	c	Notes	Sources
XXXV.	<u>Collisional Vibrational Energy Exchange:</u>					
1.	$O_2(v=1) + H_2O \rightarrow O_2(v=0) + H_2O(0,0)$	(1.7), -11, 12	(-0.5)	0	Note <u>bu</u>	Chp. 20 (Table 20-5)
2.	$N_2(v=1) + O_2(v=0) \rightarrow N_2(v=0) + O_2(v=1)$	$\left\{ \frac{2.5 \times 10^{-7}}{1 - \exp(-3390/T)} \right\} \exp(-1.82 \times 10^7 T^{-1/3})$			T = 1000 - 10,000 K; $k_{3000}^{(1.3) - 11}$	Chp. 20 (Table 20-2)
3.	$N_2(v=1) + N_2(v=0) \rightarrow N_2(v=0) + N_2(v=1)$	(3) $\left[\begin{smallmatrix} -13.0^{+1.5} \\ -0.3 \end{smallmatrix} \right]$	0	0	Note <u>bu</u>	
4.	$N_2(v=1) + CO_2(000) \rightarrow N_2(v=0) + CO_2(001)$	(6-2), -13	(-0.5)	0	T = 300 - 1200 K	

NOTES

- a - Very small compared to dissociative recombination (Section IV).
- b - "Top of the atmosphere" calculation from Chapter 13 data.
- c - Wavelength and flux dependent.
- d - For $T_{iv} > \sim 1000$ K, multiply given k by a factor $[1 - \exp(-2677/T_{iv})]$ (Gst.).
- e - Branching measured at 300 K; branching ratio should change with T .
- f - For $T_{iv} > \sim 1300$ K, multiply given k by a factor $[1 - \exp(-3230/T_{iv})]$ (Gst.).
- g - According to Ref. 24-3, this represents the theoretical state prediction at 300 K, where $(80 \pm 15)\%$ of total recombination is for ions in the ground or first vibrational state, and respective yields of $N(^2D)$ are 67 or 98% by adiabatic calculation, 94 or 58% by diabatic calculation. Ref. 24-6 gives fraction of $N(^2D)$ as 0.76 ± 0.06 from time-dependent resonance absorption data. The chapter authors have consulted H.H. Michels, M.A. Biondi, and M. Scheibe, and ascertained: (a) for the theoretical case where purely $NO^+(\nu=0)$ produces purely $N(^2D)$, $k = (1.2 \pm 0.3) \times 10^{-7}$. $(T_e/300)^{(-0.4^{+0.2}_{-0.1})}$; (b) for the reverse reaction (associative ionization) $N(^2D) + O \rightarrow NO^+ + e$, calculated by detailed balance:
- $$k = (7.6 \pm 0.3) \times 10^{-13} (T/300)^{(0.6^{+0.2}_{-0.1})} \exp(-4416/T) \text{ at } T \leq 1300 \text{ K; } k_{300} = (3.1 \pm 0.1) \times 10^{-19}$$
- $$k = (2.0 \pm 0.1) \times 10^{-12} (T/1500)^{(0.6^{+0.2}_{-0.1})} \exp(-4416/T) [1 - \exp(-3230/T)] \text{ at } 1300 \text{ K} \leq T \leq 2000 \text{ K; } k_{1500} = (9.3 \pm 0.5) \times 10^{-14}$$
- $$k = (3.9 \pm 0.5) \times 10^{-12} (T/3000)^{(1.1^{+0.2}_{-0.1})} \exp(-4416/T) [1 - \exp(-3230/T)] \text{ at } 2000 \text{ K} \leq T \leq 6000 \text{ K; } k_{3000} = (5.9 \pm 0.8) \times 10^{-13}$$
- h - For $T_{iv} > \sim 1200$ K, multiply given k by a factor $[1 - \exp(-3162/T_{iv})]$ (Gst.).
- i - Theoretical branching ratio (Est. Ref. 24-7).
- j - Temperature dependence may be steeper for $T < 200$ K.

NOTES (continued)

- k - Temperature dependences estimated by analogy with $\text{NH}_4^+(\text{NH}_3)_n$ series (Ref. 24-9).
- l - Measured temperature dependence (Ref. 24-10).
- n - For the analogous reactions for higher hydrates, i. e., $\text{H}_3\text{O}^+(\text{H}_2\text{O})_n + e \rightarrow (n+1)\text{H}_2\text{O} + \text{H}$, where $n \geq 6$, use the rate coefficients for Reaction IV.28.
- n - Values based on afterglow results, omitting the merged-beam results of Peterson, Moseley, et al. (Refs. 24-12, 24-13). The much larger values, e. g., $(5-8) \times 10^{-7} \text{ cm}^3 \text{ sec}^{-1}$ at 300 K, obtained in the latter works may result from the presence in the beams of molecular ions in vibrationally and rotationally excited states (Ref. 24-14). Such excited states are not normally expected in the atmosphere.
- o - X^+ and Y^- are either atomic or molecular, including clustered species.
- p - X^+ , Y^- , and M are either atomic or molecular "air" species.
- q - $\text{X}^+(\text{cluster})$ and $\text{Y}^-(\text{cluster})$ are any clustered ions.
- r - Detailed balance calculation.
- s - Values are for normal-incidence unattenuated solar flux at top of earth's atmosphere.
- t - Based on experimental data and theoretical extrapolation.
- u - Varies with altitude and solar zenith angle.
- v - No experimental data.
- w - Observed to be a saturated three-body process; k is the effective two-body value, in units of $\text{cm}^3 \text{ sec}^{-1}$.
- x - May react if N_2 is vibrationally excited.
- y - Non-isothermal condition, i. e., if $T_v = T_i$, transition temperature between the two sets of parameters decreases below 1000 K. See Reaction XIV.1.
- z - The sum of Reactions XIII.10 and XIV.6 represent one overall reaction, as measured experimentally, for which the division into the channels indicated is somewhat uncertain, and for which the energy dependence of the

NOTES (continued)

separate branches has not been measured. The rate constants k_{Σ} for the overall process (both reactions) in the respective temperature ranges are:

$$k_{\Sigma} = (5.5 \pm 0.5) \times 10^{-10} \left(\frac{T_i}{300} \right)^{(0.00 \pm 0.17)} \quad \text{at } T_i < 4600 \text{ K};$$

$$k_{\Sigma} = (1.2 \pm 0.2) \times 10^{-10} \left(\frac{T_i}{300} \right)^{(0.57 \pm 0.05)} \quad \text{at } T_i > 4600 \text{ K}.$$

These values have been arbitrarily halved between the two channels, as seemingly the most reasonable resolution of the problem at this time (Ref. 24-33).

- aa - $N(^2D)$ is a probable product.
- ab - Reported as a quenching reaction. See Reaction XXXII. 23.
- ac - $N_2(A^3\Sigma_u^+)$ or $NO^+(a^3\Sigma^+)$ may be formed.
- ad - Rate constant k_{Σ} for the sum of reactions XIII. 34 and XIV. 22 is:

$$k_{\Sigma} = 2.2 \times 10^{-9}.$$
- ae - Temperature dependence may be based on T_i or T_v interchangeably, since both are in agreement within the limits of experimental error (Ref. 24-27). Values shown may be a lower limit (Ref. 24-39). They have been determined using monatomic buffer gases, e.g., He, Ar, and may vary for diatomic buffer gases, e.g., N_2 (Ref. 24-40). See also Reaction XIX. 1.
- af - Not detected for kinetic energies $< \approx 5$ eV.
- ag - Endothermic by 0.163 eV.
- ah - Chp. 18A gives $k < (1)[-15]$.
- ai - Some $N(^2D)$ produced.
- aj - Branching ratio uncertain.
- ak - The k values indicated for the three branches are not necessarily equal. Their measured sum is: $k_{\Sigma} = (1)[-10]$. However, secondary reactions are possible and may be a factor in determining the products observed.
- al - Products uncertain; compare Reactions XV. 16 and XVI. 15.

NOTES (continued)

- am - Products may include $\text{O}_3^- \cdot \text{H}_2\text{O}$.
- an - Ref. 24-50 identifies products as $\text{NO}_3^- + \text{O}$. This is incorrect.
- ao - When $T - T_g < 600 \text{ K}$, the "b" parameter = (-0.64) (Ref. 24-28).
- ap - Reactions XVI. 36, 39 are both important as reverse processes to Reaction XVI. 24.
- aq - A minor product channel may be: $2\text{O}_2 + \text{O}^-$.
- ar - A minor product channel may be: $\text{CO}_2 + \text{O}_3^-$.
- as - Extrapolated from experimental data where $680 \leq \lambda \leq 440 \text{ nm}$; error overestimated to compensate.
- at - Value of "b" parameter estimated.
- au - Recalculated for $M = \text{N}_2$ at 300 K, from measured rate constant $k = 5.4 \times 10^{-29} \text{ cm}^6 \text{ sec}^{-1}$ at 82 K, where $M = \text{He}$. N_2O^+ appears to predissociate.
- av - Error limits indicated for "b" parameter have been estimated by Handbook Editor.
- aw - Recalculated for $M = \text{N}_2$, from measured rate constant $k = 2.6 \times 10^{-30} (T/300)^{(-3.2)} \text{ cm}^6 \text{ sec}^{-1}$, where $M = \text{O}_2$.
- ax - Recalculated for $M = \text{N}_2$ at 300 K, from measured rate constant $k = 8.4 \times 10^{-31} \text{ cm}^6 \text{ sec}^{-1}$ at 200 K, where $M = \text{He}$.
- ay - In Sections XX and XXIV, the "a" parameters have usually been obtained by back-calculation from measured or estimated values of the respective "c" parameters and of the corresponding rate constants at or very near 300 K, i. e., k_{300} values, as referenced in each instance.
- az - Error limits of "c" parameter have been estimated.
- ba - Calculated for $M = \text{N}_2$ from measurements where $M = \text{O}_2$.
- bb - Calculated for $M = \text{N}_2$ from measurements where $M = \text{CO}_2$.
- bc - The "b" parameter has been based on the corresponding value for Reaction XX. 6, but may be more steeply negative.
- bd - The "b" parameter has been based on the corresponding value for Reaction XX. 15.

NOTES (continued)

- be - The "b" parameter has been based on the corresponding value for Reaction XX.14, but may be more steeply negative.
- bf - Reaction XII.5 is dominant.
- bg - Rates and uncertainties beneath the "top of the atmosphere" vary with altitude and solar zenith angle (Ref. 24-75).
- bh - The "a" parameter is taken from Ref. 24-78; the "b" parameter is estimated from Ref. 24-61.
- bi - The "a" parameter is taken from Ref. 24-84; the "b" parameter is estimated from Ref. 24-85.
- bj - Based on $k = (1.20 \pm 0.09) \times 10^{-10}$ for $O(^1D) + CO_2$ (from Ref. 24-91) and the ratio $k[O(^1D) + NO_2]/k[O(^1D) + CO_2] = 1.5$ (from Ref. 24-93).
- bk - Value of k_{300} is from Ref. 24-97; "c" parameter estimated by Ref. 24-85.
- bl - Value of $k_{\Sigma} = (5.2 \pm 2.0) \times 10^{-12}$ from Ref. 24-100; ratio of k_{300} values, channel (b) to channel (a), = 1.3 from Ref. 24-101.
- bm - This is an entirely new rate constant, much higher than has been reported previously, and substantiation for which is provided to two sets of considerations:
- (i) Certain other values reported for the rate constant of Reaction XXIX.38 have depended on observed rate ratios within systems of competing reactions, viz., Reaction XXIX.38 ($NO + HO_2 \rightarrow OH + NO_2$) vs. Reaction XXIX.51 ($HO_2 + HO_2 \rightarrow O_2 + H_2O_2$) (Refs. 24-105 through 24-108), where monitoring of the $NO-NO_2$ conversion was a critical factor in calculating the values reported for Reaction XXIX.38, e.g., $k = 1.2 \times 10^{-11} \exp(-700 \pm 250)/T$, $k_{300} = 1.2 \times 10^{-(12.0 \pm 0.4)} \text{ cm}^3 \text{ sec}^{-1}$ (Ref. 24-108). A still lower rate constant for the same reaction had been reported, i.e., $k = (2.0 \pm 0.5) \times 10^{-11} \exp(-1200 \pm 150)/T$, $k_{300} = 3.7 \times 10^{-(13.0 \pm 0.3)} \text{ cm}^3 \text{ sec}^{-1}$ (Ref. 24-109), where monitoring depended on the observed rate of OH production. Either of these results would, however, be expected to have been artificially lowered by virtue of the competing fast Reaction XXIX.44 ($OH + HO_2 \rightarrow O_2 + H_2O$) (Ref. 24-103).

NOTES (continued)

- (2) The recent work of C. J. Howard (Ref. 24-103) was based on three different determinations involving three different methods of OH removal or accountability (viz.: fast scavenging of OH; high system dilution with helium; admixture of excess H_2O_2 to achieve OH: HO_2 steady-state by promoting Reaction XXIX, 46 ($\text{OH} + \text{H}_2\text{O}_2 \rightarrow \text{HO}_2 + \text{H}_2\text{O}$) as a counter-process to Reaction XXIX, 38). When coupled with absolute species detection by laser magnetic resonance, of the order of $10^9(\text{HO}_2)\text{cm}^{-3}$ and $10^7(\text{OH})\text{cm}^{-3}$, all three techniques yielded the same rate constant $k = (8 \pm 3) \times 10^{-12}\text{cm}^3\text{sec}^{-1}$ (with unknown temperature dependence) which we now recommend.

- bn - Pressure-dependent.
- bo - For additional quenchants of $\text{O}(^1\text{D})$, see Table 20-8 (Chp. 20).
- bp - T_p -dependent rate coefficients have been calculated from the data of Ref. 24-111 for the reverse (excitation) reaction, by detailed-balance computation (Ref. 24-112) at each energy, and curve-fitting (by Handbook Editor) throughout the temperature range indicated.
- bq - Cf. Figure 20-9 (Chp. 20).
- br - For additional quenchants of $\text{O}_2(^1\Delta_g)$, see Table 20-6 (Chp. 20).
- bs - Products may include $\text{O}(^1\text{S})$ or $\text{N}(^2\text{D})$ (Ref. 24-118).
- bt - Endothermic by 39 cm^{-1} ($\sim 0.005\text{ eV}$).
- bu - Case of resonant vibrational energy exchange at $T = 300\text{ K}$.

REFERENCES

- 24-1. Huffman, R.E., and T.J. Keneshea, private communication (1977).
- 24-2. Huang, C.M., M.A. Biondi, and R. Johnsen, Phys. Rev. A11, 901 (1975).
- 24-3. Lee, C.M., Phys. Rev. A16, 109 (1977).
- 24-4. Michels, H.H., United Technologies Research Center, Rept. AFCRL-TR-75-0509, Sci. Rept. No. 2 (1975).
- 24-5. Walls, F.L., and G.H. Dunn, J. Geophys. Res. 79, 1911 (1974).
- 24-6. Kley, D., G.M. Lawrence, and E.J. Stone, J. Chem. Phys. 66, 4157 (1977).
- 24-7. Michels, H.H., private communication (1973).
- 24-8. Heppner, R.A., F.L. Walls, W.T. Armstrong, and G.H. Dunn, Phys. Rev. A13, 1000 (1976).
- 24-9. Huang, C.M., M.A. Biondi, and R. Johnsen, Phys. Rev. A14, 984 (1976).
- 24-10. Huang, C.M., M.A. Biondi, and R. Johnsen, private communication (1976).
- 24-11. Moseley, J.T., R.E. Olson, and J.R. Peterson, in Case Studies in Atomic Collision Physics, Vol. 5, E.W. McDaniel and M.R.C. McDowell, Eds., North-Holland, Amsterdam (1975); p. 1.
- 24-12. Peterson, J.R., W.H. Aberth, J.T. Moseley, and J.R. Sheridan, Phys. Rev. A3, 1651 (1971).
- 24-13. Moseley, J.T., W.H. Aberth, and J.R. Peterson, Bull. Am. Phys. Soc. 16, 208 (1971).
- 24-14. Biondi, M.A., private communication (1976).
- 24-15. Eisner, P.M., and M.N. Hirsch, Phys. Rev. Lett. 26, 874 (1971).
- 24-16. Smith, D., and M.J. Church, Intl. J. Mass Spectrom. Ion Phys. 19, 185 (1976).
- 24-17. Hotop, H., T.A. Patterson, and W.C. Lineberger, private communication (1973).

REFERENCES (continued)

- 24-18. Peterson, J.R., COSPAR, 19th Plenary Meeting, Philadelphia, Pa. (1976); Paper B. 1.10.
- 24-19. Churchill, D.R., B.H. Armstrong, R.R. Johnston, and K.G. Müller, J. Quant. Spectry. Radiative Transfer 6, 371 (1966).
- 24-20. Wong, S.F., T.V. Vorburger, and S.B. Woo, Phys. Rev. A5, 2598 (1972).
- 24-21. Herbst, E., T.A. Patterson, and W.C. Lineberger, J. Chem. Phys. 61, 1300 (1974).
- 24-22. Swider, W., private communication (1973).
- 24-23. Lindgren, R.G., private communication (1973).
- 24-24. Chantry, P.J., private communication (1970).
- 24-25. Fehsenfeld, F.C., C.J. Howard, and A.L. Schmeltekopf, J. Chem. Phys. 63, 2835 (1975).
- 24-26. Fehsenfeld, F.C., J. Chem. Phys., to be published.
- 24-27. McFarland, M., et al., J. Chem. Phys. 59, 6620 (1973).
- 24-28. Fehsenfeld, F.C., private communication (1976).
- 24-29. Ferguson, E.E., Accts. Chem. Research 3, 402 (1970).
- 24-30. Howard, C.J., F.C. Fehsenfeld, and M. McFarland, J. Chem. Phys. 60, 5086 (1974).
- 24-31. Fehsenfeld, F.C., J. Chem. Phys. 63, 1686 (1975).
- 24-32. Graham, E., R. Johnsen, and M.A. Biondi, J. Geophys. Res. 80, 2339 (1975).
- 24-33. Ferguson, E.E., private communication (1973).
- 24-34. Fehsenfeld, F.C., A.L. Schmeltekopf, and E.E. Ferguson, J. Chem. Phys. 44, 4537 (1966).
- 24-35. Lindinger, W., D.L. Albritton, F.C. Fehsenfeld, and E.E. Ferguson, J. Geophys. Res. 80, 3725 (1975).
- 24-36. Lindinger, W., et al., J. Chem. Phys. 62, 4101 (1975).
- 24-37. Lindinger, W., et al., J. Chem. Phys. 63, 5220 (1975).
- 24-38. McFarland, M., et al., J. Geophys. Res. 79, 2925 (1974).
- 24-39. Heaps, M.G., private communication (1977).

REFERENCES (continued)

- 24-40. Albritton, D.L., et al., J. Chem. Phys. 66, 410 (1977).
- 24-41. Fehsenfeld, F.C., A.L. Schmeltekopf, and E.E. Ferguson, J. Chem. Phys. 45, 23 (1966).
- 24-42. Fehsenfeld, F.C., Planet. Space Sci. 25, 195 (1977).
- 24-43. Lindinger, W., J. Chem. Phys. 64, 3720 (1976).
- 24-44. Puckett, L.J., and M.W. Teague, J. Chem. Phys. 54, 2564 (1971).
- 24-45. Fehsenfeld, F.C., and E.E. Ferguson, Radio Sci. 7, 113 (1972).
- 24-46. Fehsenfeld, F.C., and E.E. Ferguson, J. Chem. Phys. 61, 3181 (1974).
- 24-47. Dotan, I., D.L. Albritton, and F.C. Fehsenfeld, J. Chem. Phys., to be published.
- 24-48. Lindinger, W., D.L. Albritton, F.C. Fehsenfeld, and E.E. Ferguson, J. Chem. Phys. 63, 3238 (1975).
- 24-49. Fehsenfeld, F.C., and E.E. Ferguson, J. Chem. Phys. 64, 1853 (1976).
- 24-50. Bohme, D.K., P.P. Ong, J.B. Hasted, and L.R. Megill, Planet. Space Sci. 15, 1777 (1967).
- 24-51. Beyer, R.A., and J.A. Vanderhoff, J. Chem. Phys. 65, 2313 (1976).
- 24-52. Vanderhoff, J.A., private communication (1976).
- 24-53. Moseley, J.T., R.M. Snuggs, D.W. Martin, and E.W. McDaniel, Phys. Rev. 178, 240 (1969).
- 24-54. Bohme, D.K., D.B. Dunkin, F.C. Fehsenfeld, and E.E. Ferguson, J. Chem. Phys. 51, 863 (1969).
- 24-55. Payzant, J.D., A.J. Cunningham, and P. Kebarle, J. Chem. Phys. 59, 5615 (1973).
- 24-56. Fehsenfeld, F.C., J. Chem. Phys. 61, 1588 (1974).
- 24-57. Fehsenfeld, F.C., M. Mosesman, and E.E. Ferguson, J. Chem. Phys. 55, 2115 (1971).
- 24-58. Johnsen, R., C.M. Huang, and M.A. Biondi, J. Chem. Phys. 63, 3374 (1975).

REFERENCES (continued)

- 24-59. Heimerl, J.M., Ballistic Research Laboratories, Rept. BRL 1917 (1976).
- 24-60. Dunkin, D.B., F.C. Fehsenfeld, A.L. Schmeltekopf, and E.F. Ferguson, J. Chem. Phys. 54, 3817 (1971).
- 24-61. Scheibe, M., private communication (1976).
- 24-62. Peterson, J.R., J. Geophys. Res. 81, 1433 (1976).
- 24-63. Heimerl, J.M., private communication (1976).
- 24-64. Niles, F.E., private communication (1976).
- 24-65. Payzant, J.D., private communication (1972) (via Ref. 24-64).
- 24-66. Pack, J.L., and A.V. Phelps, Bull. Am. Phys. Soc. 16, 214 (1971).
- 24-67. Payzant, J.D., and P. Kebarle, J. Chem. Phys. 56, 3482 (1972).
- 24-68. Parkes, D.A., Trans. Far. Soc. 67, 711 (1971).
- 24-69. McKnight, L.G., and J.M. Sawina, Phys. Rev. A4, 1043 (1971).
- 24-70. McNeal, R.J., and S.C. Durana, J. Chem. Phys. 51, 2955 (1969).
- 24-71. Young, R.A., and G. Black, J. Chem. Phys. 44, 3741 (1966).
- 24-72. Sharma, R.D., and K.L. Wray, J. Chem. Phys. 54, 4578 (1971).
- 24-73. Gross, R.W.F., and N. Cohen, J. Chem. Phys. 48, 2582 (1968).
- 24-74. Gross, R.W.F., J. Chem. Phys. 48, 1302 (1968).
- 24-75. Turco, R.P., private communication (1977).
- 24-76. Slinger, T.G., and G. Black, J. Chem. Phys. 64, 3767 (1976).
- 24-77. Campbell, I.M., and C.N. Gray, Chem. Phys. Letts. 18, 607 (1973).
- 24-78. Hampson, R.F., and D. Garvin, Natl. Bur. Stds., Rept. NBS-TN-866 (1975).

REFERENCES (continued)

- 24-79. Ham, D.O., D.W. Trainor, and F. Kaufman, *J. Chem. Phys.* 53, 4395 (1970).
- 24-80. Whytock, D.A., J.V. Michael, and W.A. Payne, *Chem. Phys. Letts.* 42, 466 (1976).
- 24-81. Slinger, T.G., and G. Black, *J. Chem. Phys.* 53, 3722 (1970).
- 24-82. Gaedtke, H., et al., Fourteenth Symp. (Intl.) on Combustion, The Combustion Institute, Pittsburgh, Pa. (1973); p. 295.
- 24-83. Anderson, J.G., J.J. Margitan, and F. Kaufman, *J. Chem. Phys.* 60, 3310 (1974).
- 24-84. Trainor, D.W., and C.W. von Rosenberg, Jr., *J. Chem. Phys.* 61, 1010 (1974).
- 24-85. Hampson, R.F., and F. Kaufman, private communication (1976).
- 24-86. Wray, K.L., and J.C. Teare, *J. Chem. Phys.* 36, 2582 (1962).
- 24-87. Appleton, J.P., M. Steinberg, and D.J. Liquornik, *J. Chem. Phys.* 48, 599 (1968).
- 24-88. Findlay, F.D., and D.R. Snelling, *J. Chem. Phys.* 54, 2750 (1971).
- 24-89. Gilpin, R., H.I. Schiff, and K.H. Welge, *J. Chem. Phys.* 55, 1087 (1971).
- 24-90. Johnston, H.S., Natl. Bur. Stds., Report NSRDS-NBS-20 (1968).
- 24-91. Davidson, J.A., et al., *J. Chem. Phys.* 64, 57 (1976).
- 24-92. Hampson, R.F., private communication (1976).
- 24-93. Paraskevopoulos, G., K.F. Preston, and R.J. Cvetanovic, *J. Chem. Phys.* 54, 3907 (1971).
- 24-94. Chapman, C.J., and R.P. Wayne, *Intl. J. Chem. Kin.* 6, 617 (1974).
- 24-95. Slinger, T.G., B.J. Wood, and G. Black, *J. Geophys. Res.* 76, 8430 (1971).
- 24-96. Wayne, R.P., *Annals N.Y. Acad. Sci.* 171, 199 (1970).

REFERENCES (continued)

- 24-97. Clyne, M.A.A., and I.S. McDermid, J. Chem. Soc. Faraday Trans. 1 71, 2189 (1975).
- 24-98. Clyne, M.A.A., and P. Monkhouse, J. Chem. Soc. Faraday Trans. 1, to be published.
- 24-99. Baulch, D.L., D.D. Drysdale, D.G. Horne, and A.C. Lloyd, Evaluated Kinetic Data for High Temperature Reactions, Vol. 1: Homogeneous Gas Phase Reactions of the H₂-O₂ System, Butterworths, London (1972).
- 24-100. Klemm, R.B., W.A. Payne, and L.J. Stief, Intl. J. Chem. Kin. 7 (Symp. 1), 61 (1974) (Publ. 1975).
- 24-101. Meagher, J.F., and J. Heicklen, J. Photochem. 3, 455 (1975).
- 24-102. Hampson, R.F., private communication (1977) (Based on Preliminary Output, NASA Chlorofluoromethane Assessment Workshop, Goddard Space Flight Center, March 1977).
- 24-103. Howard, C.J., and K.M. Evenson, Geophys. Res. Letts. 4, 437 (1977).
- 24-104. Kaufman, F., private communication (1977).
- 24-105. Cox, R.A., Intl. J. Chem. Kin. 7 (Symp. 1), 379 (1974) (Publ. 1975).
- 24-106. Cox, R.A., and R.G. Derwent, J. Photochem. 4, 139 (1975).
- 24-107. Simonaitis, R., and J. Heicklen, J. Phys. Chem. 80, 1 (1976).
- 24-108. Simonaitis, R., and J. Heicklen, Penna. State Univ. Ionospheric Research Laboratory, Report PSU-IRL-SCI-454 (1977).
- 24-109. Hack, W., K. Hoyeremann, and H. Gg. Wagner, Intl. J. Chem. Kin. 7 (Symp. 1), 329 (1974) (Publ. 1975).
- 24-110. Margitan, J.J., F. Kaufman, and J.G. Anderson, Intl. J. Chem. Kin. 7 (Symp. 1), 281 (1974) (Publ. 1975).
- 24-111. Ali, A.W., Naval Research Laboratory, NRL Memorandum Report 3371 (1976).
- 24-112. Ali, A.W., private communication (1978).

REFERENCES (continued)

- 24-113. Stuhl, F., and K.H. Welge, Can. J. Chem. 47, 1879 (1969).
- 24-114. Young, R.A., G. Black, and T.G. Slanger, J. Chem. Phys. 50, 309 (1969).
- 24-115. Black, G., T.G. Slanger, G. St. John, and R.A. Young, J. Chem. Phys. 51, 116 (1969).
- 24-116. Kummier, R.H., and M.H. Bortner, General Electric Company, Rept. TIS R67SD20 (1967).
- 24-117. Arnold, S.J., and E.A. Ogryzlo, Can. J. Phys. 45, 2053 (1967).
- 24-118. Swider, W., private communication (1976).

DISTRIBUTION LIST

DEPARTMENT OF DEFENSE

Assistant to the Secretary of Defense
Atomic Energy

ATTN: Executive Assistant

Defense Advanced Research Project Agency

ATTN: TID

Defense Documentation Center

12 cy ATTN: DD

Defense Intelligence Agency

ATTN: DI-1C

Defense Nuclear Agency

5 cy ATTN: RAAE

4 cy ATTN: TITL

ATTN: RAEV, H. Fitz, Jr.

ATTN: DDST

Field Command

Defense Nuclear Agency

ATTN: FCPR

ATTN: FCT, W. Bengard

Interservice Nuclear Weapons School

ATTN: ITV

ATTN: TTV, B. Adams

Joint Strategic Target Planning Staff

ATTN: JPST, J. Green

Livermore Division Fld. Command, DNA

Lawrence Livermore Laboratory

ATTN: FCPL

DEPARTMENT OF THE ARMY

Atmospheric Sciences Laboratory

U.S. Army Research and Development Command

ATTN: M. Diamond

ATTN: H. Ballard

ATTN: R. Olsen

ATTN: DELAS-ED, F. Niles

ATTN: M. Heaps

SMD Advanced Technology Center

Department of the Army

ATTN: ATC-T, M. Capps

ATTN: ATC-D, W. Davies

Dep. Chief of Staff for Rsch. Dev. and Acq.

Department of the Army

ATTN: ABMDA-00

ATTN: Safeguard and Space Div.

FRADCDM Technical Support Activity

Department of the Army

ATTN: DRSEL-PL-ENV, H. Bomke

ATTN: Inst. for Exploratory Res.

ATTN: S. Kronenberg

DEPARTMENT OF THE ARMY (Continued)

Harry Diamond Laboratories

Department of the Army

ATTN: DELHD-ID, W. Carter

ATTN: DELHD-YI, M. Weiner

ATTN: DELHD-NP

ATTN: DELHD-I-TL

U.S. Army Ballistic Research Labs

Aberdeen Proving Ground

ATTN: B. Hendrikson

ATTN: J. Vanderhoff

ATTN: J. Vanderbilt

ATTN: DRXBR-CA, T. O'Brien

ATTN: DRXRD-BSP, J. Heimerl

ATTN: DRXBR-AM, J. Batten

ATTN: I. Chidsey

ATTN: DRXBR-AM, D. Snider

ATTN: M. Kregel

ATTN: J. Mester

ATTN: DRXBR-AM, W. VanAntwerp

U.S. Army Materiel Development & Readiness, CMD

ATTN: DRCDE-D, L. Flynn

U.S. Army Nuclear and Chemical Agency

ATTN: Library

U.S. Army Research Office

ATTN: CRDARD-P, R. Mace

U.S. Army TRADOC Systems Analysis Activity

ATTN: C. Andrews

DEPARTMENT OF THE NAVY

Naval Ocean Systems Center

ATTN: Code 532, W. Moler

3 cy ATTN: Code 4471

ATTN: Code 22DD, I. Rothmuller

ATTN: Code 22DD, J. Richter

ATTN: Code 22DD, H. Hughes

ATTN: Code 22DD, R. Pappert

ATTN: Code 327D

ATTN: Code 4471 for T. Keary

ATTN: Code 22DD, V. Hildebrand

Naval Postgraduate School

ATTN: Code 61 DY, J. Dyer

ATTN: Code 61 MN, E. Milne

Naval Research Laboratory

ATTN: Code 77D9, W. Ali

ATTN: Code 675D, D. Strobel

ATTN: Code 541D, J. Davis

ATTN: Code 675D, K. Hain

ATTN: Code 670D, T. Coffey

ATTN: Code 2627

ATTN: Code 6730, E. McClean

ATTN: Code 7701, J. Brown

ATTN: Code 7127, C. Johnson

DEPARTMENT OF THE NAVY (Continued)

Naval Surface Weapons Center

ATTN: D. Land
ATTN: Code 731
ATTN: L. Rudlin
ATTN: X211

Naval Surface Weapons Center

ATTN: D. Hudson

Office of Naval Research

ATTN: Code 421, R. Yonker
ATTN: Code 461, R. Joiner
ATTN: Code 422, L. Cooper
ATTN: Code 421, B. Junker

Office of the Chief of Naval Operations

ATTN: OP 981

DEPARTMENT OF THE AIR FORCE

Aerospace Defense Command/XPD

Department of the Air Force
ATTN: XPDQQ, G. Kuch

Air Force Geophysics Laboratory

ATTN: LKD, C. Philbrick
ATTN: LKB, E. Murad
ATTN: LKB, W. Swider, Jr.
ATTN: LKB, J. Paulson
ATTN: LKB, K. Champion
ATTN: LKB, T. Keneshea
ATTN: OPR, J. Kennealy
ATTN: LKO, R. Huffman
ATTN: LKD, R. Narcisi
ATTN: LKB, F. Innes
ATTN: LKS, R. Van Tassel
ATTN: OPR, H. Gardiner
ATTN: DP, J. Garing
ATTN: DPR, A. Stair
ATTN: OPR, F. Delgreco
ATTN: DPR, J. Schummers
ATTN: DPR, R. O'Neill
ATTN: OPR, R. Murphy
ATTN: SULL

Air Force Systems Command

ATTN: SDR
ATTN: DLTW

Air Force Technical Applications Center

ATTN: TF, Maj E. Hines
ATTN: TF, Maj Wiley

Air Force Weapons Laboratory

3 cy ATTN: DYT
ATTN: CA
2 cy ATTN: DYC
ATTN: SUL
ATTN: EL, C. Baum

Assistant Chief of Staff

Intelligence
Department of the Air Force
ATTN: INS

Electronic Systems Division/ES

Department of the Air Force
ATTN: ESTI

DEPARTMENT OF THE AIR FORCE (Continued)

Deputy Chief of Staff

Research, Development, and Acq.

Department of the Air Force

ATTN: AFROQSM
ATTN: AFROQ
ATTN: AFRO

Foreign Technology Division, AFSC

ATTN: NICD Library
ATTN: WE

Rome Air Development Center, AFSC

ATTN: Documents Library/TSLD
ATTN: OCSE, J. Simons
ATTN: OCSE, V. Coyne

Space and Missile Systems Organization/AW

Air Force Systems Command
2 cy ATTN: AWA

Space and Missile Systems Organization/SZ

Air Force Systems Command
ATTN: SZJ

Strategic Air Command/XPFS

ATTN: ADW, J. Greene, Jr.
ATTN: ADWATE, B. Bauer
ATTN: XPFS, B. Stephen

USAFETAC/CB

ATTN: STOP 825

DEPARTMENT OF ENERGY

Argonne National Laboratory

Records Control

ATTN: Doc. Con. for L. Leibowitz
ATTN: Doc. Con. for J. Berkowitz
ATTN: Doc. Con. for Lib. SVCS Rpts. Sec.
ATTN: Doc. Con. for S. Gabelnick
ATTN: Doc. Con. for D. Green
ATTN: Doc. Con. for G. Reedy

Department of Energy

ATTN: Doc. Con. for Classified Library
ATTN: Doc. Con. for Rpts. Section

EG&G, Inc.

ATTN: Doc. Con. for P. Lucero

Lawrence Livermore Laboratory

ATTN: Doc. Con. for L-71, J. Chang
ATTN: Doc. Con. for L-404, G. Haugan
ATTN: Doc. Con. for L-96, A. Kaufman
ATTN: Doc. Con. for L-142, D. Wuebbles
ATTN: Doc. Con. for L-404, W. Duerer

Office of Military Application

Department of Energy

ATTN: Doc. Con. for D. Haycock

Sandia Laboratories

ATTN: Doc. Con. for C. Mehl
ATTN: Doc. Con. for C. Williams
ATTN: Doc. Con. for T. Wright
ATTN: Doc. Con. for D. Dahlgren
ATTN: Doc. Con. for 3141

DEPARTMENT OF ENERGY (Continued)

Los Alamos Scientific Laboratory

ATTN: Doc. Con. for W. Barfield
 ATTN: Doc. Con. for W. Maier
 ATTN: Doc. Con. for L. Bieniewski
 ATTN: Doc. Con. for H. Hoerlin
 ATTN: Doc. Con. for E. Bryant
 ATTN: Doc. Con. for M. Johnson
 ATTN: Doc. Con. for J. Malik
 ATTN: Doc. Con. for J. Judd
 ATTN: Doc. Con. for W. Hughes
 ATTN: Doc. Con. for D. Kerr
 ATTN: Doc. Con. for J. Zion
 ATTN: Doc. Con. for D. Rohrer
 ATTN: Doc. Con. for M. Tierney
 ATTN: Doc. Con. for D. Steinhaus

OTHER GOVERNMENT AGENCIES

Albany Metallurgy Research Center

U.S. Bureau of Mines
 ATTN: L. Abshire

Central Intelligence Agency

ATTN: RD/51, Room 5648, HQ Building
 for NLD/051-2648 HQS

Department of Commerce

National Bureau of Standards

ATTN: R. Hampson, Jr.
 ATTN: S. Abramowitz
 ATTN: J. Devoe
 ATTN: I. Gevantman
 ATTN: M. Krauss
 ATTN: K. Kessler
 ATTN: G. Simatt
 ATTN: J. Cooper

Department of Transportation

Transportation Resch. System Center

ATTN: F. Marmo

Department of Transportation

Federal Aviation Administration

ATTN: A. Broderick
 ATTN: W. Smith
 ATTN: J. Rogers

Institute for Telecommunications Sciences

National Telecommunications & Info. Admin.

ATTN: W. Utlaut
 ATTN: L. Berry
 ATTN: G. Falcon

NASA

Goddard Space Flight Center

ATTN: A. Aiken
 ATTN: Technical Library
 ATTN: S. Bauer

NASA

ATTN: A. Gessow
 ATTN: J. Haughey
 ATTN: P. Kurzthals
 ATTN: D. Cauffman

NASA

Langley Research Center

ATTN: C. Schexnayder

OTHER GOVERNMENT AGENCIES (Continued)

NASA

AMEL Research Center

ATTN: N. Farlow
 ATTN: W. Storr
 3 cy ATTN: R. Whitten

National Bureau of Standards

ATTN: S. Smith
 ATTN: P. Bender
 ATTN: G. Dunn

National Oceanic & Atmospheric Admin.

Environmental Research Laboratories

Department of Commerce

ATTN: E. Ferguson
 ATTN: F. Fehsenfeld
 ATTN: G. Reid
 ATTN: W. Spjeldvik

National Science Foundation

ATTN: R. Zapolsky
 ATTN: I. White
 ATTN: M. Wilson
 ATTN: R. Manka
 ATTN: W. Adams
 ATTN: R. Sinclair
 ATTN: L. Todd

Pittsburgh Mining and Safety Resch. Ctr.

Bureau of Mines

ATTN: F. Spencer, Jr.

DEPARTMENT OF DEFENSE CONTRACTORS

Aero-Chem. Research Labs, Inc.

ATTN: H. Calcote
 ATTN: A. Funtijn
 ATTN: H. Pergament

Anrodyne Research, Inc.

Redford Research Park

ATTN: F. Bien
 ATTN: M. Camac

Aerojet Electro-Systems Co.

Div. of Aerojet General Corp.

ATTN: D. Stuart

Aerospace Corp.

ATTN: V. Josephson
 3 cy ATTN: S. Crowe
 ATTN: R. Grove
 ATTN: N. Cohen
 ATTN: T. Widhoph
 ATTN: S. Kash
 ATTN: R. Cohen
 ATTN: F. Morse
 ATTN: J. Reinheimer
 ATTN: Library
 ATTN: T. Taylor
 ATTN: R. McNeal
 ATTN: H. Mayer

Albright College

Department of Physics

ATTN: M. Kim

American Science and Engineering, Inc.

ATTN: Document Control

DEPARTMENT OF DEFENSE CONTRACTORS (Continued)

Analytical Systems Engineering Corp.
ATTN: J. Canuso

Avco Everett Research Lab, Inc.
ATTN: G. Sutton
ATTN: AR30
ATTN: C. Von Rosenberg, Jr.

Battelle Memorial Institute
ATTN: R. Inatsher
ATTN: SIOTAC

Bell Labs
ATTN: G. Mohnstreiter

Berkeley Research Associates, Inc.
ATTN: J. Workman

Boeing Co.
ATTN: H. Harrison
ATTN: H. Ritland

Boston College
2 cy ATTN: Chairman, Dept. of Physics
2 cy ATTN: Chairman, Dept. of Chem.
ATTN: Library

Bowhill, Professor A. Sidney
ATTN: Document Control

Brown Engineering Company, Inc.
Cummings Research Park
ATTN: J. Dobkins
ATTN: J. Cato
ATTN: W. Barnes
ATTN: N. Passino

University of California at Riverside
ATTN: J. Pitts, Jr.

University of California at San Diego
Marine Physical Lab P-001
Security Office
ATTN: L. Lin

University of California at San Diego
Bldg B-010
Dept. of Applied Mech. & Engrg. Sciences
ATTN: D. Miller

University of California at Santa Barbara
Physics Department
ATTN: M. Steinberg

California Institute of Technology
ATTN: A. Williams
ATTN: J. Laudenslager
ATTN: V. Anieich

California Institute of Technology
Jet Propulsion Lab
ATTN: J. Ajello

State of California
Air Resources Board
ATTN: L. Zafonte

DEPARTMENT OF DEFENSE CONTRACTORS (Continued)

University of California
ATTN: H. Johnston
ATTN: W. Miller
ATTN: F. Mozer

Calspan Corp.
ATTN: M. Dunn
ATTN: R. Fluegge
ATTN: C. Treanor
ATTN: W. Wurster
ATTN: G. Valley

Clark University
Department of Physics
ATTN: K. Oyedeji

University of Colorado
Office of Contracts and Grants
ATTN: J. Pearce
ATTN: C. Barth
ATTN: A. Phelps
ATTN: C. Linberger
ATTN: C. Beaty

Columbia University
Low Memorial Library
ATTN: H. Foley

Columbia University
La Monte Doherty Geological
Observatory-Torrey Cliffs
ATTN: H. Phelan

Computer Sciences Corp.
ATTN: C. Hulbert

University of Denver
Colorado Seminary
Denver Research Institute
ATTN: Sec. Officer for V. Zyl
ATTN: Sec. Officer for D. Murcay

F. I. Dupont De Nemours and Co.
Savannah River Lab
Document Transfer Station 703-A
ATTN: R. Hirsch
ATTN: K. Saum
ATTN: R. Ward

Ecometrics, Inc.
ATTN: N. Utterback

Epsilon Labs, Inc.
ATTN: C. Accardo
ATTN: J. Dulchinos
ATTN: H. Miranda

ESL, Inc.
ATTN: W. Bell
ATTN: J. Marshall

University of Florida
ATTN: Security Officer for R. Anderson
ATTN: Security Officer for R. Isler
ATTN: Security Officer for O. Keffer
ATTN: Security Officer for W. Person

DEPARTMENT OF DEFENSE CONTRACTORS (Continued)

General Electric Co.
Space Division
Valley Forge Space Center
ATTN: P. Zavitsanos
ATTN: J. Burns
ATTN: R. Edsall
ATTN: T. Baurer
ATTN: M. Linevsky
ATTN: M. Bortner
ATTN: F. Alyea

General Electric Company—TEMPD
Center for Advanced Studies
ATTN: M. Stanton
ATTN: M. Alferieff
ATTN: J. Thompson
ATTN: L. Ewing
ATTN: W. Knapp
ATTN: J. Barrett
ATTN: B. Gambill
ATTN: T. Stevens
ATTN: J. Schoutens
ATTN: D. Chandler
50 cy ATTN: DASIAC

General Motors Corp.
Delco Electronics Division
ATTN: R. Primich

General Research Corp.
ATTN: J. Ise, Jr.

General Research Corp.
ATTN: T. Zakrzewski

General Telephone Co. of Florida
Security Dept.
ATTN: M. Dunn

Geophysical Institute
ATTN: N. Brown
ATTN: J. Wagner
ATTN: T. Davis
ATTN: R. Parthasarathy
ATTN: H. Cole

Govt. Fiscal Relations & Patent Off.
ATTN: K. Clark
ATTN: R. Geballe

Harvard College Observatory
Smithsonian Astrophysical Observatory
Center for Astrophysics
ATTN: Library

Harvard University
Department of Atmospheric Sciences
ATTN: M. Kanai
ATTN: M. McElroy

High Voltage Engineering Corp.
ATTN: Document Control

Honeywell, Inc.
Radiation Center
ATTN: W. Williamson

DEPARTMENT OF DEFENSE CONTRACTORS (Continued)

Howard University
Department of Chemistry
ATTN: W. Jackson

HSS, Inc.
ATTN: D. Hansen
ATTN: M. Shuler
ATTN: H. Stewart

IIT Research Institute
ATTN: Documents Library

Illinois Institute of Technology
ATTN: Technical Library

University of Illinois
Aeronomy Lab
ATTN: J. Schroeder

University of Illinois
Physics Department
ATTN: W. Otting

Information Science, Inc.
ATTN: W. Dudziak

Institute for Defense Analyses
ATTN: E. Bauer
ATTN: P. Selwyn
ATTN: J. Bengston
ATTN: H. Wolfhard

Ion Physics Corp.
ATTN: C. Hauer

IRT Corp.
ATTN: J. Rutherford
ATTN: R. Neynaber
ATTN: D. Vroom

JAYCDR
ATTN: H. Levine

Johns Hopkins University
Applied Physics Lab
ATTN: Document Librarian

Johns Hopkins University
ATTN: J. Kaufman

Kaman Sciences Corp.
ATTN: P. Jesson
ATTN: F. Shelton
ATTN: B. Bittner

Kansas State University
Department of Physics
ATTN: C. Rosenkilde

KMS Industries, Inc.
ATTN: Library

Dr. Harold W. Lewis
ATTN: H. Lewis

University of Lowell
Center for Atmospheric Research
ATTN: G. Best

DEPARTMENT OF DEFENSE CONTRACTORS (Continued)

Lockheed Missiles and Space Co., Inc.

ATTN: J. Reagan
ATTN: T. James
ATTN: J. Eumer
ATTN: B. McCormac
ATTN: M. Walt
ATTN: R. Sears
ATTN: R. Johnson
ATTN: R. Guntton

M.I.I. Lincoln Lab

ATTN: B. Watkins

University of Maryland

ATTN: H. Griem
ATTN: W. Benson
ATTN: R. Munn
ATTN: J. Vanderslice
ATTN: T. Rosenberg

University of Maryland

Department of Chemistry
ATTN: S. Fischer

Maxwell Labs, Inc.

ATTN: A. Shannon
ATTN: A. Rostocker
ATTN: R. Hunter

McDonald Observatory at Mt. Locke

ATTN: B. Grabar

McDonnell Douglas Corp.

ATTN: A. Goedeke
ATTN: W. Olson
ATTN: J. Moule

Midwest Research Institute

ATTN: F. Greene

University of Minnesota

ATTN: J. Winkler

University of Minnesota

ATTN: M. Hirsch

Mission Research Corp.

ATTN: R. Christian
ATTN: R. Kilb
ATTN: R. Hendrick
ATTN: R. Wilson
ATTN: D. Higgins
ATTN: W. White
ATTN: W. Crevier
ATTN: D. Sowle
ATTN: R. Bogusch
ATTN: P. Fischer
ATTN: D. Sappenfield
ATTN: M. Scheibe
ATTN: N. Carron
ATTN: R. Stoerkly
ATTN: C. Longmire
ATTN: D. Archer

MITRE Corp.

ATTN: S. Morin
ATTN: J. Freedman

MITRE Corp.

ATTN: A. Schneider

DEPARTMENT OF DEFENSE CONTRACTORS (Continued)

National Academy of Sciences

ATTN: Committee on Atmospheric Sciences
for J. Sievers
ATTN: Committee on Atmospheric Sciences
for E. Dyer
ATTN: Committee on Atmospheric Sciences
for W. Bartley

State University of New York at Buffalo

ATTN: G. Brink

Pacific-Sierra Research Corp.

ATTN: E. Field, Jr.

Panametrics, Inc.

ATTN: B. Sellers

Pennsylvania State University

Industrial Security Office
ATTN: L. Hale
ATTN: J. Nisbet

University of Pennsylvania

Department of Chemistry
ATTN: W. Benner

Photometrics, Inc.

ATTN: I. Kofsky

Physical Dynamics, Inc.

ATTN: A. Thompson

Physical Sciences, Inc.

ATTN: R. Taylor
ATTN: K. Wray

Physics International Co.

ATTN: Technical Library
ATTN: E. Swan

Physical Science Laboratory

ATTN: W. Barring

University of Pittsburgh

Cathedral of Learning
ATTN: W. Fite
ATTN: M. Biondi
ATTN: E. Gerjuoy
ATTN: F. Kaufman

Princeton University

ATTN: A. Kelly

Quantum Systems, Inc.

ATTN: S. Ormonde

R&D Associates

ATTN: R. Lelevier
ATTN: F. Gilmore
ATTN: A. Latter
ATTN: B. Gabbard
ATTN: R. Lindgren
ATTN: H. Ory
ATTN: R. Turco
ATTN: C. MacDonald
ATTN: R. Latter
ATTN: D. Dee

DEPARTMENT OF DEFENSE CONTRACTORS (Continued)

R&D Associates

ATTN: J. Rosengren
ATTN: B. Yoon
ATTN: H. Mitchell

Rand Corp.

ATTN: C. Crain

Rice University

Department of Space Science

ATTN: R. Stobbings

Rice University

ATTN: J. Chamberlain

Science Applications, Inc.

ATTN: B. Myers
ATTN: D. Hamlin
ATTN: R. Lowen

Science Applications, Inc.

ATTN: N. Byrn

Science Applications, Inc.

ATTN: R. Johnston

Science Applications, Inc.

ATTN: R. Meredith

Science Center

Rockwell International Center

ATTN: H. Coogan

Professor Chalmers F. Sechrist

ATTN: C. Sechrist

Solar Energy Research Institute

ATTN: T. Miller

University of Southern California

ATTN: S. Benson

Space Data Corp.

ATTN: E. Allen

SRI International

ATTN: D. Huestis
ATTN: A. Peterson
ATTN: D. Hildenbrand
ATTN: R. Leadabrand
ATTN: F. Smith
ATTN: R. Hake, Jr.
ATTN: J. Peterson
ATTN: G. Black
ATTN: J. Moseley
ATTN: W. Chesnut
ATTN: T. Slanger
ATTN: E. Kindermann
ATTN: V. Wickwar
ATTN: D. Eckstrom

SRI International

ATTN: M. Morgan

Technology International Corp.

ATTN: W. Boquist

University of Texas at Dallas

ATTN: A. Christensen

DEPARTMENT OF DEFENSE CONTRACTORS (Continued)

University of Texas System

ATTN: J. Browne

TRW Defense & Space System Group

ATTN: J. Frichtenicht
ATTN: R. Watson
ATTN: Technical Information Center
ATTN: R. Plebuch

United Technologies Corp.

ATTN: H. Michels
ATTN: R. Bullis

Utah State University

Contract/Grant Office

ATTN: K. Baker
ATTN: C. Wyatt
ATTN: D. Burt
ATTN: W. More

University of Virginia

School of Engineering & Appl. Sciences

Resch. Labs of the Engineering Sciences

ATTN: R. McKnight
ATTN: H. Kelly
ATTN: R. Ritter

Visidyne, Inc.

ATTN: C. Humphrey
ATTN: R. Walz
ATTN: T. Oegges
ATTN: J. Carpenter
ATTN: O. Manley

Wayne State University

ATTN: R. Kummier
ATTN: P. Rol

Wayne State University

Department of Physics

ATTN: W. Kauppila

Yale University

ATTN: V. Hughes
ATTN: Engineering Department